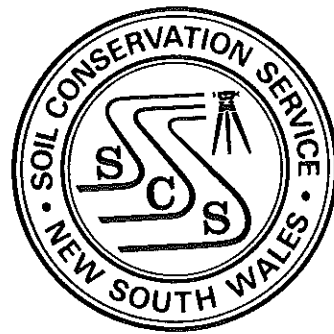


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SOILS OF NEW SOUTH WALES

THEIR CHARACTERIZATION
CLASSIFICATION
AND CONSERVATION



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SOILS OF NEW SOUTH WALES

Their Characterization
Classification
and Conservation

SOIL CONSERVATION SERVICE
Technical Handbook No. 1

Compiled and Edited
by
P.E.V. Charman
Special Soil Conservationist

February 1978

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CONTENTS

	Page
List of Tables	1
List of Figures and Appendices	3
Preface to Second Edition	4
1. Introduction	6
2. Soils Information Required	11
2.1 Soils in Relation to Erosion	11
2.1.1 General	11
2.1.2 Sheet Erosion	15
2.1.3 Gully Erosion	16
2.1.4 Tunnel Erosion	18
2.1.5 Landslip Erosion	18
2.1.6 Wind Erosion	20
2.2 Soils in Relation to Vegetation	22
2.3 Soils in Relation to Land Use	27
2.3.1 General	27
2.3.2 Agricultural Production	28
2.3.3 Urban Development	29
2.4 Soils in Relation to Hydrology and Design	30
2.4.1 Infiltration Capacity	31
2.4.2 Drainage	31
2.5 Soils in Relation to Earthworks	31
2.5.1 Permeability	32
2.5.2 Compaction	32
2.5.3 Stability	33
3. The Soil Profile	36
3.1 Soil Formation	36
3.1.1 Parent Material	39
3.1.2 Weathering	39
3.1.3 Leaching	39
3.1.4 New Mineral Formation	40
3.1.5 Lateral Transport of Soils and Rock Material	40

	Page
3.1.6 The Formation of a Soil	41
3.2 Soil Morphology	42
3.3 Soil Profile Examination	47
3.3.1 Describing the Profile	47
3.3.2 Soil Testing Kits	53
3.4 Soil Distribution	54
3.5 Soil Surveying and Mapping	57
3.5.1 Planning the Soil Survey	58
3.5.2 Soil Survey Methodology	60
3.5.3 Soil Survey and the Role of A.P.I.	62
3.5.4 Presentation of Soil Survey Data	64
3.5.5 Mapping Classes of Traditional Soil Maps	65
3.5.6 Soil Mapping for Soil Conservation	68
4. Soil Classification	70
4.1 The Purpose of Classification	70
4.2 Traditional and Genetic Systems	71
4.3 The Great Soil Group System	72
4.4 The Northcote Factual Key System	77
4.5 Soil Recognition and Correlation	85
4.6 The S.C.S. System of Classification	87
4.7 Soil Classification for Western Lands	88
4.7.1 Basis of the Classification System	89
4.7.2 The Classification System	90
4.8 Other Systems of Soil Classification	97
4.8.1 United States Soil Classification System	97
4.8.2 FAO/UNESCO Soil Classification System	100

4.9	Univariate and Multivariate Statistical Analysis in Soil Classification	104
4.9.1	Application of Univariate Statistical Methods to Soil Survey	104
4.9.2	Two Methods of Determining Map Unit Quality	105
4.9.3	Application of Multivariate Statistical Methods to Soil Survey	106
5.	Soils in Relation to Land Use	109
5.1	Introduction	109
5.2	Dryland Agricultural Land Use	109
5.2.1	Capability Assessment	110
5.2.2	Farm Planning	116
5.3	Urban Capability Assessment	116
5.3.1	The Urban Capability Assessment Scheme	116
5.3.2	Soil Factors	117
6.	Soils in Relation to the Design of Earthworks	130
6.1	Introduction	130
6.2	Soil Erodibility	131
6.3	Runoff Coefficient	136
6.4	Critical Velocities	140
6.5	Bank Spacing	143
7.	Soils in Relation to the Construction of Earthworks	146
7.1	Engineering Properties of Soil Materials	146
7.1.1	Soil Components	146
7.1.2	Properties of Soil Components	147
7.1.3	Unified Soil Classification System	152
7.1.4	Engineering Characteristics of Soil Groups	160

	Page
7.2 Soil Compaction and Stabilization	160
7.2.1 Compaction	160
7.2.2 Soil Stabilization	165
7.3 Soil Testing	173
7.3.1 Standard Soil Tests carried out by Soil Conservation Service Laboratories	174
7.4 Recommendations from Soil Test Data	184
7.4.1 Unified Soil Classification System	185
7.4.2 Particle Size Analysis	186
7.4.3 Tunnelling Susceptibility	187
7.4.4 Emerson Aggregate Test	187
7.4.5 Shrink-Swell Potential	187
7.4.6 Recommendations for Homogeneous Structures	188
7.4.7 Recommendations for Heterogeneous Structures	192
7.4.8 Embankment Settlement	194
7.5 Soil Sampling	196
7.5.1 Soil Sampling Methods	196
8. General Summary and Conclusions	198
9. References	203
Appendix I Soil Identification	208
Appendix II Identification of Soil Groups	223

LIST OF TABLES

<u>No.</u>	<u>Title of Table</u>	<u>Page</u>
2.1	Soils Susceptible to Wind Erosion as a Percentage of Pastorally used Semi-arid and Arid Australia.	22
2.2	Relative Fertility of N.S.W. Soils.	25
3.1	Some Data on Mapping Scale and Field Observations.	59
3.2	Soil Classification Categories.	66
4.1	Major Soil Groups of Australia.	73
4.2	Great Soil Groups arranged under Solum Classes, Soil Orders and Suborders.	74
4.3	Great Soil Groups in Order of Degree of Profile Development and Degree of Leaching.	76
4.4	Soil Properties used in the Northcote Factual Key.	86
5.1	Water Holding Capacity of Soils.	114
5.2	Identification of Expansive Soils.	121
5.3	Identification of Saline and Sodic Soils.	124
5.4	The Unified Soil Classification System as it Relates to Urban Capability Studies.	127
6.1	Scheme for Inferring Infiltration and Permeability Properties of Soil Horizons.	137
6.2	Scheme for Inferring Infiltration Capacity of Soil Horizons.	137
6.3	Erodibility Index Values for a Range of Soil Properties.	138
6.4	Runoff Index Values for a Range of Relevant Soil Properties.	139

		Page
6.5	Maximum Permissible Velocities for Bare Soil Channels.	141
6.6	Maximum Permissible Velocities for Vegetated Channels.	141
6.7	Hydraulic Conductivity of Soils and Relationship to USCS Groups.	142
6.8	Relative Erodibility of N.S.W. Soils.	145
7.1	Engineering Characteristics of Soil Groups.	155
7.2	Qualitative Comparison of Engineering Properties for Compacted Soil and Suitability for Various Purposes.	156
7.3	Recommended Slopes for Small Homogeneous Earthfill Dams on Stable Foundations.	158
7.4	Recommended Slopes for Small Zoned Earthfill Dams on Stable Foundations.	159
7.5	Various Roller Types and their Uses.	164
7.6	Typical Properties of Cement-Stabilized Soils.	168
7.7	Generally Appropriate Recommendations for Gully Control Structures.	190

LIST OF FIGURES AND APPENDICES

<u>Figure No.</u>	<u>Title of Figure</u>	<u>Page</u>
3.1	Soil Profile Nomenclature.	46
3.2	Soil Reaction Trend.	52
3.3	Soil Catenas.	55
4.1	A Simple Soil Dendrogram.	108
7.1	Unified Soil Classification System.	150
7.2	Plasticity Chart for the Laboratory Classification of Fine-Grained Soils.	151
7.3	Compaction Characteristics - Soil.	161
7.4	Compaction Characteristics and Index Properties.	166
7.5	Compaction Characteristics - Lime Treated Soil.	167
7.6	Loss in Strength Due to Delay in Compaction.	170
7.7	Tunnelling Susceptibility.	178
7.8	Emerson's Aggregate Classes.	181
7.9	Zoned Cross Section Embankments.	193
8.1	Soils of New South Wales - Characterization, Classification and Conservation.	201
<u>Appendices</u>		
I	Soil Identification. List of approximate correlations between Principal Profile Forms and Great Soil Groups.	208
II	Identification of Soil Groups. Tables to assist in the identification of Great Soil Groups and other groups, based on the Northcote Factual Key and further diagnostic features. Includes general notes.	223.

PREFACE

This is the second edition of a Service handbook, the first edition of which was originally proposed as an internal publication of about twenty or so pages! It was found, however, that its size could not be contained to that level, and it subsequently grew like 'topsy'.

The demand for the handbook, particularly from organisations outside the Soil Conservation Service, far exceeded the printing of that first edition. This, it must be admitted, had not been anticipated. The exercise did, however, stimulate considerable interest in the format and content of such a handbook, and this second edition has been developed accordingly. It has also been written with the wider readership in mind.

The handbook retains, however, its primary purpose as a practical compendium of information on soils for the soil conservationist. Its aim is to assist him in those aspects of his work where technical knowledge of this vital resource is required. The format has been changed somewhat, and I hope the result is an improvement in logical presentation. The content has been substantially increased, mainly to cover soils in relation to land use. It is in this area that the Service's activities have been much expanded since the production of the first edition. The chapter dealing with soils in relation to the design of earthworks has also been developed, and a section on the compaction and stabilization of soils has been added to the chapter on the construction of earthworks. Other parts of the handbook have also had additions made to them, in keeping with advances in technology and general knowledge of soils.

There are some areas of discussion which have been given somewhat less emphasis - mainly due to more recent trends in thinking on various issues - both within the Service and more broadly through the general field of soil science. This applies especially to some of the more traditional concepts within the field of soil classification, and to the use of some soil testing procedures within the Service which are gradually assuming lesser significance and being replaced by other tests.

A number of people have made substantial contributions to the text. I would therefore like to express my sincere thanks to Mr. G. Hamilton, Mr. C. Rosewell, Mr. J. Dixon, Mr. J. Lawrie and Mr. K. Styles who have all provided significant inputs to the new and revised material included. My continuing gratitude to the authors of the original papers on which the first edition was based should also be recorded. Mrs. Mary Collins has been a most patient and accurate typist.

Finally, I am deeply grateful for the assistance given me by Mrs. Cathy Hird, who has not only contributed to the material development of this handbook, but also has carried out much of the preliminary collation and editing. Without her help my task would have been a formidable one indeed.

P.E.V. Charman,
Sydney.

February, 1978.

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Chapter 1

INTRODUCTION

Soil erosion is both a natural phenomenon and a man-made degradation of the environment. It occurs in most parts of the world but in all instances the intensification of man's use of the land has resulted in increased soil erosion of one form or another, over and above that which is part of the natural wearing away of the earth's surface.

In Australia the problem is accentuated because of the extremes of climate occurring. In New South Wales all types of erosion are common due to the variety of soils and modes of land use.

The Soil Conservation Service of New South Wales is the State Government organization responsible for the overall protection and conservation of the State's soil resources.

Its work concerns the prevention and mitigation of soil erosion, the reclamation of eroded lands of all types, and the planning of land use according to the principles of soil conservation. Under the Service's control, soil conservation programmes are carried out on rural properties throughout the Eastern and Central Divisions of the State, in catchment areas of major water storages, on eroded beaches along the New South Wales coastline, in alpine areas, and throughout the arid and semiarid pastoral lands of the Western Division.

In recent years the Service has also become increasingly involved in giving planning advice to various bodies regarding the development of urban areas, the rehabilitation of mined sites and the control and prevention of erosion along freeways and at industrial locations.

The Service was established about the time of the second world war, due to the increasing awareness of soil erosion as a major problem affecting rural land in the State. The operations of the Service gathered momentum after that war, and as early as 1948 a plant hire scheme was initiated to enable farmers to hire equipment for the construction of erosion control measures. Where mechanical treatment was not appropriate, vegetative methods were applied to stabilize the land surface. Thus the early emphasis in the Service's work was, of necessity, restorative.

The design of works was based on climatic data, and the vegetative methods used depended heavily on the selection of appropriate plant species suitable for soil conservation purposes. Investigations in the early years thus had a strong meteorological and agrostological bias.

After ten years of the plant hire scheme a number of problems in the use of soil as a construction material had shown up. Prominent amongst these was the tunnelling problem in dispersible soils and the cracking problem in swelling soils.

The tunnelling problem mainly manifested itself in soil conservation structures built from dispersible soil in sub-optimal conditions. Slow seepage would develop which removed clay particles and eventually led to failure of the structure. The phenomenon was also recognized as a more natural form of erosion in certain areas, and referred to as field tunnelling. The problem was tackled by first developing a laboratory test for the recognition of dispersible soils, and then by investigating methods of overcoming the failures by using model dams. Amelioration of the soils with lime or gypsum was found to be one way of reducing failures, due to the replacement, by calcium ions, of the exchangeable sodium responsible for the high dispersibility. The most important factor, however, was found to be the compaction level achieved at construction. The importance of good construction techniques aiming for high compaction, and the possibilities in soil amelioration, have formed the basis for a considerable reduction in failures since then. In more recent years the field tunnelling problem has been given more attention. Also the wider implications of soil dispersibility as it relates to the instability or erodibility of soils has been more fully recognized.

The cracking problem occurs mainly on the black soils of the north west which have high clay contents of the montmorillonite type. Such soils, when used in banks built for soil conservation purposes, tend to dry out and crack severely in dry weather. At the onset of intense summer storms such structures fill with runoff and may fail if cracks do not seal rapidly. Field research has established the importance of bank size and shape in controlling this problem, and also the great need for regular earthwork maintenance, particularly in arable areas.

The cracking nature of these soils also gives rise to problems of pasture establishment on soil conservation earthworks as well as over broad areas. The investigations in this area have so far concentrated on species selection and germination studies. In the latter field success has been achieved with certain species whose germinating seeds appear to have the ability to withstand a period of moisture stress and resume active growth when moisture again becomes available.

The attention given to the soil problems of dispersibility and cracking in the late fifties and early sixties had two broad benefits for the Service apart from those directly related to the problems themselves. These were, firstly, the increasing involvement in soil testing, due to the need to establish laboratory criteria

for identifying dispersible and cracking soils. Secondly, the development of expertise in soil survey, due to the need for recognizing and mapping areas of these soils in the field.

During the late sixties, following the successful earlier development of a soil conservation farm planning scheme and the Service's wider involvement in the prevention of soil erosion, the accent in the Service's operations moved more towards one of land use. The farm planning scheme, based on assessment of the capability of land consistent with its need for protection, showed a demand for more objective soil data on which to base land capability decisions. There was also demand for better soils information to assist in the planning of, and in the design of works for, soil conservation projects. Projects involve areas treated on a whole catchment basis, and soil surveys became an increasingly important part of their execution.

Due to the increasing demand for soils information related to soil conservation and land use there has been, over the last ten years or so, a greatly increased interest in the study of soils within the Service. This interest has been further activated by the need for preparation of Technical Manuals for the whole State, by the appointment of more soil specialists to the research staff, and by the introduction of the "Factual Key for the Recognition of Australian Soils" (Northcote 1971).

During the pre-1971 development period of the Northcote Key a number of officers considered that it had considerable practical potential for the normal field work of the soil conservationist. As a result of their interest and the many training sessions and conferences which have been devoted to the subject, there is now a good understanding of the system on the part of most officers.

In June 1971 a system of soil classification involving the correlation of Great Soil Groups with Northcote codings was adopted for a trial period. After this period a survey was conducted by questionnaire to determine all soil conservationists' opinions as to the usefulness of soil classification, and the possibility of adopting a standard system. The results of the survey were studied in detail by a small committee of soil specialists, who prepared a report for comment by a cross-section of soil conservationists from all parts of the State. A final recommendation was then prepared, and approval for the adoption of a standard system was given in April 1974. The approved system is an extension of the Northcote classification to include surface soil features of importance in soil conservation. It will be described fully in Chapter 4 of this handbook. The correlation scheme has been retained as a guide to the recognition of broader genetic soil groups.

With all these developments there arose a widely felt need for a soils handbook - a straightforward text setting out what we need to know about soils in soil conservation work, and how soil classification and testing can assist in practical decisions concerning erosion, land capability, land use and the design and construction of soil conservation earthworks. This is what this handbook aims to achieve.

Numerous internal publications, bulletins and reports have been used in its preparation, although much of the material has been written specifically with this handbook in mind. Acknowledgement of all source material and references is made at the end of the text.

As far as possible a logical sequence has been adopted to assist in the understanding of the relationship between soil properties, classification and conservation. The sequence broadly is: soils information required - properties of soils - classification - agricultural use - urban use - soil conservation - earthwork construction. The sequence of chapters is as follows:

Chapter 2 is designed to provide general background to the soils information we require. The aspects of erosion, vegetation, land use, hydrology and earthworks are considered.

Chapter 3 is devoted to the soil profile or the soil as it occurs naturally in the field. Included are sections on the formation, morphology and distribution of soils and how one goes about studying, surveying and mapping them in their field situation.

Chapter 4 concerns soil classification - why and how we classify soils, particularly for the purposes of soil conservation. Traditional and modern systems are described as well as those used particularly by the Soil Conservation Service. A section on multivariate techniques as applied to soil classification is also included.

Chapter 5 deals with land use and the soil factors which are important with respect to different uses. The capability of land for agricultural and urban use, with emphasis on soil conservation considerations and the soil factors involved, is considered.

In Chapter 6 we discuss the soil as a material in danger of being eroded, and how the properties of that soil affect the design of earthworks to control erosion. Soil erodibility, runoff, infiltration, critical velocities for soil movement and bank spacing are all given consideration.

Chapter 7 concerns the use of soil as a material for building soil conservation earthworks. It is a comprehensive chapter as earthworks are of prime importance in controlling soil erosion in New South Wales. It deals with the engineering properties of soils, their compaction, stabilization and testing. Detailed recommendations for the construction of small earthen gully control structures are set out, based on the properties of the soil concerned.

Chapter 8 is a summary chapter which attempts to bring the threads of the whole handbook together by emphasizing the salient points from each chapter. It highlights the theme of the text which as applied to soils is:

CHARACTERIZATION - CLASSIFICATION - CONSERVATION.

SOILS INFORMATION REQUIRED

What does the soil conservationist need to know about soil - the material he is trying to conserve? Soils are infinitely variable in character, and therefore to know everything about them is an unattainable ideal. In practical terms he needs to understand as much as he can of soils in relation to the different aspects of the erosion/conservation situation. These can be summarised as follows:

- (a) Soils in relation to erosion.
- (b) Soils in relation to vegetation.
- (c) Soils in relation to land use.
- (d) Soils in relation to hydrology.
- (e) Soils in relation to earthworks.

The site factors involved in soil conservation work such as slope, topography, land use, climate and vegetation are relatively easily categorized when planning control of prevention measures. However, with soils, the situation is not so straight-forward. Soil factors are not so easily defined because of the infinite variation and complexity involved. To further complicate the issue, we may be interested in soil factors from one or all of three points of view - the properties of the surface soil only, the properties of the soil profile as a whole or the intrinsic properties of the soil as a material. The intrinsic properties of interest may relate to plant growth, water movement, stability or engineering behaviour.

To attempt some clarification of the things we need to know the above aspects of the soil erosion/conservation situation will be considered.

2.1 Soils in relation to erosion

2.1.1 General

Soil erosion is a complex process depending on the interaction of many factors such as rainfall intensity, rainfall amount and duration, vegetative cover, land form, land slope and land usage and management factors. Wind patterns, vegetative growth and surface roughness are important factors in considering wind erosion.

Apart from all these "external" factors, however, there are intrinsic differences between soils with respect to their resistance to erosion. The basic process of water erosion is due to:

- (a) The shattering and splash effect of rain drops on soil aggregates.
- (b) The dispersion of some soil aggregates in water.
- (c) The removal of soil particles by rain drop splash and runoff flow.

The basic process of wind erosion is due to:

- (a) The removal of soil particles by wind, aggravated by -
- (b) The abrasion of the soil surface by wind-borne soil particles, and the
- (c) development of the process known as saltation, which is the successive movement of soil particles and sand grains resulting from the impact of other moving particles.

The resistance of a soil to erosion has therefore two aspects:

- 1. The basic resistance of the soil material in its field state to detachment by falling rain drops and splash, flowing runoff, dispersion or wind.
- 2. A combination of the soil material characteristics and soil profile characteristics which allow the soil to absorb rain as it falls and thus prevent runoff (infiltration characteristics).

Considering the water erosion situation, this can be expressed in a general sense as:

$$E \propto \frac{D}{I}$$

which merely states that erodibility is directly proportional to the soil's tendency to break down or disperse in water (D), and inversely proportional to the soil's capacity for infiltration (I). That is to say, a soil with low aggregate stability is more likely to be erodible; and a soil more absorptive to rainfall is less likely to be erodible. Aggregate stability is related to the tendency of soil aggregates to deflocculate or break up into smaller particles. This property, or the lack of it, is a most important factor in the susceptibility of many soils to normal forms of erosion, as aggregation not only affects soil breakdown and dispersion but also controls infiltration to a large extent.

Aggregate stability is a result of both physical and chemical processes. The main properties controlling it chemically are the percentage of exchangeable sodium ions held on the clay particle surfaces, and the degree to which clay particles and organic matter react to produce inter-particle bonds. Clay type is also of considerable importance. Physically, the pressures created by shrinking/swelling, freezing/thawing, and wetting/drying are all important in the aggregation process. Combinations of different sizes of particles lend themselves to the formation of aggregates more readily than homogeneous soils.

Infiltration is defined as the movement of water into soil. The infiltration rate of a soil is variable and different from hydraulic conductivity which is the lowest rate at which water is absorbed by soil. Initially, water

infiltrates at a rate well in excess of the saturated hydraulic conductivity. The rate then rapidly declines until it reaches this value. The saturated hydraulic conductivity of a soil is therefore a meaningful measure of infiltration because its variability is small and, more importantly, it is a property which can be inferred from other soil characteristics.

The saturated hydraulic conductivity of soils is directly related to the size and distribution of pores in them (Marshall, 1959). The larger the particle size and/or aggregate size, the larger is the pore size and hydraulic conductivity. Thus the hydraulic conductivity of soils, in terms of distinguishable field characteristics, is dependent on soil aggregation and texture.

Texture is an expression of the proportions of different particle sizes in soils, and as the texture ranges from sand to clay, the hydraulic conductivity decreases. Soil structure is an expression of the arrangement of soil particles into aggregates which are always much larger than the size of the comprising particles. Consequently, the pore sizes between aggregates will always be larger than those between individual soil particles. It is obvious, therefore, that texture and structure interact in such a way that within each of the texture classes there will be a range of permeabilities dependent on the degree of structural development.

Thus the soil factors that need to be assessed with regard to erodibility are as follows:

1. Soil structure.
2. Soil texture.
3. Soil dispersibility.

The inter-relation of soil structure, texture and erodibility is complex. In an attempt to clarify the matter, the following general statements may help:

- a. Coarse-grained (sandy) soils tend to be poorly aggregated and therefore are highly detachable. They can therefore give rise to high rates of soil loss when saturated under heavy rainfall conditions. This particularly applies to water-repellent sands which have organic coatings which resist absorption of water.
- b. In contrast, because of their relatively large size, particles of the coarser-textured soils are less subject to movement by splash and/or runoff when compared with fine sands or silts. Sandy soils also have high infiltration rates and can absorb rainfall which would erode finer-textured soils in similar circumstances. (This does not apply to the water repellent sands mentioned above).

- c. Some clayey soils, although highly aggregated, are also highly detachable because of their friability or the ease with which they break into small aggregates. These soils (e.g. some krasnozems) can also be subject to high loss rates when saturated, although fortunately their infiltration capability is generally high also. This also applies to some self-mulching soils, whose friable surface structure is due to the cracking character of the clay present (e.g. black earths).
- d. In general, the more clayey soils have better aggregated profiles in an overall sense, and therefore are more resistant to erosion.
- e. Dispersible soils are generally clayey, and their normally large aggregates are very stable when dry, but become most unstable when wet.
- f. As clay contents increase, the character of soils is determined more by the type of clay present than by anything else. The contrast of significance to the soil conservationist is between the montmorillonite type which shrinks and swells markedly with changes in moisture content, and the kaolinite type which does not.

The montmorillonite clays characterize the cracking black and self-mulching soils which give rise to structural problems in banks, and high erodibility as mentioned under c. above, when cultivated.

The kaolinite clays, in soils of high clay content, give rise to massively-structured soils which are fairly resistant to erosion although having low infiltration rates.

- g. Soils with high silt and fine sand contents tend to lack coherence and be very unstable when wet, and are therefore highly erodible (cf. b. above).
- h. The most erosion-resistant soils are well-structured non-dispersible clay loams. These have sufficient clay to ensure adequate aggregation, but not sufficient to give rise to the problems described above. Their texture is well-graded which ensures reasonable infiltration rates and stability under more intensive usage.

In considering soil factors it must be realized that the basic erodibility of soils is only one component of a complex set of interactions which actually causes erosion. Some soils are particularly erodible only when cultivated, others only on steeper slopes. Management also plays a vital part - some soils can be "flogged" for years without undue damage, whereas others react violently under poor management the first year they are ploughed.

The main point at issue is that soils vary in their basic resistance to erosive forces, and the soil properties that determine this variation are largely dependent on texture, structure and dispersibility.

The various forms of soil erosion will now be briefly described. In general, we are concerned with erosion which is in excess of the natural or geologic erosion of the earth's surface - namely, that caused by man's use of the land. This is normally referred to as accelerated erosion.

Three main erosional forms occur in New South Wales; these are water erosion, wind erosion and landslip. Their names are self explanatory. Water erosion is normally divided into the three categories of sheet erosion, gully erosion and tunnel erosion.

2.1.2 Sheet Erosion

This is the name commonly used for the erosion process in which a fairly uniform layer of soil is removed from the land surface by rainfall and runoff water. It occurs where the land slope and form is such that the runoff does not significantly concentrate in small channels (rills) which increase in size down the slope. A combination of raindrop splash effects and overland flow of runoff is responsible for the process of sheet erosion.

However, it is likely that in most instances the word 'sheet' is a misnomer, as such erosion is unlikely to occur due to actual sheet flow in which runoff occurs evenly over the whole surface. Splash erosion would be the main process for the detachment of soil particles, with overland runoff assisting their passage downhill where it occurred.

Splash erosion is that soil movement resulting from the impact of raindrops on the soil. Soil particles are thus moved both upslope and downslope but because of normal gravitational effects the net movement is downslope.

Maximum effects of sheet and splash erosion occur on bare unprotected soils, particularly those which are loose in the surface due to cultivation or which have naturally friable or self mulching surfaces which do not crust.

However, soils which are loose and/or well structured in the surface will probably have higher infiltration rates and thus runoff will be minimal. Only when such soils become saturated will sheet erosion reach serious proportions. Soils which form a surface crust will naturally tend to shed more rainfall as runoff, but the associated soil loss may not be very high, particularly if the crust is well established. Some soils only seal rapidly with the onset of rainfall and the effect of splash erosion in blocking surface soil pores with finer soil particles.

The uniformity of soil particle and/or aggregate size, and the smoothness of the surface are also factors which contribute to the amount of sheet erosion which is likely to occur. Low, even slopes are most prone to this form of erosion - as slopes increase above 3-4% rill and gully erosion become the more common form. This is because runoff is then more likely to concentrate into channels.

The main factors in the reduction of sheet erosion are:

- (i) Maintenance of plant or trash cover to protect soil from splash and retard overland flow.
- (ii) Maintenance of a rough, cloddy soil surface.
- (iii) Cultivation on the contour.
- (iv) Elimination of unnecessary cultivations which tend to reduce soil aggregation.
- (v) Structural soil conservation measures such as contour banks, graded banks and contour furrows.

Any practice which encourages rainfall to enter the soil, having first lost its kinetic energy, will keep sheet erosion to a minimum. Cultural practices based on retention of plant residues, build-up of soil structure, contour working and avoidance of unnecessary cultivation will complement structural soil conservation measures to achieve complete control except during extreme rainfall events.

2.1.3 Gully Erosion

On slopes steeper than 3-4% sheet erosion becomes very localised and runoff tends to concentrate, firstly in rills or small channels a few centimetres in depth. The concentrated runoff then moves much faster than overland flow and is able to remove and carry a greater load of soil particles. This in turn scours the rills more deeply and the end result is gully erosion.

The difference between rills and gullies is only a matter of degree. Rills are generally regarded as those erosion channels which can be dealt with (filled and restored) by normal cultivation practices. Gullies are those which require earthmoving plant to fill them and special soil conservation treatment to prevent them washing out again. Any badly rilled or gullied land requires soil conservation treatment to maintain long term stability and productivity, particularly that which is regularly required to be cropped.

It could be said that rilling is generally associated with arable land because it commonly occurs under bare soil conditions and its more extreme form, gullying, can usually not be tolerated under a regular arable cropping situation. It either has to be treated and controlled or the land is

sown (or naturally reverts) to pasture. For this reason gullying tends to be associated with grazing land where it can be tolerated to a greater extent, and even controlled without filling the gullies in. Complete treatment including gully filling, however, is recommended where practicable.

The process of gullying is a fairly complex one, and depends on many factors including soils, geomorphology, land form, slope, land use and the characteristics of the catchment contributing to the gully system. A number of separate processes can be distinguished which either proceed at different rates and times or at the same time. These processes can be summarised as follows:

- (i) Channel scouring from rill to gully as already described.
- (ii) Headward erosion whereby the gully head migrates uphill by waterfall action. In the case of dispersible soils this is hastened by subsoil dispersion and undercutting and slumping of topsoil at the gully head.
- (iii) As the gully lengthens uphill the channel below widens and deepens. The catchment area directly above the gully decreases and the area on either side contributes to gully branching.
- (iv) In the latter stages of gully development, given reasonable climatic conditions for plant growth, the gully system will tend to reach an equilibrium. The gully heads will have progressed towards the tops of their respective catchments, thus reducing the rate of runoff to each one. The channels will tend to achieve stable gradients and with slumping the gully walls will reach a stable slope upon which vegetation can start to stabilize the whole system.

Whilst climatic factors have an overall controlling effect, soil characteristics have a significant role in determining the rate of gully development and the shape of the gully formed. V or U-shaped gullies will form depending on the relationship between the erodibilities of topsoil and subsoil and, indeed, other sub-surface layers. Dispersible soils contribute to some of the most dramatic gully erosion - often because of the sheer amount of soil removed and the consequent size of the eroded channel, but also because of the effects of undercutting and the phenomenon of "cathedralism" so well known to the soil conservationist on the Central and Southern Tablelands. This occurs due to the rapid vertical rilling of gully sides which subsequently get cut back leaving isolated pinnacles or "cathedrals". Tunnel erosion is often associated with these soils.

2.1.4 Tunnel Erosion

This form of erosion occurs in soils whose subsoil is more unstable than its topsoil. The most typical form of tunnel erosion results from the saturation of the subsoil clay with sodium during the soil's formation or even following a major change in land use in the area concerned. The sodic clay is very unstable (or dispersible) in water, and in wet conditions any weakness, crack or channel in such material allows movement of dispersed clay downhill (underground) provided an outlet is available somewhere. This results in the formation of 'tunnels' which get bigger gradually, eventually joining up and causing slumping of the topsoil inwards and the resumption of more normal gully erosion.

Subsoils with high exchangeable sodium are not, however, always a necessary prerequisite for this type of sub-surface erosion. It can occur when surface water soaks through permeable soil layers until restricted in its downward movement by a more impermeable layer. The tendency then is for lateral movement to take place to an outlet lower down the slope or in the side of a gully. Depending on the velocity of flow, very fine material is then transported towards the outlet and a tunnel formed through which further (and larger) material can be moved.

This type of subsoil failure is also an important cause of tunnelling in earth dams built from such soil materials. This aspect will be considered fully in later sections of the handbook.

2.1.5 Landslip Erosion

The problem of soil mass movement occurs within both agricultural and urban environments of New South Wales. However, its effects are more serious within urbanised areas due to the high economic costs involved. The occurrence of landslip or slope failure depends on several factors, the main ones being soil mineralogy, site drainage and slope-soil morphology. The combination of these factors predetermines the occurrence of mass movement. Using soils information in conjunction with other site data it is possible to delineate areas susceptible to mass movement with considerable accuracy.

Mass movement refers to the displacement of material on slopes, in which the centre of gravity of the unstable mass moves downslope.

The main factors responsible are:

- (i) increase of shearing stress without change in the shearing resistance of the slope. A typical example occurs when the average slope is increased by 'cut and 'fill'.
- (ii) unaltered shearing stress associated with a change in the shearing resistance of the slope. For example, a change in the drainage pattern can increase pore water pressure of the soil material on the slope and this increases the susceptibility to movement.

The major types of mass movement can be broadly classified into two groups - slides and flows. A complex type occurs as a combination of both processes.

In the "slide process", movement results from shear failure along one or several surfaces. Varnes (1958) distinguished two subgroups of this movement.

- (i) those in which the moving mass is not greatly deformed, and
- (ii) those which are greatly deformed or comprise a number of small units.

The "flow-process" is defined as the displacement of rock or soil material in a form similar to the behaviour of a viscous fluid. The material is unconsolidated at the time of flow but may consist of rock fragments, fine granular material or plastic clays.

Slope failure usually occurs within the soil mantle rather than within unweathered bedrock, hence soil data provide a valuable means of analysing the physical behaviour of a slope. Soil investigations for land slip studies are divided essentially into two categories; firstly, field data, and secondly, laboratory data. Field data consist of measurements and observations regarding the characteristics of the soil material as it exists in situ, but may also need to be taken from field experiments or trials. The latter category generally relates to permeability and soil movement.

The following soil properties are of particular relevance to field classification in areas susceptible to landslip:

- (a) Texture of A and B horizons
- (b) Depth to bedrock
- (c) Nature of the parent material
- (d) Presence of colluvial detritus within the solum
- (e) Soil structure of A and B horizons
- (f) Profile and site drainage
- (g) Soil colour - especially presence of mottles within B horizon
- (h) Special features, i.e. indurated horizon, gravel layers or evidence of water table.

An important procedure in landslip analyses is the use of geophysics to identify soil and slope characteristics in areas susceptible to mass movement. Soil depth, the nature and thickness of parent material and bedrock lithology can be determined by interpretation of seismic travel-times using a signal enhancement seismograph. This technique overcomes two of the basic problems to date, the depth limitation of soil augers and the difficulties involved with truck and trailer mounted machinery on terrain associated with, or suspected of, mass movement.

Many laboratory procedures are available for evaluation of the engineering properties of soils. They

generally relate in some way or can be related to, soil strength, although they do not all necessarily measure this particular parameter. The laboratory tests commonly used to define the physical behaviour of a soil in relation to mass movement are:

- (i) Particle size distribution and Unified Soil Classification.
- (ii) Atterberg limits - plastic and liquid limits, plasticity index.
- (iii) Linear Shrinkage
- (iv) Emerson Aggregate Test - dispersibility
- (v) Shear Strength - direct, confined, unconfined, triaxial, California Bearing Ratio (CBR)
- (vi) Proctor compaction - for bulk density and optimum moisture content.
- (vii) Cone penetrometer
- (viii) Field moisture content
- (ix) Cation Exchange Capacity
- (x) X-ray Diffraction and X-ray Fluorescence for identification of clay mineralogy.

In most cases it is not necessary to carry out all the laboratory tests listed above because many are time consuming or too costly for routine survey. Prior to each investigation a thorough examination should be undertaken of the laboratory facilities and resources available, together with the scale and purpose of survey. Methods such as cation exchange capacity and x-ray diffraction are impractical for routine analyses, although they provide conclusive evidence for interpretation of clay mineralogy from Atterberg Limits.

The scale of the survey is an important consideration in selection of laboratory tests, triaxial shear tests are appropriate for intensive surveys (large numbers of samples) on small sites at large scales, but are meaningless on a few samples at small scales over a large area. Therefore, prior to commencing a survey which involves landslide analysis it is necessary to carefully analyse the practicality and predictive value of laboratory tests with the requirements and purpose of the study.

2.1.6 Wind Erosion

This form of erosion occurs as a result of the direct action of wind on soil particles. Three processes are involved, which overlap and interact with each other:

- (a) Surface creep - the movement of large particles too heavy to be lifted into the air.
- (b) Saltation - smaller particles are lifted off the surface but because of their size cannot be carried in suspension. They therefore 'bounce' across the surface, and in so doing dislodge smaller particles each time they land - thus further eroding the surface.
- (c) Suspension - fine particles of silt and clay size ($<.02\text{mm}$) are carried along by the wind in suspension, and do not rapidly return to the surface. Such particles can be carried great distances in dust storms.

Saltation is probably the most important of these processes and typically affects particles in the fine sand range. Thus soils with single-grain structure and very sandy surfaces are likely to be most susceptible to wind erosion. Clay and silt will naturally give rise to more aggregated soils and these will tend to resist removal by wind, as will very coarse sandy or gravelly soils by virtue of their larger particle sizes. Any of the aggregation - promoting substances such as clay, organic matter, ferric iron and other polyvalent cations will tend to enhance a soil's resistance to wind erosion, as will the presence of moisture.

One of the main factors, however, in the reduction of wind erosion, is the presence of relatively large objects at the soil surface such as stones and vegetation. These can have a very marked effect even if their distribution is fairly sparse. Their effectiveness depends largely on their shape, with tall narrow objects being more effective than low wide ones. Thus the role of vegetative cover, and the growth habit of plants comprising that cover, are of paramount importance in protecting the land surface from erosion by wind. The roughness of the soil surface is also worthy of consideration.

Soils most susceptible to wind erosion tend to be single grained with poor aggregate stability and predominance of fine sand particles. Thus, soils of arid and semiarid Australia subject to pastoral use, in which accelerated wind erosion is most prevalent, can be classified for wind erodibility depending on texture (Marshall 1973) as follows:

Table 2.1 Soils Susceptible to Wind Erosion as a Percentage of Pastorally used Semi-arid and Arid Australia.

Category	Silt and Clay Content	Percentage of Area
Highly erodible (including desert sand, desert sand plains, mallee sand hills, brown mallee soils, podzols)	<20 per cent	14.8
Moderately erodible (including desert loam, brown soils of light texture, skeletal soils of ranges, red brown earths)	20-40 per cent	58.7
Non-erodible (including stony desert, grey and brown soils of heavy texture, black earths, coastal soils)	>40 per cent	26.5

It can therefore be seen that texture is a key property in assessing the susceptibility of a soil to wind erosion, and structure at the surface is also of considerable importance. However, the likelihood of such erosion actually occurring is more likely to be dependent on climatic conditions in the area concerned. Drought and wind erosion are thus related through the effect of dry conditions in reducing vegetative cover, drying out the soil and adversely affecting surface aggregation by exposure.

2.2 Soils in relation to vegetation

Soil is, of course, the natural medium in which plants grow. Without man's intervention, therefore, soil would be largely protected by the most suitable vegetation adapted to each climatic environment, and accelerated erosion as we know it would be virtually non-existent. It is important to remember this, as the role of vegetation in any long-term soil conservation programme is vital.

Vegetation has direct and indirect effects on soil, when considered from the soil conservation angle. Directly, it protects the soil by one or more of a number of means which can be summarized as follows:

- (a) It creates a canopy which reduces the impact of falling rain drops on the soil.

- (b) It creates a near-ground retardance to overland runoff flow.
- (c) It develops a root system which generally tends to bind the soil together.

Indirectly, vegetation breaks down with time to give organic matter which tends to favour aggregation of the soil and resistance to detachment by erosive forces.

In order that plants may grow and survive in a soil, suitable conditions must exist for their establishment, development and reproduction. With some soils, for example, the survival of small germinating seeds (e.g. grasses) is dependent on the surface soil not cracking. This is a major problem with the black earths of the north west, on which difficulty is experienced in satisfactorily establishing productive pastures on a broad-acre basis. Thus the benefits of a pasture phase to the stability of many of these soils is denied, once they have been cultivated.

The soil's fertility is the soil's ability to support plant life. Low fertility in soils can be caused by a number of factors which can be broadly classified under two headings, physical and chemical, depending on whether the low fertility is related to the physical features of the soil such as water relations, air space, structure or texture, or to the chemical features of the soil such as pH, plant nutrient availability, or salinity.

The soils which are found in the potentially agricultural parts of New South Wales have been grouped into five fertility groups in table 2.2. The table is a general one and relates to those areas with potential for cropping and/or pasture improvement.

Naturally, climate has an over-riding part to play in the growth of crops or pasture, and the rainfall/evaporation pattern in particular will determine what areas can be developed for agriculture or pasture improvement. The removal of topsoil by erosion, in many parts of the State, will also affect the soil's potential for more intensive use of the land for crop growing. This is because the fertility of major importance to crop growth tends to be concentrated in the surface soil horizons. The subsoil is of importance in relation to drainage, overall water holding capacity, growth of deep rooting plants and long term supply of minerals and nutrients. The groupings in table 2.2 are therefore based on the physical and chemical features of soils in their natural, uneroded condition.

Group 1 includes soils which due to their poor physical and/or chemical status only support limited plant growth. The maximum agricultural use of these soils is

sparse grazing. This group includes shallow and sandy or stony soils which by virtue of their poor water retention characteristics can support only limited plant growth. The solonchaks are chemically inhibitive to plant growth, while the calcareous sands are so deficient in cobalt and copper that animals grazing on them are affected (Stace et al 1968).

Group 2 includes soils with low fertilities, such that generally only plants suited to grazing can be supported. Large inputs of fertilizers are required to make the soil usable for arable purposes.

The podzols, due to their poor water retention characteristics, are borderline between this group and group 1. The remaining soil types within this group are generally chemically deficient in nitrogen, phosphorus and many other elements. The solodized solonetz, solodic soils and soloths also have poor physical conditions and difficult moisture relationships (Stace et al 1968). The red earths are a highly variable group of soils and some of the finer textured types could be placed in group 3.

Group 3 soils have low to moderate fertilities and usually require fertilizer and/or have some physical restrictions for arable use.

Except for the terra rossa and alpine humus soils, the soils within this group are moderately deficient in nitrogen and phosphorus and some other elements. The terra rossa soils and alpine humus soils have better chemical fertilities, but their shallow total depths limit their potential for plant growth. The grey, red and brown clays also have a somewhat better chemical status than the other soils within this group, but many of them are sufficiently hardsetting for seedling emergence to be restricted. The high clay contents and strongly coherent nature of the subsoils restrict water and root penetration. The red podzolic soils are a highly variable group and some of the lighter textured types may be more appropriately placed in group 2.

Group 4 soils have a high level of fertility in their virgin state, but this fertility is significantly reduced after only a few years of cultivation.

The chocolate soils and euzozems have a high level of fertility in their virgin state, but phosphate fertilizers are generally required after only a few cultivations. Physically, the krasnozems are better off than most soils; their high clay content gives them a high water holding capacity; their structural condition and comparatively low swelling ability enable water to penetrate easily.

Chemically, krasnozems are not so well off. They have a moderately acid pH which, if too low, allows solution of iron and aluminium leading to serious phosphorus fixation (Corbett 1972).

Table 2.2 Relative Fertility of N.S.W. Soils

Group 1 -		
	Solonchaks	LOW
	Lithosols	FERTILITY
	Calcareous sands	
	Siliceous sands	
	Earthy sands	
	Grey brown and red calcareous soils	
	Ironstone gravels	
Group 2 -		
	Solodised solonetz and solodic soils	
	Solods	
	Red earths	
	Yellow earths	
	Solonised brown soils	
	Yellow podzolic soils	
	Lateritic podzolic soils	
	Podzols	
	Acid grey earths	
	Acid bleached grey earths	
Group 3 -		
	Grey, brown and red clays	
	Red-brown earths	
	Non-calcareous brown soils	
	Terra rossa soils	
	Xanthozems	
	Red podzolic soils	
	Alpine humus soils	
	Humic gleys	
	Deep red and yellow friable loams	
Group 4 -		
	Chocolate soils	
	Euchrozems	
	Krasnozems	
Group 5 -		
	Black earths	
	Chernozems	HIGH
	Prairie soils	FERTILITY

Group 5 soils have high fertilities and these soils generally only require treatment with chemical fertilizers after several years of cultivation.

These soils generally provide good chemical and physical conditions for plant growth. The black earths are well known for their high fertility and have produced high yields without added fertilizers. However, the use of nitrogenous fertilizers is now increasing and responses to phosphates are being obtained on some soils (Stace et al 1968).

Fertility is naturally of paramount importance to the growth of vegetation in all soils. One of the main problems in the revegetation of eroded areas is that the more fertile topsoil has often been removed. The exposed subsoil presents a harsh environment for new plant growth, usually lacking in sufficient nutrients. It also often lacks a suitable surface structure to enable penetration of air, water and plant roots. If these problems of chemical and physical infertility can be overcome then there is every reason to expect any revegetation work to succeed.

Another soil factor which may be of importance in relation to vegetation is that of soil pH. pH is a measure of the acidity or alkalinity of a soil on a scale of 0-14, with low figures representing very acid soils and high figures very alkaline soils. A pH of 7.0 means the soil is neutral, and most plants thrive best at a pH between 6.0 and 7.5. Different plants have different tolerances to acidity or alkalinity, some preferring quite acid soils while others do better under alkaline conditions. For the establishment of legumes certain rhizobia are inhibited under acid conditions, hence the benefits of lime pelleting of legume seeds. Soil pH levels generally fall between 4.0 and 10.0 with extreme figures being rare. Surface soils are normally more acid than subsoils, because of the effects of leaching and organic matter in producing more acid conditions in the surface soil, and the more likely accumulation of lime and similar alkaline compounds in subsoil. The availability of various nutrient elements also varies with pH, with the majority being available on the acid side of neutral.

Salinity is another soil factor which may affect vegetative growth. Salinity is due to the accumulation of soluble salts in soil, mainly sodium chloride. As with pH, plants vary widely in their tolerance of salts in soils, but most pasture species and crop plants will not grow well when salt contents rise above normal levels. Salinity is assessed by measuring the ability of a soil/water extract to conduct electric current. The standard conductivity is expressed in millimhos /cm at 25°C and a level of 4.0 is generally accepted as the upper limit of salinity for normal plants. (The standard S.I. unit of electrical conductance is now the Siemen - millisiemens (mS) and millimhos being directly equivalent).

Soil moisture relations are clearly of paramount importance when plant growth is under consideration. The ability of a soil to absorb and hold water to sustain growth in dry periods characterizes the best agricultural soils, and this is no less important in revegetation work. Infiltration has already been mentioned in section 2.1, and this concept will be further developed in section 2.4, dealing with soils in relation to hydrology.

Other soil properties important to vegetation growth are soil cation exchange, the soil microbial population and the breakdown of organic matter. An excellent account of soil properties in relation to plant growth is given by Russell (1973) and the reader is referred there for further detailed information.

The things the soil conservationist needs to know about soils in relation to vegetative establishment and growth can be summarized as follows:

1. Fertility.
2. Structural condition, particularly at the surface. (Aeration, water penetration and holding, root penetration).
3. Soil pH and salinity.
4. Presence or absence of the topsoil (A₁ horizon).

2.3 Soils in Relation to Land Use

2.3.1 General

All forms of land use depend to a greater or lesser extent on the soil and its characteristics. Whether one wants to develop a ski-run, an open-cut coal mine, a wheat property, a dairy farm, a sewerage works, a residential subdivision or an airport - the actual process of development and the long term stability of the development will depend, to some degree, on the properties of the soils in the area concerned. The soils may be used for a variety of purposes.

These include:

- (a) Traffic - people, animals
- (b) Permanent vegetation - grass, trees
- (c) Non-permanent vegetation - cultivation, crops
- (d) Filtration -sewerage treatment, catchment hydrology
- (e) Support - foundations of roads, buildings
- (f) Earthworks - levees, embankments, soil conservation structures
- (g) Restoration - disturbed sites (topsoil)
- (h) Water retention - dams, septic tanks

For each use a different set of soil properties will be of critical importance. In addition, given the extremes of climate and landform present in New South Wales, each will be subject to some form of soil erosion. The extent and form of this erosion will again depend on soil properties.

We are thus concerned, not only with those soil properties which allow a certain form of land use, but also with the soil conservation properties which allow the land to sustain such use without degradation.

The two main areas of land use where soil erosion can be a major problem are agricultural production and urban development, and it is therefore with these two aspects that this text deals. The emphasis herein is on the soil data which are necessary inputs into the assessment of land capability for these two broad types of use. It is acknowledged that climate, landform and land slope are also of great importance to each, with climate being the critical factor particularly in any agricultural production. However, discussion of climate and landform in this context is considered beyond the scope of this book.

2.3.2 Agricultural Production

All agriculture depends ultimately on the capacity of the soil to grow and sustain the growth of plants of one sort or another. Land capability for agriculture will therefore relate to the soil properties concerned with:

- (a) Physical and chemical fertility (capacity to grow plants)
- (b) Cultivation (capacity to be disturbed regularly where arable crops are to be grown)
- (c) Soil conservation (capacity to permanently sustain a and b without deterioration)

Generally speaking agriculture is concerned with the use of the topsoil or the uppermost soil horizons, since it is these layers in which plant roots concentrate, which are involved in the majority of cultivations, and which are eroded most readily if not protected. Subsoil or the lower soil horizons are of secondary importance in relation to drainage and stability when wet, and in as far as they determine to a large extent the character of the topsoil in a long term (pedologic) sense.

The soil properties which need to be understood in relation to agricultural production can be summarised as follows:

- (a) Physical and chemical fertility
 - Physical - aeration, structure, infiltration and drainage; surface stability water holding capacity, texture,
 - Chemical - nutrient supply, pH, salinity, toxicity, alkalinity, organic matter.
- (b) Cultivation - aggregate stability, texture, consistence, wet and dry strength, depth, wetness and drainage, rockiness or stoniness.
- (c) Soil Conservation - Soil erodibility, texture, structure, dispersibility, infiltration and permeability. Suitability for conservation methods - earth structures, stubble mulching, minimum tillage, existing erosion.

The role of these soil characteristics in relation to agricultural land use is further developed in more detail in Section 5.2.

2.3.3 Urban Development

In urban applications the capacity of the soil to grow plants becomes of somewhat less importance although the long term stability of urban areas (disturbed or otherwise) will still depend on the use of vegetation in many instances. We are more concerned here with the engineering properties of soils, as urban development can be regarded as a far more intensive use of land than agriculture, and the stresses on the soils in such areas are far greater, particularly in the development period.

Land capability for urban development will therefore relate to the soil properties concerned with:

- (a) Engineering suitability (or limitations) for residential, commercial, industrial and recreational use.
- (b) Engineering suitability (or limitations) for sewerage disposal facilities, building foundations, storage reservoirs, embankments etc.
- (c) Location of roads, railways, pipelines etc.
- (d) Suitability for sand, gravel and other mineral supplies.

Soil conservation considerations during the period of development are particularly important, and the soil properties relating to them will also be relevant to the long term stability of the urban area generally.

Whereas agriculture is more concerned with topsoils, urban developments involve subsoils to a much greater extent. This is because topsoil is generally removed and replaced afterwards (or should be), and the majority of structures which typify the urban scene are built in or on, or involve the excavation of, subsoil.

The soil properties which need to be understood in relation to urban development can be summarised as follows:

- Susceptibility to mass movement (engineering properties)
- Shrink-swell potential (engineering properties)
- Suitability for foundation material (engineering properties)
- Soil dispersibility and erodibility
- Permeability
- Salinity
- Fertility

The role of these soil characteristics in relation to urban land use is further developed in more detail in Section 5.3.

2.4 Soils in Relation to Hydrology and Design

Hydrology can be defined as the study of the fate of rainfall - both that which is absorbed by the soil and that which runs off. Runoff occurs when the soil cannot absorb rainfall at the rate at which it falls. This normally is due to the soil having a low absorptive capacity, a surface which seals rapidly, or being already saturated with water. The runoff which occurs is one of the chief agents for soil removal, and thus this aspects of hydrology is of prime interest to us. Hydrological studies seek to quantify and inter-relate the factors which cause runoff such as rainfall intensities, land slopes, land form, land use, ground cover and soil characteristics.

The information gained from such studies forms the basis for soil conservation design principles. These are applied to the determination of the coefficient of runoff, times of concentration, rates of flow in various types of channels, bank spacings and so on.

The soil naturally has a big part to play in hydrology. It is the soil type which, to a significant extent, determines the fate of rainfall, particularly under arable conditions. Once runoff occurs, soil type also determines the extent of erosion damage that will occur. The soil's ability to absorb rainfall is, however, the factor which has the most bearing on the runoff aspects of hydrology. This depends on structural features of both the surface soil and the soil profile, the profile depth, soil texture, surface-sealing characteristics and cracking patterns.

A grouping of the interactions between texture class and structure grade of A horizon soils, plus the resultant qualitative assessment of soil permeability is presented in Table 6.1 (Chapter 6).

2.4.1 Infiltration Capacity

Infiltration capacity is defined here as the maximum quantity of water a soil is capable of absorbing. That is, no regard is taken of the restrictions placed on the rate of entry to, or drainage from, the profile. In this form, infiltration capacity is a property dependent on the porosity and depth of soil. Porosity is defined as the ratio of the volume of voids to the total volume (voids + solid) of soil, and is therefore a function of the soil texture. The porosity increases as the texture becomes finer.

Description of the interactions between soil texture and depth, to give three classes of infiltration capacity, are presented in Table 6.2 (Chapter 6).

2.4.2 Drainage

Drainage is normally inferred from the texture and structure of the lowest soil horizon. An arbitrary soil depth of 0.5m is chosen to separate the appropriate horizon properties that are to be used to infer the permeability class, which then by definition becomes the drainage class.

These groupings of soils, according to infiltration characteristics, form a basis for the understanding of soils in relation to hydrology. Later, in Chapter 6, these aspects will be discussed in more detail.

2.5 Soils in relation to earthworks

The Service is largely responsible, in New South Wales, for the construction of soil conservation earthworks. This generally means that the extension soil conservationist is concerned with earthmoving. Soil has to be moved from its normal situation to form gully control structures, banks, waterways, flumes and gully fill. For these structures to be successful, therefore, the officer responsible must understand something of the likely behaviour of the soil material in the new situation. It will now have a different role to perform. Questions to be answered are - how will it react to drying and wetting, to pressure from stored water, to cultivation, to compaction, to new exposure or to erosive forces?

Consideration must therefore be given to soil problems associated with structural works and the relevant properties of importance in the practical situation of an earth embankment. (Further details of soil as an engineering material, and its testing, will be dealt with in Chapter 7).

The earth embankment of a bank, a dam, or a gully control structure must be designed and constructed so that there is no appreciable amount of water movement through the bank and so that it will be stable. By stable we mean that it will be able to retain its position, shape and ability to retard water movement over time. Three general considerations are therefore appropriate - permeability of the embankment, its compaction and its stability.

2.5.1 Permeability

The voids in a soil mass provide passages through which water may move. These vary in size and the paths are tortuous and interconnected. The water movement through these paths in a soil mass is known as percolation or seepage and the measure of it is called permeability.

Permeabilities vary widely. If less than 1m per year the material is considered impervious; if between 1m and 30m per year semi-pervious; if greater than 30m per year pervious.

No soil mass is completely impermeable and if the structure holds water for a sufficiently long period, seepage will result in the saturation of much of the material. The time taken to reach a steady state condition will depend on the seepage rate, which in turn will depend on the nature of the voids, the hydraulic head and the length of the path. The route this path takes (or phreatic line) depends on the uniformity and permeability of the material in the wall.

2.5.2 Compaction

Compaction of the soil moves air and water from the mass and moves the soil particles and aggregates into positions such that the volume of voids is decreased. Reduction in the volume of the voids results in a reduced rate of percolation.

The amount that a volume of soil is compacted will depend on:

(a) The work applied

This will involve the force applied and the duration of the application. The greater the force the more the compaction. Records show that the loading intensity under the track of a typical dozer is about 50 kPa (7.5 lb/sq.in). The implement with the higher loading exerts the greater force and achieves more compaction. Repeated passes over the soil will mean the application of the force for a longer period and so greater compaction.

Pressures applied at the surface of the soil are distributed within the soil mass. This means that if soils are to be compacted, they must be in thin layers when the compacting force is applied. The thickness that can be used will depend on the moisture content and the compacting machinery.

(b) The nature of the material

Soil materials vary in the degree to which they can be compacted and in the amount of work necessary to achieve compaction. Materials from which air and water can readily be excluded, and the particles of which can be readily moved into new positions, will be easier to compact than those with opposite properties. Thus sandy materials are easier to compact than are silts and low plasticity clays, with plastic clays the most difficult.

(c) The water content

Every cohesive material has an optimum moisture content at which maximum density is obtained. At moisture contents lower than optimum, the presence of air gives

elasticity (as air is easily compressible) and there may be insufficient moisture to provide adequate lubrication for the particles. At moisture contents above optimum, insufficient moisture is excluded to give maximum density.

Consolidation will naturally take place because of the weight of the material in the bank. Settlement of the bank is a result. Some consolidation will take place in dry material as air is expelled, but most will occur after moisture content has been raised to a high level or to saturation. Air is excluded on wetting, large aggregates are slaked, particles are lubricated, and there is the extra weight resulting from the water. Water is gradually excluded and consolidation takes place.

The amount of consolidation will depend on the nature of the material and the degree of initial compaction. Compressibility of the material is a measure of the amount of consolidation that is likely to occur. If compressibility is high, a large amount of consolidation may result in excessive settlement resulting in danger of over-topping or cracking.

2.5.3 Stability

Stability will be affected by the likelihood of the four main destructive processes occurring. These are:

(a) Tunnelling

Tunnelling results when two conditions occur within an embankment.

Firstly, seepage takes place at a relatively high rate. This may be as a result of the materials being loosely placed and so very permeable, the presence of cracks following soil drying and shrinking, or the presence of a line of weakness following uneven consolidation. The rate of seepage will also be governed by the hydraulic gradient, that is by the hydrostatic head and the length of the seepage path.

Secondly, dispersible soil occurs within the embankment. The soil aggregates when wet separate into the individual particles and translocation of these takes place in seepage and the tunnel rapidly enlarges.

Although the soil may contain potentially dispersible clay, the actual occurrence of dispersion will be governed to some extent by the electrolyte (soluble salt) content of the seepage water. With a low electrolyte content dispersion may take place, but with a higher content the soil may remain flocculated. Rapid runoff following heavy rains would contain little electrolyte; by contrast, spring water may have an appreciable content of salt.

Control of tunnelling is achieved by controlling seepage and dispersion. The rate of seepage may be lowered by decreasing the voids in the embankment, i.e. by compaction. Adequate compaction will also reduce the risk of lines of weakness being formed by differential settlement within the embankment.

The rate of seepage can also be reduced by reducing the hydraulic gradient by the use of longer batters and greater top widths so as to increase the length of the water path. For a structure built in a gully the filling of the gully for some 5 to 10 m below the structures should help appreciably.

In large dams seepage is controlled by the use of zoned embankments. In many soil conservation structures this is impracticable but a modified form may be useful. The placing of some of the waste pervious material in the downstream toe or the leaving of topsoil under the lower quarter of the wall could assist in seepage control and help prevent tunnelling. Topsoiling of the embankment could also be of assistance, as a buffering zone is provided on both upstream and downstream batters.

Dispersion results from chemical phenomena so chemical control would appear a possible solution. Further investigations are still needed in this field. The matter is discussed more fully in chapter 7.

Replacement of the sodium ion with a cation which would not cause dispersion is now possible. This is not simple and large quantities of chemical would be needed. The modification of the electrolyte content of the water may also be possible. This would be difficult under field conditions and where rapid inflow takes place.

(b) Cracking

Cracking results from expansion and subsequent contraction within the clay particles as water content changes. It is associated principally with montmorillonite clays.

The amount of cracking will depend not only on the proportion of clay, the clay type and the water content changes, but also on the cations present. If sodium is the dominant cation then cracking will be more severe than if calcium is dominant.

After prolonged drying a cracking pattern seems to form in the subsoil and these cracks or lines of weakness appear to be very persistent even when re-wetting takes place. This could be due to the slow rate of water intake and movement within the soils subject to cracking.

At this stage no fully effective methods for the control of cracking can be given. The following would appear to have some beneficial effects. The destruction of existing cracks and cracking patterns on the bank site prior to construction. Measures designed to minimise moisture changes within the bank should be helpful; e.g. cultivation and weed control.

The use of broad-based, relatively massive structures means that only cracks that extend for some distance pass beneath the full width of the bank. Broad-based banks also allow for cultivation which will tend to keep cracks full of soil. With large banks and dams the compaction of the core, (particularly if this is constructed when the moisture content approaches optimum) may reduce moisture content changes. The compacted core should be keyed into underlying material.

(c) Settlement

Unexpected settlement may result in overtopping of the embankment. Control is by recognition of the problem and allowing adequate freeboard.

(d) Collapse of the batters and slumping

This results from low shear strength of the materials when they become very wet or saturated. The cause is over-steep batter gradients for the particular material and prevention lies in the use of adequate batters.

It should be apparent from the foregoing section that an understanding of soils in relation to earthworks is a very different matter from considerations related to vegetation or even erosion. The soil has to be studied from a different viewpoint - from that of being a mixture of material with certain physical properties.

We are particularly concerned with the way the soil material reacts when used in a soil conservation structure of some sort, and then subjected to periods of inundation, wetting and drying. For this reason a chapter of this handbook has been devoted to a study of the engineering properties of soil materials which control their behaviour in these situations. This will be found in Chapter 7.

Chapter 3

THE SOIL PROFILE

This chapter considers the soil as it occurs in the field. The natural variability of soils is due to a multitude of factors; parent material, climate and erosional/depositional processes over many years being the most important. These and many other factors have contributed to the formation processes which have given rise to present soils. Any study of soils is therefore incomplete without some effort to set out the principles and processes which have made soils the way they are.

Some traditional and up-to-date ideas on soil formation are therefore presented followed by an account of soil morphology - or the overall structure of the whole soil. This structure is best seen and studied in a soil profile, and a standard system for studying and naming the different parts of a profile is then set out.

Sections follow on the distribution of soils, both vertically and laterally, and how they can be surveyed and mapped. The particular requirements of the Service in this regard are described.

3.1 Soil Formation

It is not intended here to present a long treatise on the subject of soil formation, which has been surrounded by controversy since it was first studied seriously in the later part of last century. However, it is useful to have a general background to the subject, particularly regarding the basic principles which have been developed, and which apply to the formation of soils in all situations.

The Russians were the first soil scientists to study soil formation in any depth. Led by Dokuchaev, they developed the concept of the zonality of soils, with emphasis being placed on the climate as the primary controlling factor. Three broad classes of soils were defined, based on this principle.

Zonal soils were those typical of a certain climatic zone, and which reflected that climate in their properties and morphology. They developed a full profile as the result of the overriding effect of climate on whatever parent material was present.

Intrazonal soils were then those where other, more local effects also came into play. Parent material had a stronger influence, as did relief, drainage, and vegetation. These other influences were reflected in the morphology of the soils in various ways, although full profiles were developed.

Azonal soils were those where the time factor became important, and circumstances did not allow the development of full profiles which were in balance with the environment. Examples such as skeletal soils on hill slopes, and alluvial soils on bottom lands, lacked profile development due to the interaction of the erosion/deposition cycle and the time factor.

These ideas were not completely accepted in America, where geologically-based soil studies had been pre-dominant. Marbut translated some of the earlier Russian work, but considered that climatic or geological concepts on their own were not adequate. He developed the first classification of soils based solely on soil properties. Jenny was another American who developed Marbut's ideas and much later (in 1941) put forward the proposal that soil variation could be accounted for by the following five factors:

Climate

Parent material

Organisms

Relief

Time

The term Climate includes all atmospheric forces acting on the soil.

The term Parent material means the material from which the soil horizons have developed.

The term Organisms includes all soil flora and fauna and their remains.

The term Relief means the configuration of the soil surface, including slope, exposure, position on a slope, water table and drainage.

The term Time refers to the duration of weathering.

Jenny first considered these five factors as independent variables, but later acknowledged that it would be more realistic to consider them as dependent, particularly climate and organisms. Another problem with this approach was the implication that soils develop under a constant set of conditions, which is only likely to be true for very young soils. However, despite these objections to such a factorial system, Jenny's ideas still stand as the basic framework on which soil formation theories are built.

The American work on soil formation was mirrored to a certain extent in Australia, where early work, by Jensen, had a strong geological bias. Prescott later developed the concept of soils and their formation being dependent on vegetation and climate, and presented these ideas in a classic text in 1931. Stephens followed this work through and, applying Jenny's factorial approach in a more realistic manner, developed a classification for the full range of Australian soils based on their mode of formation. To Stephens must go

the credit for developing the Great Soil Group concept in Australia, which has been the basis for Australian soil studies to the present day.

The main way in which climate is reflected in soils is by the degree of downward movement of soluble and fine material. This is dependent on the degree of downward movement of water in the soil profile, which in turn is dependent on the relationships between precipitation (P) and evaporation (E).

Where P is greater than E over a long period, the net movement of water in the soil is downwards, and soluble and fine materials get washed or leached to lower levels, and possibly removed altogether. The main materials under consideration are soluble salts, organic compounds from plant breakdown, oxides of iron, and various clay materials. In soils of wet climates, therefore, these tend to be moved into the subsoil, or removed altogether in the case of soluble salts. Thus in true podzols, which are normally the leached soils of cool temperate climates, there is accumulation of clay, dark-coloured organic compounds and red or brown coloured oxides of iron in the subsoil. In podzolic soils, which tend to occur in somewhat drier climates, there is only removal of clay and oxides. Such leached soils, because of the marked accumulation of clay in the subsoil, are typically "duplex" in character. Prairie soils, typical of still drier areas only show a slight tendency for clay concentration in the subsoil.

Where P is approximately equal to E, then evidence of leaching is still less strong and soil profiles tend to be more uniform in texture. In addition, some of the less soluble compounds will tend to accumulate at depth, as water movement through the soil is not complete. Thus, in black earths and prairie soils there is a tendency for calcium carbonate or lime to be found in the subsoil (less so in prairie soils than black earths).

Where P is less than E, an arid climate is indicated, and soils do not get leached to any depth. Thus the net movement of water in the profile is upwards - the soils getting wet only to a shallow depth, and then drying out again so that all moisture is eventually lost to the atmosphere. In this situation leaching is minimal, and lime and other more soluble compounds (typically gypsum or calcium sulphate) tend to accumulate at quite shallow depths in the soil.

This broad principle covers the effect of climate on the distribution of soils in Australia but there are obvious anomalies - for example the red-brown earth, which is markedly duplex but is characterized by accumulation of lime in the subsoil. Also the krasnozem which is typically formed under high rainfall conditions but is fairly uniform in colour and texture. In this soil one would expect obvious evidence of leaching. The solonetzic soils are markedly duplex but can contain both lime and soluble salts in the subsoil. These three soils can be regarded as intrazonal, and are examples of where parent material and other local influences have come into play more strongly.

Such anomalies as those just mentioned have, in the last twenty years, caused pedologists to question some of the soil formation theories of the past. Scientific evidence has also thrown some of them into doubt. The following factors have caused other ideas to be developed:

Evidence that duplicity in a soil is not necessarily the result of leaching.

The processes of erosion/deposition have not been taken into account sufficiently.

Previous over-emphasis on the role of climate and vegetation.

Previous under-emphasis on the role of parent material.

Newer concepts, particularly those developed in Australia at Macquarie University, explain soil formation in terms of the balance achieved between the alteration of minerals, surface movement of material due to gravity and the interaction of these processes with climatic and biological elements (Paton 1978). Before these concepts can be fully understood it is necessary to clarify the terms parent material, weathering, leaching, new mineral formation and lateral transport.

3.1.1 Parent Material

The rock type will determine the rate of weathering and thus the supply of fresh particles to the soil, and the primary mineral assemblage of the particles. Igneous rocks tend to weather rapidly, yielding abundant coarse particles, whereas sedimentary rocks, particularly sandstone, will weather slowly and the particles will not alter greatly after release from the rock. Acid rocks yield quartz grains, while basic rocks yield ferro-magnesian minerals which decompose rapidly to clay and oxides.

3.1.2 Weathering

Although controlled primarily by the rock type, the rate of weathering also reflects the activity of the various agents - water, wind, temperature fluctuations and vegetation. While weathering affects the supply of fresh particles to the soil, it also affects topography. Changes in topography are predominantly due to variations in the resistance of adjacent rock types.

3.1.3 Leaching

This is the movement, mostly downwards, of compounds in solution in the soil water. The most easily leached materials are the highly soluble bases - sodium, magnesium and calcium. Strong leaching removes most of these ions and for this reason, soils of the upper parts of slopes are commonly acid, while soils lower down, where the bases are

accumulating, are often neutral or alkaline. Leaching also causes the formation and bleaching of A_2 horizons, in the following way. During rainfall, water enters the surface of the soil and percolates downwards until it reaches the impervious B horizon. The A horizon then starts to become saturated from the bottom upwards. The height to which saturation reaches will determine the thickness of the A_2 horizon. After rain, this layer remains saturated for long enough to dissolve bases and even some of the oxides, which then move downwards as the water is absorbed into the B horizon. In this way, the A_2 horizon is gradually depleted of its bases and oxides, so that it gains an earthy fabric and pallid colour.

Strong leaching also inhibits clay formation, as many of the compounds needed to form clay are transported away as soon as they are released from the primary minerals.

3.1.4 New Mineral Formation

This refers principally to the formation of clays and oxides from primary rock minerals. There is no need for us to study the chemical processes involved in the breakdown of primary rock minerals and their re-assembly into clays. It is sufficient to appreciate that the rate of new mineral formation and the type of clays produced depends upon the mineralogy of freshly weathered rock particles, the availability of moisture in the soil and the intensity of leaching. Vegetation also plays a part, by releasing organic compounds which assist in primary mineral breakdown and by "locking up" some of the bases in organic compounds.

3.1.5 Lateral transport of soil and rock material

There is a natural tendency for soil and rock particles to move from regions of high potential energy, i.e. near the top of slopes, to regions of low potential energy, near the base of slopes. The speed of this movement is dependent upon the degree of slope, the fabric and pedality of the soil material, the density of vegetation cover and the severity of surface erosion. Downslope transport occurs in two principal ways - by cyclical periods of erosion and deposition and by slow, continuous mass movement or soil creep, under the influence of gravity. Lateral transport has a strong influence on the depth and development of the soil at any particular site and is an essential process in the formation of duplex soil types.

Where downslope movement is proceeding rapidly, soils near the top of the slope are thin, gravelly and poorly developed. Conversely, soils near the foot of the slope will be much thicker, are normally uniform or gradational in texture and will be coarse, medium or fine grained, depending on the relative rates of transport and new mineral formation.

In the central parts of slopes, lateral transport causes duplex soil formation in the following way:-

Coarse-grained, partly weathered rock particles, released near the top of the slope, spread out as a sheet of coarse grained material over the remainder of the slope. This sheet protects the material below it from erosion and excessive weathering and leaching. The underlying material thus remains essentially in situ, where it becomes converted to clays and oxides. In this way, a soil type develops which has a marked texture contrast, between coarse-grained relatively unweathered surface horizons and a darker coloured, clayey B horizon. Particles in the surface soil are, of course, also being converted to new minerals, but the profile is continually being replenished with coarse particles from up slope and thus a coarse texture is retained.

3.1.6 The formation of a soil

The nature of soil material and its distribution is dependent upon the processes of soil formation and the balance which is achieved between these soil forming processes, which fall into three main groups:

- (i) Alterations of minerals in response to changed conditions near the lithosphere surface to which the general term EPIMORPHISM can be applied.
- (ii) Movement of material across the surface in response to the action of gravity.
- (iii) The reaction of elements of the biosphere on the processes included under (i) and (ii). It is possible for various biospheric elements to both aid and hinder these processes.

Epimorphism can be divided into WEATHERING, the breakdown of the more complex silicates into simpler entities; LEACHING, the differential movement of the simpler entities resulting from weathering; and NEW MINERAL FORMATION, the stabilization of these simpler entities generally in the more complex form of clay minerals. (It should be particularly noted that these terms are here used in a very precise manner and not in a general and rather loosely defined way).

The lateral movement of material across the surface of the lithosphere includes both the movement down hillslopes as a result of wash or creep and that due to stream flow. The result of such movement is a sorting of the material according to its particle size.

Considering the balance that is achieved between epimorphism and lateral surface movement in relation to a gently undulating landscape it is possible to differentiate three areas of interaction.

Residual sites of plateaux where epimorphic processes are dominant.

Transportational sites of hillslopes where lateral movement is dominant near the surface and epimorphic processes are dominant at the bedrock surface.

Depositional sites of the valleys where lateral movement and concomitant sorting are dominant and epimorphism is of little importance.

By relating the processes active at these three sites to particular bedrock sequences it is possible to develop an understanding of soil distribution within New South Wales, as follows:

- (1) Those areas underlain by gently dipping sandstone/shale sequences or by acid plutonic rocks. The prime example of this is the Sydney Basin.

Red and Yellow earths (Gn2 or Um5 of the Northcote Key) are characteristic of the alteration of bedrock in situ at residual sites; podzolic and solodic soils (any duplex soils) result from a combination of the downslope movement of the lighter textured A horizon, over the sporadically developed in situ derived heavier textured B horizon at transportational sites. Relatively uniform accumulations of quartz sand are typical of depositional sites. In such areas it is common, under the influence of a particular vegetation, for podzols to develop (Uc 2.32).

- (2) This relationship of soil material, process and landscape can be extended to the case of steeply dipping sedimentary rocks characteristic of large areas of the Palaeozoic rocks of fold belts. The main difference lies in the contraction of recognisable residual sites and the expansion of transportational sites. The resulting soil material is a mixture of duplex soils (podzolic and solodic types) and uniform shallow stony soils (lithosols).

- (3) The same idea can be used to take account of landscapes in which the bedrock is of a basic nature. If we consider an area of gently rolling topography, on residual sites the dominance of in situ alteration has led to the development of krasnozems (Gn3 or Uf5) or in some cases Red Earths (Gn2, Um5). On the transportational sites of the gentle hillslopes there is an abrupt change to the dark coloured clay soils variously referred to as black earths, prairie soils, chernozems etc. (Uf6). However, it is possible to rationalize the soils on this hillslope by equating it with the Sydney basin situation already described. The dark coloured clay soil is equivalent to the lighter textured mobile A horizon and the sporadic development of a calcareous rich subsoil is equivalent to the B horizon clays. In this case, however, a fabric-contrast rather than a texture-contrast soil occurs. Up to this time the concept of fabric-contrast soils as a major type has not been recognized. The evidence for the mobility of the dark-coloured clay layer and its consequences with regard to the development of gilgai have been developed elsewhere (Paton, 1974). It is thus possible to regard these

hillslopes as a mixture of dark clay soils directly overlying bedrock (prairie soils Uf6) and fabric-contrast soils in which the dark clay surface layer overlies in situ derived highly calcareous clay (again Uf6). On lower hillslopes there is a gradation into depositional sites dominated by deep dark clay soils (Ug soils).

Situations in which both red and dark coloured soil materials occur in close juxtaposition within the same landscape unit are relatively infrequent. However, such occurrences provide a key to understanding soil development in which either the red or dark coloured materials occur on their own over considerable areas. Krasnozems, the highly pedal uniform (Uf5) or gradational (Gn3 Gn4) soils are often found occupying sites that would normally be thought of as being transportation as well as residual. This would appear to be because of their extremely strong pedal fabric which resists the processes of breakdown and lateral movement by raindrop impact and runoff so that processes of in situ alteration tend to dominate across the whole of the landscape. At the other extreme there are many landscapes where dark coloured clay soils are dominant (a mixture of prairie soils and fabric contrast soils).

The lack of red earths or krasnozems on residual sites would seem to be connected with the lack of resistant basaltic lava flows. Ease and speed of epimorphism would appear to produce dark coloured clay soils.

By elaborating from these three fundamental models it is possible to gain a general understanding of soil distribution on residual and transportation sites throughout New South Wales. At the same time it is possible to recognize from this analysis that depositional sites must be treated in a totally different manner to achieve any understanding of the distribution of soil material within them. Such an understanding must be based on a knowledge of the source(s) of the materials and the environmental conditions under which they were deposited. In short the stratigraphic history of a depositional unit will tend to give a much better understanding of the distribution of soil material than more classical concepts of pedology.

There is no implication in the foregoing account that climate and vegetation are not important as soil forming factors, for it is obvious that all three groups of soil forming processes (epimorphism, lateral surface movement and biospheric interaction) are fundamentally dependent upon them for their operation. However, within the confines of this State, despite this undoubted overall influence of climate and vegetation, the soil pattern is generally explicable in terms of the differential control of process by bedrock and topography.

To see how the processes described interact to produce a soil, we shall follow the formation of a typical duplex soil situated towards the foot of a long 10 - 15 percent slope in the Central Tablelands. To avoid complexity, we will assume that the rock type is uniform throughout the slope, and that bare rock is exposed along the ridge crest.

The parent material must be one which weathers to produce abundant medium to coarse-grained particles. Its mineral composition must be such that a large proportion of the particles resist breakdown near the surface but given sufficient time will produce a reasonable proportion of clays in the subsoil. This eliminates the basic igneous rocks, which decompose too rapidly, and sandstones and quartzites, which will not produce any clay. Most of the acid igneous and sedimentary rocks however, have the proper requirements.

Soil formation commences with the weathering of exposed rock near the ridge crest to produce large quantities of coarse to medium sized particles. Since these particles contain little clay and oxides the first formed soil will be coarse textured, will have an apedal fabric and massive structure. These particles are then moved by lateral transport to form a sheet over the remainder of the slope.

This blanket of coarse material buries the soils forming on the lower parts of the slopes, protecting them from erosion and excessive weathering and leaching. The buried material remains essentially in situ and commences to be transformed into new minerals - mainly clay and oxides. In the initial stages, while clay content is low, this material will also have an apedal earthy fabric, but the release of oxides into the soil tends to produce a porous, massive structure and gives the soil a strong red or brown colour. Leaching of bases, by water moving down the slope, leaves the soil with an acid reaction trend.

Further down the slope, a larger catchment area and perhaps slightly flatter terrain favours the retention of moisture in the soil for longer periods. Leaching is less severe and clay formation occurs more

rapidly. As clay content increases in the B horizon, water movement is impeded. This has two effects - leaching is restricted in the B horizon and bases may begin to accumulate, and a marked difference in infiltration capacity develops between A and B horizons. This difference in infiltration capacity causes the lower part of the A horizon to become periodically saturated, which leads to the formation and bleaching of an A₂ horizon as discussed previously. Accumulation of bases in the B horizon gives the soil an alkaline reaction trend where sodium is one of the dominant bases, the clays become dispersed, leading to even lower infiltration capacity and giving the sub-soil a coarse, blocky structure.

By varying the rates of activity of the soil forming processes we have been able to explain, in quite simple terms, the formation of three very common soil types, in sequence down this one slope. The top of the slope contains a thin, coarse-textured lithosol (Uc5.11), which is followed by a red podzolic soil (Dr4.51) and then by a yellow solodized solonetz (Dy2.43).

Naturally this type of description cannot be applied as simply to all soils, as it can be seen that soil formation is a very complex interaction of a number of factors and processes. These will vary with each different situation. It is only by understanding something of the principles of soil formation that we can evaluate the significance of the resulting soil morphology in practical terms.

3.2 Soil morphology

The morphology of a soil refers to the form and/or properties of that soil as seen in the field. The concept of soil horizons ("layers"), which develop during soil formation, has already been introduced in the preceding section. Thus the most suitable way of studying a soil is in vertical section, the sequence of horizons down to and including the parent material being referred to as the soil profile. This term is generally restricted to horizons which are known to be all part of a single soil. Where a sequence of older, buried soils is overlain by the modern active soil, the sequence may be referred to as a series of soil profiles.

The soil profile normally consists of two parts, the solum and the weathered parent material. The solum is made up of horizons which have been changed from the parent material by the processes of soil formation; they therefore have their own organisation and differ markedly from the parent material. Beneath the solum there is usually a zone of weathered parent material which is too deep to be transformed into solum horizons, but which is weathered. This zone of weathered parent material is found even in soils derived from the underlying rock and is often much deeper than the solum. Since the weathered parent material is not sorted into horizons, it is more like the fresh rock than the solum in its properties.

The naming of the horizons of the soil profile is one of the most important tasks of the pedologist: it requires a thorough understanding of the processes of soil formation and the relationships between the soil horizons. Many systems for the designation of soil horizons are in use. In most of these, the letters used for the horizons relate to the movements of constituents through the profile and therefore stress the genetic relationship between the horizons.

In most systems the first distinction to be made is between horizons that have lost constituents and horizons that have gained constituents: the former are termed eluvial horizons and the latter are termed illuvial horizons. The removal of constituents from the upper soil horizons is referred to as eluviation and the deposition of some of the eluviated constituents into lower soil horizons is referred to as illuviation. Most systems of designating soil horizons use the letter A for the eluvial horizons and the letter B for the illuvial horizons. Clay, iron, humus and lime are the most commonly eluviated and illuviated constituents so that the A and B horizons may be subdivided on the basis of properties which reflect the movements of these constituents.

Horizons used in this handbook, and in the Northcote (1971) Key, are the O, A, B, C and D horizons. They are recognized by the nature of their organization. The form and nature of A horizons result largely from biological processes and physico-chemical processes which occur at the soil surface. The form and fabric of B horizons results from physico-chemical processes which occur below the surface and are relatively deep-seated. C horizons are characterized by their lack of pedologic development, and the remains of geological materials and organisation. The form and fabric of D horizons has resulted from some earlier cycle of soil-forming processes, and thus their character contrasts with that of the solum of the soils with which they are currently associated.

The following notes are given to outline briefly some of the more salient features of these horizon designations. It is suggested that these designations be adopted in practice. In undifferentiated profiles such as alluvial soils, simple depth-description is usually more suitable. Measurements of depth for all horizons are referred back to the top of the A, or, where absent, of the uppermost mineral horizon.

The Organic horizon - O

The organic horizon is a layer of organic material above the surface of the mineral soil.

It can be divided into the organic sub-horizons of O_1 and O_2 .

O_1 - consists of relatively fresh leaves, twigs and other plant debris, which do not show visual evidence of decomposition.

O_2 - consists of partially decomposed/decomposing litter. These may or may not be recognizable plant remains.

The Surface horizon - A

The A horizon is a master horizon consisting of; surface mineral horizons with maximum organic accumulation (relative to B and C horizons); or, of horizons which are lighter in colour, having a lower content of clay minerals, iron and aluminium than the underlying horizons; or of horizons belonging to both these categories.

The sub-horizons are:

A_1 - This is a surface mineral horizon having a relatively high content of organic matter mixed with mineral matter and usually dark in colour. It may or may not be a horizon of eluviation. In nearly all soils it is the mineral horizon of maximum biological activity and subject to the greatest changes in temperature and moisture. It is normally referred to as the topsoil.

A_2 - This surface or sub-surface horizon is a horizon of eluviation - of leaching of materials out in solution and suspension. It is usually lighter in colour than the underlying horizon, has lost clay minerals, iron or aluminium, or all three, with the resultant concentration of the more resistant minerals.

A_3 - Transitional horizon - more like A than B. It is a relatively sharp transition layer. Where the transitional horizon between A and B is not a clear gradation, especially where this zone is thin, it may be designated AB - a zone of diffuse transition - often indeterminate.

The Subsoil - B

The B horizon is a master horizon of altered and distinct material characterised by; more or less block-like or prism-like structure, together with other characteristics, such as stronger colours, heavier texture, etc. which differ from those of the A horizon above or the C horizon below; or, by an accumulation of clay, iron or aluminium or other compounds with organic material; or, by both characteristics.

B_1 - horizon is transitional to A above, but more like B than A.

B_2 - The main subsoil horizon showing typically

strong colour and structure with maximum clay accumulation.

B₃ - transitional to C, more like B than C -
(same comments as for A₃).

B/C - transitional (comments as for A/B).

C horizon and underlying layers

The C horizon is a master horizon embracing the parent material and parent rock. Where it comprises a weathering layer above the parent rock, it is divided into two sub-horizons:

C₁ - layer of unconsolidated and distinctly weathered material, relatively little affected by organisms and evidently similar in chemical, physical and mineralogical composition to the material from which a significant part of the over-lying solum has developed.

C₂ - layer of relatively unweathered material - parent rock of the soil from which the C₁ horizon or, (where no C₁), the solum itself has evidently developed.

D horizon - any layers that lie beneath the C horizon (or the solum in the absence of C) which are of importance to the over-lying soil but are not necessarily related to it. These layers do not include parent rock material.

Other useful designations

G horizon - commonly formed in wet soils, or soils developed under wet conditions. It is a layer of intense chemical reduction, characteristically exhibiting ferrous iron and neutral grey and dark grey colouring, which changes colour to brown upon exposure to air. It is a characteristic horizon developed wholly or partly by gleying (wet conditions in the presence of organic matter).

It is often found in soils with a shallow water table and poor internal drainage. The G horizon is most frequently developed within the B horizon.

The following diagram shows the horizons in vertical sequence in a fully developed but somewhat theoretical soil. In most soils, horizons will not be defined with such precision. Some may not be present at all. Many New South Wales soils do not possess marked O horizons, even in their virgin state. Where accelerated erosion has taken place the O, A and even B horizons (or part thereof) may have been removed. In cultivated soils the O horizon will be missing and the A₁, A₂ and possibly B horizons will be mixed to varying extents.

N.B. In general discussion on soils the horizon designations mostly used are O, A₁, A₂, B, C and D. The O₁ and O₂ horizons are sometimes referred to as A₀₀ and A₀ respectively, and the A₂ is sometimes called the E horizon (based on FAO - international nomenclature). The transitional horizons, where they occur, are probably best referred to as A/B or B/C - the terms A₃ and B₃ are not widely used.

Figure 3.1 Soil Profile Nomenclature

Organic horizons - above the mineral soil bodies, usually thin or absent in soil developed on grassland areas.		0 ₁	Organic surface	Loose leaves and organic debris, largely undecomposed.	
		0 ₂		Organic debris in various stages of decomposition; frequently matted.	
THE SOLUM - the part of the soil body that owes its main characters to soil forming processes	Horizons of maximum biological activity, of eluviation, or both	A ₁	Topsoil layers	First layer of mineral profile. Dark coloured, containing organic matter. Loss of soil. Alteration by man etc.	
		A ₂		Generally lighter colour than A ₁ - constituted by erosion and/or leaching. Generally a zone of maximum eluviation - prominent where eluviation is strong; may be weak or absent.	
				Lighter due to eluviation and less organic matter.	
		A ₃		Transition to B, but more like A than B. Relatively distinct gradation.	
		A/B		May or may not be present - may be narrow or wide - but diffuse.	
		Horizons of illuviation or of blocky or prismatic structure, or both	B ₁	Subsoil layers	Often transitional B - more like B than A.
			B ₂		Zone of max. accumulation of silicate clay materials and/or iron and organic matter. Max. development of blocky or prismatic structure, or both.
			B ₃		Transitional to C, more like B than C.
			B/C		May or may not be present; narrow, wide, diffuse, irregular.
		Gleying likely under wet conditions		Geological layers	May or may not be parent material for above sited soil. Zone unconsolidated, not affected by biological activity. Distinctly weathered. May be absent.
C ₁					
C ₂	Relatively unweathered, may or may not be seen at depth examined. May not be related to above sited soil.				
The weathered parent material. In places, absent (i.e. soil building may follow weathering so rapidly, that no weathered material that is not included in the solum is found between B+C ₂).					
The relatively unweathered parent rock from which the horizon is derived (underlying rock of significance to the soil other than parent rock is labelled D).		C ₁			
Material of significance to soil but not parental rock material.		D		May or may not be present at depth examined. Designation given to any layers below C horizon.	

3.3 Soil Profile Examination

The soil morphology as described in Section 3.2 can best be observed in a vertical section of soil exposed in a pit or cutting dug for the purpose.

The site of the pit should be chosen very carefully, taking into account such factors as ground cover, degree of erosion/deposition, surface drainage, proximity to new/old trees and stumps, etc - in fact anything likely to affect the soil as being representative of the area being considered. The site should normally be chosen only after preliminary exploratory test hole boring. Once selected, the location of the soil site should be accurately marked on a map.

As far as possible, dig the pit so that the sun shines on one side of the pit for as long as possible - especially at the time of sampling. The depth of a soil profile pit will vary with the soil body and sampling requirements. In deep soils 2 metres is usually adequate (if you're energetic). The main consideration in these soils is that the B₂ horizon should be penetrated. Sampling of layers below the floor of the pit can be taken using an auger.

If using an existing trench or cutting it may be necessary to cut it back at least 30 cm to ensure that the profile is not contaminated by slump, wash or lateral silt movement. Where it is not possible to dig a pit, a spade and auger may be used. Use the spade to cut down and bring out the top 30-45 cm of soil, place this on the ground. Then auger out the soil, beginning at the bottom of the spade hole and placing each boring in order by the soil taken with the spade so that measurements can be made and the profile viewed as a whole. Continue augering to the required depth, as for the pit.

3.3.1 Describing the Profile

When the face of the pit or cutting has been cleaned down, or when the auger borings are complete, the profile is ready to be described. One method is to take a metre rule and mark the soil profile (trench face or augered profile) into 10 cm portions starting with the surface of the predominantly mineral soil as 0 cm and working downwards. Surface accumulations of organic matter are measured upwards from their junction with the mineral soil. When this is done examine each 10 cm portion to determine whether or not a visible soil change occurs between the 10 cm markings, and where it does, mark this also. Now the process of describing the profile by 10 cm and part 10 cm portions may be started. Another method is to mark out the observable changes and describe the soil above each boundary change.

The following soil properties should be recorded for each portion of soil examined.

- a. Texture
- b. Colour
- c. Pedologic organisation
- d. Character of the A₂ horizon

- e. Structure (pedality)
- f. Nature of the surface soil
- g. Mottling
- h. Coherence
- i. Soil reaction trend
- j. Consistence
- k. Pans

N.B. The descriptions below relate particularly to those properties used in the Northcote Factual Key which will be further discussed in Chapter 4.

a. Texture

Texture is reflected in the mechanical analysis of the soil in terms of clay, silt and sand, and its behaviour when worked at different moisture contents. For the purposes of this key six main texture groups are recognised.

<u>Texture Group</u>		<u>Approx. clay content</u>
1. Sands	Coarse Textures	Less than 5%
2. Sandy loams		10-15%
3. Loams	Medium textures	20-25%
4. Clay loams		30%
5. Light clays	Fine textures	35-40%
6. Heavy clays		greater than 45%

Each of these texture groups is further sub-divided for the purpose of field identification. The full procedure is set out in the Factual Key (pp26-28) and is based on the ribboning behaviour of moist soil worked in the hand. Considerable experience is necessary to obtain consistent results with the method described, and the following simpler procedure will be found suitable for the less experienced officer in the majority of cases.

The method depends on the degree to which moist soil can be rolled out in the hand. Take a small quantity of soil and knead with water until a homogenous ball is obtained. Large pieces of grit and organic material should be discarded. Small clay peds should be crushed and worked in with the rest of the soil. The feel, behaviour and resistance of the soil to manipulation during this process is important. The soil ball should be kept moist so that it just fails to stick to the fingers. The six main texture groups should be apparent as follows:-

1. Sands have very little or no coherence and cannot be rolled into stable ball. Individual sand grains adhere to the fingers.

2. Sandy Loams have some coherence and can be rolled into a stable ball, but not a thread. Sand grains can be felt during manipulation.
3. Loams can be rolled into a thick thread, but this will break up before it is 3-4 mm thick. The soil ball is easy to manipulate and has a smooth spongy feel with no obvious sandiness.
4. Clay loams can be easily rolled to a thread 3-4 mm thick, but it will have a number of fractures along its length. Soil becoming plastic, capable of being moulded into a stable shape.
5. Light clays can be rolled to a thread 3-4 mm thick without fracture. Plastic behaviour evident, smooth feel with some resistance to rolling out.
6. Heavy clays can be rolled to a thread 3-4 mm thick and formed into a ring in the palm of the hand without fracture. Smooth and very plastic, with moderate-strong resistance to rolling out.

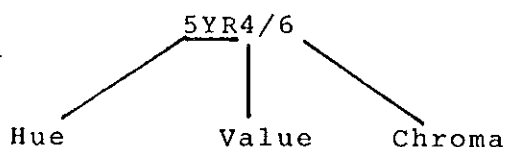
Sampling of the profile should be frequent enough to detect the requisite texture changes, which are defined by Northcote as follows:-

<u>Division</u>	<u>Range of texture down the solum</u>
Uniform soils (U)	Within one main texture group or the span thereof.
Gradational Soils (G)	Exceeds one main texture group or the span thereof (Gradual increase in clay content).
Duplex soils (D)	Texture contrast between A and B horizons at least 1½ main texture groups, or the span thereof, (occurring over 10 cm or less).

b. Colour

It is important that colours are determined on the moist soil (except where otherwise stated) with a MUNSELL soil colour chart or its equivalent. This is the standard chart for soil colour determination. Colour is expressed as a letter/number code combining hue (spectral colour in terms of red and yellow), value (dark and light), and chroma (intensity of colouration).

For example:



Each page of the standard soil colour chart represents one level of hue which is shown at the top of the page (5YR, 10R etc). Changes in value occur down the page and

changes in chroma across the page. Thus light colours are at the top of each page and dark ones at the bottom, dull colours on the left of each page and bright colours on the right. Northcote has grouped the combinations of value and chroma into five categories. These are set out in a diagram on page 11 of the key, and for convenience the boundaries can be drawn in on each page of the colour chart if desired. The categories are called value/chroma ratings (V/C 1-5).

c. Pedologic organization

Evidence of this is to be found in all soils in which chemical, biological or physical changes have taken place. It reflects soil-forming processes and may be revealed as horizons, colour changes, texture changes, mottling, concretions of lime or iron compounds, structural development and consistence changes.

d. Character of the A₂ horizon

The presence, absence or degree of "bleaching" of A₂ horizons is used as a diagnostic feature. The A₂ horizon in a soil is defined as being lighter in colour than the A₁ above and the B horizon below, by specified amounts of value, chroma or hue. A bleached A₂ is a very light horizon which has a high value and low chroma (typically V/C = 3), which must be determined on DRY SOIL. "Sporadically bleached" and "conspicuously bleached" are terms used to describe the amount of bleaching present.

e. Structure (pedality)

The term STRUCTURE refers to the arrangement of all soil particles, and if this includes natural aggregates these are called PEDS. Thus a soil may be described as PEDAL or APEDAL depending on the presence or absence of peds. Examples of pedal soils are those with blocky or prismatic - structured B horizons typical of many podzolic and solodic soils, and those with naturally self-mulching A horizons such as many in the black earth group. Examples of apedal soils are loose incoherent sands, B horizons of red earths, or massive clays in which the sub-soil layer appears as a solid mass without any marked aggregation.

Peds are described as smooth or rough-faced. The former are relatively dense, tough, easily defined structural units in which the ped surfaces are almost shiny. The latter are less dense and characteristically porous and friable - they lack any lustre and are not easily distinguished.

The term "fabric" is used to describe the appearance of the soil material (best viewed under a x10 hand-lens). Four categories of earthy, sandy, rough-ped and smooth-ped fabric are used - the first two generally applying to the apedal condition, and the second two to pedal soils. (Refer Factual Key p14).

f. Nature of the surface soil

This feature is used to define a number of soil groups. The surface horizon may be hard-setting, not hard-setting, characterised by the presence of a surface crust, self-mulching or massive. If hard-setting, the soil surface would become firm enough in the dry season to resist depression under moderate pressure with the thumb. It is said to be typical of the majority of soils in the wet-dry climatic zones, except for some sandy soils and well-structured soils like those developed from basic parent materials, which would be non hard-setting.

The surface crust is a thin flake which can be lifted away from the underlying loose soil when dry. It is typical of many saline soils and desert loams. Self mulching soils are those which naturally form a loose surface structure as a result of the wetting/drying process. Soils with massive surfaces represent the opposite condition of self-mulching, and are similar to the hard-setting group.

g. Mottling

Soil material is either whole-coloured or mottled. Mottles are blotches of colour different from the main soil colour, and must constitute at least 10% for the soil to be described as mottled. Estimation charts are included in the standard soil colour charts for this purpose.

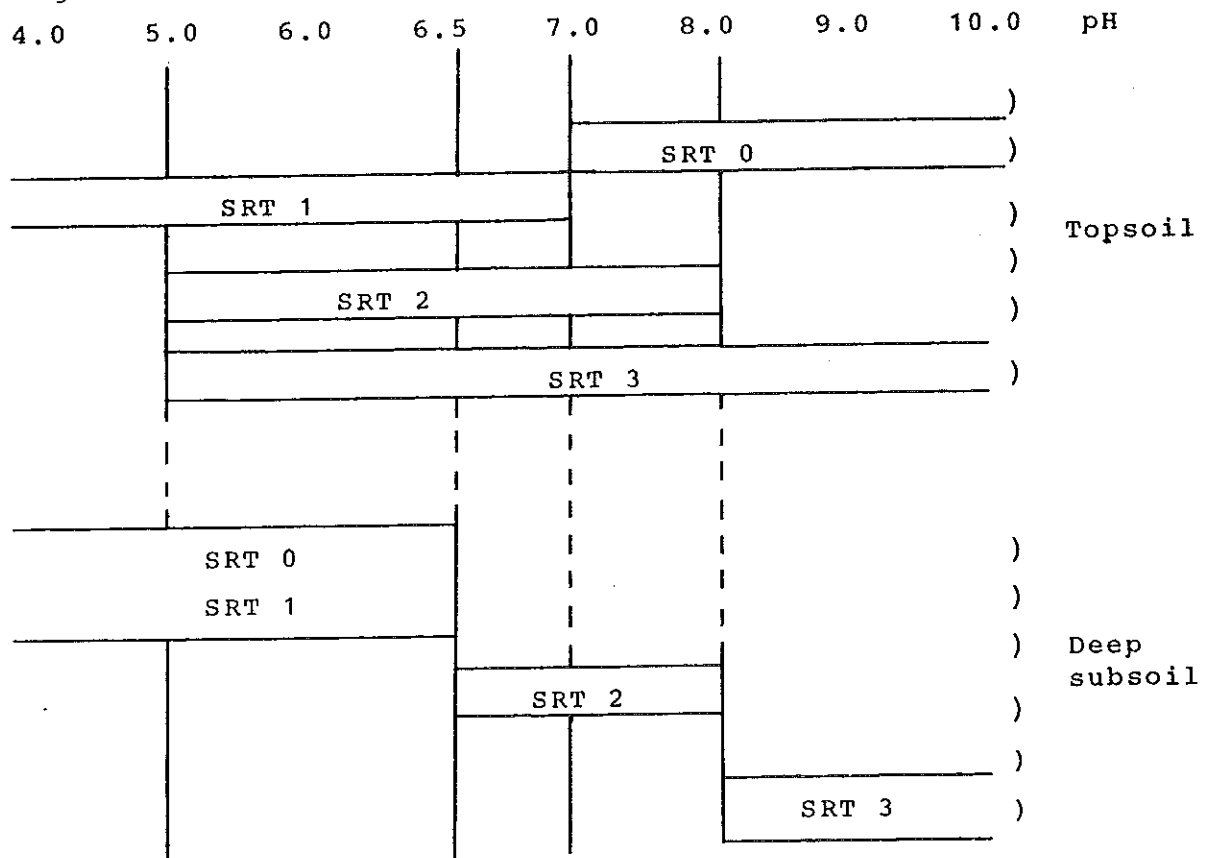
h. Coherence

This term describes the degree to which soil material is held together at different moisture levels. At least two-thirds has to remain united for a soil to be described as "coherent", at the given moisture level.

i. Soil reaction trend

This is the second of the features which must be determined by simple chemical tests - in this case either Universal Indicator or Raupach's Solution can be used in the field, but a check of these methods against more accurate determinations by electronic pH meter is essential to maintain a satisfactory standard. At present four trends are acknowledged as in the following diagram. In each case they represent the general direction of pH change down the profile.

Figure 3.2 Soil Reaction Trend



For many soils the pH in the deep subsoil (lower B horizon) is diagnostic.

j. Consistence

This refers to the resistance of a soil aggregate to deformation, (or soil material at different moisture contents), and can be measured by the force required to crumble an air-dry 2 cm lump of soil between thumb and finger as follows:

1. Very small force required.
2. Small but significant force required.
3. Moderate force required.
4. Strong force required.
5. Very strong force required, beyond power of thumb and finger.

k. Pans

Pans are hardened and/or cemented layers in the soil which present considerable resistance to the manual boring of an auger hole under normal conditions. Their hardness would not generally be greatly affected by changes in moisture content. The common types of pans are caused by cementation due to calcium carbonate, silica, sesquioxides, humus or iron oxides. Clay pans are concentrations of dense clay in the subsoil.

3.3.2 Soil Testing Kits

Contents The contents and usage of a typical soil testing kit is described below:

Reagents: Distilled water, 5% Silver Nitrate solution, 5% Barium Chloride solution, Barium Sulphate powder, Hydrochloric Acid (N/1), Hydrogen Peroxide, Universal and/or Raupach indicator (N.B. a colour chart and a special grade of Barium Sulphate is necessary for use with Raupach indicator).

Apparatus: Test tubes, evaporating dish, petri dish, beaker, spatula, corks, spotting tile, hand lens, dropper bottles for indicator and acids.

Soil Tests

(1) Physical Tests

- (a) Soil Texture: Refer to Northcote Key pp 26-29 as well as page 48 of this manual.
- (b) Emerson Aggregate Test: A beaker should be partly filled with distilled water and a natural clod of soil (1cm diameter) carefully placed in the water. Appearance of a "cloud" of clay surrounding the clod indicates a degree of dispersibility. Quick disintegration of the particle indicates high erodibility. The test should also be repeated in ground water if this is available. DO NOT STIR OR SHAKE. (See Section 7.3 for a more detailed description of the test).

(2) Chemical Tests

- (a) Soil pH Place about 1 cm depth of soil in a test tube and the same depth of barium sulphate powder. Fill the test tube about 1/3 full of distilled water, add a few drops of universal indicator and shake thoroughly for one minute. Allow to settle and compare colour with chart. If cloudy or poorly coloured, add more barium sulphate and indicator and re-shake. OR mix a small amount of soil with a few drops of Raupach indicator and make into a paste, on the spotting tile. Sprinkle the paste with barium sulphate powder (special grade) and compare colour formed with chart after 3 minutes.
- (b) Calcium Carbonate Effervescence visible on the application of a few drops of hydrochloric acid indicates presence of calcium carbonate in soil.
- (c) Soluble Carbonates in seepages: Add barium chloride solution - a white precipitate which clears on the addition of hydrochloric acid indicates presence of soluble carbonates.

- (d) Soluble Chlorides in seepages: Add silver nitrate solution - a white precipitate gradually turning purple indicates presence of chlorides (probably NaCl).

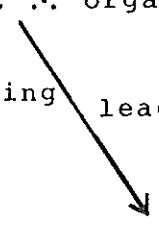
Presence of carbonates or chlorides in seepages may indicate dispersible soils. To determine presence of soluble salts in soils, an extract of the soil can be made by shaking the soil thoroughly with distilled water, filtering and treating the filtrate as above.

- (e) Soluble Sulphates in seepages: Add barium chloride solution - a white precipitate which does not clear in hydrochloric acid indicates presence of sulphates.
- (f) Organic matter: Add hydrogen peroxide - effervescence usually indicates organic matter (H_2O_2 also reacts with nodules of manganese compounds).

3.4 Soil distribution

Soil variation is almost infinite, even over quite small areas in some instances. On a continental scale changes in soil type occur with changes in climate. One would therefore expect, as outlined in Section 3.1, that if we started in the Snowy Mountains and drove westwards for 800 km, we would encounter a pattern of soils of the following general form:

Alpine humus soils	High P, low E	∴ organic soils
Podzolic soils		
Solodich soils	decreasing	leaching
Grey, brown and red clays		
Solonized brown soils		
Desert loams	High E, low P	∴ gypseous soils



On a more regional level the soil pattern would be influenced to a greater extent by parent material. Thus in areas dominated by granites the soils would be coarser-grained and subject to more efficient leaching. In areas of marine sedimentary rocks the effect of higher sodium contents and susceptibility to weathering would give rise to more dispersible and duplex-type soils. Where basalt was the common rock type, soils would have higher clay contents, darker, brighter colours due to iron and manganese, and much stronger aggregation (viz. krasnozems in higher rainfall areas and black earths in lower rainfall areas).

On a more local level still, the soils would depend very much on topography and the erosion/deposition state of the landscape. Irrespective of man's effect on soils and erosion, natural erosion is taking place all the time. It has been suggested that soil development is subject to a continual cyclic process, whereby phases of deposition and soil-building alternate with phases of erosion and soil

degradation. In many areas, where deep cuttings are available for study, the succession of such phases can be observed quite clearly. Buried soils can be recognized, showing the "truncation" which resulted from an erosional phase, and the subsequent burial in a period of deposition. The effect of man's use of soils in recent times has, of course, accelerated the degradation process. In fact, man's activities must now be regarded as a modifier to the soil-forming factors.

Some of the most interesting soil patterns result from the effects of topography or relief on a more local basis. On upper slopes leaching and drainage tend to be more efficient due to the greater slope and greater purity of the water passing through the soil. Moving down the slope, water from the soils above contains more salts due to leaching. Lower soils will therefore tend to contain more salts and lime and have a higher pH. Drainage will not be so efficient and the effect is therefore multiplied down the slope. On the lowest slopes, waterlogging may occur, and salts may accumulate to the detriment of vegetation in dry periods. Soils in these lower situations will tend to have yellower colours due to the hydration of iron oxides and the reduction from ferric (red) compounds to ferrous (yellowish) compounds under waterlogged conditions.

The pattern of soils which develops on a slope is generally known as a catena, although strictly this should only apply where only one parent material is involved. A better term might be toposequence - a related sequence of soils dependent on topography. Such a sequence is often mapped as a soil association (See next section 3.5).

The following are examples of soil catenas:

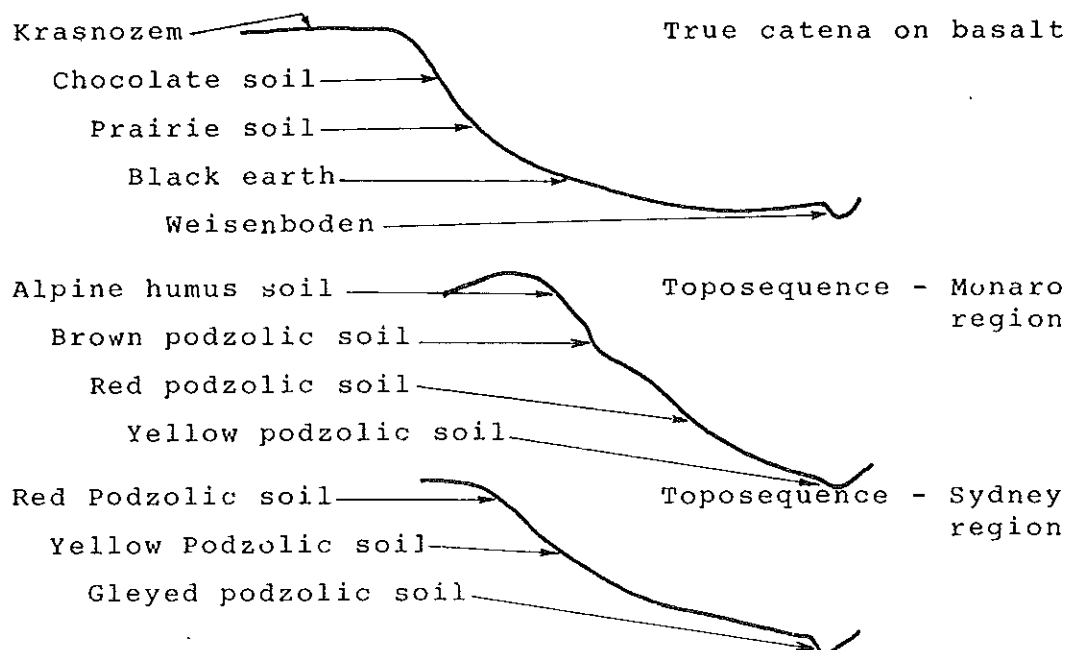
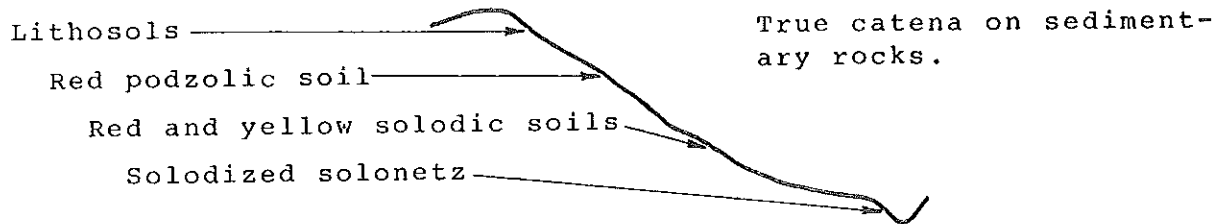


Figure 3.3 Soil Catenas



One of the consequences of these topographic effects of interest to the soil conservationist is that the stability of soils on a slope may vary quite markedly because of the chemical effects described. Vegetation, too, will vary considerably because of the same effects.

Salting on a lower slope is a fair indication of dispersible soil problems higher up the gully, and the location of structures to control erosion may be a problem. On such a slope there is typically a zone of maximum hazard where the level of leaching on the one hand, and salt accumulation on the other, balance in such a way that soil dispersibility is likely to be a critical problem. The answer may be a site further up (or further down) the gully, depending on other local circumstances.

Where red and yellow soils occur in toposequence, as a general rule the red soils will be the more stable with respect to structures, cultivation etc. This is because of their content of ferric iron which has a stabilizing (flocculating) effect on soil clays. They have the disadvantage of, in some instances, being too strongly flocculated and therefore likely to leak in structures. Being located on the upper parts of slopes they may also be rather shallow for (say) gully control structures.

Because of the erosion/deposition pattern on slopes it is natural that lower slope soils will be deeper than those higher up. On the steepest slopes even natural erosion may be sufficiently active to exceed or equal the rate of soil formation. Thus shallow soils are typical, and dominated by the weathered fragments of the parent rock. Soil development is minimal and organic accumulation and influence only slight. There is typically no horizon development.

Moving downslope there will be first, a zone of soil which is gradually having its surface washed downhill. However, active leaching and weathering in this area may be deepening the B horizon and the upper B horizon will gradually become the A horizon with the removal of surface material. Moving further downslope, there will be a second zone which is less steep and which is receiving the material from the first zone. Thus its A horizon will slowly get buried and the lower A horizon will become B horizon. This will tend to produce a deeply weathered profile of widely varying properties.

Further down the slope still the land will tend to flatten out, and may come under the influence of periodic flooding from watercourses. The soils at this point merge into the true alluvial soils which result from material brought down by the stream from land higher in the catchment. Its character will vary with the frequency and character of floods, the size, shape and form of the channel as well as the geology and topography of the catchment.

The pattern of soils on slopes can be even more complicated where accelerated erosion has taken place due to man's use of the land. The soil conservationist usually becomes aware of this in gullies where he might be searching for a suitable gully control structure site. Local pockets of active deposition or erosion can easily spoil an otherwise perfect site. The highly variable pattern of flows which can occur results in a much greater variability in the type of material washed downslope when a gully is present. For this reason many soil conservationists avoid putting large structures in gully lines, preferring to divert flows out to storages excavated in "safer" sites.

For the reasons set out in this section it is essential for the soil conservationist to understand the reasons behind soil variation on slopes. Whilst it is acknowledged that the foregoing treatment is not exhaustive, it should provide a better basis for the adjustment of design work to soil type. It may also assist the farm or urban planner to take more account of soil changes in determining land classes and soil conservation treatments.

3.5 Soil Survey and Mapping

Soils are one of the most important of our natural resources and influence both agricultural and urban development. Pressures upon land are increasing and therefore the soil is becoming a more valuable resource. Soil survey is a fundamental aspect of efficient planning and land management. Abuse and poor planning lead to degradation of the soil and substantial economic loss to the community.

In New South Wales there has been an increased awareness of the importance of soil suitability for uses other than crop production, especially in the urban environment. This trend has created a need for rationalisation of soil survey methods and mapping procedures. Soil survey work must be subject to careful planning. Most of the characteristics that identify soils are determined in the field, although a few need to be analysed in the laboratory. Even without laboratory investigation, however, a fairly precise interpretation of soil properties can be gained from field observation, experience and existing reference material on soils and geology.

Soil survey involves:

- (i) deciding which properties of the soil are important for the particular purpose,
- (ii) organizing the knowledge relating properties to use,
- (iii) classifying soils into map units,
- (iv) locating and plotting the boundaries of these units on maps; and
- (v) preparing maps and reports for publication.

3.5.1 Planning the Soil Survey

The first step in planning a soil survey is to thoroughly ascertain the purpose and requirements of the 'user'. This is a two way exchange because not only can the soil surveyor determine exactly what requires investigation and why, but the user's expectations can also be discussed. Users are often unaware of the problems and requirements of soil survey and this type of discussion will eliminate many misconceptions. Soil bodies are variable and heterogeneous in character, and it is important to discuss this aspect and to stress the need for intelligent use of the data. Unfortunately, the history of soil investigation is littered with many useless surveys, because this very basic requirement was not fulfilled.

Once the basic requirements are formulated it is possible to determine the scale of the survey. This is often dependent on the availability of existing base maps or the facilities of a drafting office. However, the factors which must determine scale are related to budget, the time available, the level of detail and type of information required. The effort required for soil survey increases as the map scale approaches reality, that is, becomes larger. A large scale survey therefore requires more sample points per unit area than a small scale survey. Obviously, the time and cost depend on the size of the study area.

Once the scale is determined and survey requirements are designed to satisfy the particular scale, then the soil map must be used and interpreted at the chosen or a reduced scale. To enlarge or 'blow-up' the scale constitutes an abuse of the information and leads to mis-interpretation of data and inevitably to incorrect decision making.

Vink (1963) discusses in some detail the sampling requirements and number of observations necessary for soil survey at a variety of scales. Table 3.1 is reproduced from this reference because it provides a clear and concise appraisal of map scale and relative cost-benefit, with and without the use of air photograph interpretation (API). The technique of API is routine procedure for soil survey within the Soil Conservation Service of New South Wales.

Table 3.1 Some Data on Mapping Scale and Field Observations (after Vink 1963)

Publishing scale of map	Main purpose of map	Approximate average number of observat- ions per 100 ha without with API API	Approx. scale of sample areas	Approx. scale of aerial photo- graphs
1:2 500	farm surveys very detailed projects	500-4000 500-4000	-	1:10 000
1:10 000	research surveys, sample area surveys for detailed projects	100-500 100-500	-	1:10 000
1:25 000	research surveys, sample area surveys for detailed projects	+ 100 - 10-50	-	1:20 000
1:50 000	surveys for projects regional surveys	12-25 1-3	1:20 000	1:20 000
1:100 000	reconnaissance surveys for large projects	2-45 + 1	1:20 000	1:20 000
1:200 000	national surveys	+ 1 - 0.5-1	1:20 000	1:20 000
	reconnaissance surveys for very large projects		1:50 000	1:50 000
1:400 000	national reconnaissance surveys (general inventory of areas)	-	1:50 000 1:100 000	1:20 000 1:70 000
1:600 000	national reconnaissance surveys (general inventory of areas)	-	1:50 000 1:100 000	1:40 000 1:70 000

When the map scale is determined (based on user requirement) it is possible to decide on the size of the basic mapping unit and predict the time required for completing the survey.

The size of the basic mapping unit in any conventional soil survey (without systematic air photo interpretation) is determined by the smallest area in which at least one observation is made (Vink op cit.) As the size of the basic mapping unit is normally regarded at 0.25 cm^2 of the published map, this means a 'normal' density of four observations per square centimetre. If the number is less, then the basic mapping unit should be proportionally enlarged. In cases where a detailed survey is already available, the basic mapping unit indicated on the map should be proportionally reduced. With systematic interpretation of aerial photographs, the soil surveyor is able to indicate or at least regulate and adjust the size of his basic mapping unit. This ensures that the continuity of survey is maintained.

3.5.2 Soil Survey Methodology

The aim of soil survey is to categorise soil distribution across a landscape. The criteria for formation of classes are usually based on the genetic characteristics of a soil mass, although they may well be based on single properties or morphological features of the soils in question.

Once map units, consisting of essentially homogeneous soils, are delineated it is necessary to adequately describe them. Usually a modal profile is presented for each basic map unit and the characteristics and properties of this profile are considered typical of all soils included within the map unit. However, soils are heterogeneous bodies which vary quite substantially across relatively short distances. Therefore, the modal system is often misleading. A better approach, particularly in more detailed surveys, is to provide a range of properties for each map unit. If sufficient data are available means and standard deviations for each of the measured properties can be presented. In this manner it is possible to develop a statistical framework for assessment of map accuracy and precision. This approach has considerable benefit for the user, because it is possible to evaluate the reliability of each soil unit. The use of statistics in soil survey is discussed in Section 4.9.

Soil survey procedures tend to be determined by the requirements, background and experience of the soil surveyor. However, the following framework provides the basic approach adopted by most pedologists.

Soil Survey Schedule :

<u>Location</u>	<u>Phase</u>	
Office	1. Air photograph interpretation	- basic inventory map with terrain classification. This provides a framework for field classification.
Field	2. Field reconnaissance-	first draft legend - possibly based on terrain evaluation map.
	3. Initial field mapping - assessment of catenary relationships	- draft legend raised, based on soil classification.
	4. Field survey	- sampling programme and soil classification to produce draft soil map.
	5. Revision Survey	- check continuity of legend and map unit, revision of legend, clarification of problem areas.
Office	6. Map Editing	- further check on continuity of map units.
	7. Interpretative Maps	- derived from interpretation of soil behaviour based on soil maps.
	8. Draft Report	- draft memoir.
	9. Compilation of Soil Map, Interpretative Maps and Survey Report	- full memoir and interpretative maps ready for user.

3.5.3 Soil Survey and the role of Aerial Photograph Interpretation

Air photo interpretation (API) is a technique which greatly assists the collection of physical land resource information. The nature of soil information which can be detected on an aerial photograph depends on a number of factors:

- (i) Scale of the imagery, which depends on the height of the aircraft and the focal length of the camera.
- (ii) Overlap between consecutive photos. A small overlap results in exaggeration of the relief, whereas large overlaps (90%) reduce the stereoscopic effect. A 60% forward overlap is usual and most satisfactory for interpretation of land resource information.
- (iii) Magnification of the eye piece or binocular lens attached to the stereoscope. The larger the magnification the smaller the field of view, as well as the diminution of the relative relief.

The benefit of API is largely in the reduction of field work and therefore, the increased speed of data acquisition, as well as providing a look at an area prior to initial field reconnaissance. Field work is significantly decreased because during field checking it is necessary to sample only a proportion of the total area under study. Errors in interpretation tend to recur across an area and changes to the initial API can be systematically applied to the unchecked areas in most cases.

The interpretation of soils information from aerial photographs relies largely on the deductive capabilities and experience of the interpreter, his familiarity with the site and his geomorphological knowledge in relation to soils. Because the soil profile as such is not visible on the contact print, it is necessary to deduce soil characteristics from terrain, geology and to a lesser extent, vegetation features. By classifying the terrain into hillcrests, sideslopes, footslopes, etc. it is possible to establish quite a reliable framework for soil survey.

There are three major methods of soil survey:

- (i) Physiographic survey,
- (ii) Free survey, and
- (iii) Grid survey.

(i) Physiographic Soil Survey

Air photo interpretation is the basis of physiographic soil survey. In this method a study area is classified according to its slope and terrain characteristics from aerial photographs.

(ii) Free Survey

This technique involves the delineation and mapping of soil boundaries. One or a number of boundaries are identified and the interpreter defines them on their association with external features such as geomorphology, geology, vegetation or land use. API increases the rate and precision of mapping of the boundaries, and minimises the number of soil observations necessary to confirm the soil type and verify the position of the boundary.

Obviously for effective free survey, the soil type must have some external expression in the landscape, though the association between soil and external characteristics need not be of the same kind, nor show the same degree of development, along the whole length of any one boundary.

(iii) Grid Survey

API is of limited value, because grid survey is most suitable at a large scale (less than 1:10,000). This method necessitates a very large number of samples on a fixed grid network. Therefore as the number of soil observation points increase, so the value of API decreases.

Investigation of Soil Types

Although the soil profile is not visible on aerial photographs, occasionally the soil surface is observed when vegetation is lacking, or has been removed by ploughing. Different soil types are generally identified by different tones in the aerial photograph. These tonal variations may reflect not only differences in the colour of the soil but also differing moisture contents. Variations in the moisture content indicate variations in the texture and possibly the structure of the soil. Conventional colour and colour infrared films are more suitable for soil survey than panchromatic films. However, high cost is a major limitation and, in most instances, the improved performance does not justify the financial outlay. This is especially the case when the resolution of other major attributes, such as slope, terrain, land use, erosion and geology are only marginally improved.

Generally in soil investigations by API direct evidence is lacking and indirect evidence is sought by way of correlations between soil type and other factors which influence soil distribution, particularly landforms.

For example, under the stereoscope the flat topography of a river flood plain is evident. Rich alluvial soils are subject to intensive cropping and irrigation may occur. Low-lying areas will normally appear dark on the photographs due to high levels of soil moisture and consequent vegetation response. Drainage plains and footslopes are evident.

In such locations hydromorphic or poorly drained soils would be expected. River terraces formed by alluvial soils can also be identified.

Rock outcrops and steep slopes indicate shallow, skeletal soils. Rockiness may be suspected where areas which are apparently suitable for cultivation are, in fact, excluded from cultivation.

Slope, as a soils indicator, is less reliable on undulating terrain. However, with local field experience it is possible to estimate the probable nature of soils on undulating slopes by considering such physiographic elements as the shape of slope, breaks of slope, etc. Geological structure influences rock weathering and is important in this context. For example, shallow soils are probable along the centre line of ridges and spurs, with more deeply weathered material downslope.

Certain specific landform types, clearly definable on aerial photographs, are inherently associated with particular soil types. Two notable examples are wavy gilgai soil patterns associated with fine textured cracking soils, and sand dune systems, either bare or vegetated, with coarse textured soils.

Certain vegetation types are indicative of soil type. This tends to be a function of depth and fertility. For example, kurrajongs are typical of calcareous soils, while soils developed on shale lenses between sandstone beds support different vegetation.

3.5.4 Presentation of Soil Survey Data

Soil survey usually results in the production of a soil map, or an associated interpretative map showing the distribution of homogeneous map units. The advantages of presenting resource data in this form are:

- (i) Large, unwieldy bodies of data are reduced to manageable size.
- (ii) Maps are more readily understood than copious quantities of descriptive data, tables etc.

- (iii) Comprehensive general purpose classifications based on natural groupings present information in a manner acceptable to a wide range of users.
- (iv) Interpretative or special purpose maps show the distribution of information for special planning purposes.

Although soil maps are the accepted form of presentation of soil information, many instances occur where this type of presentation is not required. Hence, a considerable reduction in overall cost can be achieved. Beckett and Bie (1975) point out that the following questions can be answered without a map.

1. What soils occur? - to which the answer is a list of soil classes according to any given system of classification.
2. What are the properties of the soils? - to which the answer is a table of means and dispersions for every relevant property.
3. What are the proportions of different soils? - which can be answered by a rapid statistical sampling programme.
4. What can the soils be used for? - a question a skilled user can answer.

According to Burrough (1976) the only questions requiring a map are "where do the soils occur?" or "what are the properties of the soil at site X?". In certain circumstances a map is not the best method of answering the latter question. Multivariate techniques are available to classify and analyse large sets of data, hence soil information is particularly amenable to computer treatment allowing a totally systematic approach to soil classification and interpretation. Computer methods are discussed in Section 4.9.

3.5.5 Mapping Classes of Traditional Soil Maps

In soil mapping there are several levels at which soil distribution can be presented. The level of classification is determined largely by the scale of the survey and the time available. It reflects the amount of variation in soil properties. The hierarchy of classification categories is not standard and varies in terminology with the system in use. Table 3.2 correlates the levels of the major classification systems used or referred to in Australia.

Table 3.2 Soil Classification Categories (after Corbett 1969)

Stephens (1962)	Northcote (1974)	Soil Taxonomy U.S.D.A (1975)
Solum class	Primary Profile Form	Soil Order
Soil Order	Subdivision	Soil Suborder
Soil Suborder	Section	Great Group
Great Soil Group	Subsection	Subgroup
Family	Class	Family
Series	Subclass	Series
Type	Principal Profile Form	Type

In each case the variation in soil properties decreases down the table. Therefore the most detailed classificatory level is at the soil type or principal profile form level. The following terms are commonly used to describe soil distribution and are discussed in increasing order of variability.

Soil Type is the common basic unit for soil mapping. In the field the soil is subdivided into a number of homogeneous segments, so that they can be classified and predictions made as to their behaviour under various conditions. Each of these segments is a soil type and identification of units is very useful in all forms of soil conservation. The soil type, which corresponds approximately to Northcote's principal profile form, is a unique combination of internal soil characteristics and site features.

The Soil Phase is a subdivision of any category of the classification, (often a sub-division of the soil type), but is not in itself a category of the system, (e.g. stony phase, scald phase, gilgai phase).

The sub-divisions are useful for indicating marked differences of practical significance, or indicating transient or artificially induced changes not accompanied by significant changes in the morphology of the soil.

Soil Variant, should be clearly distinguished, as a subdivision, from the Soil Phase sub-division. It is simply a unit of convenience, designed to avoid unnecessary multiplication of series names. It is closely related to the soil from which it derives its name, but differs in characteristics at the same level of classification. By using

the term variant, the soil surveyor recognises in the profile enough criteria to justify a new series, but for some reason it would not be conveniently established. (e.g. Waco Clay Series - light clay variant).

The Soil Series, is a grouping of soil types with similar profiles, similar temperature and moisture regimes, and the same, or very similar, parent materials.

The name given to a soil series is geographic in nature indicating the locality where the proposed soil series is best developed. Sometimes dual names are given in a combined form, (e.g. NARRADAH - Narrabri + Gunnedah). The "Modal" type of each series should have a defined "type locality", where the characteristics of the series are well developed.

The Soil Family is a grouping of like series at a level below the main Soil Group. The use of this term is not widespread in Australia and is similar to classification at the association level.

The name given to a soil family is taken from the name of the dominant series, however care must be taken to avoid confusion with the series of the same name.

The Soil Complex is a compound mapping unit, containing an intimate mixture of two or more soil types or series, that cannot be differentiated on ordinary soil maps. The complex is allotted a composite name, derived from the principal constituent units, joined by a hyphen, (e.g. Breeza-Nea Series Complex). It also indicates the inclusion of intergrades between the types or series.

As a soil complex cannot be defined in terms of a modal profile and its variations, its constituent units should be described as if mapped separately and, in addition, a description of the pattern and proportions occupied by each unit should be presented.

The Soil Association is a compound mapping unit commonly used on generalised soil maps produced at a small scale, and consisting of a pattern of geographically-associated soil units. It is especially useful where the pattern recurs repeatedly in the landscape. The association may show combinations of soil types, series, soil groups or other soil classes, such as in a catena or toposequence.

Soil associations are named and described according to their constituent units and the nature of the soil pattern in the same way as soil complexes, the more important soils being classed as dominant or sub-dominant, according to the relative area they occupy.

3.5.6 Soil Mapping for Soil Conservation

In soil survey for soil conservation purposes, identification at the soil type level is generally desirable, however practical requirements often lead to a more generalised map unit. The soil surveyor should classify the area into reasonably homogeneous map units so that the soils within each unit behave or react in a similar way to erosional forces. These units should then be treated in a similar way for any soil conservation programme. Although there may be significant variation within each soil type, this should be less than the variation between types. In general, the types should be such that the soil conservationist will know that he can make reasonably uniform predictions about all soils of one type.

The Northcote Factual Key system for the recognition of Australian soils provides a suitable basis for soil conservation mapping. In most instances, the soil class level of Northcote's Key is suitable for delineation of soils. That is, if an area is classified into Northcote soil classes, then it is possible to predict or interpret the erodibility and general soil behaviour with respect to soil conservation requirements.

However, some difficulties may occur because Northcote did not select his identifying properties from a soil conservation viewpoint. In some cases, therefore, it is necessary to classify soils to the principal profile form or further. The important point is that map units should show soils of different soil erodibility and this is generally achieved at the Northcote soil class level. Identification at this level also reduces the amount of field work for the soil surveyor. If, however, it is necessary to map according to principal profile form, then this should only be to separate soils of different erodibility or physical behaviour.

The general approach in soil mapping for Service purposes is to select representative soil sites with the aid of API and identify the soil at each site according to the standard system (see Section 4.6). Boundaries are delineated according to changes in vegetation, landform, slope, geology and variation in surface soil colour or texture. Auger holes and pits should supplement the valuable information available in the form of gullies, post holes, cuttings and other exposures. Care must be taken to ensure that each soil is as representative as possible.

Soil boundaries are often difficult to identify in the field. At Northcote soil class level, they are easier to establish than at a more intense level of classification. The rule is to keep in mind the purpose of the map as a practical aid in soil conservation planning. Map boundaries should be delineated as accurately as possible whilst considering the needs of the farm planner, soil conservationist or other user. During small scale surveys,

areas of a few hectares need not be separately delineated unless they present a particular hazard (e.g. erodible soil, scald or salt patch) or a particular asset (e.g. a disposal area). Where a boundary is transitional, occurring across twenty or thirty metres or more, the boundary should be located on the least erodible soil or area of lower limitation. That is, include the intermediate soil with the less stable soil or on the steeper slope, or with the land which is more likely to need soil conservation protection.

In this way the dictum "when in doubt, err on the safe side" is satisfied. This principle is as important in soil conservation as it is in many other activities.

Chapter 4

SOIL CLASSIFICATION

4.1 The purpose of classification

Classification is the grouping of things according to their similarities and differences. In the case of soils they may be grouped according to the parent material they were formed from, or because their morphology is similar, or because they were formed under similar climates, and so on.

The purposes of soil classification are as follows:

1. Generally, as a means of grouping soils into useful categories - so that statements about one particular soil are likely to apply to other soils in the same group.
2. With experience, the identification and categorizing involved may lead to the inference of other soil properties (apart from those used in the classification).
3. A formal system of classification encourages the scientific and logical examination of soils.
4. The standardization and objectivity involved are desirable for communication purposes.

Naturally no system of soil classification is going to satisfy everyone interested in soils. A civil engineer, a soil conservationist and a vegetable grower would have different criteria to determine the most useful soil classification. It is also likely that no one classification is going to completely fulfil the needs of one individual. This particularly applies to the soil conservationist who is interested in the soil from a number of points of view.

As far as the Service is concerned, it has been suggested that a classification suitable to our own purposes should be developed. The suggestion has some merit, but it is unlikely that any system developed would suit all soil conservationists any better than one of the systems already available. Communication with outside organisations also might be a problem.

There has been a strong move in recent years towards adopting a standard system, and this step was taken in 1971 by the Soil Conservation Service, with the adoption of the Northcote Factual Key. This was followed up in 1974 with the extension of the adopted system to include an indication of surface texture, structure and depth of A horizon.

The purpose of this chapter is to give some background to soil classification so that the limitations and values of systems currently in use can be more clearly understood.

4.2 Traditional and genetic systems

The following list is an example of the range used:

- | | |
|-------------------------------|---|
| a. Great Soil Groups | e.g. Red podzolic soils, krasnozems, black earths. |
| b. Descriptive | e.g. Hard-setting loamy soils with red clay subsoils, cracking clay soils. |
| c. Engineering (Unified) | e.g. SM-SC, ML, CL, CH etc. |
| d. Northcote Factual Key | e.g. Dy3.43, Ug5.12, Gn3.1 etc. |
| e. Western Division of N.S.W. | e.g. SR2, HR3, SB7 etc. |
| f. Textural | e.g. Clay-loam, sandy clay, loam over clay. |
| g. Location | e.g. Upper Manilla red soils, Northern red brown earths. |
| h. Colour | e.g. Black soils, red soils etc. |
| i. Parent Material | e.g. Granite soils, lateritic soils, basaltic soils etc. |
| j. Genetic | e.g. Podzolic soils, solodic soils, hydromorphic soils. |
| k. Topographic | e.g. Gilgai soils, mountain soils. |
| l. Combination of the above | e.g. Basaltic red loams, Krasnozems (Gn4.11), Brown wavy gilgai soils, white clays. |
| m. Soil Series | e.g. Curlewis sandy loam (soil series name combines type location and surface texture). |
| n. Miscellaneous | e.g. Trap soils, mallee soils, brush soils, meadow soils, dispersible soils. |

The most successful and widely-used systems have been those based on soil formation theory, although geological systems have also enjoyed some popularity, as have those based on soil morphology. This success of the genetic classifications has been due to the breadth of information about a soil which can be directly deduced or indirectly inferred from its classification. The fact that genesis and morphology are so strongly linked has been the main reason for this. In contrast, some of the other systems

such as geologic, textural, colour, topographic or vegetational, allow little additional inference apart from the information conveyed by the group name.

The genetic systems of classification, developed first by the Russians, and modified and improved by the Americans, lead to the widespread adoption of the concept of Great Soil Groups. This has been the basis of soil classification in Australia to the present time, and therefore will be dealt with in some detail.

4.3 The Great Soil Group system

The Russian system was first introduced to Australia by Prof. J.A. Prescott in the 1930's. His map of Australian soils introduced the Great Soil Group concept here, and also introduced Great Soil Groups not previously described.

He discussed in an historic bulletin the genesis of soils, with particular emphasis on the role of climate and vegetation. The concept of genetic classification and zonality was, however, stated to be complicated by the presence of ancient landscape elements in Australia. Past climates played an important role in the development of existing soils.

Table 4.1 shows an outline of some of Prescott's original proposals.

Prescott's system, with some modifications based on local and U.S. developments, has been the basis for study and development of Australian soils until recently. The most important modifications to Prescott's Australian expression of the broader great soil groups, were made by Stephens in the early 1960's, especially as presented in Stephens (1962). See Table 4.2.

The grouping depends solely on the appraisal and interpretation of features found in the soil itself - at least this is the concept. The principal features considered are colour, texture, structure and consistence of the various horizons or layers found in the soil profile or section, and the nature of the horizon boundaries. In addition, the presence, form and approximate amounts of various inclusions and microfeatures are noted. Parent material is also recognised.

Stephens felt that a sound morphological system would benefit by relating to genetic development and so the dominant soil-forming factors were indicated in the outline to the scheme. Stephens (1962) outlines the Great Soil Groups and their possible sub-division into families, series, types and phases. Great Soil Groups have, however, been the major expression given to Australian soils to date, little use being made of the higher degrees of classification.

Stace et al (1968) have presented a further and significant modification to the Great Soil Group System

Table 4.1 Major Soil Groups of Australia

(After J.A. Prescott (1931)).

Soil Group	Colour	Horizons	Character of Profile
Desert sandhills	Yellow to red	A ₀	Blown sand
Desert-steppe & semi desert	Red and Brown	AC	Surface feature important.
Mallee Soils	Light red-brown	A	Sand or sandy loam
		B	Solonized clay, calcium carbonate, soluble salts.
Red-brown earths	Brown surface	A ₁	Sandy with some humus
		A ₂	Sandy, red
	Red subsoil	B ₁	Clay, weakly podzolized.
		B ₂	Calcium carbonate
Black earths	Black, grey black	A	Clay with humus
		AB	Black clay with calcium carbonate
		BC	Calcium carbonate, gypsum
Grey and brown soils	Grey, dark chesnut,	AB	Little humus, calcium carbonate.
	Brown	BC	Calcium carbonate, gypsum
Podzolized soils	Dark grey surface, light texture	A ₁	Sandy with humus
	grey sub-surface	A ₂	Sandy
	yellow subsoil	B ₁	Rarely ironstone pan or concretions
		B ₂	Clay
Red loams	Uniformly red or chocolate profile		No separation of horizons, permeable, occasional concretionary oxides of iron and manganese
High moor and mountain soils		A ₀	Peat over clay or skeletal soils over rocks.
Lateritic sand plain	Light grey to yellow with ironstone gravels		Presumed to be Tertiary podzols

Table 4.2 Great Soil Groups arranged under Solum Classes,
Soil Orders, and Sub-Orders

(C.G. Stephens, 1962)

1. SOLUM UNDIFFERENTIATED

1. Alluvial soils: showing only sedimentary horizons (amorphic)
2. Skeletal soils: shallow stony soils with no significant profile development (amorphic).
3. Calcareous coastal sands: with no significant profile development (amorphic)

11. SOLUM DIFFERENTIATED

A. Pedalfers	B. Pedocals
<p>a. Solum dominated by acid peat or peaty eluvial horizon</p> <p>4. Moor peats (phytomorphic)</p> <p>5. Alpine humus soils (mesomorphic)</p> <p>6. Moor podzol peats (polymorphic)</p> <p>7. Acid swamp soils (polymorphic)</p> <p>b. Solum acid, and with organic, sesqui-oxide and sometimes clay illuvial horizons</p> <p>8. Podzols (mesomorphic)</p> <p>9. Ground-water podzols (hydro-morphic)</p> <p>c. Solum acid, and with clay and sesqui-oxide illuvial horizons</p> <p>10. Lateritic podzolic soils (polymorphic)</p> <p>11. Grey-brown podzolic soils (meso-morphic)</p> <p>12. Brown podzolic soils (mesomorphic)</p> <p>13. Red podzolic soils (mesomorphic)</p> <p>14. Yellow podzolic soil (mesomorphic)</p> <p>15. Meadow podzolic soils (hydro-morphic)</p> <p>16. Non-calcic brown soils (poly-morphic)</p>	<p>e. Solum dark coloured and slightly acid to neutral in eluvial horizons, calcareous illuvial horizons.</p> <p>23. Black earths (mesomorphic)</p> <p>24. Wiesenboden (hydro-morphic)</p> <p>25. Brown forest soils (calcimorphic)</p> <p>26. Rendzinas (calcimorphic)</p> <p>27. Ground-water rendzinas (polymorphic)</p> <p>28. Fen soils (polymorphic)</p> <p>f. Solum saline or showing post-saline structure in the illuvial horizon</p> <p>29. Solonchaks (halomorphic)</p> <p>30. Solonetz (halomorphic)</p> <p>31. Solodized solonetz (halomorphic)</p> <p>32. Soloths (halomorphic)</p> <p>33. Solonized brown soils (polymorphic)</p> <p>g. Solum with slightly acid to neutral eluvial horizons and calcareous illuvial horizons.</p> <p>34. Red-brown earths (mesomorphic)</p> <p>35. Brown earths (mesomorphic)</p> <p>36. Brown soils of light texture (polymorphic)</p> <p>37. Arid red earths (polymorphic)</p> <p>38. Grey calcareous soils (calcimorphic)</p>

Table 4.2 (Cont'd)

A. Pedalfers	B. Pedocals
<p>d. Solum acid to neutral and lacking pronounced eluviation of clay</p> <p>17. Yellow earths (haemomorphic)</p> <p>18. Krasnozems (haemomorphic)</p> <p>19. Lateritic krasnozems (polymorphic)</p> <p>20. Lateritic red earths (polymorphic)</p> <p>21. Terra rossa (calci-morphic)</p> <p>22. Prairie soils (mesomorphic)</p>	<p>h. Solum with neutral to alkaline weakly developed eluvial horizons and calcareous and/or gypseous illuvial horizons</p> <p>39. Grey soils of heavy texture (hydromorphic)</p> <p>40. Brown soils of heavy texture (mesomorphic)</p> <p>i. Solum with deflated, slightly acid to alkaline eluvial horizons and calcareous and/or gypseous illuvial horizons</p> <p>41. Desert loams (mesomorphic)</p> <p>42. Grey-brown and red calcareous desert soils (calcimorphic)</p> <p>43. Red and brown hardpan soils (hydromorphic)</p> <p>44. Desert sand plain soils (polymorphic)</p> <p>45. Calcareous lateritic soils (polymorphic)</p> <p>46. Stony desert tableland soils (polymorphic)</p> <p>47. Desert sandhills (mesomorphic)</p>
<p><u>Definitions:</u></p> <p>Pedalfers: Soils in which lime carbonate does not accumulate in any part of the profile, but such carbonate as may have been present in the parent material is continually in process of disappearance from the soil profile.</p> <p>Pedocals: Soils in which, regardless of the presence or absence of lime carbonate in the parent rock, lime carbonate (and/or sulphate) has accumulated in the soil during the progress of soil making and as a result of the soil-forming processes.</p>	

Table 4.3 Great Soil Groups in Order of Degree of Profile Development and Degree of Leaching
(Stace et al 1968)

1. No Profile Differentiation	1. Solonchaks 2. Alluvial soils 3. Lithosols 4. Calcareous sands 5. Siliceous sands 6. Earthy sands
2. Minimal Profile Development	7. Grey, brown and red calcareous soils 8. Desert loams 9. Red and brown hardpan soils 10. Grey, brown and red clays
3. Dark Soils	11. Black earths 12. Rendzinas 13. Chernozems 14. Prairie soils 15. Wiesenboden
4. Mildly leached soils	16. Solonetz 17. Solodized solonetz and solodic soils 18. Soloths (Solods) 19. Solonized brown soils 20. Red-brown earths 21. Non-calcic brown soils 22. Chocolate soils 23. Brown earths
5. Soils with predominantly sesqui-oxidic clay minerals	24. Calcareous red earths 25. Red earths 26. Yellow earths 27. Terra rossa soils 28. Euchrozems 29. Xanthozems 30. Krasnozems
6. Mildly to strongly acid and highly differentiated	31. Grey-brown podzolic soils 32. Red podzolic soils 33. Yellow podzolic soils 34. Brown podzolic soils 35. Lateritic podzolic soils 36. Gleyed podzolic soils 37. Podzols 38. Humus podzols 39. Peaty podzols
7. Dominated by organic matter	40. Alpine humus soils 41. Humic gleys 42. Neutral to alkaline peats 43. Acid peats

in the light of recent developments in Australian soil science - including the contribution of Northcote on soil recognition and Brewer (1964) on soil micromorphology.

The groups are now given in an order such that they represent an overall progressive increase in the degree of profile development and degree of leaching (Table 4.3).

Within the sequence a number of categories are recognised, beginning with those in which there is little or no profile development, and ending with soils dominated by the accumulation of organic matter. Thus the dark soils follow the category with minimal profile development, and are followed in turn by categories which are progressively more strongly leached and more highly differentiated.

The Great Soil Group form of classification is extremely useful in that once a soil is identified, many of its properties and probable formation patterns are automatically inferred. Another advantage is that the system has been reasonably correlated with world groups, both of the traditional type, and of the modern UNESCO-FAO world soil maps. (Dudal 1968). However, with the increasing knowledge of soils and soil variations currently becoming evident the system has some distinct disadvantages which may be summarised as follows:

- (a) The system is too subjective, depending on individual interpretation.
- (b) There are wide variations within and between great soil groups which are not adequately covered.
- (c) The system is based on the ZONAL concept of soil formation, which is now losing favour. This assumes knowledge of the climate in which a soil has formed and, particularly in Australia, there is evidence that the morphology of some soils does not accurately reflect the current climate.
- (d) Other soil formation assumptions which have been proved partially erroneous.

Several attempts were made to develop a factual system - one based on the features of the soil only - but there were many setbacks. It was K.H. Northcote who, in 1960, first brought out his "Factual Key for the Recognition of Australian Soils". This has since been further developed and widely applied in this country and overseas. It forms the basis for the system of soil classification used in the Service, and therefore is now described in some detail.

4.4 The Northcote Factual Key System

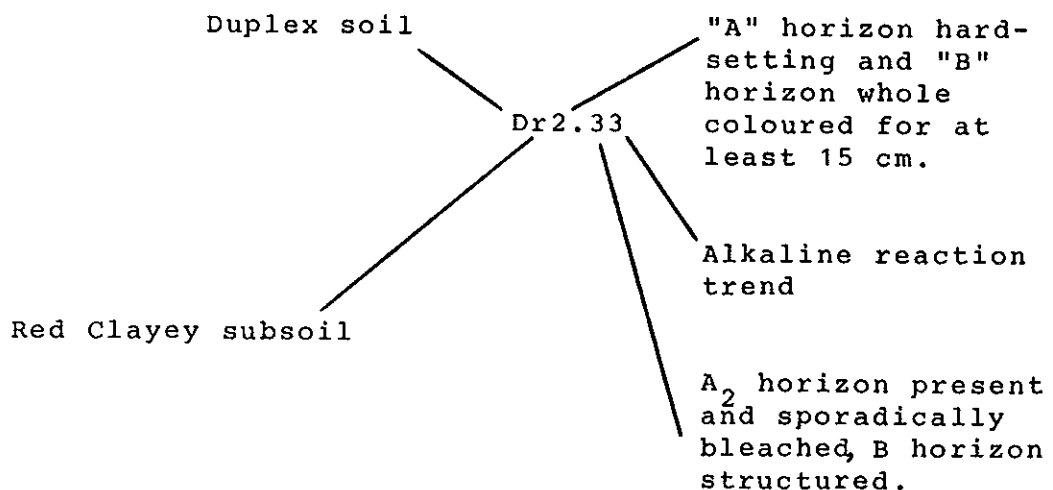
The account here is based on the fourth edition of the Factual Key which was published in 1974.

The key depends on the recognition of a number of

features of the soil profile - this being done either by observation, handling, or in two cases - simple chemical tests which can be easily carried out in the field. Because of this the identification of a soil is made almost completely objective, as definitions used to describe each feature have been precisely set out in a comprehensive glossary. The method is essentially a field one, and does not depend on any laboratory determinations.

Five main levels of classification have been included - those of division, sub-division, section, class and principal profile form. The soil description is expressed as a letter/number combination. As each feature of the soil profile is determined a letter or number is added to the coding to account for that feature, letters being used for divisions and sub-divisions, and numbers for sections, classes, and principal profile forms. Each letter and number (and their position) has, therefore, a precise meaning to anyone using the system.

Example



The coding Dr2.33 classifies the soil at the principal profile form level, and this represents the level at which a reasonably concise statement can be made which would apply to all soils of that designation. A soil coded Dr2.33 near Manilla is likely to have very similar form and properties to a soil of the same designation at Cowra. The classification can be taken past this stage if desired, to account for other variations, as in the standard S.C.S. format. If insufficient data is available, the coding still has meaning at a simpler level - Dr2 has a precise meaning, but Dr2.33 is a more useful classification.

In some parts of the key sub-sections and sub-classes are used to facilitate differentiation between certain groups of soils, but these are not included in the final coding of the particular soil. For example, the section Ucl is composed as follows:

Sub-section a : Classes Uc1.1 and Uc1.2

Sub-section b : Classes Uc1.3 and Uc1.4

(here the sub-sections are separated according to the coherence of material below the A₁ horizon).

Throughout the key accent is placed on the characters of the A₂ and B horizons, as it was found during the study of hundreds of profiles for this work that these were the most consistent and expressive features. However, other special features are used such as the hard-setting nature of the surface and amount of calcium carbonate present in the profile.

Levels of Classification

1. Division

Four soil divisions are recognised, and for precise definition reference should be made to the glossary in the Key itself.

Organic (O) soils are those dominated by organic matter, and at this stage have not been further subdivided except to acknowledge two reaction trends.

Uniform (U) soils are soils of uniform texture throughout the profile.

Gradational (G) soils show increasingly fine texture (more clayey) down the profile, but without any sharp change.

Duplex (D) soils are those with a marked texture contrast between the A and B horizons.

2. Sub-division

The sub-divisions within each division are simply defined.

The U division is split into Uc - coarse textures, Um - medium textures, Uf - fine textures, and Ug - fine textures with seasonal cracking. The term "seasonal cracking" applies to those clay soils which crack open in the dry season. Cracks should be at least 6 mm wide and 30 cm deep. This phenomenon is typical of most black earths, heavy textured and cracking-clay soils, and those clays showing gilgai formation. It does not include those which show only a self-mulching effect in the dry season.

The G division is split into Gc - those soils which are calcareous throughout the solum and Gn - those which are not. Calcareous soils contain nodules of calcium carbonate (lime) which will effervesce clearly with 2-3 drops of Hydrochloric acid (N) applied from a dropper.

The D division is split into sub-divisions Dr-red; Db brown; Dy - yellow; Dd - dark and Dg - gleyed, these colours applying to the upper 15 cm (at least) of the clayey B horizon.

Soil colour is of importance throughout the operation of the key, not only in the Duplex division. It is therefore essential to have a clear understanding of how colour is determined, and not be colour blind!

3. Section, Class and Principal Profile Form

At these levels of classification a number of key features of the soil are used for identification, some of which are common to all divisions, and some of which are used in combination. The main ones are as follows:

- | | | |
|-----|---|-----------------|
| (a) | Pedologic organisation | |
| (b) | Character of the A ₂ horizon | |
| (c) | Structure (pedality) | See Section 3.3 |
| (d) | Nature of surface soil | for detailed |
| (e) | Mottling | explanations of |
| (f) | Coherence | (a) to (i) |
| (g) | Soil reaction trend | |
| (h) | Consistence | |
| (i) | Pans | |

Operation of the Key

The operational part begins on pages 35-36 of the Key with the distinguishing features of divisions and sub-divisions. Each soil identification should start here, and once the correct sub-division has been determined a page number is given for the continuation of the classification.

The sequence of operation in the key is governed by letter or number symbols, so that for every feature "A" there is a place for the feature "not A".

It is important when a number of widely separated alternatives are presented, and the first alternative is not applicable, to proceed to the second alternative with the same subscript (numbers in sequence, letters (A) or (B) or double letters (AA) or (BB)) disregarding anything in between. This is continued until the applicable alternative is found - then the alternatives for the next level of classification are found immediately underneath.

Three examples are presented to demonstrate the procedure.

Example 1

Assume a soil profile with the following distinguishing features:

- A Horizon - Seasonally hard setting surface
- Topsoil pH = 6.5.
- Upper colour 5YR4/2 moist
- Lower colour 5YR6/4 moist 5YR7/2 dry
- Texture - loam

Clear change over 5 cm to:

- B Horizon - Texture - light clay
- Structure - blocky
- Upper colour 2.5YR4/6 moist (no mottling)
- Lower B horizon pH = 5.8

Pages in Key	Procedure	Decision	Reason
35 - 36	The DIVISION will be one of the 4 alternatives (A)	D	Texture-contrast of two field classes between A & B horizons (Loam to light clay)
36	Under D, the SUB-DIVISION will be one of the 5 alternatives (B) <u>PROCEED TO PAGE 88 FOR SUB-DIVISION Dr</u>	Dr	Upper subsoil colour value/chroma rating = 5. Hue redder than 5YR.
88	Under Dr, the SECTION will be one of the 5 alternatives (1) - (5)	Dr2	A ₁ horizon hard-setting. B horizon whole-coloured for upper 15 cm (less than 10% mottling).
90	Under Dr2, the SUBSECTION will be one of the 2 alternatives AA	a	Peds evident in clayey B horizon.
90	Under 'a', the CLASS will be one of the 4 alternatives A.	Dr2.4	A ₂ horizon present and conspicuously bleached (these criteria determined by comparing colour of lighter horizon with that of the A ₁ and B).
90	Under Dr2.4, the PRINCIPAL PROFILE FORM will be one of the 3 alternatives B	Dr2.41	Acid reaction trend, deep subsoil pH less than 6.5, topsoil pH less than 7.0.

Principal Profile Form is therefore Dr2.41.

Example 2

Assume a soil profile with the following distinguishing features:

- A Horizon - Upper colour 7.5YR 3/4 moist
- Lower colour 7.5YR 4/4 moist 7.5YR5/3 dry
- Texture - clay loam

Gradual change to:

- B Horizon - Texture - clay loam
- Structured with dense smooth-faced peds
- Upper colour 7.5YR3/6

<u>Pages in Key</u>	<u>Procedure</u>	<u>Decision</u>	<u>Reason</u>
35 - 36	The DIVISION will be one of the 4 alternatives (A)	U	Uniform texture profile (clay loam)
35	Under U, the SUB-DIVISION will be one of the 4 alternatives (B)	Um	Clay loam is medium texture
46	<u>PROCEED TO PAGE 46 FOR SUB-DIVISION Um</u> Under Um, the SECTION will be one of the 7 alternatives (1) - (7)	Um4	Pedological organisation A ₂ horizon present but not bleached (determined on colour)
49 - 50	Under Um4, the CLASS will be one of the 4 alternatives A	Um4.4	B horizon with smooth-faced peds
50	Under Um4.4, the PRINCIPAL PROFILE FORM will be one of the 3 alternatives B	Um4.42	Colour of B horizon value/ chroma = 5. Hue yellower than 5YR.

Principal Profile Form is therefore Um4.42

Example 3

Assume a soil profile with the following distinguishing features:

- A Horizon - Upper Colour 2.5YR3/3
- Lower Colour 2.5YR3/4
- Topsoil pH 6.2, not calcareous
- Texture - clay loam

Gradual change to:

- B Horizon - Texture - light clay
- Coherent, structured, with rough-faced peds
- Upper colour 10R4/6 - mottled
- Deep subsoil pH 8.1, calcareous

<u>Pages in Key</u>	<u>Procedure</u>	<u>Decision</u>	<u>Reason</u>
35 - 36	The DIVISION will be one of the alternatives (A)	G	Gradual change to more clayey texture - exceeds span of one texture group.
35 - 36	Under G, the SUBDIVISION will be one of the alternatives (B)	Gn	Profile not calcareous throughout.
75	<u>PROCEED TO PAGE 75 FOR SUBDIVISION Gn</u>		
	Under Gn, the SECTION will be one of the alternatives (1) - (4)	Gn4	B horizon coherent with rough-faced peds.
84 - 86	Under Gn4 the SUBSECTION will be one of the alternatives AA	e	B horizon V/C rating 5, mottles
85 - 86	Under 'e' no alternatives for CLASS. One choice only	Gn4.7	No A ₂ horizon
86	Under Gn4.7, no alternatives for SUBCLASS One choice only	a	No A ₂ horizon
86	Under 'a', PRINCIPAL PROFILE FORM will be one of the alternatives B.	Gn4.73	Alkaline reaction trend. Subsoil pH>8.0.
<u>Principal Profile Form is therefore Gn4.73</u>			

Practical problems

One problem which occurs in the field is the lack of an A₁ horizon, particularly under eroded conditions where the topsoil has been removed. Although the key mainly depends on the properties of the A₂ and B horizons, it is desirable to assess the profile where a minimum of disturbance to the surface soil has taken place. Thus, while a gully may give a satisfactory exposure when cut back, the topsoil characteristics may have to be inferred from a less disturbed situation nearby.

Road cuttings or roadside gullies have to be viewed with particular care because of the possibility of extraneous material having been incorporated with the profile at some stage during the formation of the road. However, a fresh cutting in a new area does often give an excellent profile exposure for study.

Where a suitable gully, cutting or pit of some kind is not available, and time, situation or circumstances preclude the digging of a profile pit, a soil auger can be used. In this case it must be kept in mind that augering affects the natural structural condition of soil, and does not allow the profile to be viewed in situ. However, if due allowance is made for these restrictions, a reasonably accurate identification can still be made.

From experience gained using the key in many centres and with many different officers, the main problem seems to be the field assessment of soil texture. A fair degree of subjectivity remains associated with this determination, and it is recommended that familiarity with the full range of textures and their handling qualities should be prerequisite to using the key for identifying soils. The feel of the soil and its resistance to working are as important as the degree to which it rolls out or ribbons. The relevance of the dictum "practice makes perfect" cannot be stressed too strongly.

Another major problem concerns recognition of the solum, i.e. that portion of the soil profile influenced by current soil processes. Buried soil profiles and recent sediments should not be included in the analyses of the solum. The presence of these layers should be recorded as follows: Gn2.11 overlying buried clay material or 5cm silt layer overlying Ug 5.15 etc.

Other practical problems will be avoided if the general procedures for studying the soil profile, as set out in Section 3.3, are followed.

It should be noted here that, whilst the horizons used in the key generally have the same genetic significance as in the great soil group system, no genetic assumptions have to be made in identifying them. Their recognition is based objectively on determinations of colour, texture etc.

Summary

Table 4.4 summarizes the whole scheme by showing the distinguishing features of each group of soils at all levels of classification. It may have particular use in the field as a guide to the soil features which must be recorded, especially if classification is to be carried out later on. However, it is emphasized that this is essentially a field method, and practice in use should facilitate reasonably rapid "on-the-spot" identification of the soil.

4.5 Soil recognition and correlation

At the end of this text are two appendices relevant to soil recognition. Appendix I is a list of correlations between Northcote codings and soil group names. Appendix II is a set of tables to assist in the identification and characterization of Great Soil Groups and other soil groups using the Northcote Key.

The concepts behind these two types of classification are very different, and thus any correlations between them are far from absolute. However, for recognition purposes both the Great Soil Group and Factual Key systems rely heavily on the characteristics of the soil profile. There is thus a considerable amount of common ground which can be utilized with benefit.

In some cases the Northcote Key is sufficient to identify recognized groups (e.g. Black earths, krasnozems and desert loams). In other cases, however, further diagnostic features are given to assist identification (e.g. Solonchaks, alluvial soils, lithosols).

Where soil consistence is used as a diagnostic feature, it is expressed in the dry/moist condition, i.e. V. hard/tough consistence means the material is very hard when dry and has a tough consistency when moist. Terminology used is generally that of the Factual Key.

Soil names used are those from "A Handbook of Australian Soils" (Stace et al 1968) with minor modifications only. The use of slashes between soil names indicates alternatives which must be then selected on the basis of further diagnostic features. Soils not named in the "Handbook of Australian Soils" have been given simple descriptive names based on the Northcote coding.

Any scheme of correlations such as this is likely to involve some overlapping, because of the infinite variations which occur in the field, and the different concepts behind each classification. For simplicity, this has been reduced as far as possible with the aid of the Northcote Key. It is strongly emphasized that in this scheme the typical or "modal" soil of each group has been sought, but at the same time an attempt has been made to satisfactorily accommodate all principal profile forms recognized to date. The list should be regarded as a guide to the likely relationship between soils recognised under the two different systems.

Table 4.4 Soil properties used in the Northcote Factual Key

Division	Sub-division	Section	Class	Principal Profile Form
O	Neutral or acid reaction			
U	Texture Uc (coarse) Um (medium) Uf (fine) Ug (fine and seasonally cracking)	Pedologic organisation of profile and character of A ₂ horizon. Pedality (7)	Nature of material below A ₁ and/or A ₂ Colour Coherence CaCO ₃ Pedality Hardpans (7)	Colour of material below A ₁ horizon Soil depth and underlying material (9)
G	Presence of calcium carbonate Gc (calcareous throughout) Gn (not calcareous throughout)	Structure (pedality) and fabric of B horizon (4) Gc1-2 ----- Gn1-4	CaCO ₃ concentration in A horizon (2) Colour of B horizon. Character of A ₂ horizon (10)	Colour of the A ₁ horizon (2) OR coincidence of maximum clay and CaCO ₃ horizons (2) Character of A ₂ horizon Soil reaction trend (12)
D	Colour of upper B horizon Dr (red) Db (brown) Dy (yellow) Dd (dark) Dg (gleyed)	Nature of A horizon and Degree of mottling of Upper B horizon (5)	Pedality of B horizon. Character of A ₂ horizon (8)	Presence of pans or laterite Soil reaction trend (6)

Note: The figures in brackets represent maximum numbers of that group occurring at that level of classification e.g. The maximum number of classes per section in the duplex soils is 8.

4.6 The S.C.S. System of Classification

When considering a soil classification system for adoption, the Service saw Northcote's Factual Key as a scheme that took account of many soil properties which were relevant to soil erosion and conservation. The list includes soil structure, texture change, colour, coherence, profile morphology, hardpans, reaction, depth, surface characteristics, consistence and cracking.

Despite the fact that all these properties are not coded for all soils, it is obvious that many of them are of direct relevance to soil conservation. Soil texture and texture change, soil structure and profile organization are clearly pertinent to infiltration and erodibility. Soil surface characteristics strongly relate to runoff production. Soil coherence, consistence and texture also relate strongly to a soil's behaviour when used in earthworks. Soil colour, bleaching and reaction trend are chemical parameters which relate, less directly perhaps, to soil stability and fertility. Thus there is a strong link between these soil properties and the soil's behaviour in a soil conservation or erosion situation.

The system adopted by the Soil Conservation Service is thus based on the Northcote Factual Key. It consists of an extended principal profile form to account for surface texture, surface structure and depth of A horizon. These features are added as in the following example:

Ug5.15 - 5/2/20 (Black earth)

where Ug5.15 is the principal profile form

5 is the surface texture class

2 is the surface structure class

20 is the depth of the A horizon in cm.

(Black earth) is the Great Soil Group.

Definitions for the additional surface parameters are as follows:

Surface texture - the texture, as determined in the field, of the top five centimetres of soil, disregarding any surface litter or crust, in terms of Northcote's texture groups 1-6 (See Factual Key, p. 29).

Surface structure - the general structural condition of the top five centimetres of soil, disregarding any immediate surface crust or self-mulching characteristic. Terms should be those of Northcote's structure grades 0-3. (See Factual Key p. 25).

Depth of A horizon - the depth in centimetres of the whole A horizon (if any) as defined by Northcote. (See Factual Key p.17).

Other examples of the nomenclature are listed hereunder:

Uf5.11 - 5/2/10 (Structured sub-plastic clay)
 Uc2.36 - 1/0/30 (Humic podzol)
 Um7.11 - 3/2/5 (Alpine humus soil)
 Gc2.12 - 2/1/10 (Solonized brown soil)
 Gn2.17 - 2/0/25 (Red leached earth)
 Dr2.23 - 3/1/5 (Red-brown earth- eroded)
 Db3.12 - 4/3/8 (Chocolate soil)

This system was developed following a review of soil classification usage in the Service which was mentioned in the introduction to this handbook. One of the results of this review was an indication that approximately 60% of soil conservationists were in favour of the adoption by the Service of a standard system based on the Northcote Factual Key.

The two main limitations of the Key, as revealed in the review, were its complexity and its limited use of soil properties of importance in soil conservation work. With regard to complexity, it was felt by the review committee that this was the result of unfamiliarity rather than a genuine criticism.

However, it was felt that the criticism about soil conservation properties was to a certain extent valid, although many of the soil properties used in the key are pertinent. After considerable thought it was decided to add three more parameters. These are texture and structure of the surface soil and depth of the A horizon. These are thought to be the most important properties of relevance to soil conservation which were not generally indicated by the Northcote classification.

The review also indicated that many soil conservationists wanted the Great Soil Group names (and concepts) to be retained, at least until the factual system was fully understood and in use by all concerned. This requirement has been acknowledged, and the group names (as per the correlation list) retained. The Great Soil Groups used have been aligned with those described in "A Handbook of Australian Soils" (Stace et al 1968) which is the most suitable general text on Australian soils available.

4.7 Soil Classification for Western Lands

Soil data in the Western Division of N.S.W. is used mainly in broad-scale mapping, for land system surveys (scale 1:250,000) and Western Lands Lease Management Planning (scale 1:50,000).

The former surveys are used for basic descriptions of large areas of pastoral country, whilst the latter are used to map each pastoral holding in the Western Division into its land and vegetation types. These are then used to determine erosion susceptibility, stocking capacity, and management requirements for maintenance or improvement of the resources available.

In the semi-arid to arid environment, drought is the rule rather than the exception, and vegetation has become delicately balanced with the environment. Overgrazing upsets this balance, sometimes irreversibly, causing degradation of pastures and then erosion of susceptible soils, especially when the overgrazing occurs in dry or drought conditions when vegetation has already become naturally depleted. Hence, it is the ability of the soil to produce vegetation and maintain it into dry periods and the susceptibility of the soil to erosion that are of prime concern to the western soil conservationist.

4.7.1 Basis of the Classification System

Soil physical properties such as infiltration rate, water-holding capacity and presence of root-restricting layers, along with micro-topography (eg. gilgais where extra water accumulates), erodibility and inherent fertility are the main soil properties which need to be characterized. Accordingly, a soil classification system, suitable for use at the mapping scales required, has been developed to map the soils on each pastoral holding. This system takes into account the above features, using soil texture as an indicator of infiltration rate and water-holding capacity.

Sandy soils have a high infiltration rate, but low waterholding capacity and inherent fertility, and are highly susceptible to erosion because of their easily detachable surface. Heavy clays normally have relatively higher fertility and waterholding capacity and lower erodibility. Whilst vegetation growing on sandy soils responds rapidly to small falls of rain, the low water-holding capacity and low fertility of the soils does not favour the growth of perennial plants in dry periods. The soil thus becomes bare and susceptible to movement by wind. Vegetation on heavy clays responds to larger falls of rain, and once these soils are wet they retain moisture for long periods and are therefore more able to support perennial vegetation. However, these soils can become completely bare in droughts or after heavy stocking, but very little erosion occurs. Hence, generally speaking, as texture becomes finer the soil is better able to produce perennial vegetation, has higher fertility, and is less susceptible to erosion.

As most plant roots are in the surface soil layers, the depth of the surface soil is also taken account of in the classification system. Presence of layers which impede root penetration such as hardpans, stone layers, bedrock, or dense clay B horizons are also integrated into the system.

The presence of calcium carbonate throughout most soils reflects the generally high pH's of these soils. The high pH in turn reduces the availability of some plant nutrients.

The present classification system was developed to meet the particular need for describing soils in the detail suitable for range assessment and management work. Previous broad-scale surveys of the area were not sufficiently detailed, whilst mapping at a larger scale (eg. by using Northcote classification) was not warranted.

Further, the classification has a "practical" basis. For example, soil studies have revealed that many soil profiles comprise two or more layers of different ages, and in the Northcote classification system, only the topmost layer is usually classified, and noted as overlying other layers. The present system describes all profiles as single profiles, even if layers of different ages and origins occur within the profile. This is of most significance where a sandy layer overlies an older clay layer. The present system classifies such a profile as a "texture contrast" soil (i.e. duplex) rather than (for example) "Uc5.11 over clay".

4.7.2 The Classification System

The broad groups used are as follows -

SR	Soft Red Soils
HR	Hard Red Soils
SB	Solonized Brown Soils
TC	Texture Contrast Soils
SK	Skeletal Soils
HC	Heavy Clay Soils
GR	Granite Soils
BG	Brown Gibber Soils
DL	Desert Loam Soils

Soft Red Soils

Red and red-brown sands to clay loams showing little or no change in the profile with depth except a gradual increase in clay content from the surface soil. Massive structure. The soils are non-calcareous at the surface but may be calcareous at depth. Subject to windsheeting with variable amount of drift.

These soils are further sub-divided on the basis of texture, as follows:

- SR1 The surface soil is a clay loam to 15 cm deep.
- SR2 The surface soil is a loam to 15 cm deep.
- SR3 The surface soil is a sandy loam to 15 cm deep.
- SR4 The surface soil is a sandy loam 15-30 cm deep.
- SR5 The surface soil is a loamy sand to 15 cm deep.
- SR6 The surface soil is a loamy sand 15-30 cm deep.
- SR7 The surface soil is a sand to 15 cm deep.
- SR8 The surface soil is a sand 15-30 cm deep.
- SR9 The surface soil is a sand 30-60 cm deep.
- SR10 The surface soil is a sand 60-90 cm deep.
- SR11 The surface soil is a sand greater than 90 cm deep.

These soils occur on plains, as sand-dunes, and in major creek-beds. On the plains the soils are mainly gradational calcareous or neutral red earths (Gn2.13 and Gn2.12) with smaller areas of uniform soils such as Um5.52 (SR1, SR2 and some SR3 soils). On sand-dunes and in creek-beds coarse textured uniform profiles (Uc5.11, Uc5.21, Uc1.2) or gradational sandy earths (Gn1.13) occur (SR3-SR11 depending on depth and degree of profile development).

Extended codings describing surface texture, surface structure and depth of A horizon (outlined earlier in this book) can be used to more fully describe these soils in terms of the Northcote classification. For example,

an SR1 would be Gn2.13 - 4/0/15 or Gn2.12 - 4/0/15;

an SR2 would be Gn2.13 - 3/0/15 or Um5.52 - 3/0/15;

an SR4 would be Uc5.11 - 2/0/30;

and an SR10 would be Uc5.11 - 1/0/90 or Uc1.23 - 1/0/90

Hard Red Soils

Red and red-brown sandy loams to clay loams with little or no change in the profile with depth except for an increase in texture. They are acid, compact, with stone and gravel and frequently have an earthy hardpan at 20 to 70 cm depth. Structure is massive. They are subject to watersheeting and windsheeting, frequently with minor to moderate rilling and gullyng of the lower slopes.

These soils are sub-divided as follows:

- HR1 The surface soil is a clay loam to 15cm deep.
- HR2 The surface soil is a loam to 15cm deep.
- HR3 The surface soil is sandy loam to 15cm deep.
- HR4 The surface soil is sandy loam 15-30cm deep.

These soils are more compact, "harder", than the soft red soils, and occur on undulating country (mainly the Cobar pediplain, but also in other areas) and some adjacent plains. On the upper ridges the soils are truncated acid red earths, Um5.51, which are shallow and stony and overlies bedrock. On lower slopes and in drainage lines the soil profile overlies a hardpan which severely restricts root penetration. The soils here are gradational red earths (Gn2.12, Gn2.11) or uniform hardpan soils (Um5.31). Surface sandy deposits from rill-lines, or residual topsoils give rise to the HR3 and HR4 soils. Similar soils with a true red-brown hardpan occur around White Cliffs. These are associated with Tertiary lateritic landforms and occur mainly on mesa plateaux, crests of hills and stony rises. The soils are predominantly uniform (Um5.31), gradational (Gn2.12) and duplex (Dr1.54, Dr1.55, Dr1.56) soils.

These hard red soils could be differentiated from the soft red soils under the Northcote classification by further extending the classification with an addition to indicate the presence and depth of a hardpan.

For example,

Gn2.11 - 4/0/15 - H60 would be a HR1 with a hardpan commencing at 60 cm depth.

Solonized Brown Soils

These are red, red-brown to yellow-brown sands to light clays showing little or no change in the profile with depth except gradual increase in clay content and lime content. Light to heavy amounts of nodular limestone are found to 90 cm. They have massive structure. These soils are subject to windsheeting with variable amount of drift.

These soils are sub-divided on the basis of texture as follows:

- SB1 The surface soil is a clay loam to 15 cm deep.
- SB2 The surface soil is a loam to 15 cm deep.
- SB3 The surface soil is a sandy loam to 15cm deep.
- SB4 The surface soil is a sandy loam 15-30 cm deep.
- SB5 The surface soil is a loamy sand to 15cm deep.
- SB6 The surface soil is a loamy sand 15-30 cm deep.
- SB7 The surface soil is a sand to 15 cm deep.
- SB8 The surface soil is sand 15-30 cm deep.
- SB9 The surface soil is sand 30-60 cm deep.
- SB10 The surface soil is sand 60-90 cm deep.
- SB11 The surface soil is sand greater than 90 cm deep.

These soils occur on plains with some sand dunes or low sandy rises. They mostly have gradational texture profiles and carbonate at or near the surface (Gc1.12,

Gc1.22 and small areas of Gc2.12). Some slightly heavier textures (light clay surface) Uf soils have also been included in this group as SB1.

Texture Contrast Soils

These soils show a sudden marked change in texture. The sandy to clay loam surface horizon is generally of massive structure and extends to 30 cm in depth overlying a clay with either a nutty or compact structure. Colour is generally red-brown or grey over red, reddish brown or grey subsoil. These soils are subject to scalding with a variable amount of drift.

They are sub-divided on the basis of texture, as follows:

- TC1 The surface soil is a clay loam to 15 cm deep.
- TC2 The surface soil is a loam to 15 cm deep.
- TC3 The surface soil is a sandy loam to 15 cm deep.
- TC4 The surface soil is a sandy loam 15-30 cm deep.
- TC5 The surface soil is a loamy sand to 15 cm deep.
- TC6 The surface soil is a loamy sand 15-30 cm deep.
- TC7 The surface soil is a sand to 15 cm deep.
- TC8 The surface soil is a sand 15-30 cm deep.
- TC9 The surface soil is a sand 30-60 cm deep.

These soils usually occur on plains, on or adjacent to heavy clay floodplains, and are very susceptible to wind erosion when the surface soil is exposed. This classification includes Northcote's duplex profiles (in the Western Division mainly Dr2.33, Dr2.32, Dr2.23, Dy3.42 and Db1.33, Db1.43 and many others including Dr2.53, Dr4.53, Dy4.53, Dy5.13), as well as soils which actually consist of two profiles - a sandy profile over a clayey profile.

Skeletal Soils

Immature and poorly developed, shallow, stony, gravelly and rocky soils associated with the steeper hills and ranges.

These soils are usually less than 30 cm deep and differ from the shallow hard red (Um5.51) soils in that no pedological development has taken place.

Northcote classifications for these soils are Um 1, (Um 1.43 when deeper than 30 cm) and Uc1. The soils are often acidic and contain large amounts of organic matter. They are protected from erosion by surface rocks and boulders and usually carry perennial vegetative cover.

Heavy Clays

The grey, brown and red-brown clays and silty clays form a very broad group of soils whose common properties are determined by their high clay content. Typically they are moderately deep to very deep soils with little change in colour or texture as depth increases. Any marked change is in structure differentiation. Some lime and/or gypsum occurs in the subsoil.

These soils occur along the floodplains of the major rivers, the Riverine plain and in gilgais or drainage sinks in "red" country. They are sub-divided according to the presence of gilgais, nature of the surface, or micro-topography, as follows:

- HC1 Gilgais and/or crab-holes are slightly to obviously present. They do not present an erosion hazard.
- HC2 The soils are deeply cracking on drying out and the surface is loosely self-mulching. Gilgais are not present. They do not present an erosion hazard.
- HC3 These soils have a compact, firm surface, crack little or only slightly on drying out. They are slightly to moderately subject to scalding with little or no drift particularly following pasture degeneration under drought conditions.
- HC4 These grey soils are always associated with lake beds, pans and other drainage lines subject to periodic flooding. They are usually extremely deep and wide seasonal cracking soils (on drying) with a surface that is strongly self-mulching. Although easily disturbed, they do not present an erosion risk.

The HC1, HC2 and HC4 soils are uniform cracking clays (Ug soils). The main types occurring are Ug5.24 and Ug5.25 on the Riverine and Macquarie-Upper Darling floodplains, and Ug5.28 and Ug5.29 along the middle-Darling. Other types occurring include Ug5.38, Ug5.35 and Ug5.34 (brown clays), Ug 5.4 and Ug.5.5.

HC3 soils are usually cracking (Ug) clays, the surface of which has become smooth and compact or scalded. Below the scalded surface the profile is similar to those described above. These soils occupy slightly higher positions than the other HC soils, and the surface soil is probably more saline than that of the lower soils, resulting in surface slaking.

The soils of these four sub-divisions cannot be differentiated by the Northcote key.

Granite Soils

These are uniform, gradational or duplex soils with a massive, neutral, non-calcareous sandy loam to sandy clay topsoil, overlying a usually mottled red and brown clayey subsoil which often contains calcium carbonate nodules.

The soil surface is non-crusting and usually has a light veneer of small quartz gravel, and gravel is often present throughout the profile.

The soils are moderately resistant to windsheeting, but slopes are susceptible to watersheeting and rilling, and drainage lines are highly susceptible to gullyng.

These soils are sub-divided as follows:

- GR1 The surface is a clay loam to 15cm deep.
- GR2 The surface is a loam to 15 cm deep.
- GR3 The surface is a sandy loam to 15 cm deep.
- GR4 The surface is a sandy loam to 30 cm deep.
- GR5 The surface is a loamy sand to 15 cm deep.
- GR6 The surface is a loamy sand to 30 cm deep.
- GR7 The surface is a sand to 15 cm deep.
- GR8 The surface is a sand to 30 cm deep.
- GR9 The surface is a sand to 60 cm deep.

These soils occur in relatively small areas in the eastern part of the district which are formed on granite bedrock. The soils have been separated from the soft red or hard red groups because of their greater susceptibility to water erosion, their grittiness, and their slightly yellower colour. These soils fit into the Gn2.12 (mainly) Gn2.13, Dr2.43, Dy3.43, Dr3.33 and Uc Northcote classifications.

Brown Gibber Soils

These soils have a surface crust with a heavy mantle (20% cover) of silcrete, ferricrete, quartz or quartzite stone and gravel. Beneath the stone there is a thin massive loam abruptly overlying a stone free red or brown, strong, fine structured (nutty) clay changing gradually to a coarse structured, paler clay often with gypsum and lime at depth. Severe gullyng occurs in the highly dispersible subsoil when the surface stone is disturbed.

These soils are subdivided as follows:

- BG1 The soils have well developed gilgai microrelief.
- BG2 These soils have not or only infrequently have poorly developed microrelief.
- BG3 These soils have a hardpan layer between 20 and 100 cm depth.

These soils are found on undulating tableland relicts of a former landscape (mainly associated with Tertiary lateritic landforms west of the Darling River). They are predominately thin duplex (Dr1.1, Dr1.3, Dr1.4, Dy1.1, Dy1.3 and Dy1.4) soils often with a hardpan layer. Uniform red and brown cracking clays (Ug5.3) usually occur in gilgai depressions.

Duplex brown gibber soils with hardpan can be differentiated from those without hardpans by extending Northcote's classification for all of the Dr. and Dy. soil classifications in the same way as that which was used for the Dr1.1 soils which have a hardpan. For example, Dr1.35, Dr1.36. Further extension could also be made to include depth to the hardpan layer. For example, Dr1.35 - 3/0/5 - H 50.

Brown gibber soils with gilgai microrelief can also be distinguished from those without, using the Factual Key, because they normally are a complex of duplex soils and uniform cracking clays.

Desert Loams

These soils have a strong vesicular surface crust with a scattered (20% cover) of rounded gravel. The shallow loamy surface abruptly changes to a red or brown, stone free, strong, fine structured (nutty) clay then changing gradually to a coarse structured paler clay often with gypsum and lime at depth. They are susceptible to wind sheeting and minor water sheeting erosion and form soft scalded surfaces when the structured saline subsoil is exposed.

These soils are subdivided as follows:

- DL1 These soils have well developed gilgai microrelief.
- DL2 These soils have not or only infrequently have poorly developed gilgai microrelief.
- DL3 These soils have a hardpan layer between 20 and 100 cm. depth.

These soils are found on level to slightly undulating country including backplains associated with alluvial tracts and footslopes of hilly country.

They are predominantly thin duplex (Dr1.3, Dr1.4, Dy1.1, Dy1.3, Db0.2, Db0.3, Db0.4) soils, occasionally with a hardpan layer. Uniform brown and red cracking clays (Ug5.3) occur in gilgai depressions.

Desert loams can be distinguished from brown gibber soils by their lower position in the landscape and in general by the absence of a heavy mantle of stone. Northcote's classification does not adequately separate the desert loam soils which lack a protective cover of stone, from the brown gibber soils. However, the three groups of desert loams can be differentiated in a similar manner to that used for the brown gibber soils.

4.8 Other Systems of Soil Classification

Many other systems of soil classification are in use throughout the world, but of these only two have received much recognition outside their country of origin. These are, firstly the U.S. Soil Taxonomy, and secondly the FAO/UNESCO system developed for the Soil Map of the World.

It is not recommended that either system be considered for soil conservation use at this stage.

However, a brief description of these two systems will be given here for the sake of comparison and completeness.

4.8.1 United States Soil Classification System.

The Soil Taxonomy was developed over many years and became known internationally during the latter part of this developmental period when it was known as the "Seventh Approximation". It was published in its present format in a most comprehensive volume as Agriculture Handbook No. 436 (U.S.D.A. 1975).

The taxonomy differs in many ways from earlier systems and from others in current use. It has been in use in the United States for about ten years, and also in some other countries for a lesser period.

One of the disadvantages of the system is the complexity and difficulty of pronunciation of the soil names used, despite the fact that they are named according to a logical system. What soil conservationist wants to grapple with a Ferrudalfic Haplohumod?

This classification system is based on soil properties, but, unlike Northcote's system, laboratory measurement is needed for full classification, although some of the properties are observable in the field. Preference is given to properties which are estimated quantitatively rather than qualitatively. The properties selected are those which relate to the soil-forming processes and indicate soil genesis. Where properties have equal genetic significance, preference is given to the one that has most influence on plant growth. Like Northcote's classification, the division of categories is not made on the basis of common properties but according to properties most useful to that division. Because the upper soil horizons tend to be altered by man, emphasis is placed on the subsoil.

There are six categories in the system, order, suborder, great group, subgroup, family and series.

There are 10 orders. They are differentiated by the presence or absence of diagnostic horizons or pedological features. These features are marks of differences in the degree and kind of soil-forming processes that have been dominant in the particular soil.

Alfisols (from alf meaning pedalfer), this order of soils indicate processes which translocate silicate clays without excessive depletion of bases. They would have characteristics similar to grey-brown podzolic soils.

Aridisols (from aridus meaning dry). The unique properties common to Aridisols are a combination of a lack of water available to mesophytic plants for very extended periods, one or more pedogenetic horizons, a surface horizon/s not significantly darkened by humus, and absence of deep wide cracks. Aridisols are primarily soils of arid areas. They would have characteristics similar to solonchaks earthy sands and grey, brown and red calcareous soils.

Entisols (from ent meaning recent). The unique properties common to Entisols are dominance of mineral soil materials and an absence of distinct pedogenic horizons. Siliceous sands, calcareous sands, alluvial soils and some lithosols would have characteristics similar to Entisols.

Histosols (from histos meaning tissue). The unique property of Histosols is a very high content of organic matter in the upper 80 cm of soil. Most Histosols are peats or bog soils which consist of more or less decomposed plant remains that accumulated in water, but some have formed from forest litter or moss in a humid environment and are freely drained.

Inceptisols (from inceptum meaning beginning). Most Inceptisols have formed on relatively young geomorphic surfaces. The unique properties of these soils include one or more pedogenic horizons of alteration or concentration with little accumulation of translocated materials other than carbonates or amorphous silica; texture finer than loamy sand, some weatherable minerals and moderate to high capacity of the clay fraction to retain cations.

Mollisols (from mollis meaning soft). The unique properties of Mollisols are a combination of; a very dark brown to black surface horizon that makes up more than one-third of the combined thickness of the A and B horizons; or that is greater than 25 cm thick and that has structure; or soft consistence when dry; a dominance of calcium among the extractable cations in the A₁ horizon and upper B horizons; a dominance of crystalline clay minerals of moderate or high cation exchange capacity; and greater than 30 percent clay in some horizon above 50 cm. The properties of these soils are similar to prairie soils, chernozems and rendzinas.

Oxisols (from oxide meaning a compound with oxygen). The unique properties of Oxisols are extreme weathering of most minerals other than quartz to kaolin and free oxides; very low activity of the clay fraction; and a loamy or clayey texture. Oxisols characteristically occur in tropical or subtropical regions on land surfaces that have been stable for a long time. The properties of these soils would be similar to krasnozems and lateritic soils.

Spodosols (from spodos meaning wood or ash). The unique property of Spodosols is a B horizon of accumulation of black or reddish amorphous materials with a high cation exchange capacity. The properties of this soil are similar to those of podzols.

Ultisols (from ultimus meaning last). Ultisols like Alfisols have marks of clay translocation, but they have also marks of intense leaching that are absent in Alfisols. The unique properties common to Ultisols are a clay horizon, a low supply of bases, particularly in the lower horizons and a mean annual soil temperature higher than 8°C. The properties of these soils would be similar to those of the red and yellow podzolic soils.

Vertisols (from verto meaning turn). These soils indicate processes that mix the soil regularly and prevent development of diagnostic horizons that one might otherwise expect to find. The unique properties common to Vertisols are a high content of clay; pronounced changes in volume with changes in moisture, deep wide cracks at some season; and evidences of soil movement in the form of slickensides, gilgai microrelief, and wedge-shaped structural aggregates that are tilted at an angle from the horizontal. These soils would have properties similar to black earths and cracking grey, brown and red clays.

Forty-seven suborders currently are recognised (U.S.D.A. 1975). The differentiae for the suborders vary with the order but they are generally based on the characteristics producing the greatest degree of genetic homogeneity. The colour of the wet soil is used with other properties. The suborders form prefixes to the orders; for example, a strongly mottled entisol is called an aquent. Some of the suborder prefixes are:

- acr (from acros meaning highest) - most strongly weathered.
- alb (from albus meaning white) - presence of a bleached horizon.
- aqu (from aqua meaning water) - characteristics associated with wetness i.e. mottling
- arg (from argilla meaning clay) - a horizon with illuvial clay
- ferr (from ferrum meaning iron) - the presence of iron
- psamm (from psammos meaning sand) - sandy textures
- ust (from ustus meaning burnt) - of dry climates with hot summers

About 185 great groups are currently known to occur in the United States (U.S.D.A. 1975). The great groups are defined mainly by the presence in them of diagnostic horizons and the arrangement of those horizons. The great groups form prefixes on the suborders and include all the prefixes used in the suborders as well as new prefixes such as:

<u>brun</u> - dark colours	<u>crypt</u> - hidden
<u>cru</u> - crusting	<u>gloss</u> - tongued
<u>cry</u> - cold	<u>therm</u> - warm

About 970 subgroups are currently recognized in the United States (U.S.D.A. 1975). These can be defined only with reference to the great groups and refer mainly to the intergrades between great groups. An adjective is used for the subgroups, e.g., orthic which refers to the normal great group.

In the family category, the intent has been to group the soils within a subgroup having similar physical and chemical properties that affect their responses to management and manipulation for use. Soil properties are used in this category without regard to their significance as indicators of processes or lack of them. About 4,500 families are currently recognized in the United States.

Families are defined primarily to provide groupings of soils with restricted ranges in:

1. Particle-size distribution in horizons of major biologic activity below plough depth.
2. Mineralogy of the same horizons that are considered in naming particle size classes;
3. Temperature regime;
4. Thickness of the soil penetrable by roots; and
5. A few other properties that are used in defining some families to produce the needed homogeneity.

The series is the lowest category in this system. About 10,500 series have been recognized in the United States, although a number of them have been divided or replaced. The differentiae used for series are mostly the same as those used for classes in other categories, but the range permitted in one or more properties is less than is permitted in a family or in some other higher category.

4.8.2 FAO/UNESCO Soil Classification System

The soil classification used in the FAO/UNESCO system is designed to produce world soil maps at a scale of 1:5,000,000 so lower members of the soil classification hierarchy are not needed. The soil mapping units correspond most closely to the Great Soil Group level.

Because the classification is an international one, the soil names selected were ones that did not change much on translation and had similar meanings in different countries.

Where possible, traditional soil names are used, for example, podzols, chernozems, solonetz, rendzinas and lithosols, but names which have become recently popular in some of the newer soil classifications are also included, for example, vertisol from the United States Soil Classification System. Where soil terms are particularly confusing in soils literature, such as podzolised and brown forest soil, new terms have been selected.

There are 79 Great Soil Groups. Within the Great Soil Groups there are main groupings which may be considered as soil suborders. The following notes give the derivation of the suborder names and a brief description of the soils.

Fluvisols (Latin fluvius, a river) alluvial soils with little profile differentiation

Rhegosols (Greek rhegos, blanket) very poorly developed soils overlying hard rock.

Arenosols (Latin arena, sand) poorly differentiated sands.

Gleysols (Russian gley, mucky soil mass) soils containing reduced or mottled horizons resulting from excess water.

Rendzinas (Polish word meaning shallow, sticky soils over limestone).

Rankers (Austrian rank, steep slope) shallow soils on siliceous material, no horizon formation.

Andosols (Japanese an, dark) soils formed from material rich in volcanic glass and having a dark surface horizon.

Vertisols (Latin verto, turn) heavy textured, deeply cracking soils prone to gilgai formation.

Ermosols (Latin eremus, solitary desolate) soils of the open deserts; desert sand plain soils and desert loams; poorly differentiated desert soils.

Xerosols (Greek xeros, dry) desert soils with profile differentiation, but no strong salt accumulations.

Halosols (Greek hals, salt) desert soils with salt accumulation and sodium domination, differentiated profiles.

Planosols (Latin planus, flat, level) soils in level or depressed topography with poor drainage.

Castanozems (Latin castaneo, chestnut; Russian zemlya, earth) soils rich in organic matter with a brown or chestnut tinge at the surface.

Phaeozems (Greek phaios, dusky; Russian zemlya, earth) soils rich in organic matter having a dark coloured surface.

Cambisols (Latin cambiare, change) soils in which changes in colour, structure and consistence have occurred as a result of weathering in situ rather than illuviation.

Luvisols (Latin luvi, to wash) soils in which clay illuviation has occurred, but not strong base depletion.

Acrisols (Latin acris, very acid) soils with illuvial clay and strong base depletion.

Paramosols (Spanish paramo, land with scarce vegetation) soils of high altitude grasslands.

Podzols (Russian pod, under; zola, ash) soils with a strongly bleached eluvial horizon.

Ferralsols (Latin ferrum, iron; and al from aluminium) soils high in sesquioxides.

Histosols (Greek histos, tissue) soils rich in fresh or partly decomposed organic matter.

Lithosols (Greek lithos, stone)

To make up the 79 Great Soil Groups the following adjectives may be added to the "Soil suborders" described above.

Dystric (Greek dys, ill, infertile) soils with a very low pH.

Eutric (Greek eu, good, fertile) soils with a higher pH from recent deposits.

Ochric (Greek ochros, pale) soils with a light coloured surface soil.

Humic (Latin humus, earth) soils with surface layers rich in organic matter.

Calcic from calcium, soils accumulating calcium carbonate or gypsum.

Salic (Latin sal, salt) saline soils.

Sodic (from sodium) soils accumulating sodium.

Thionic (Greek theion, sulphur) soils containing sulphur.

Plinthic (Greek plinthos, brick) soils containing mottled clay materials which harden irreversibly on exposure.

Halpic (Greek halpos, simple) soils with a simple, normal horizon sequence for their suborder.

Vitric (Latin vitrum, glass) soils rich in glassy material.

Pellic (Greek pellos, dusky, lacking colour) soils with low colour intensity.

Chromic (Greek chromos, colour) soils with high colour intensity.

Calxic (Latin calxis, lime) soils accumulating lime.

Gypsic (from gypsum) soils accumulating gypsum.

Takyric (Uzbek takyr, barren plain) soils of barren regions.

Brunic (Anglo-Saxon brun, brown) brown coloured soils.

Rhodic (Greek rhedon, rose) soils with a red to deep red colour

Albic (Latin albus, white) soils with a prominent bleached eluvial horizon.

Glossic (Greek glossa, tongue) soils with tongues of eluvial material penetrating to the B horizon.

Helvic (Latin helvus, yellow to yellowish-red) soils with reddish-yellow colours.

Placic (Greek plax, flat stone) soils with a thin iron pan.

The soil units dealt with here have been selected on the basis of present knowledge of the genesis, characteristics and distribution of the major soils covering the earth's surface, their significance as resources for production, and on the feasibility of representing them on a small scale map. As a result, the subdivisions may not strictly adhere to taxonomic rules and consequently may belong to different levels of generalization. In principle, however, the soil units used here correspond to the "group" level as distinguished in different soil classification systems.

In order to secure a reliable identification and correlation of the proposed units on a world-wide basis, each unit is characterized by a set of measurable and observable properties, which reflect the effects of the dominant soil forming processes and which at the same time are of importance to predict soil behaviour under different management practices. In addition to the information provided in the definitions of soil units, complementary elements for practical use may be given by indicating textural and slope classes or by the use of phases related to stoniness, the presence of indurated layers or hard rock at shallow depth, salinity or alkalinity.

4.9 Univariate and Multivariate Statistical Analysis in Soil Classification

To account for the heterogeneous nature of soil distribution a large quantity of information must be collected in any detailed soil survey. The following example illustrates the requirements for a study involving only 150 profiles. Within each profile there are generally 5 to 6 layers from which 20-30 field and laboratory observations may be made. Therefore in a relatively small survey some 27000 ($150 \times 6 \times 30$) pieces of information may require interpretation. Rationalisation of this amount of data by a soil surveyor alone represents a most difficult task. However, with computer assistance, it is possible to analyse the data in a fast, systematic and highly efficient manner.

Numerical techniques are of considerable value in soil classification and they serve three main functions. The first is for description of the variation of soil attributes classified in a single map unit. These are broadly referred to as univariate methods. Secondly, numerical techniques can be used to classify soils into groups and thirdly, they can be used to study the relationship between attributes. The latter two are multivariate methods and come under the general heading of pattern analysis.

Univariate statistics are generally used to evaluate the usefulness of a map in terms of the variance within and between map units. This enables the prediction of reliability limits and sample requirements based on the map scale.

Multivariate techniques are used for classification and grouping of data. The analysis and treatment of soil properties are suited to this type of treatment. Classification is on the basis of similarity or dissimilarity between component properties and this type of sorting produces a taxonomy or hierarchy of individuals.

4.9.1 Application of Univariate Statistical Methods to Soil Survey

The foremost problem of interpreting a traditional soil map is that it is usually impossible to assess the variability within each mapping unit. It is beneficial if a measure of the map or map unit variability is presented. This indicates the degree of precision and map accuracy and provides a means of assessing the reliability of map boundaries. This approach enables the production of better and more meaningful maps than can be achieved by merely quoting the 'modal-profile' for each unit.

When producing a map it is important that, not only the average value of the soil characteristics within a given mapping unit are known, but also that a measure of the spread of the values is available. A common method of achieving this is to calculate the arithmetic mean and the variance

(or the square root of the variance known as the standard deviation). Other measures include the median, the mode and the range of these values. Calculation of these allows a comparison between the magnitude and reliability of data between mapping units in and between soil surveys. In practice, the soil surveyor tries to achieve the maximum reduction in the within-unit variance compared with the variance in the mapping units of previous maps, or within the total area if no previous map exists. In addition, this approach enables the determination and assessment of sampling density. A high degree of variation within a map unit indicates that further sampling is required.

These methods can be applied to any data for any method of soil classification be it traditional or numerical.

4.9.2 Two Methods of Determining Map Unit Quality

There are two common univariate methods for determining map quality.

1. Intraclass Correlation: Webster and Beckett (1968) use the intraclass correlation (P_1) to determine map quality for individual soil properties. This is expressed as:

$$P_1 = \frac{s_a^2}{s_a^2 + s^2}$$

where s^2 is the within-class variance and s_a^2 is the between-class variance.

It is obvious that if each class is uniform then s^2 equals zero, and p_1 has a maximum value of 1. If the difference between the classes is not significant and s_a^2 and p_1 are not significantly greater than zero, then the map has achieved nothing. The potential user of a soil map therefore is interested in the within-class variance, s^2 , and will in general wish s^2 to be as low as possible, but more importantly that it does not exceed some critical value. Thus, if s^2 falls below a particular threshold value then the survey is adequate. It is possible to calculate threshold values based on the requirements of any particular type of survey.

2. Coefficient of Variation: Beckett (1967) uses the coefficient of variation (CV) to describe lateral change in soil variability. This statistic is similar to the intraclass correlation and is a measure of within-class variance, in relation to class mean, expressed as a percentage. The coefficient of variation is defined by the following expression -

$$CV\% = \frac{s_a}{\bar{x}_a} \times 100$$

where s_a is the standard deviation of a property, a , and \bar{x}_a is the mean value of the group a . As CV increases so does the variability of the mapping unit. Therefore, it is possible to specify a value of CV and use it for quality control during the survey. However, care is necessary because if the sample means are not similar then comparison of the CV's may be ambiguous. Alternatively, it can be used to define the variation of individual properties once the mapping units are established.

4.9.3 Application of Multivariate Statistical Methods to Soil Survey

The use of multivariate techniques became practical with the advent of easily accessible computer programmes with the capacity to handle very large sets of data. These methods comprise the two main aspects - classification and ordination.

(a) Classification

Two broad types of classificatory programmes are available - agglomerative and divisive. An agglomerative strategy is one that proceeds by progressive fusion, beginning with the individuals and ending with the complete sample. A divisive strategy progressively splits the sample into smaller and smaller groups. These strategies can then be either monothetic or polythetic. A monothetic system is one based on a single attribute; in contrast, a polythetic system is one based on a measure of similarity applied over all attributes, so that an individual is grouped with those individuals which it most resembles. All agglomerative classifications are polythetic and the most commonly used divisive classifications are monothetic.

A number of alternatives are available for calculation of similarity indices. The commonly used indices are -

- (i) absolute differences,
- (ii) Euclidean distance squared, and
- (iii) Canberra metric.

There are advantages and disadvantages associated with each index, and the choice depends on the data to be classified.

In many cases the data is standardised prior to classification. This process eliminates the effect of measurements of attributes being in different units. The range and standard deviation are frequently used to standardise the attributes. The strategy adopted for combining individuals and groups also offers a range of choice to the user.

The technique of pattern analysis has two basic functions. Firstly, to examine the similarities between all pairs of sites in a data matrix, in terms of the properties measured at each. Secondly, to examine the similarity indices so calculated and to fuse the most similar profiles into groups, this being repeated until all profiles are sorted into one group. Those profiles which join together first are the most similar, those joining last are least similar. As a visual aid to the interpretation of an agglomerative classification, a dendrogram is frequently used. It illustrates the successive fusions from individuals to the complete sample. The more similar two individuals are then the fewer fusions there will be between them (Figure 4.1).

The dendrogram may show definite groups, and therefore pattern analysis is an alternative way of constructing general purpose soil classifications. The value of this technique lies in its ability to examine a set of soil profiles for affinities which cannot be detected from examination of morphological properties.

Lynch and Edwards (1976) describe one of the pattern analysis programmes, CLU, used in soil classification, by the Soil Conservation Service of N.S.W.

- (b) Ordination is primarily to simplify the relationships between sites or individuals or, the attributes that define them, so they can be presented as a simple visual representation of points. Ordination basically partitions a data set of correlated attributes into a smaller set of independent or orthogonal attributes.

Principal components analysis underlies most modern methods of ordination. This analysis allows the user to establish which attributes contribute most to the variability of his data. This technique is useful for preliminary analysis of data to investigate inter-relationships between soil properties or soil profiles. Large data sets can be condensed into sets of partially correlated variables with fewer independent variables with a minimum loss of information. A number of principal components (equal to the number of attributes under study) can be determined from the data set. These components are presented in decreasing order of magnitude and indicate what proportion of the variability is explained by each attribute. The first component includes, subject to the mathematical constraints of the programme, a maximum proportion of the total variability of the original data matrix, the second component includes as much variability remaining and so on.

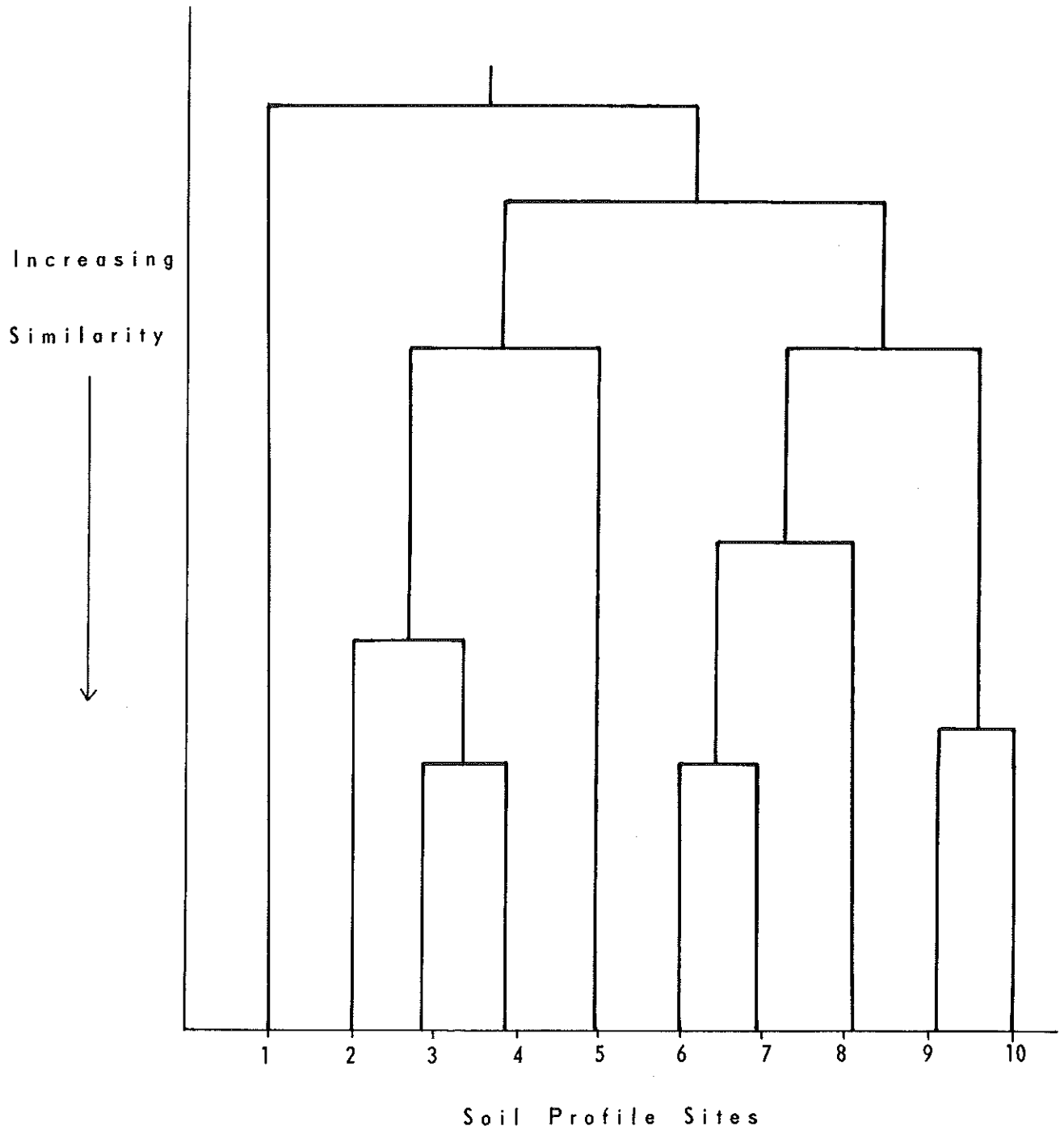


Fig. 4.1 A Simple Soil Dendrogram

Chapter 5.

SOILS IN RELATION TO LAND USE

5.1 Introduction

Most land is more or less capable of profitably maintaining more than one form of land use, and the final decision as to use rests with the entrepreneur, and the cost he is prepared or able to pay to maintain the land's ability to support his enterprise. The Soil Conservation Service's assessments of land capability do not directly determine land use, but they do provide information on which to judge the long term viability of various enterprises, which in turn determines land use. Land capability assessments provide this information by outlining what practices, and hence costs, are necessary to maintain the existing landsurface in a stable, productive condition.

The Service is involved in assessing land capability for two broad areas of land use; dryland agriculture and urban development. The data inputs for both of these assessments are generally similar. However, because of the differences involved in the landsurface treatments involved, the methods used to derive the assessments differ in the way the data are combined and weighted.

The basic data inputs required for both types of capability assessment are climate, landform and slope, and soils, all of which interact with one another. The most important of these, in terms of the effects of prolonged land usage, are soils data. Soil is, after all, the material which is directly affected in all forms of land use.

5.2 Dryland Agricultural Land Use

The Service's capability assessments of agricultural land are always supplemented by farm plans of the area concerned. Although closely related, these two operations are essentially different. In the case of the former, land is classified according to its capability for agricultural use. With the latter, areas of land of one capability class or closely related classes are arranged into parcels on the basis of the practicability of using and maintaining their general capability. Accordingly, the amount and type of soils data and the use made of it varies with each task.

Soils information required for land capability assessments mainly concerns the properties of the surface soil layers or A horizons. It is the surface soil layers which are of prime importance to dryland agriculture: plant roots grow in it and absorb moisture and nutrients from it, grazing animals and agricultural implements disturb it, and rainfall infiltrates or runs off it. The soil factors considered in these assessments include the erodibility of surface horizons, soil water holding

capacity, existing erosion and soil salinity or alkalinity.

The amount and type of soils information required for farm planning must, on the other hand, include more profile data than that of just the surface soil, although this remains important. For instance, deeper soil horizon information is required for assessing the quality of soil for earthwork construction and for assessing the behaviour of deeper layers in case they are exposed during earthwork construction. If subsoil horizons are subjected to prolonged wet periods they can affect the runoff behaviour of the surface soil and hence the need for banks.

The value of the soils information for both tasks is best seen in context with overall requirements of each, which follow, first land capability classification, second farm planning.

5.2.1 Capability Assessment

Basically, the Service's agricultural capability classification scheme involves considerations of environmental factors that may limit the use of land. The factors considered include those with general or wide-spread influence, such as climate, land slope and form, and soil erodibility; as well as those with specific or local influence, such as soil depth and water holding capacity, wetness, rocks and stone, existing erosion conditions and salinity or alkalinity.

Each of these factors is considered separately in a limiting factor type of analysis, i.e., either one or a combination of factors may limit the capability of an area of land to a restricted use. Based on this type of analysis, land is classified into one of eight classes, and the limitations to the use, or the risks of damage, or the needs for soil conservation measures become greater from class I to class VIII.

There are obviously limitations to the applicability and to the long term value of this method of assessment. These limitations must be understood for the scheme to be properly used and interpreted: they are apparent in the schemes basic assumptions and class definitions.

Classification Scheme Assumptions

- (i) Land classification takes account of present technology only. Future developments in agricultural technology may necessitate that land capability classifications be altered.
- (ii) The scheme is based on the interpretation of the effects exerted on dryland usage by a combination of permanent environmental characteristics.

- (iii) Lands with the same classification are necessarily similar only in respect of the limitations placed on their use in terms of the intensity of soil conservation measures required for the maintenance of that use.
- (iv) Permanent limitations are those considered to be unalterable by man, or uneconomically alterable.
- (v) Lands are classified according to their most productive capability, irrespective of whether or not that capability is being or will be realized.

Capability Class Definitions

Class I: Land that is suitable for regular cultivation without requiring any special soil conservation measures.

Class II: Land that is suitable for regular cultivation provided simple soil conservation measures, such as contour cultivation, adequate crop rotations, and generally good soil management are applied.

Class III: Land that is suitable for regular cultivation provided intensive soil conservation measures, such as graded banks, waterways and diversion banks, in addition to those measures required for class II lands, are applied.

Class IV: Land best suited to grazing (because it is not suitable for regular cultivation) on which are required simple soil conservation measures, such as pasture improvement, livestock control, fertilizer applications, and contour chisel ploughing. Slopes generally less than 15%.

Class V: Land best suited to grazing (because it is not suitable for regular cultivation) on which are required intensive soil conservation measures, such as level banks, diversion banks, gully control structures, deep contour ripping, in addition of those measures required for class IV lands. Slopes generally less than 33%.

Class VI: Land suited to judicious grazing on which are required good management practices, such as those required of class IV lands, but not those of class V, because the slope steepness or other limitations preclude all forms of cultivation and structural soil conservation work. These are generally steep lands, with slopes in excess of 33%.

Class VII: Land best suited for green timber because of any combination of erosion hazard, steepness, infertility, or shallow soils.

Class VIII: Land unusable for agriculture, such as cliffs, lakes, swamps.

Consideration of land capability can be divided into two parts. The first part involves the consideration of environmental factors which are always present; the second part those environmental factors which are only sometimes present. The former are referred to as 'General Limitations', the latter as 'Special Limitations'.

General Limitations

(i) Climate

The inclusion of climate as a factor which limits land capability is required because in some areas of the State climate does limit land capability, irrespective of the attributes of the land surface. The influence that climate exerts on land capability in this scheme, however, is primarily restricted to determining the capability of land for either cereal cropping or grazing. This is because the scheme applies only to dryland agriculture, most of which is extensive cropping and/or grazing. Where land capability is being considered for intensive dryland cropping (e.g. orchards, vineyards), special adjustments must be made to ensure the climatic considerations are realistically adjusted to the known requirements of the proposed crop.

Generally, the climatic factors considered are temperature and moisture availability (i.e. frost occurrence and severity, and rainfall and evaporation). Clearly, the type of cropping proposed will alter the values at which these become critical enough to limit productivity. The assessment as to whether or not it limits land capability is left as purely subjective specifically to allow for such adjustment should it be needed.

In some areas in the State, especially those where neither temperature nor moisture limit the suitability of land to regular cropping, summer rainfall amount and/or intensity is an additional climatic factor that must be considered, particularly as it affects erosion hazard.

(ii) Land Slope and Form

Landslope limits the use of land because erosion hazard generally increases with slope steepness. Also, increasing slope steepness imposes increasing difficulty on the use of machinery for ploughing, cultivating, harvesting, or constructing soil conservation earthworks.

Land slope thus acts as a major capability limiting factor on land classes up to and including class III. It is less of a limiting factor in capability classes above III. In this group it acts as a possible criterion for distinguishing between classes V and VI (see class VI definition), where it is relevant.

To a lesser extent, landform exerts a similar influence on land capability through the effects of the size and shape of drainage basins on machinery operations and the design of soil conservation measures.

(iii) Soil Erodibility

When considering the capability of land, the main soil property that differs between soil types and thus sets them apart is erodibility. Soil erodibility is a composite expression of those soil factors that affect the physical behaviour of a soil: it takes account of texture, structure, aggregate stability (all good indicators of physical fertility), infiltration, drainage and water holding capacity. Each soil type has a unique combination of these attributes that combine to manifest themselves as a certain erodibility.

The erodibility of soil directly affects the capability of land by imposing limitations on the management and intensity of soil conservation measures necessary for a particular usage. Generally, erodibility interacts with slope in such a way that, as the slope of land becomes steeper, the more critical erodibility becomes, and vice versa. Thus, the steeper land becomes, the lower the particular erodibility assessment becomes that is used as a criterion for distinguishing capability classes. For example, on land with a slope between 5 - 10 per cent an erodibility assessment of 'high' or worse would be used to specify class V, whereas on slopes between 10 - 15 per cent an erodibility assessment of 'moderate' or better would be used to specify class V.

The erodibility criteria used are those determined using the erodibility index scheme (See section 6.2) which uses the Service's standard five descriptions, namely 'low', 'moderate', 'high', 'very high', and 'extreme'.

(iv) Summer Rainfall Amount/Intensity

Certain areas of the State require land capability classification to take special account of the nature and amount of summer rainfall. These areas are those where the major portion of the annual average rainfall falls in the six month period October to March, as such rains have a nature and incidence that often produce serious erosion. They generally result from convectional storms, which produce intense falls composed of large drop sizes. They occur in a period of the year when vegetative cover is sparse or the land is laid bare in a cultivated fallow.

The summer rainfall factor can be accounted for by describing it as 'high' where it does influence land capability and 'moderate' where it does not influence land capability. Generally, the factor can be assessed as falling into either the 'moderate' or the 'high' category if the percentage of the annual average rainfall in the October to March period is respectively lesser or greater than 60 per cent. As a rough guide, the State divides into two, with a line running through Maitland, Merriwa, Coolah, and Gilgandra separating the southern area (i.e. 'moderate' category) from the northern area (i.e. 'high' category).

Special Limitations

(i) Water Holding Capacity

Plants will only grow in a soil which has sufficient depth and water holding capacity for the roots to be able to physically support the aerial parts of the plant, as well as to absorb enough water for them to photosynthesize.

The water holding capacity (WHC) of a soil results from an interaction between soil depth and texture. The effectiveness of a given WHC will, in terms of limiting plant productivity, interact with climate, but certain generalizations can be made. For instance, sandy soils will have a low WHC and will be generally unproductive irrespective of their depth. Conversely, clayey soils will have a moderate or better WHC whilst being quite shallow, and will be usefully productive to a greater or lesser extent. The WHC of a soil is determined from the following table.

Table 5.1 WATER HOLDING CAPACITY OF SOILS

Soil Depth cm	Texture*		
	Sand	Loam	Clay
0-25	low	low	moderate
25-50	low	moderate	high
50-75	moderate	moderate	high

* Texture assessments are based on the following amalgamations of the texture groups defined by Northcote (1974). Sand: includes sands and sandy loams. Loam: includes loams and clay loams. Clay: includes light, medium and heavy clays.

Depending on whether or not the annual average rainfall is able to sustain plant growth given an adequate supply of plant nutrients, soils with a WHC of 'low' should be classed as VII or VI, respectively. Soils with a WHC of 'moderate' should be limited to judicious grazing usage, i.e., classes IV - VI. Soils with a WHC of 'high' are not in any way limited by this factor.

(ii) Wetness

Permanently wet soils, such as those found in swamps, or hillsides possessing permanent springs, are severely restricted in their agricultural usefulness and will be classed as VII or VIII.

Periodically inundated and saturated areas obviously have severe limitations on their agricultural productivity and must be treated with great care. Depending mainly on the area concerned, land so afflicted would be classified as class IV or V.

(iii) Rocks and Stones

The occurrence of rocks and stones obviously affects land capability. Rock outcrops do not support plant growth, and shallow rock beds limit the WHC and nutrient level of soils. But the most severe effect of rock or stone outcrops is on less steeply sloped land where it limits and often prevents cultivation and thereby restricts the use of otherwise arable land to grazing.

(iv) Existing Erosion

The existing erosion of the landsurface will influence the future capability of the land in terms of whether it is or is not economically alterable to a more productive condition. Apart from the extent of erosion present, the assessment of the importance of this factor depends very much on the erodibility assessment of the various horizons down the profile.

Where erosion is considered not to be economically alterable the influence on capability is regarded as permanent. However, where it is economically alterable to a more productive condition, capability classifications should be adjusted.

(v) Salinity/Alkalinity

Salinity and alkalinity in soils can affect both plant growth and soil infiltration. Areas badly affected by either are obviously permanently unproductive. These areas periodically affected will produce some plant growth and should therefore be carefully managed. Land so afflicted will mostly be classified as class V because of the input into reclamation and their generally flat nature. However, it is conceivable, because saline areas are generally small in extent, that they will not be mapped as distinct areas.

5.2.2 Farm Planning

The soils information required for planning farm layouts has to be more applied than that used for land capability assessments. This is because it must relate directly to the design specifications of conservation earthworks, which nearly all sloping lands require to a greater or lesser extent, to ensure the maintenance of their capability for a particular usage. In particular, this information must indicate the need for the number and type of earthworks required, as well as the optimum gradients they should possess to ensure no erosion occurs within their channels. Details of the manner in which such information is obtained from soil survey data are outlined in the following chapter (6).

5.3 Urban Capability Assessment

An urban capability classification has been designed by the Soil Conservation Service to assist in planning of potential urban areas. The classification is based on information collected during a land inventory and defines the constraints for urban use in terms of erosion and sedimentation during the development stage, as well as possible instability and drainage problems in the long term.

Further, when the land resource data are collected, with emphasis on soils, wider use is possible. It permits planners and engineers to select appropriate land uses and construction methods to minimize inputs while avoiding unacceptable deterioration of the land.

5.3.1 The Urban Capability Assessment Scheme

Firstly we are concerned with land characteristics measurable or observable at single sites. These include local relief, slope, soil type, soil depth, soil permeability, vegetation, bedrock, climate etc. Very often it is not these land characteristics themselves that one is so concerned with, as the anticipated performance of the land for the stated purpose which can be inferred from them. These land attributes, particularly soils and geology, are often inadequately quantified or interpreted because planners, engineers, developers and builders involved do not recognise their implications for development.

Secondly, we need to know the location and extent of kinds of land which are fairly homogenous with respect to a set of relevant physical characteristics. In this way, a map of different kinds of land is generated. The resulting land inventory shows areas of land which are relatively uniform in their characteristics, and is a valuable tool for predicting performance in different areas. Thus an appropriate map can tell the planner such things as whether or not a new urban development will need reticulated sewerage. It would also show areas prone to flooding, liable to slope failure or other erosion hazard, or where foundations would need special attention because of soil shrink/swell problems.

The preparation of the urban capability report involves evaluation of the natural features of the landscape; terrain, slope, soils, geology and climate.

Landforms (terrain and slope) affect urban capability both directly and indirectly. The general topography, its surfaces, slopes and local relief amplitude, its natural drainage lines and basins all affect the cost of provision of services. The proportion of land which can be practically developed is to a large extent defined by these landforms. The utilisation, the maximum dwelling density and hence the population density are related to the general slope. The location of transport corridors is restricted by the natural slopes and topography. At a more detailed level the amount of excavation required for buildings and roads generally increases with increasing slope, while that for providing underground reticulation works depends on the relationship between the natural fall of the land and the fall required in the reticulation system. Very steep slopes and very flat land both involve high costs for gravity reticulation systems.

5.3.2 Soil Factors

A soil map is prepared of the area under study, as well as maps of terrain units, slope and drainage pattern, prior to the compilation of the urban capability map.

A primary aim of the soil map is to differentiate soil units on the basis of their erosion potentials. Soils susceptible to mass movement, shrink-swell, very low and excessive permeabilities, salting and other soil problems related to urban development are differentiated.

However, in practice these concepts are difficult to map in the field. Hence, the soil surveyor maps soils using an accepted classification system such as the Northcote Factual Key or the Great Soil Group System and correlates the characteristic soil properties mentioned above with a particular principal profile form or great soil group. (See Chapter 4 for discussion on soil classification). Thus it is important that the land use options in a region are made known to the soil surveyor and that he has a knowledge of how different physical attributes of the landscape affect different land uses.

In many instances significant variations in soil characteristics pertinent to urban planning occur within one principal profile form or great soil group. In this case it is necessary to further subdivide the mapping unit using criteria such as changes in rock lithology, depth of specific horizons or the total soil, or topographic location.

During urban development, vegetative cover is cleared from the soil and extensive cut and fill operations occur. Thus A,B and C horizons are exposed for periods long enough to cause excessive erosion on the site, and siltation of drainage lines, pipes and culverts downstream. The erodibility of each horizon within a soil type generally varies, hence it is important that descriptions of soil mapping units contain assessments of the erodibility of each horizon.

Also, soil map units usually contain more than one soil type. For this reason a "general erodibility" for each horizon of the "typical" soil of the mapping unit should be assessed. It should be noted that the erodibility of a soil horizon does not take into consideration other factors which influence the erosion process, such as climate, slope and terrain. It is an intrinsic characteristic of the material in that horizon.

However, it is important that the soil surveyor take note of microtopographical features which affect the erosion hazard of an area such as presence of large boulders, scalded areas and springs. These features may not be recognized in the terrain evaluation of the area under study.

The erosion hazard of a site or mapping unit is defined as the potential for erosion when all factors that contribute to the erosion process are considered (slope, run-on, soil erodibility, cover etc.).

The erodibility index described in Section 6.2 is useful for assessing the erodibilities of soil horizons. Using this assessment along with field observation it is possible to rank each soil horizon as having "low", "moderate", "high", "very high" or "extreme" erodibility.

Survey Technique

Soil surveying and mapping techniques are discussed generally in Section 3.5. The following comments are pertinent to urban surveys.

Soil auger holes or pits should be dug to at least 100 cm depth for every sampling (unless rock is encountered). Also it is necessary to dig some pits to bedrock or parent material in order to adequately determine the characteristics of the soil mapping unit. Soil depth can be critical to foundation design, and cut and fill operations during urban development can expose soil material at depths of two metres or greater.

During an urban survey, samples are taken for laboratory testing. Soil map units are based on field descriptions. However, laboratory testing of selected sites enables the soil surveyor to confirm decisions based on field data. Laboratory results will often identify soil limitations which may not be apparent from field evidence, such as expansive clays, soils with low bearing strengths and dispersible soils. Basic engineering tests provide results which assist planners and construction engineers.

The frequency and depth of sampling soils for laboratory testing depend on a number of factors such as variability of the soil units and the surveyor's experience of the study area. Sampling must also be geared to the capacity of the available laboratory facilities.

Laboratory testing of uniformly coarse textured soils is usually unnecessary since their engineering characteristics are obvious from their field descriptions. Also, since topsoil is generally removed prior to any construction it is pointless to test its engineering characteristics.

If laboratory test results indicate serious stability problems within a mapping unit, intensive sampling at building block level is required. This is the responsibility of the land developer. Even if laboratory results do not indicate stability problems within a mapping unit this does not preclude the engineer from routine tests normally required for the planning of services etc.

Interpretation of Soil Data

Soil field characteristics examined during a soil survey are discussed in Section 3.3 and laboratory tests are discussed in Section 7.3. Apart from soil erodibility, some of the main soil limitations to urban development include mass movement, expansive soils, dispersible soils, soils with very low or excessive permeabilities and saline soils. The way in which soil field and laboratory data can be used to identify these limitations is discussed below.

Mass Movement

The identification of existing areas and areas susceptible to mass movement is critical in urban surveys. The occurrence of mass movement is due to a particular set of conditions in terms of slope, terrain component, site drainage, soils, geology and to a lesser extent aspect and rainfall regime. The processes of mass movement are discussed in Section 2.1.5.

For urban capability assessments areas with slope gradients exceeding 30 percent are regarded as suspect as well as bench formations occurring below steep escarpments. In some areas, specific soil types are found associated with mass movement on gradients significantly less than 30 percent. For example in the Hills district to the north-west of Sydney mass movement is associated with red podzolic soils (Dr2.11) on slopes of 7 to 10%. Usually a steep slope segment is found upslope of these areas and instability also occurs within this steep sideslope. In the Kiama and Grafton areas mass movement is found on slopes with gradients as low as 10% where the soil type is a krasnozem (typically Gn 4.11).

In the prediction of mass movement, field and laboratory data should be considered in relation to the position of the soil type in relation to the general land-form. The following features are often indicators.

- (a) Existence of slumps or "terracette" formations already in the landscape.
- (b) Perched water tables and seepage zones.
- (c) Total soil depths generally exceeding 1 metre (except on very steep slopes where debris avalanches are possible).
- (d) Subsoil textures of clay loam or finer (except on very steep slopes).
- (e) Other factors such as presence of a dead line of trees with bent trunks, known histories of breakages in water mains and other services, slumped batters etc.

At this stage, there are no reliable sets of laboratory test results that indicate a soil's susceptibility to mass movement.

Expansive Soils

The occurrence of expansive soils can cause major long term stability problems in urban areas. When the moisture content of an expansive soil is changed, volume expansion in both the vertical and horizontal direction will take place. In fact, slight changes of moisture content, in the magnitude of only 1 to 2 percent are sufficient to cause significant swelling. This characteristic can be highly detrimental to rigid structures, particularly brick walls and concrete slabs unless appropriate precautions are taken in the design of foundations.

In New South Wales expansive soils are often found associated with black and red soils derived from basalt rocks. A strong correlation exists between the occurrence of grey, brown and red clays, black earths and rendzinas and the occurrence of expansive soil problems. Also, potentially expansive soils are associated with semi-arid regions of tropical and temperate climatic zones, such as the wheat belt. However, the problem is not confined to these areas and expansive soils are known to also occur in the Wollongong and Grafton areas.

Expansive soils generally contain a high proportion of the clay mineral, montmorillonite. The crystal units comprising this mineral are only weakly held by oxygen bonds and water may freely enter and enlarge the space between the units allowing the mineral to swell extensively.

The following features are indicators of the presence of these soils:

- (a) Surface cracking of soils.
- (b) "Gilgai" micro relief.

- (c) Strong subsoil structure, with the structural units oriented away from the vertical.
- (d) Presence of "Slickensides" - clay skins, on the surface of subsoil peds.
- (e) Surface soil texture at least as fine as light clay.

It is important to identify total soil depth and the depth at which a water table occurs, as these factors may further modify foundation designs for structures. In broad scale planning the following tests are suitable for the identification of expansive soils:

Table 5.2 Identification of Expansive Soils.

Test	Shrink-Swell Potential	Critical Values
Linear Shrinkage	low	0-12
	medium	12-17
	high	17-22
	very high	> 22
Liquid Limit	low	< 45
	medium	45-55
	high	55-75
	very high	> 75
Plasticity Index	low	< 25
	medium	25-35
	high	35-45
	very high	> 45

Data from Dept.of Public Works, Soils Laboratory, Manly Vale, and Mills et al. (1977).

Dispersible Soils

Dispersible soils are those soils in which the clay fraction of the soil partly or completely disperses in water due to the presence of a relatively high proportion of sodium on the clay surfaces.

Identification of dispersible soils is critical for the soil erodibility assessment described in Section 6.2. In the urban situation the presence of dispersible

soils may preclude the use of absorptive type septic systems, and localised tunnelling may occur around underground services, particularly any that are permeable to water. It may also be necessary to alter foundation designs in dispersible soils.

The following features aid in the identification of these soils:

- (a) "Wormy" appearance of natural soil cuttings.
- (b) Existence of tunnels or pipes already in the landscape.
- (c) Great Soil Groups - Solodic, solodized, solonetz.
- (d) Principal Profile Form Dy 3.43.
- (e) Predominance of yellow grey colourations in the subsoil.
- (f) Presence of bleached A_2 horizons.
- (g) Laboratory data - Dispersal Index Test and Emerson Aggregate Test (See Section 7.3).

Soil Permeability

Water falling on a natural landscape infiltrates vertically into the soil until it reaches a zone of different permeability. This may be a highly permeable sand or gravel seam or a less permeable zone such as compact clay or rock. Water will then move horizontally in the permeable layer or on top of the impermeable layer. These layers usually continue underground but may surface, further down the slope.

Where subsurface drainage water surfaces naturally or is brought to the surface after interception of potential water bearing layers by building foundations or excavation, special drainage provisions may be required. In addition this situation will aggravate any pollution problems such as contamination by septic water, garden fertilizers etc.

Restricted drainage may cause -

- Increased surface runoff.
- Increased soil dispersion.
- Slope instability.
- Rank and undesirable plant growth.
- Differential settlement of building and road foundations.
- and/or undermining.
- Flooding and dampness in basements.

The following features are indicators of the presence of these soils:

- (a) Soil texture of permeable layers coarser than sandy loams. Soil texture of impermeable layers finer than light clay, structure massive or apedal.
- (b) Soil structure of permeable layers strongly aggregated with iron sesquioxides. Structure of impermeable layers weakly pedal to apedal.
- (c) Soil colour - yellow, grey mottles as yellow, or yellower, than 10YR indicate the presence of seasonal water tables and hence drainage problems.
- (d) pH - generally acid
- (e) Other features - vegetative growth is generally tussocky. Sedges and rushes may occur. There is usually active, green, plant growth for longer periods than in the surrounding soil. The underlying rock may be close to the surface. Water bearing rock strata are usually sedimentary or metasedimentary rock types.
- (f) Laboratory Data
 - (i) Particle size analysis. The relative proportion of various particle size fractions together with structure in the soil determine the permeability of a soil material and hence it is difficult to assign limiting values. However, gravel contents in excess of 10 percent and coarse sand contents in excess of 25 percent enhance free drainage through a soil. Clay percentages greater than 45 percent, if soil structure is weak, generally suggest impeded drainage.
 - (ii) Emerson Aggregate Test. This test is the most suitable for assessing soil structure in the laboratory. Emerson classes of 3 or less (provided other criteria are consistent) would be associated with low permeabilities, whereas classes 4 and 5 would generally be associated with moderate permeabilities, and class 6 with good to excessive permeabilities.

Identification of saline soils is necessary for revegetation programmes, which in turn determine the time taken to control erosion and sedimentation that is a consequence of urban development.

The following features assist in the identification of these soils:

- (a) Soil pH >8.5.
- (b) Presence of soluble chlorides (White precipitate occurs when silver chloride solution is added to the soil water).
- (c) Great Soil Group - Solodized solonetz and many soils of arid regions.
- (d) Other features - absence of, or minimal plant growth, presence of halophytic species and salt encrustations on the surface of the soil.
- (e) Laboratory Data

Northcote and Skene (1972) use the following criteria for defining Saline Soils: Salinity (percent sodium chloride equivalent), Sodicity (exchangeable sodium as a percentage of the total cation exchange capacity - E.S.P.) and Alkalinity (pH of a 1.5 soil:water suspension).

Table 5.3 Identification of Saline and Sodic Soils

	Salinity	Sodicity	Alkalinity
Category 0	Non Saline - no chloride in either the surface soil or subsoil	Non sodic ESP* < 6	Acid or insignificantly alkaline. pH < 8.0.
Category 1	Surface salinity: Soils containing in their A horizons, or in the surface 20 cm if either the A & B horizons are undifferentiated or the A horizon is less than 10cm thick, more than 0.1% NaCl in loam and coarser soils and over 0.2% in clay loams and clays.	ESP 6-14	Alkaline pH 8.0-9.5
Category 2	Subsoil Salinity: Soils lacking surface salinity but containing more than 0.3% sodium chloride in the B horizon, or below 20cm if the A and B horizons are undifferentiated.	Strongly ESP > 15	Strongly Alkaline pH > 9.5

* ESP = Exchangeable sodium percentage.

Other Limitations to Urban Development

Other limitations to urban development can also be recognised during the soil survey. These limitations generally do not affect the Urban Capability classification as such but recognition of these limitations is important to engineers and planners.

Soil Fertility

A knowledge of the soil fertility of various mapping units is important for:

- (1) Revegetation programmes during and after urban development.
- (2) The erosion hazard of areas which are to remain in their original condition (e.g. nature reserves).

Soil fertility is a combination of desirable soil chemical and physical features. However, since it is simple to modify soil chemical features (by the addition of appropriate fertilizer) more emphasis should be placed on physical features.

The following characteristics, which can be determined in the field, aid in assessing the relative fertilities of soils. Soil fertility is also discussed in Section 2.2

- (a) pH; acid soils pH <6.0, neutral soils pH 6.5 - 8.0, alkaline soils pH >8.5.
- (b) Organic matter; high-Value Chroma (V/C) rating 1, moderate-V/C 5, low V/C 2,3,4.
- (c) Structure; Excellent - strong fine crumb structure, Moderate - moderately strong crumb to strong subangular blocky structure. Poor - structure moderately blocky or less structured.
- (d) Depth of topsoil; - shallow 0-10cm, moderate 10-30cm, deep >30 cm. (Refers to depth of A₁ horizon).
- (e) Surface features - hardsetting so as to restrict plant growth, hardsetting but plant growth not restricted, self mulching or sandy.

Soil Suitability as a Foundation Material

Table 5.4 indicates broad correlations between the U.S.C.S. soil type (See Section 7.1) and certain soil properties relevant to urban capability studies, Column 1 suggests a bearing value for conventional house foundations for each soil type. The soils are then ranked in terms of their relative desirability for housing subdivision and this ranking varies, depending of whether absorptive type septic systems are envisaged, or a waste disposal system that does not require an absorptive medium (Columns 2 and 3).

If these soils are to have water retention structures built on them the general requirements for the control of seepage on these structures is given in columns 4 and 5.

Some of the terms used in the table need explanation. Permanent storage structures are used in urban areas for water supply and/or recreational purposes. Temporary storage structures may be incorporated into an urban drainage system to provide water retention during periods of heavy runoff thus reducing or preventing flooding of low lying areas. Positive cutoff, the core in an embankment, must extend (via a core trench) into the underlying soil, if possible, to bedrock.

A blanket is a layer of relatively impermeable material which is placed on the floor and sometimes on the upstream batter face of the embankment.

Toe drains are wedges of rubble inserted into the base of the downstream batter of the embankment to reduce pressure caused by moisture build-up.

A well is a core drilled vertically into the downstream batter of an embankment and subsequently filled with coarse textured material such as sand.

Table 5.4 The Unified Soil Classification System as it Relates to Urban Capability Studies
(adapted from U.S. Soil Conservation Service "Engineering Field Manual" 1975.)

U.S.C.S. Class	Bearing Value	Relative Desirability for Housing*		Requirements for Seepage Control	
		Septic Tank	Pan, Pumpout Reticulated Sewerage	Permanent Storage Structure	Temporary Storage Structure
GW	Good	Unsuitable	1	Positive cutoff or blanket	Control Storage below outlet** level plus pressure relief if required.
GP	Good	Unsuitable	3	As above	As above
GM	Good	2	4	Core trench in some situations	None
GC	Good	1	6	None	None
SW	Good	Unsuitable	2	Positive cutoff blanket & toe drains or wells	Control storage below outlet level plus pressure relief if required.

Table 5.4 Cont'd.

SP	Poorly graded sands, gravelly sands, little or no fines	Good to poor depending on density	Unsuitable	5	As above	As above
SM	Silty sands, sand-silt mixtures	As above	4	7	None	None
ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clay silts with slight plasticity	Very poor, subject to liquefaction	6 (if wetted)	9	Positive cutoff or upstream blankets and toe drains or wells	Sufficient control to prevent piping in and below embankment
CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	Good to poor	5	10	None	None
OL	Organic silts and organic silty clays of low plasticity	Fair to poor may have excessive settlement	7	11	None	None

Table 5.4 Cont'd

MH	Inorganic silts, mica- ceous or diatomaceous fine sandy or silty soils, elastic silts	Poor	8	12	None	None
CH	Inorganic clays of high plasticity, fat clays	Fair to Poor	9	13	None	None
OH	Organic clays of medium to high plasticity, organic silts	Very Poor	10	14	None	None

Footnote:

* No. 1 is the best numerical rating.

**

For temporary structures seepage control in the form of wells is provided in the embankment only below the level of the outlet pipe. The rapid removal of water through the pipe after the bankfull stage may cause slips on the face of the upstream batter. The removal of this hazard requires the incorporation of wells cored vertically into the upstream batter.

Chapter 6.

SOILS IN RELATION TO THE DESIGN OF EARTHWORKS

6.1 Introduction

The extended Factual coding used by the Service for soil classification (see Section 4.6) specifically includes soil properties of the A horizon, as this is the soil layer of most importance to agricultural production and hence soil conservation. These properties are the texture, structure and depth of the A horizon and, in a subjective way, they express the general behaviour of the surface soil to rainfall and runoff.

The inclusion of this extra amount of coded soil information does not, however, provide a complete statement of the susceptibility of a soil to erosion: similar descriptions of the B horizon are also required. Such B horizon information is necessary because this horizon is capable of affecting the water regime and thus the erosion susceptibility of A horizons. This is particularly so when B horizon properties contrast markedly to those of a shallow A horizon. Some such particularly erodible B horizon soils can erode beneath an undisturbed A horizon and ultimately cause its collapse and erosion. Furthermore, B horizon soil properties need to be known for the sake of its own conservation. This soil may be exposed through erosion or construction, and, if allowed to erode unabated, can be the source of large amounts of sediment.

Clearly, the two behavioural properties of soils, infiltration and erodibility, are very important to water induced erosion. These change as texture, structure and depth of soil horizons change, and greatly affect the amount of runoff and erosion a soil is likely to experience. Hence, they affect in a basic way the criteria used for the design of soil conservation earthworks. In particular, infiltration properties affect the estimation of the time of concentration (or the design storm intensity), the runoff coefficient, and bank spacings on permanently pasture covered land. Erodibility properties affect the maximum permissible velocities for flows in open channels and the spacings of banks on cultivated land.

These fundamental influences that infiltration and soil erodibility have on the design of soil conservation earthworks make the appropriate and objective assessment of them very important. In the past they have been subjectively assessed. Recently, however, a scheme assessing soil erodibility has been developed which provides an objective basis for the assessment of both from simple, qualitative soil survey data, which has, in turn, provided a more rational basis for earthwork design specifications.

6.2 Soil Erodibility

The existing erosion on lands is not necessarily indicative of the erodibility of the soil or soils on which it is occurring. This is because erosion is the end result of a complex interaction of factors: factors which include the erodibility of soil, the erosivity of the rainfall, the steepness and length of slope of the topography, and the past and existing management of the land. True comparisons of the erodibility of soils are thus only possible when one compares the erosion of the soil or soils under consideration when the same conditions of erosivity, topography and land management exist. Such comparisons are most often possible in paddock size areas, for at this scale all other factors except soil erodibility are mostly constant.

The resistance of a soil to water induced erosion depends on the following factors:

- (i) the ability of its surface aggregates to withstand disintegration from raindrop impact;
- (ii) the ability of its surface aggregates to withstand transportation in overland flows;
- (iii) the ability of its sub-surface aggregates to withstand disruption caused by rapid wetting;
- (iv) the rate at which the surface can absorb water;
- (v) the rate at which sub-surface layers allow infiltrated water to drain; and
- (vi) the amount of water each soil horizon or layer is capable of absorbing. Given a stable surface soil, the last four factors become important in that they determine the speed with which a particular soil reaches fully saturated surface soil conditions and runoff commences.

The rainfall erodibility of soil can thus be described when expressed in the following form:

$$\text{Rainfall Erodibility} = \text{function} \left(\frac{\text{soil detachability}}{\text{(water transmissivity)}} \right)$$

where: soil detachability = function (density, size and stability of aggregates)

water transmissivity = function (size, shape, arrangement and texture of aggregates)

Soil detachability, in terms of simply identified soil properties, is thus related to the texture (T), structure (S) and dispersibility (D) of soils. Similarly, water transmitting properties of soils are related to T, S and the depth of the horizon or soil layer under consideration.

Soil detachability has two aspects to it; aggregate breakdown and dispersion under the influence of raindrop impact, and the transportation of disaggregated fragments or dispersed soil particles. The size and stability of aggregates, determines the time taken for them to disintegrate into fragments and particles fine enough to substantially block pores and increase runoff. However, the more unstable the aggregate, the more rapid the breakdown. The size and density of aggregates, their fragments and ultimate particles determine, on the other hand, their transportability. Larger, less dense particles move easiest. Smaller particles, irrespective of their density, do not dislodge easily unless there is sufficient turbulence in the overland flow to swirl them into faster moving water. Once so disturbed, however, they are easily transported. Texture and structure thus interact in such a way that medium textured, well structured soils are the most easily detached soils. But this does not necessarily mean that they are the most erodible. Such soils have good hydrologic properties which moderate the effects of their detachability in terms of their erodibility.

There are three aspects of the water transmitting properties of soil which are important to the erodibility of soil to rainfall; infiltration (the rate of water entry at the surface); internal drainage (the rate of water movement from horizons within the profile); and water holding capacity (the volume of water a soil can absorb before becoming saturated). The first two are rate aspects which depend solely on the distribution of pore sizes on a two-dimensional or cross-sectional basis. The third is a volumetric aspect which depends on the distribution of pore sizes on a three dimensional basis, i.e. cross-section x depth. All three are thus related to the texture and structure of soils, which combine to produce a unique distribution of structural (large diameter) and textural (small diameter) pore space. The larger the diameter of pores, the faster the rate at which water may move through them but the fewer the total number of pores and the smaller the total pore space. The smaller the diameter of pores, the slower the rate at which water may move through them but the greater the total number of pores and total pore space. Thus, given stable soil structure conditions the hydrologic soil properties important in erodibility are related to the texture, structure and depth of soil horizons.

Taking all factors into consideration, then, the erodibility of soil to water can be rationally based on the texture (T), structure (S), depth of soil horizons and some measure of aggregate stability (D). A scheme which provides descriptions of both the detachability and the water transmitting properties from field assessments of T, S, depth and D properties, and then combines them all in an equation to obtain an index of erodibility, is currently in use. This scheme represents the first Australian attempt to introduce objectivity into assessments of erodibility and is in use on a trial basis, subject to qualitative and quantitative experimental verification.

The erodibility index EI is calculated from numeric values ascribed to field descriptions of T, S, D and depth. The product of T, S, D values gives a numerator value representing soil detachability. Combinations of the qualitative descriptions of T and S, plus data on depth, allow the inference of infiltration I, horizon permeability K, and water holding capacity C, numeric values of which are multiplied and square rooted in a denominator representing the water transmitting properties of soil. The EI equation is thus

$$EI = \frac{T S D}{\sqrt{I K C}} \quad (1)$$

The range of values calculated from this equation are arranged into five erodibility classes, as follows:

Slight	zero - 1.0
Moderate	1.0 - 2.0
High	2.0 - 3.0
Very High	3.0 - 4.0
Extreme	>4.0

(a) Texture Assessment

The texture assessment required as an input to the index is simply arrived at and reasonably generalized. The six texture groups of Northcote (1974) are used and these each include two or more texture grades. The texture groups used, the numeric values given each (in brackets) and the grades included in each group are as follows:

Sand (6) - includes sand; loamy sand; and clayey sand.

Sandy loam (5) - includes sandy loam, fine sandy loam; and light sandy clay loam.

Loam (4) - includes loam; loam-fine sandy; silt loam; and sandy clay loam.

Clay loam (3) - includes clay loam; silty clay loam; and fine sandy clay loam.

Light clay (2) - includes sandy clay; silty clay; light clay; and light medium clay.

Medium-heavy clay (1) - includes medium clay; and heavy clay.

The numeric values given each texture group are based on the generalization that, in terms of texture alone, sands are more easily detached than sandy loams and sandy loams are more easily detached than loams, and so on.

particles), slake (break rapidly into much smaller but still discrete soil aggregates), or remain largely unaffected. Generally, soils that disperse are very erodible, soils that slake are moderately erodible and soils that remain unaffected are only slightly erodible.

The field assessment of aggregate stability can be made using a crumb test or a visual assessment of soil structure behaviour on an exposed face over which water often runs. The use of both methods together is much preferred, however.

The crumb test consists of placing a few small, air-dry aggregates (5-10 mm diameter) into a small beaker partly filled with distilled water, and observing their reaction. This simple test allows the classification of aggregate stability into three aggregate stability groups. (A total of eight aggregate stability classes are capable of differentiation if the complete procedure of Emerson (1967) is followed, but this requires laboratory work.)

The visual assessment of aggregate stability consists of observing the surface of an exposed gully wall for the presence or absence of 'wormy' appearance and, if present, assessing the degree of 'worminess' relative to the amount of water running over the surface. A 'wormy' appearance results when soil aggregates in such a wall have their surfaces disaggregated and run together when water passes over them.

The value of combining both assessments lies in the fact that visual assessments often result in the modification of a crumb test assessment more in line with what may be perceived as reality. Used alone, the crumb test is not always reliable because of the dual difficulties of obtaining undisturbed air-dry aggregates in sufficient number to ensure representativeness. Adjustments to crumb test aggregate stability assessments as a result of visual observations almost always result only in the movement of that assessment to an adjacent stability group.

The three groups of aggregate stability assessed, their descriptions, in terms of dispersibility, the numeric values given them for the index (in brackets), and the aggregate classes and definitions of Emerson (1967) included in each are as follows:

Very dispersible (3) - This includes Class 1 aggregates, which slake and apparently disperse completely.

Moderately dispersible (2) - This includes Class 2 aggregates, which slake and partly disperse.

Texture is determined by placing some soil in the palm of the hand, and slowly moistening it while kneading it between the thumb and forefinger until the soil mass is just wet enough to fail to stick to the fingers. Kneading is then continued, with frequent additions of water to maintain the moisture content, until the feel of the soil is constant. The soil is then formed into a ribbon by progressively squeezing it between the thumb and forefinger. The feel and the length of the ribbon determine the texture. (Definitions of each texture are given in Northcote (1974): pp 26-28).

(b) Structure Assessment

Soil structure concerns the arrangement of soil particles into aggregates and may be described in terms of three characteristics - grade, class and form. We are concerned here only with grade. Grade expresses the degree and strength of soil aggregation, both of which vary with moisture content. Structure assessments, therefore, should always be made at the standard moderately moist soil condition.

Structure grade is determined by assessing the proportion of naturally occurring aggregates or peds remaining after a handful of soil has been subjected to a moderate crushing force. A naturally occurring aggregate or ped, be it rough-faced or smooth-faced, has a skin-like coating (a cutan) over two thirds of its surface. The structure grades, the numeric values given each for the index (in brackets), and the required proportions of aggregates in each grade are as follows:

Apedal (1) - no observable aggregation. The soil is massive if coherent, and single-grained if not;

Weakly pedal (2) - less than 1/3 of the soil material is comprised of aggregates;

Peds evident (3) - between 1/3 and 2/3 of the soil material is composed of aggregates;

Highly pedal (4) - more than 2/3 of the material is composed of aggregates.

The numeric values of each structure grade are based on the generalization that, in terms of structure alone, highly pedal soils are more easily detached than weakly pedal soils, and so on.

(c) Aggregate Stability (or Dispersibility) Assessment

When suddenly wet, aggregates can behave in three basically different ways. They can disperse (lose all of their structural entity and disintegrate into ultimate

Slightly or non-dispersible (1) - This includes aggregate Classes 3-8. Class 3 aggregates slake but do not disperse. Some dispersion does occur, however, after moist working. Class 4 aggregates slake but do not disperse after moist working, and contain carbonate or gypsum. Class 5 aggregates slake, do not disperse after moist working, but do disperse when shaken in a 1:5 soil:water mixture for ten minutes. Class 6 aggregates slake but do not disperse after a 1:5 ten minute shaking. Class 7 aggregates swell only. Class 8 aggregates do not slake or swell.

The schemes used to relate T, S and horizon depth to the hydrologic properties I, K and C are presented as Tables 6.1 and 6.2. The numeric values used in the index for each inferred description are included in brackets.

Because there is a reasonably limited range of possible combinations of the soil properties involved in the determinations of the erodibility index, a table of calculated index values and their descriptive classes has been constructed. This table is presented as Table 6.3, and it facilitates the rapid determination of the erodibility index by relating the four independent soil properties considered, T, S, depth and D, directly to index values without reference to the inferred hydrologic soil properties which must be included during the calculation process.

6.3 Runoff Coefficient

In the calculations necessary for the design of earthworks, the assessment of the runoff coefficient is of prime importance. The runoff coefficient, which must be assessed in a way consistent with the statistical nature of the Rational Formula presently used for design, and the catchment conditions likely on average for the set frequency of the design rainstorm, is affected by rainfall intensity, vegetative cover and soil conditions. The first of these is arbitrarily chosen, the second is relatively simple to assess, but the influence that the soil has is generally difficult for untrained personnel to assess.

The runoff from a catchment that is likely to occur as a direct result of the soil is affected by all three hydrologic soil properties used in the erodibility index - infiltration I, horizon permeability K, and water holding capacity C - as these properties interact with one another. For instance, shallow sandy soils have large I and large K but small C properties and can saturate quickly and produce substantial runoff flows. Deep clayey soils, on the other hand, have small I, small K and large C properties, and saturate at their surface very quickly, because rainfall intensity is greater than I, and produce substantial runoff flows.

TABLE 6.1

SCHEME FOR INFERRING INFILTRATION AND PERMEABILITY
PROPERTIES OF SOIL HORIZONS

TEXTURE	STRUCTURE	INFILTRATION ⁺	PERMEABILITY	
Sand (6)*	_____ Apedal (1)	Very rapid (7)	Rapid (3)	
Sandy Loam (5)	Weakly pedal (2)			
	_____ Apedal (1)	Rapid (6)		
Loam (4)	_____ Peds evident (3)			
	_____ Weakly pedal (2)	Moderately (5) rapid		
	_____ Apedal (1)			
Clay Loam (3)	_____ Peds evident (3)	Moderate (4)	Moderate (2)	
	_____ Weakly pedal (2)			
	_____ Apedal (1)			
		Moderately (3)		
		slow		
Light Clay (2)	_____ Highly pedal (4)	Moderate (4)		
	_____ Peds evident (3)	Moderately (3)		
	_____ Weakly pedal (2)	slow		
		Slow		
Med./Heavy Clay	_____ Highly pedal (4)	(2)	Slow (1)	
	_____ Peds evident (3)	Very slow (1)		
	_____ Weakly pedal (2)			

+ Table 6.7 relates these infiltration classes to the soil groupings of the USCS system.

TABLE 6.2

SCHEME FOR INFERRING INFILTRATION
CAPACITY OF SOIL HORIZONS

TEXTURE	HORIZON DEPTH		
	< 0.2 m	0.2 - 0.4m	> 0.4 m
SAND	Small (1)*	Moderate (2)	Moderate (2)
LOAM	Small (1)	Moderate (2)	Large (3)
CLAY	Moderate (2)	Large (3)	Large (3)

(* Numbers in parenthesis are ratings for the calculation of erodibility indexes. See text for explanation.)

TABLE 6.3

ERODIBILITY INDEX VALUES FOR A RANGE OF SOIL PROPERTIES

Texture Group	Structure Grade	Horizon Depth	Dispersibility		
			None	Moderate	High
Sand	apedal	< 0.2m	1.3 (M)	-	-
		0.2-0.4m	0.9 (L)	-	-
		> 0.4m	0.9 (L)	-	-
Sandy Loam	apedal	< 0.2m	1.2 (M)	2.4 (H)	-
		0.2-0.4m	0.8 (L)	1.7 (M)	-
		> 0.4m	0.8 (L)	-	-
	weakly pedal	< 0.2m	2.7 (H)	5.4 (E)	-
		0.2-0.4m	1.9 (M)	3.8 (V)	-
		> 0.4m	1.5 (M)	-	-
Loam	apedal	< 0.2m	1.3 (M)	2.5 (H)	-
		0.2-0.4m	0.9 (L)	1.8 (M)	-
		> 0.4m	0.7 (L)	-	-
	weakly pedal	< 0.2m	2.5 (H)	5.1 (E)	-
		0.2-0.4m	1.8 (M)	3.6 (V)	-
		> 0.4m	1.5 (M)	-	-
	peds evident	< 0.2m	2.8 (H)	5.6 (E)	-
		0.2-0.4m	2.0 (H)	-	-
		> 0.4m	2.0 (H)	-	-
Clay Loam	apedal	< 0.2m	1.2 (M)	2.4 (H)	-
		0.2-0.4m	0.9 (L)	1.7 (M)	-
		> 0.4m	0.7 (L)	-	-
	weakly pedal	< 0.2m	2.3 (H)	4.6 (E)	-
		0.2-0.4m	1.5 (M)	3.0 (V)	-
		> 0.4m	1.2 (M)	-	-
	peds evident	< 0.2m	2.9 (H)	5.7 (E)	-
		0.2-0.4m	2.0 (H)	4.0 (E)	-
		> 0.4m	1.6 (M)	-	-
Light Clay	weakly pedal	< 0.2m	2.0 (H)	4.0 (E)	6.0 (E)
		0.2-0.4m	1.6 (M)	3.3 (V)	4.9 (E)
		> 0.4m	1.6 (M)	3.3 (V)	4.9 (E)
	peds evident	< 0.2m	1.7 (M)	3.5 (V)	5.2 (E)
		0.2-0.4m	1.4 (M)	2.8 (H)	4.2 (E)
		> 0.4m	1.4 (M)	2.8 (H)	4.2 (E)
	highly pedal	< 0.2m	2.0 (H)	4.0 (E)	-
		0.2-0.4m	1.6 (M)	3.3 (V)	-
		> 0.4m	1.6 (M)	3.3 (V)	-
Medium to Heavy Clay	weakly pedal	< 0.2m	1.4 (M)	2.8 (H)	4.3 (E)
		0.2-0.4m	1.2 (M)	2.3 (H)	3.5 (V)
		> 0.4m	1.2 (M)	2.3 (H)	3.5 (V)
	peds evident	< 0.2m	2.1 (H)	4.2 (E)	6.4 (E)
		0.2-0.4m	1.7 (M)	3.5 (V)	5.2 (E)
		> 0.4m	1.7 (M)	3.5 (V)	5.2 (E)
	highly pedal	< 0.2m	2.0 (H)	4.0 (E)	6.0 (E)
		0.2-0.4m	1.6 (M)	3.3 (V)	4.9 (E)
		> 0.4m	1.6 (M)	3.3 (V)	4.9 (E)

L - low M - moderate H - high V - very high E - extreme
 N.B. Borderline values are included in the higher category.

In essence, then, runoff likelihood is inversely related to hydrologic properties of soils - high infiltration, low runoff, and vice versa - and a runoff index for the influence of soil properties on the runoff coefficient assessment is present in the denominator of the erodibility index.

$$RI = 1/\sqrt{IKC} \quad (2)$$

In using the denominator of the erodibility index for determining the runoff index only the top 50 cm of soil are considered. This restriction in the depth of soil considered is based on the assumption that in most cases no greater depth of soil will influence a runoff event. Assessments of RI must thus include separately relevant properties of each horizon down to a depth of 50 cm, and the appropriate value of RI for the soil under consideration is the mean of the RI values of the horizons concerned. For example, a profile with horizon depths 0-25, 25-40 and 40-150 cm, say, would have the following horizon depths for each consecutive horizon; 25 cm, 15 cm and 10 cm, and the I for the soil would be the mean of the RI values determined for horizons of these depths.

Like the EI data of Table 6.3, the RI data have been tabulated directly with T, S and depth and are presented in Table 6.4, below. Also like EI data, RI values are grouped into value ranges and given appropriate infiltration description, viz:

Rapid Infiltration	Moderate Infiltration	Slow Infiltration
RI = 0.15-0.25	RI = 0.26-0.45	RI = 0.46-0.70

TABLE 6.4

RUNOFF INDEX VALUES FOR A RANGE OF RELEVANT SOIL PROPERTIES

Texture	Structure	Horizon Depth		
		Shallow (0-20 cm)	Moderate (20-40 cm)	Deep (>40 cm)
Sand	apedal	0.22 (R)	0.15 (R)	0.15 (R)
Sandy loam	apedal	0.22 (R)	0.15 (R)	0.15 (R)
	weakly pedal	0.22 (R)	0.15 (R)	0.15 (R)
Loam	apedal	0.32 (M)	0.22 (R)	0.18 (R)
	weakly pedal	0.32 (M)	0.22 (R)	0.18 (R)
	peds evident	0.24 (R)	0.17 (R)	0.15 (R)
Clay loam	apedal	0.41 (M)	0.29 (M)	0.24 (R)
	weakly pedal	0.35 (M)	0.25 (R)	0.20 (R)
	peds evident	0.32 (M)	0.22 (R)	0.18 (R)

Table 6.4 cont'd.

Texture	Structure	Horizon Depth		
		Shallow (0-20cm)	Moderate (20-40cm)	Deep (>40 cm)
Light clay	weakly pedal	0.50 (M)	0.41 (M)	0.41 (M)
	peds evident	0.29 (M)	0.24 (R)	0.24 (R)
	highly pedal	0.25 (R)	0.20 (R)	0.20 (R)
Medium-Heavy clay	weakly pedal	0.70 (L)	0.58 (L)	0.58 (L)
	peds evident	0.70 (L)	0.58 (L)	0.58 (L)
	highly pedal	0.50 (M)	0.41 (M)	0.41 (M)

R - rapid; M - moderate; L - slow;

Where a catchment under consideration has two or more soils with different infiltration properties, the appropriate value of RI for the catchment is the weighted average. This is determined by multiplying the RI values for each soil by the percentage of total catchment area covered by the particular soil, summing all such values, and dividing by 100.

The infiltration properties of soils determined using RI can be inserted into any scheme currently in use for assessing the runoff coefficient in the Rational Formula. The scheme presently used by the Service for assessing the runoff coefficient is basically that of Turner (1960) and RI soil infiltration assessments should be fed into it appropriately.

6.4 Critical Velocities

Soil conservation earthwork channels, be they bank, waterway, flume or spillway channels, must all cope regularly with volumes of runoff and do so without deterioration over long periods of time. One way of ensuring continued deterioration - free performance is to so construct the grade of the channel that water will flow along it at a velocity that will not erode the soil in it. This velocity is called the maximum permissible channel flow velocity (critical velocity). Such gradient choices will, of course, be based on other factors besides the erodibility of the soil, such as the nature and permanence of vegetative cover.

The erodibility of the surface soil in earthwork channels (whether it be topsoil or subsoil) is the obvious criterion to use for assessing their maximum permissible flow velocity. The erodibility index has been used for this purpose, and the index values have been related directly to such velocities, as set out in the tables below.

TABLE 6.5
MAXIMUM PERMISSIBLE VELOCITIES
FOR BARE SOIL CHANNELS

Erodibility		Maximum Permissible Velocity (m/sec)
Assessment	Index Value	
Extreme	> 4.0	0.3
Very High	3.0-4.0	0.4
High	2.0-3.0	0.5
Moderate	1.0-2.0	0.6
Low	0-1.0	0.7

TABLE 6.6
MAXIMUM PERMISSIBLE VELOCITIES FOR VEGETATED
CHANNELS (m/sec)

Cover Type*	Channel Slope(%)	Erodibility Index Assessment				
		0-1.0	1.0-2.0	2.0-3.0	3.0-4.0	>4.0
Kikuyu and other	0-5	2.6	2.4	2.3	2.2	2.0
dense, high growing,	5-10	2.5	2.3	2.2	2.1	1.9
prostrate perennials	> 10	2.4	2.2	2.1	2.0	1.8
Couch and other low	0-5	2.1	2.0	1.9	1.7	1.5
growing, prostrate	5-10	2.0	1.9	1.8	1.6	1.4
perennials	> 10	1.9	1.8	1.7	1.5	1.3
Perennial improved	0-5	1.7	1.6	1.4	1.2	1.0
pastures	5-10	1.6	1.5	1.3	1.1	0.9
	> 10	1.5	1.4	1.2	1.0	0.8
Native tussocky						
grasses,	0-5	1.4	1.2	1.0	0.8	0.6
sparse high growing	5-10	1.3	1.1	0.9	0.7	0.5
legumes (eg lucerne)						
and self-regenerating						
annuals**						

* The velocities shown for each cover description assume good (i.e. > 80 per cent) cover conditions.

** Tussocky grassed slopes of > 10 per cent gradient are not recommended for vegetated channels because of the channelizing effect such vegetation has on flow conditions.

TABLE 6.7
HYDRAULIC CONDUCTIVITY OF SOILS AND RELATIONSHIP
TO USCS GROUPS (adapted from Kinori (1970))

Infiltration Class	Hydraulic Conductivity cm/day	USCS Group
Very slow	<3	CH OH
Slow	3-50	CL MH OL SC GC
Moderately slow	3-50	SM ML GM
Moderate	50-600	SW
Moderately rapid	50-600	SP
Rapid	50-600	GW
Very rapid	>600	GP

N.B. Infiltration classes are those used in the assessment of soil erodibility (See Table 6.1). Hydraulic conductivity values shown give an indication of the range of likely infiltration rates of soils in saturated condition. USCS groups are those of the Unified Soil Classification System (See Section 7.1.3).

6.5 Bank Spacing

There are essentially two approaches used for deciding bank spacing, but, basically, both are arrived at as a result of matching the quantity of runoff expected from the catchments they delineate (a direct function of the spacing) with a practical size of bank that is likely to retain its channel capacity, and thus efficiency, over a long period of time. Of course, other factors also affect bank spacing, such as topographic limitations like slope steepness and the availability of stable outlets, but these are, by and large, secondary considerations. It is the likelihood of a bank retaining its channel capacity which creates the different approaches, both of which are controlled by land usage.

(a) Bank Spacing on Grazing Land

Land used permanently for grazing always has a vegetative cover that effectively prevents any raindrop splash erosion and minimizes overland flow erosion. The need for banks on such lands is therefore not as great as it is on arable lands, but it is still real. Banks are required on these lands where drainage lines are eroding or are potentially likely to erode and where ridges are bare and sheet eroded.

The primary consideration of earthwork design on such lands is the safe, slow disposal of runoff away from eroding or erosion prone areas of the landscape. Almost exclusively, the spacings of such banks are flexible, being dependent only on matching the bank capacity of practically sized banks with the expected volume of runoff from the catchment it delineates. Where bank locations are affected by topographic influences, bank size or bank numbers or both are altered to fit the situation.

(b) Bank Spacing on Cropping Land

Land used for cropping does not always have a protective vegetative cover, and banks must be spaced to afford maximum protection to the land surface when it is in a cultivated state. In contrast to the spacing criterion on grazing land, then, bank spacing on cropping land is fixed in accordance with minimizing erosion between banks. The effect of such spacing is to reduce the length of travel (and thereby the velocity) of overland flow. Once it has been decided the size or capacity of the bank is adjusted to cope with the expected runoff.

Interbank erosion cannot be tolerated in banking systems. Such erosion is not only detrimental to the landscape above a bank but it causes the siltation of the bank channel, which, if allowed, predisposes the land below the bank to much more catastrophic erosion through the artificial concentration of runoff wrought by the bank itself.

In considering bank spacings on cultivated land, the factors affecting the susceptibility of the soil to erosion, excluding for the moment management, are the erosivity of the rainfall, the erodibility of the soil, and the degree of slope. Bank spacings thus vary between geographical regions because of changing rainfall erosivity, within geographical regions because of varying soil erodibility, and within a soil type because of varying slope.

Ideally, therefore, a bank spacing rationale should be capable of adjustment for all three factors, but adjustments for erosivity are unfortunately not possible in Australia. There are no Australian data on rainfall erosivity, and differences in bank spacings between geographically different regions have to be subjectively set on the basis of experience. However, objective adjustments for erodibility and slope are possible, through the erodibility index and the equation:

$$K = HI \cdot \sqrt{S} \quad (3)$$

where; K = constant (m); HI = horizontal interval between banks (m); and S = per cent slope. Here the horizontal interval between banks changes in proportion with $1/\sqrt{S}$. K , after having been set from experience in a geographical region for the most erodible soil, is altered according to the erodibility index descriptions, as follows:

extreme erodibility	-	$K \times 1.0$;
very high erodibility	-	$K \times 1.1$;
high erodibility	-	$K \times 1.2$;
moderate erodibility	-	$K \times 1.3$;
low erodibility	-	$K \times 1.4$

This adjustment to K takes account of all the factors involved in bank spacing, including past management. Assessments based on predictions of future management are not encouraged as they have no firm basis.

Table 6.8 gives a general ranking of soils in terms of their relative susceptibility to erosion caused by water. The table may be useful when more general decisions regarding land use and soil conservation design are required.

TABLE 6.8

RELATIVE ERODIBILITY OF N.S.W. SOILS

Soils are shown as Great Soil Groups and in order of increasing erodibility. Gradings are for soils in non-eroded condition and are intended to give a general indication of their relative resistance to erosive forces, particularly those forces related to water erosion.

LOW	Grey, Brown and Red Clays Red Earths
MODERATE	Euchrozems Prairie soils Krasnozems Terra Rossa Chocolate soils
HIGH	Alpine Humus soils Humic gley soils Gleyed Podzolic soils Lateritic Podzolic soils Xanthozems Clays (Uf soils generally) Black Earths Red Podzolic soils Brown Podzolic soils Chernozems
VERY HIGH	Yellow Earths Yellow-brown and Grey Earths Rendzina Loams (Um soils generally) Grey-brown podzolic soils Yellow podzolic soils Red Brown Earths Non-calcic Brown soils Solonized Brown soils Calcareous Desert soils Red Solodic soils
EXTREME	Desert Loams Solonchaks Yellow solodic soils Podzols Solods Sands (Uc soils generally) Solonetzic soils Solodized solonetz

Chapter 7.

SOILS IN RELATION TO THE CONSTRUCTION OF EARTHWORKS

The Service is widely involved in the construction of soil conservation earthworks, and thus each and every soil conservationist is concerned with the way soil material behaves when used in this way. The process of ripping and dozing the soil from its natural location and using it in a bank, gully fill or gully control structure substantially alters its properties and behaviour. It is therefore pertinent to have a knowledge of the soil - purely as a material, and the way it is likely to react to our use of it as a construction material.

7.1 Engineering Properties of Soil Materials

The engineering characteristics of soils are best set out in the "Unified Soil Classification System", an American scheme developed by Professor A. Casagrande in 1952. (See figure 7.1).

This system, which is particularly applicable to the design and construction of dams, takes into account the engineering properties of soils, is descriptive and easy to associate with actual soils, and has the flexibility of being adaptable both to the field and to the laboratory. Probably its greatest advantage is that a soil can be classified readily by visual and manual examination without the necessity for laboratory testing. The Unified Soil Classification System is based on the size of the particles, the amounts of the various sizes, and the characteristics of the very fine grains.

7.1.1 Soil Components

(a) Size

Particles larger than 7.5 cm are excluded from the Unified Soil Classification System. The amount of such oversized material, however, may be of great importance in the selection of sources for embankment material.

Within the size range of the system there are two major divisions; namely, the coarse grains and the fine grains. Coarse grains are those larger than the No. 200 *sieve size (0.074 mm), and they are further divided as follows:

Gravel (G), from 75 mm to No. 4 sieve (4.76 mm):
 Coarse gravel - 75 mm to 20 mm.
 Fine gravel - 20 mm to No. 4 sieve (4.76 mm)

* Sieve sizes shown are to the ASTM standard.

Sand (S), from No. 4 sieve to No. 200 sieve.

Coarse sand - No. 4 to No. 10 sieve
(4.76 to 2.0 mm).

Medium sand - No. 10 to No. 40 sieve
(2.0 to 0.42 mm).

Fine sand - No. 40 to No. 200 sieve
(0.42 to 0.074 mm).

For visual classification, 5 mm is considered equivalent to the No. 4 sieve size, and the No. 200 sieve size is about the smallest size of particles that can be distinguished individually by the unaided eye. Fine grains or fines are smaller than the No. 200 sieve size and are of two types: silt (M) and clay (C).

(b) Gradation

The amounts of the various sizes of grains present in a soil can be determined in the laboratory by means of sieving, for the coarse grains, and by sedimentation (particle size analysis) for the fines.

The laboratory results are usually presented in the form of a cumulative grain-size curve. For soils consisting mainly of coarse grains, the grain-size distribution reveals something of the physical properties of the material. On the other hand the grain size is much less significant for soils containing a preponderance of fine grains.

Typical gradations of soils are:

Well graded (W) - Good representation of all particle sizes from largest to smallest.

Poorly graded (P) - Uniform, most particles about the same size; or gap gradation - absence of one or more intermediate sizes.

In the field, soil is estimated to be well graded or poorly graded by visual examination. For laboratory purposes the type of gradation can be determined by the use of criteria based on the range of sizes and on the shape of the grain-size curve.

7.1.2 Properties of Soil Components

(a) Gravel and Sand

Both of the coarse-grained components of soil have essentially the same engineering properties, differing mainly in degree. The division of gravel and sand sizes by the No. 4 sieve is arbitrary and does not correspond to a sharp change in properties. Well-graded, compacted gravels or sands are stable materials. The coarse-grained soils when devoid of fines are pervious, easy to compact, little affected by moisture, and not subject to frost action. Although grain shape and gradation, as well as size, affect these properties, gravels are generally more pervious, more

stable, and less affected by water or frost than are sands, for the same amount of fines. Poorly graded sands and gravels are generally more pervious than well graded sands and gravels.

As a sand becomes finer and more uniform, it approaches the characteristics of silt, with a corresponding decrease in permeability and reduction in stability in the presence of water. Very fine, uniform sands are difficult to distinguish visually from silt. Dried sand, however, exhibits no cohesion and feels gritty in contrast to the very slight cohesion and smooth feel of dried silt.

(b) Silt and Clay

Even small amounts of fines may have important effects on engineering properties of the soils in which they are found. As little as 25 percent of particles smaller than the No. 200 sieve size in sand and gravel may make the soil virtually impervious, especially when the coarse grains are well-graded. Also, serious frost-heaving in well-graded sands and gravels may be caused by less than 10 percent of fines.

Soils containing moderate amounts of clay and with small amounts of silt are quite suitable for small earth structures particularly those intended for water storage. These fine materials exhibit marked changes in physical properties with change of water content. A hard, dry clay, for example, may be suitable as a foundation for heavy loads so long as it remains dry, but may turn into a quagmire when wet. Many of the fine soils shrink on drying and expand on wetting, which may adversely affect structures founded upon them or constructed of them. Even when the water content does not change, the properties of fine soils may vary considerably between their natural condition in the ground and their state after being disturbed. Deposits of fine particles which have been subjected to loading in geologic time frequently have a structure which gives the material unique properties in the undisturbed state. When the soil is excavated for use as a construction material the soil structure is destroyed and the properties of the soil are changed radically.

Silts are different from clays in many important respects, but because of similarity in appearance, they often have been mistaken one for the other, sometimes with unfortunate results. Dry, powdered silt and clay are indistinguishable, but they are easily identified by their behaviour in the presence of water. Recognition of fines as being silt or clay is an essential part of the Unified Soil Classification System.

Silts (M), are the non-plastic fines. They are inherently unstable in the presence of water. Silts are fairly impervious, difficult to compact, and are highly susceptible to frost heaving. Silt masses undergo change of volume with change of shape (the property of dilatancy), in contrast to clays which retain their volume with change of shape (the property of plasticity). When dry, silt can be pulverised easily under finger pressure (indicative of very slight dry strength), and will have a smooth feel between the fingers in contrast to the grittiness of fine sand. Silts differ among themselves in size and shape of grains, which are reflected mainly in the property of compressibility.

Clays (C), are the plastic fines. They have low resistance to deformation when wet, but they dry to hard, cohesive masses. Clays are virtually impervious, difficult to compact when wet, and impossible to drain by ordinary means. Large expansion and contraction with changes in water content are characteristic of some clays. The small size, flat shape, and type of mineral composition of clay particles combine to produce a material that is both compressible and plastic. In the Unified Soil Classification System, the liquid limit is used to distinguish between clays of high compressibility (H) and those of low compressibility (L). Differences in plasticity of clays are reflected by their plasticity indices. For the same liquid limit, the higher the plasticity index, the more cohesive is the clay. (See figure 7.2)

Field differentiation among clays is accomplished by the toughness test in which the moist soil is moulded and rolled into threads until crumbling occurs, and by the dry strength test which measures the resistance of the clay to breaking and pulverizing.

(c) Organic Matter

Organic matter in the form of partly decomposed vegetation is the primary constituent of peaty soils. Varying amounts of finely divided vegetable matter are found in plastic and in non-plastic sediments and often affect their properties sufficiently to influence their classification. Thus, we have organic silts and silt clays of low plasticity, and organic clays of medium to high plasticity. Even small amounts of organic material in colloidal form in a clay will result in an appreciable increase in liquid limit of the material without increasing its plasticity index. Organic soils are dark grey or black in colour and usually have a characteristic odour of decay. Organic clays feel spongy in the plastic range as compared to inorganic clays. The tendency for soils with significant organic content to create voids by decay or to change the physical characteristics of a soil mass through chemical alteration makes them undesirable for engineering use.

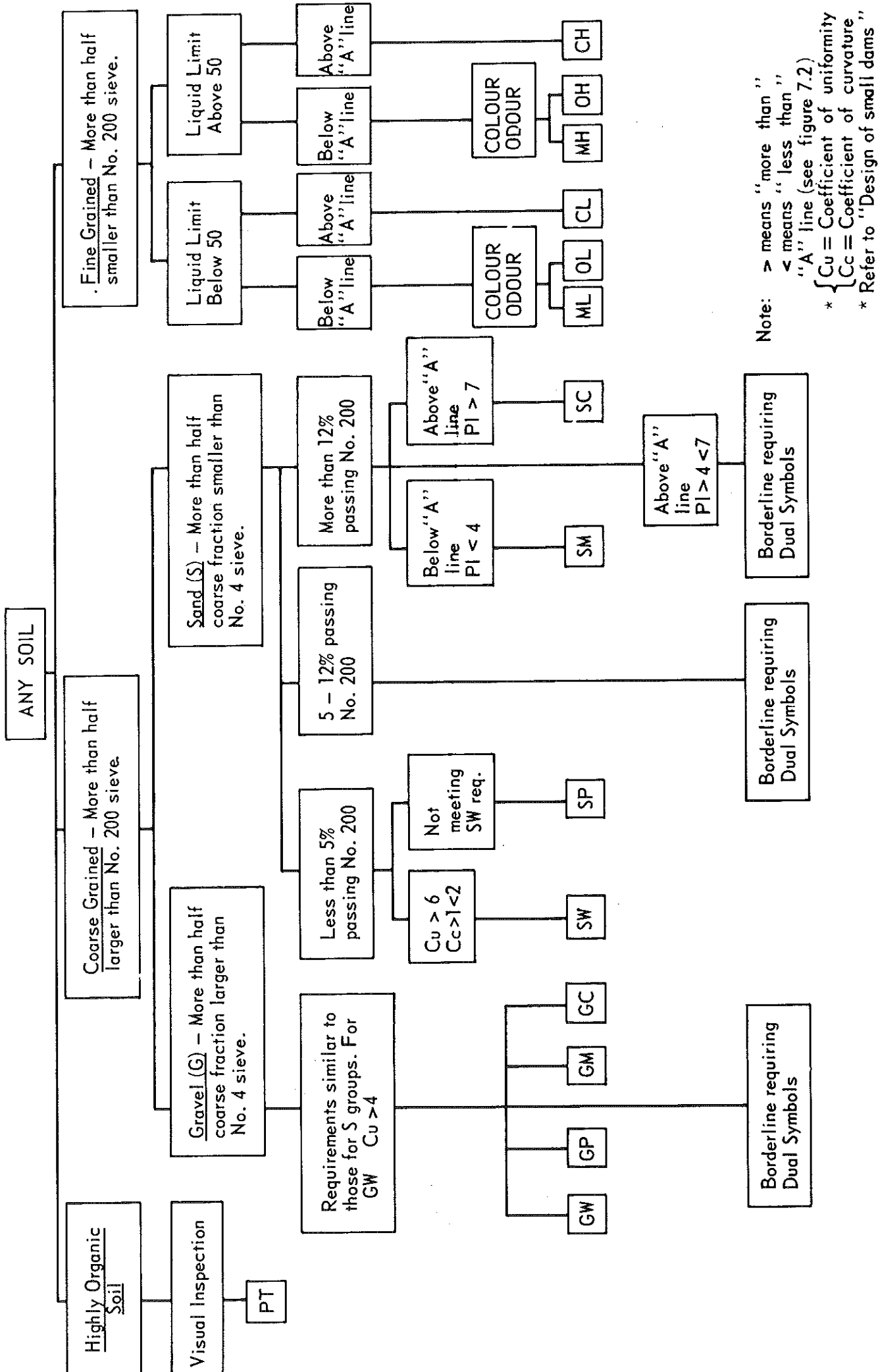


Figure 7.1 UNIFIED SOIL CLASSIFICATION SYSTEM

PLASTICITY INDEX

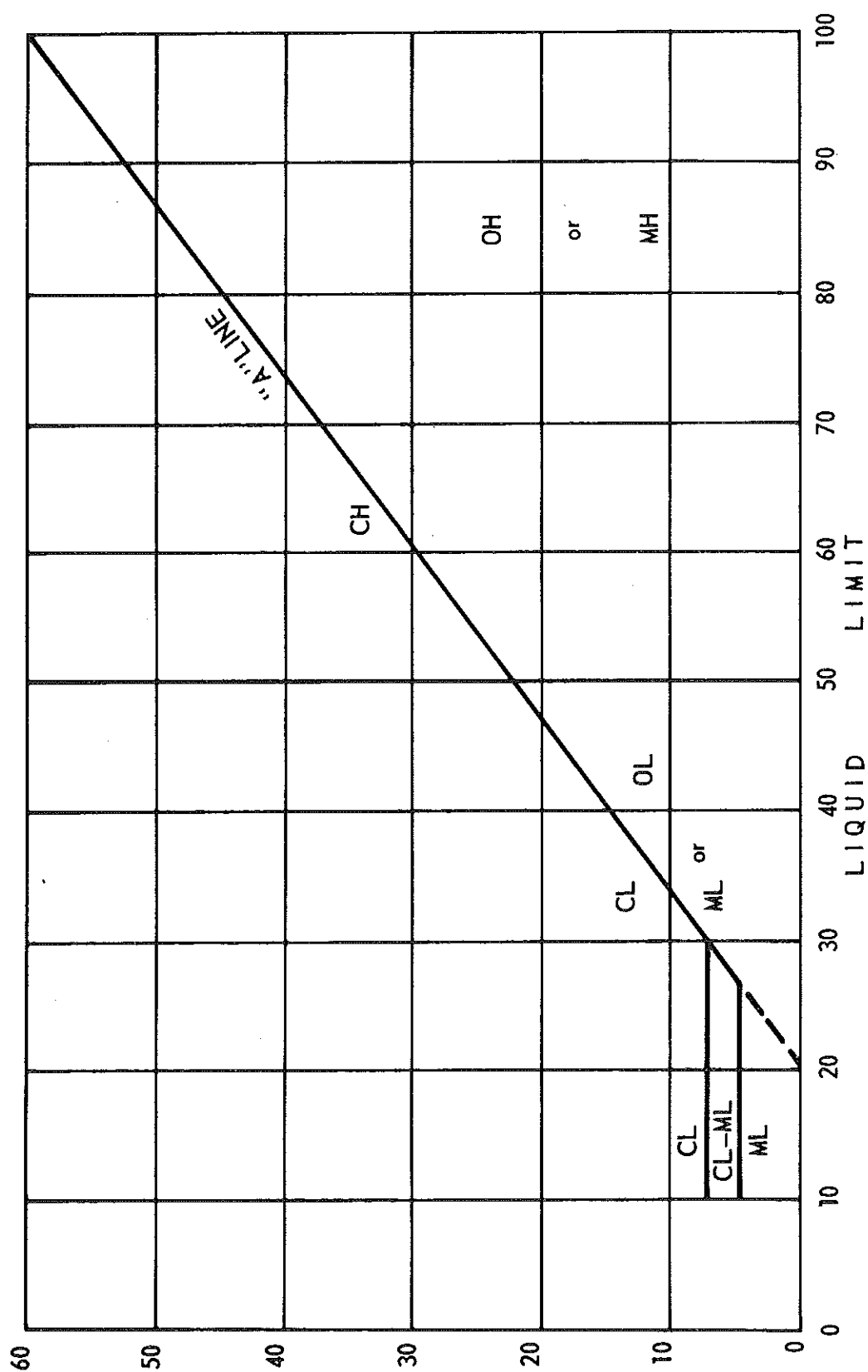


Figure 7.2 Plasticity Chart for the laboratory classification of fine-grained soils (After "Design of Small Dams")

7.1.3 Unified Soil Classification System

(a) General

Soils in nature seldom exist separately as gravel, sand, silt, clay or organic matter but are usually found as mixtures with varying proportions of these components. The Unified Soil Classification System is based on recognition of the type and predominance of the constituents, considering grain size, gradation, plasticity and compressibility. It divides soils into three major divisions: coarse-grained soils, fine-grained soils and highly organic (peaty) soils. In the field, identification is accomplished by visual examination for the coarse grains and by a few simple hand tests for the fine-grained soils or fraction. In the laboratory the grain-size curve and the Atterberg limits can be used. The peaty soils (Pt) are readily identified by colour, odour, spongy feel, fibrous texture and are not further subdivided in the classification system.

(b) Field Classification

A representative sample of soil (excluding particles larger than 7.5 cm) is first classified as coarse-grained or fine-grained by estimating whether 50 percent, by weight, of the particles can be seen individually by the naked eye. Soils containing more than 50 percent of particles that can be seen are coarse-grained soils; soils containing more than 50 percent of particles smaller than the eye can see are fine-grained soils. If the soil is predominantly coarse-grained, it is then identified as being a gravel or a sand by estimating whether 50 percent or more, by weight, of the coarse grains are larger or smaller than 5 mm (No. 4 sieve size).

If the soil is a gravel, it is next identified as being "clean" (containing little or no fines, less than 5 percent) or "dirty" (containing an appreciable amount of fines, more than 12 percent). For clean gravels final classification is made by estimating the gradation: the well-graded gravels belong to the GW group and uniform and gap-graded gravels belong to the GP group. Dirty gravels are of two types; those with non-plastic (silty) fines (GM) and those with plastic (clayey) fines (GC). The determination of whether the fines are silty or clayey is made by the three manual tests for fine-grained soils.

If a soil is a sand the same steps and criteria are used as for gravels, in order to determine whether the soil is a well-graded clean sand (SW), poorly graded clean sand (SP), sand with silty fines (SM) or sand with clayey fines (SC).

If a material is predominantly (more than 50 percent by weight) fine-grained, it is classified into one of six groups (ML, CL, OL, MH, CH, OH) by estimating its dilatancy (reaction to shaking), dry strength (crushing characteristics), and toughness (consistency near the plastic limit) and by identifying it as being organic or inorganic.

(c) Field Identification Procedures for Fine Grained Soils or Fractions

These procedures are to be performed on the less than No. 40 sieve size, about 0.4 mm (1/64 in.). For field classification purposes simply remove by hand the coarse particles that interfere with the tests.

Dilatancy (Reaction to shaking)

After removing particles larger than No. 40 sieve size prepare a pat of moist soil with a volume of about 10 cm³. Add enough water if necessary to make the soil soft but not sticky.

Place the pat in the open palm of one hand and shake horizontally, striking vigorously against the other hand several times. A positive reaction consists of the appearance of water on the surface of the pat which changes to a livery consistency and becomes glossy. When the sample is squeezed between the fingers, the water and gloss disappear from the surface, the pat stiffens and finally it cracks or crumbles. The rapidity of appearance of water during shaking and of its disappearance during squeezing assist in identifying the character of the fines in a soil.

Very fine clean sands give the quickest and most distinct reaction whereas a plastic clay has no reaction. Inorganic silts, such as a typical rock flour, show a moderately quick reaction.

Dry Strength (Crushing characteristics)

After removing particles larger than No. 40 sieve size, mould a pat of soil to the consistency of putty, adding water if necessary. Allow the pat to dry completely by oven, sun or air drying, and then test its strength by breaking and crumbling between the fingers. This strength is a measure of the character and quantity of the colloidal fraction contained in the soil. The dry strength increases with increasing plasticity.

High dry strength is characteristic for clays of the CH group. A typical inorganic silt possesses only very slight dry strength. Silty fine sands and silts have about the same slight dry strength, but can be distinguished by the feel when powdering the dried specimen. Fine sand feels gritty whereas a typical silt has the smooth feel of flour.

Toughness (Consistency near plastic limit)

After removing particles larger than the No. 40 sieve size, a specimen of soil about 10 cm³ in size is moulded to the consistency of putty. If too dry, water must be added and if sticky, the specimen should be spread out in a thin layer and allowed to lose some moisture by evaporation. Then the specimen is rolled out by hand on a smooth surface or between the palms into a thread about 3mm in diameter. The thread is then folded and rerolled repeatedly. During this manipulation the moisture content is gradually reduced and the specimen stiffens, finally loses its plasticity and crumbles when the plastic limit is reached.

After the thread crumbles, the pieces should be lumped together and a slight kneading action continued until the lump crumbles.

The tougher the thread near the plastic limit and the stiffer the lump when it finally crumbles, the more potent is the colloidal clay fraction in the soil. Weakness of the thread at the plastic limit and quick loss of coherence of the lump below the plastic limit indicate either inorganic clay of low plasticity, or materials such as kaolin-type clays and organic clays which occur below the A-line of the plasticity chart. (See figure 7.2)

Highly organic clays have a very weak and spongy feel at the plastic limit.

Soils that are typical of the various groups are readily classified by the foregoing procedures. Many natural soils, however, will have property characteristics of two groups, because they are close to the borderline between the groups either in percentages of the various sizes or in plasticity characteristics. For this substantial number of soils, boundary classifications are used; that is, the group symbols most nearly describing the soil are connected by a hyphen, such as GW-GC.

Proper boundary classification of a soil near the borderline between coarse-grained and fine-grained soils is accomplished by classifying it first as a coarse-grained soil and then as a fine-grained soil. Such classifications as SM-ML and SC-CL are common.

(d) Laboratory Classification

Although most classifications of soil will be done visually and by simple hand tests, the Unified Soil Classification System has provided for precise delineation of the soil groups by particle size analyses and Atterberg limits tests in the laboratory. Laboratory classifications are often performed on representative samples of soils which are being subjected to testing and to verify field classifications when used in the design of small dams. Laboratory classification can be used to advantage in training the field classifier of soils to improve his ability to estimate percentages and degrees of plasticity.

Table 7.1 Engineering Characteristics of Soil Groups

Soil Classification Group	Proctor Compaction		Permeability $\times 10^{-6}$ cm/sec	Compressibility		Shearing Strength	
	Max. Dry Density g/cm ³	Optimum Moisture %		at 138 k Pa	at 345 k Pa	C_o k Pa	C_{sat} k Pa
GW	> 1.90	< 13.3	26000 [±] 12500	1.4	(*)	(*)	(*)
GP	> 1.76	< 12.4	62000 [±] 33000	0.8	(*)	(*)	(*)
GM	> 1.83	< 14.5	0.3	1.2	3.0	(*)	(*)
GC	> 1.84	< 14.7	0.3	1.2	2.4	(*)	(*)
SW	1.91 [±] 0.08	13.3 [±] 2.5	(*)	1.4 [±] *	(*)	39.3 [±] 4.1	(*)
SP	1.76 [±] 0.03	12.4 [±] 1.0	14	0.8 [±] 0.3	(*)	22.8 [±] 6.2	(*)
SM	1.83 [±] 0.02	14.5 [±] 0.4	7.3 [±] 4.6	1.2 [±] 0.1	3.0 [±] 0.4	51.0 [±] 6.2	20.0 [±] 6.9
SM-SC	1.91 [±] 0.02	12.8 [±] 0.4	0.77 [±] 0.58	1.4 [±] 1.0	2.9 [±] 1.0	50.3 [±] 21.4	14.5 [±] 5.5
SC	1.84 [±] 0.02	14.7 [±] 0.4	0.29 [±] 0.19	1.2 [±] 0.2	2.4 [±] 0.5	75.1 [±] 15.2	11.0 [±] 6.2
ML	1.65 [±] 0.02	19.2 [±] 0.7	0.57 [±] 0.22	1.5 [±] 0.2	2.6 [±] 0.3	66.9 [±] 10.3	9.0 [±] (*)
ML-CL	1.75 [±] 0.03	16.8 [±] 0.7	0.13 [±] 0.07	1.0 [±] 0.0	2.2 [±] 0.0	63.4 [±] 16.5	22.0 [±] (*)
CL	1.73 [±] 0.02	17.3 [±] 0.3	0.08 [±] 0.03	1.4 [±] 0.2	2.6 [±] 0.4	86.9 [±] 10.3	13.1 [±] 2.1
MH	1.31 [±] 0.06	36.3 [±] 3.2	0.15 [±] 0.10	2.0 [±] 1.2	3.8 [±] 0.8	72.4 [±] 29.6	20.0 [±] 9.0
CH	1.51 [±] 0.03	25.5 [±] 1.2	0.05 [±] 0.05	2.6 [±] 1.3	3.9 [±] 1.5	102.7 [±] 33.8	11.0 [±] 5.9

* Insufficient data

± 90% Confidence limits

 C_o Strength of soil placed at Proctor maximum dry density C_{sat} Strength of soil placed at Proctor maximum dry density and then saturated.

After "Design of Small Dams"

Table 7.2 Qualitative comparison of engineering properties for compacted soil and suitability for various purposes.

Unified Soil Group	Permeability	Shear Strength after saturation	Compressibility after saturation	Resistance to Piping	Resistance to Cracking by Differential Settlement	Compaction characteristics	Compaction Equipment	Homogeneous Dam	Core of Zoned Dam	Shell of Zoned Dam	Earth Liner for Seepage Control
GW	Pervious	1	1	High	-	1	Tractor. Rubber Tyred roller. Flat Roller	-	-	1	-
GP	Very pervious	2	1	High to Moderate	-	2	Tractor Rubber tyred roller Flat Roller	-	-	2	-
GM	Semi-pervious to pervious	5	2	High to Moderate	3	4	Rubber Tyred Roller. Sheep-foot roller. Rubber Tyred Roller. Sheep-foot Roller	2	4	-	4
GC	Impervious	6	3	Very High	4	3	Tractor. Rubber Tyred roller. Rubber Tyred Roller. Sheep-foot Roller	1	1	-	1
SW	Pervious	3	1	High to Moderate	-	1	Tractor	1	1	3 if gravely	-
SP	Pervious	4	1	Low to Very Low	-	2	Tractor	-	-	4 if gravely	-

Table 7.2 (Cont'd).

Unified Soil Group	Permeability	Shear Strength after saturation	Compressibility after saturation	Resistance to Piping	Resistance to Cracking by Differential Settlement	Compaction characteristics	Compaction Equipment	Homogeneous Dam	Core of Zoned Dam	Shell of Zoned Dam	Earth Liner for Seepage Control
SM	Semi-pervious to pervious	7	3	Moderate to Low	3	4	Rubber Tyred Roller. Sheepsfoot roller	4	5	-	5 Erodible
SC	Impervious	8	3	High	4	3	Sheepsfoot Roller	3	2	-	2
ML	Semi-pervious to pervious	9	4	Low to Very Low	6	4 to 6	Rubber Tyred Roller	6	6	-	6 Erodible
CL	Impervious	9	5	High	2-5	4	Sheepsfoot roller	5	3	-	3
MH	Semi-pervious to impervious	10	6	Moderate to High	Variable	4 to 8	Sheepsfoot Roller. Rubber Tyred Roller	9	9	-	-
CH	Impervious	10	7	Very High	1	4 to 7	Sheepsfoot Roller	7	7	-	8 Expansive
Notes		1 has highest shear strength	1 has lowest compressibility	For non tunnelling susceptible material	1 has highest resistance	1 is best			1 is most suitable		

Table 7.3 Recommended Slopes for Small Homogeneous Earthfill Dams on Stable Foundations

Case	Type	Purpose	Subject to rapid Drawdown	Unified Classification ²	Up-stream slope	Down-stream slope
A	Homogeneous or Modified-Homogeneous ³	Detention or Storage	No	GW, GP, SW, SP,	Pervious, not suitable	
				GC, GM, SC, SM,	2.5:1	2:1
				CL, ML	3:1	2.5:1
				CH, MH	3.5:1	2.5:1
B	Modified - Homogeneous	Storage	Yes	GW, GP, SW, SP	Pervious, not suitable	
				GC, GM, SC, SM	3:1	2:1
				CL, ML	3.5:1	2.5:1
				CH, MH	4:1	2.5:1

1. Drawdown rates of 15cm or more per day following prolonged storage at high reservoir levels.
2. OL and OH soils are not recommended for major portions of homogeneous earthfill dams.
3. Modified-homogeneous is an embankment with a downstream filter zone extending upstream to within a distance equal to the height of the dam plus 1.5 m from the centreline of the dam.

After "Design of Small Dams"

Table 7.4 Recommended Slopes for Small Zoned Earthfill Dams on Stable Foundations

Case	Type	Purpose	Subject to Rapid Drawdown ²	Unified Classification		Upstream Slope	Down-Stream Slope
				Shell	Core ³		
A	Zoned with "minimum" Core ¹	Any	Not critical ⁴	Not critical; Rockfill, GW, GP, SW (gravelly), or SP (gravelly)	Not critical GC GM, SC, SM, CL, ML, CH, or MH	2:1	2:1
B	Zoned with "maximum" Core ¹	Detention or storage	No	Not critical; Rockfill, GW, GP, SW (gravelly) or SP (gravelly)	GC, GM SC, SM CL, ML CH, MH	2:1 2.25:1 2.5:1 3:1	2:1 2.25:1 2.5:1 3:1
C	Zoned with "Maximum" core ¹	Storage	Yes	Not critical; Rockfill, GW, GP, SW (gravelly), or SP (gravelly)	GC, GM SC, SM CL, ML CH, MH	2.5:1 2.5:1 3:1 3.5:1	2:1 2.25:1 2.5:1 3:1

1. Minimum core is a core with upstream slope of 1.5:1 and downstream slope of 1:1 with 3 m crest width. Maximum core is a core with slopes of 0.5:1 less than the recommended slopes.
2. "Rapid" drawdown is a drawdown rate of 15 cm or more per day following prolonged storage at high reservoir levels.
3. OL and OH soils are not recommended for major portions of the cores of earthfill dams.
4. Rapid drawdown will not affect the upstream slope of a zoned embankment which has a large upstream pervious shell. This type of zoned embankment is shown in Figure 7.9(b)

After "Design of Small Dams"

The grain-size curve is used to classify the soil as being coarse-grained or fine-grained, and if coarse-grained, into gravel or sand by size, using the 50 percent criterion. Within the gravel or sand groupings, soils containing less than 5 percent finer than the No. 200 sieve size are considered "clean" and are then classified as well graded or poorly graded. Laboratory classification criteria for coarse-grained soils and for fine-grained soils are given by Ritchie (1963). It should be noted that the Unified Soil Classification System does not distinguish between silt and clay on the basis of size.

7.1.4 Engineering Characteristics of Soil Groups

As with any system of classification the utility of the Unified system is related to the amount of useful information that can be obtained or inferred from the various groups. Table 7.1 shows some important engineering properties of the main soil groups and two frequently occurring boundary groups. The values shown are average values based on more than 1500 soil tests performed by the Bureau of Reclamation (U.S.).

Of particular importance to soil conservationists are the values of Proctor maximum dry density, Proctor optimum moisture content and permeability. Values of compressibility and shear strength are used to design stable embankments. For small dams (less than 15m high) where there are no complex problems, the average values can be used to design stable embankments. This information is shown in Tables 7.3 and 7.4.

A qualitative comparison of the engineering properties of the main soil groups is shown in Table 7.2.

7.2 Soil Compaction and Stabilization

The most single important task in any earthwork is to ensure good compaction. Compaction substantially influences the future behaviour of any earthen structure in as much as poor compaction leads to poor strength, high permeability, large settlements and lower erosion resistance. The dangers of slip or collapse are enhanced, and for expansive clays, the potential swell or shrink is more rapidly realised.

Compaction is defined as the process by which an immediate increase in density in an earth mass can be effected by the displacement of air. It should not be confused with consolidation which is a slow increase in density due to the removal of water from the soil by superimposed loads.

7.2.1 Compaction

For compaction the total weight is not the only consideration. The relevant factor is the bearing pressure exerted at the soil surface. (e.g. this is employed for dozers such that they will not sink in soft ground).

Therefore, the first principle of compaction is to ensure a substantial contact pressure with the soil.

Most rollers, when applied to embankment construction or roadways have an effective depth of compactive influence equal to about 25 cm. Thus, restriction of the thickness of each layer to 15-25 cm is desirable.

A certain level of moisture in a soil gives the easiest and best compaction and hence, the second principle of compaction is that the moisture content at which the soil is compacted determines the effectiveness of the contact pressure applied (i.e. optimum moisture content). For a given compactive effort this moisture content is a unique property of each soil.

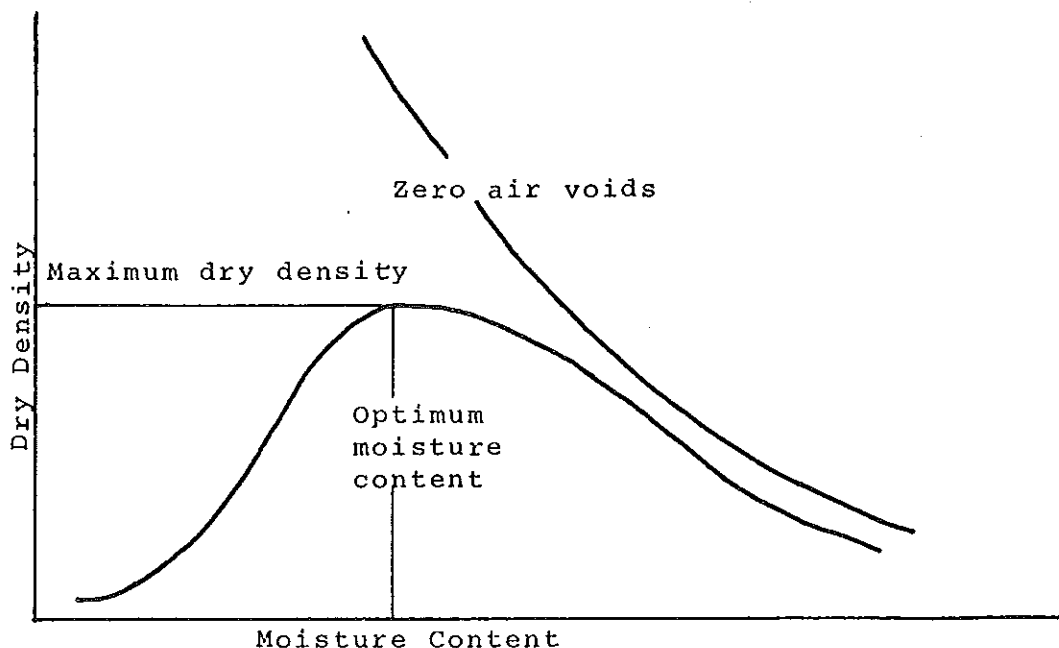


Figure 7.3 Compaction characteristics - soil

The line known as the zero air voids line, represents the densities which might theoretically be achieved if no air voids remained in the compacted mix.

(a) Density and Moisture Content

For soils wet of the optimum moisture content, compacted density declines due to an inability to expel air and excess water. Where little significant confining force exists, the material simply flows away from the compaction zone due to loss of shear strength in the soil.

Dry of the optimum moisture content, compacted density falls off in such a way that air voids increase extremely rapidly.

It is not necessarily most advantageous to compact at the optimum moisture content determined from measurements of the dry density-moisture relationship. The primary consideration for clayey soils should always be the equilibrium moisture content of the structure in service, since a soil compacted wet or dry of this final equilibrium moisture content will either shrink or swell after construction. For clayey soils it is better to compact at the maximum load which the equilibrium moisture content of the soil will sustain. In arid regions, this calls for much heavier rollers than in wetter regions.

When the moisture content of a clayey soil requires adjustment, it must be remembered that different compaction effects arise according to whether the soil is being wetted-up or dried out. This is due to the very slow redistribution of moisture within a dense clay, a process which may take weeks. Wetting up tends to aid compactibility by creating low friction skins on the clay lumps and drying out tends to oppose compaction by creating higher friction skins on the clay lumps.

(b) Soil Particles and Compaction

The effect of particle crushing due to rolling may be included as part of a more general third principle of compaction; that highest densities are achieved by mixtures of different particle sizes (particle grading).

Compaction is achieved by filling the voids between the larger particles with particles of smaller size. Overworking and re-use of soil, however, can create excessive fines, drop the shear strength and occasionally destroy natural cohesion in a soil such that loss of density occurs by over rolling.

(c) Soil Particle Packing

Those particles with a flat and flaky structure normally pack much more densely than those with rounder form (provided that their size is greater than 20 microns). The minute flat sheets of clay particles and micas possess considerable surface repulsion forces because of their small size, and thus resist compaction so effectively that they fall amongst the most difficult earthen materials to compact.

Particles with a smoother surface will pack more easily than rough and angular particles due to their lower interparticle friction (but they are also displaced more easily under shear forces).

However, it should be remembered that packing is also dependent on the type of equipment used and, of course, moisture content.

(d) Maximum Compaction

If maximum compaction is to be achieved, it is clear that the soil must be confined, i.e. a constraining layer around and below the soil being compacted is required. The confining mass may be the soil itself, provided the applied compressive forces dissipate within an acceptable distance from the point of application. Where a layer of saturated soil or other soil of low bearing capacity underlies the layer to be compacted, no real compaction can be achieved as the soft layer will deform so as to negate much of the applied compactive effort. In such circumstances (and indeed in all good compaction practice) stage compaction is adopted, i.e. the soil is first rolled with light rollers to develop its own strength, then heavier rollers are applied to complete the compaction. This change in bearing pressure can be achieved by selection of different rollers or by adjusting the ballasting of a roller, or for tyred rollers, adjusting the inflation pressure, ballasting or both.

(e) Application of Compactive Force

If a compactive force is applied in one direction it will produce a compacted state with preferred orientation of the voids, i.e., an earthwork whose properties are anisotropic (esp. strength and permeability). Secondly, a static force is usually less effective than a dynamic force of the same magnitude (the internal shearing under repeated load causes densification in much shorter time than would be achieved by steady creep under a fixed load). Shear forces provide more rapid compaction than compressive forces and vibratory forces often provide the most rapid compaction of all. (See Table 7.5 for roller types and uses).

(f) Features of Roller Compaction

The most important features of roller compaction are:-

(1) Subsequent passes of the same roller have less compaction effect at the same moisture content. This behaviour results since the increase in density leads to increases of both internal friction and cohesion and hence resistance to further compaction becomes progressively greater for a given compactive effort.

(2) The optimum moisture content for the first roller pass may well be slightly higher than for the second pass, and so on; therefore some drying time can be advantageous between successive roller passes.

(3) The speed of the roller has little effect on the compaction achieved.

(4) Different rollers are better suited to different materials. Plain and vibrating drum rollers are best for sandy type soils at low moisture contents; sheepfoot and drum rollers for loam and clay soils at low moisture contents; the pneumatic type roller for clays at high moisture contents.

Table 7.5 Various Roller Types and their Uses

Roller Type	Usual weight (approx) kN	Usual roll width (approx) m	Contact load kN	Remarks
Smooth wheel	80 - 120	1.9	0.35-0.61	Better for granular materials. Will operate successfully above O.M.C. (if not too wet).
Vibratory	40	1.8	0.21 per cm width	Better for granular materials than smooth wheel rollers; since only half the weight gives equal compaction. Frequency about 2000 Hz (cycles/min).
Sheepsfoot	30-50 unballasted 50-70 ballasted	1.7	480-1725 per m ² (on the feet)	Best suited for clays, especially in semi-arid zones. The foot pressure may be too high for saturated high moisture clays and too low for very dry clays.**
Pneumatic tyre	80 - 120	2.3	345-390 per m ² (inflation pressure)	4-11 wheels with 9-22 kN per tyre. Best for cohesionless and low cohesion soils, and for surface finishing.

** A vibratory sheepsfoot roller is especially good for dry clays.

(5) No roller adequately compacts the soil if the layer is greater than 45 cm in a loose state.

(6) Use of the heaviest roller which does not cause subgrade failures is always recommended.

(7) A sheepsfoot roller requires more passes than other rollers because of its limited bearing area and hence poor coverage. The loading intensity under a small weighted sheepsfoot roller may be as high as 700 k Pa, whereas the loading intensity under the track of a typical dozer type machine is about 50 k Pa. (D5). Despite this disparity in compacting pressures, good compaction can be achieved with a track type tractor under certain conditions. For example, considering a clay type soil:-

	Max. dry density Kg/m ³	Optimum moisture content %
Heavy sheepsfoot roller	1700	16
40 H.P. track tractor (D4 = 60 H.P.)	1500	22

The tractor achieved a relatively good compaction only at a high moisture content, and after considerably more passes of the machine.

Such a tractor only adequately compacted clay and loam soils under these circumstances, namely, higher moisture contents and more passes of the machine.

(g) Compaction Control in the field

It is not always possible to measure the most critical parameters by simply running field tests, so relationships must be established with more easily measured parameters, and the latter used for field control.

Density and moisture content are by far the best compaction control parameters, since they allow the determination of what air voids remain in the soil; and reducing air voids below 5% should be the aim of all good compaction work.

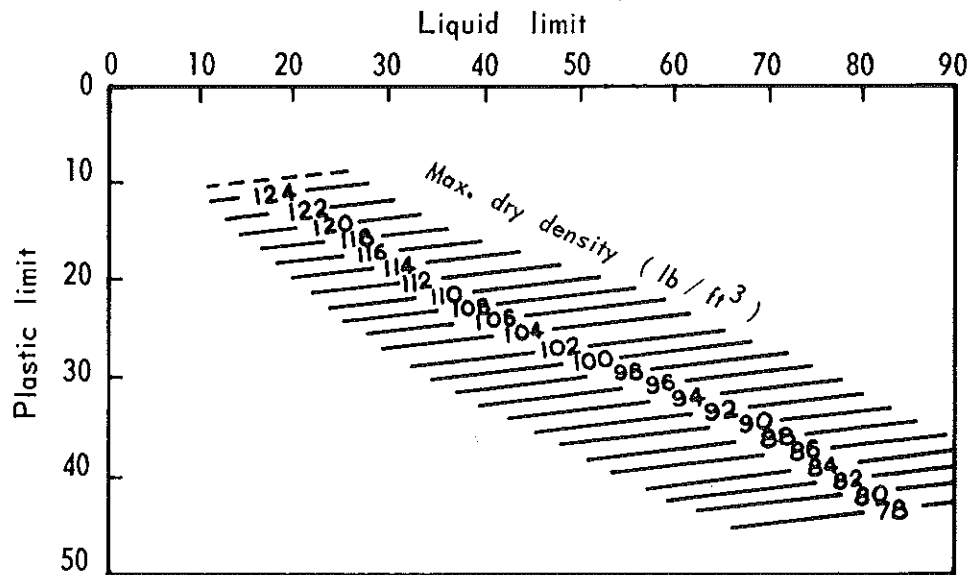
A series of curves (Figure 7.4) relating optimum moisture content and dry density to the index limits for proctor compaction are useful as a means of arriving at a first estimate of compaction optima from the simple liquid and plastic limit tests.

7.2.2 Soil Stabilization

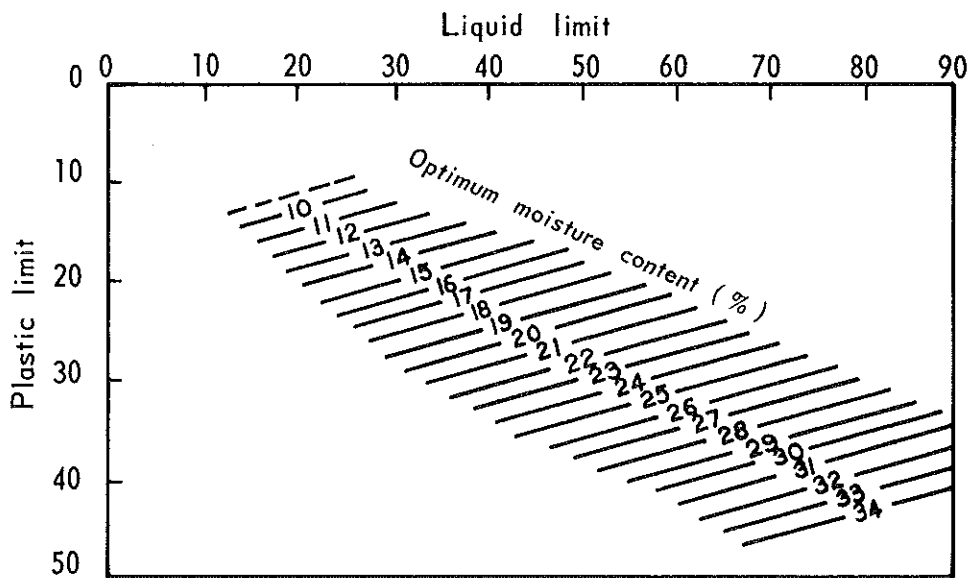
(a) Compaction and Stabilization - Lime and Cement

Dams (which require low permeability) should be constructed slightly wet of optimum, whereas stabilized soils, especially lime stabilized clays, are best constructed slightly dry of optimum.

COMPACTION



(a)



(b)

$$1 \text{ lb / ft}^3 \approx 16 \text{ kg / m}^3$$

Figure 7.4 Compaction characteristics and index properties

In the case of cement stabilized soils, higher strengths are obtained slightly dry of optimum, due to the weakening effect of excess water on the cement hydration.

For lime stabilized clay soils the compaction optima are invariably shifted to higher moisture contents and lower maximum dry densities. As shown in Figure 7.5.

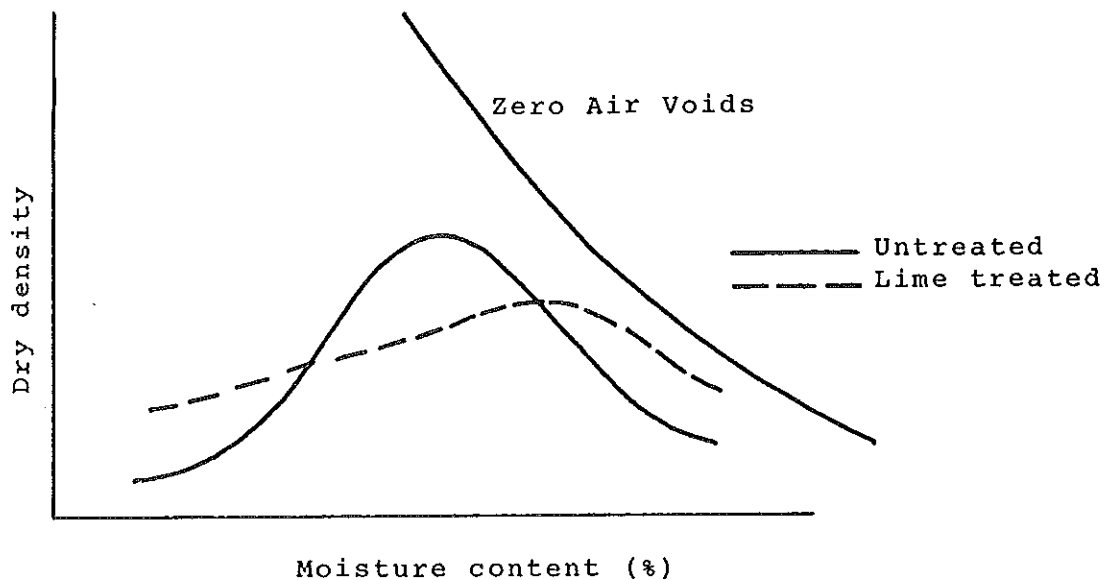


Figure 7.5 Compaction characteristics - lime treated soil

The lower compacted dry density is not a disadvantage of lime stabilization of clays for two principle reasons:-

- (1) It is offset by a greatly increased cohesive strength and shear strength in the soil even when soaked and;
- (2) It possesses the very valuable practical construction advantage of allowing much wider tolerance on construction moisture control, since the compaction curve is flatter.

(b) Properties of a Stabilized Soil

As a stabilized soil usually contains less than 12% of additive the properties of the soil naturally are reflected in the properties of the compacted mix. Granular soils have high strengths when stabilized, are usually nonplastic and are resistant to the effects of water. Permeability is usually lower as the additive acts as a pore filler. In some cases volume changes (due to moisture or temperature effects on the additive) may be higher.

Cohesive soils generally have low strengths and when stabilized usually retain some degree of plasticity and susceptibility to water softening.

Lime stabilization is only effective in well graded granular soils with a small clay fraction, or in soils with a large clay fraction. In such soils large increases in

Table 7.6 Typical Properties of Cement-Stabilized Soils

Soil Type	Strength K Pa	Permeability cm/sec	Volume Change	Comments
Well graded gravel-sand-clay; sands or gravels	2700-10000 and more. Ratio of wet/dry strength 1: 1.5	High.Decreased by cement 15×10^{-3} unstabilized 18×10^{-6} stabilized	Very small less than 1% Concrete 0.1%	Too strong. Widespaced wide cracks. Suitable for bituminous stabilization
Silty-sands; Sandy clays; sand and gravel	1400 - 3500	High.Decreased by cement.	Small	Good material Suitable for bituminous Stabilization
Silty-sandy clays; poorly graded soils	340 - 1030	Low, increased by cement		
Heavy clays; Organic and sulphate-rich soils	700 Ratio of wet/dry strength 1: 3	Very low (10^{-11}) increased by cement (10^{-9})	High.May be increased by cement 4%	Extreme difficulty in mixing. Use of lime could be beneficial

strength may be attained.

A summary of the effects of cement stabilization on the properties of a soil can be seen in Table 7.6. From the table it can be noted that huge changes in soil properties are possible, thus enhancing the uses of a particular soil.

(c) Environmental Influence on Behaviour of Stabilized Soil

Temperature

Retention of strength at high water contents and resistance to volume change under fluctuating moisture levels are important features closely related to climate and the soil properties controlling permeability.

When stabilized soils contain an appreciable clay content, the moisture regime in the stabilized material becomes of critical importance with regard to shrinkage and subsequent cracking.

Between the compaction moisture content and the air dry state, a linear shrinkage of about 4% would be possible for a cement stabilized clay and less than 1% for a cement-sandy clay before excessive cracking occurred.

Stress and Strain (Cracking)

The total strain is a function of soil type, moisture changes and temperature changes. If the material is restrained by subgrade friction then cracks will form at a width and spacing determined by the tensile strength of the material. The crack pattern in stabilized soils is often essentially the result of shrinkage due to moisture content reduction.

A movement of some 1.5 mm is necessary to develop restraint and after this movement has occurred, the material is restrained and stress builds up to the point where cracking occurs.

(d) Slope Stability

Stabilized soils show a substantial increase in the coefficient of internal friction and cohesion when compared to the untreated soils. However, the amount of cement used (or lime) is of much less significance in increasing slope stability.

(e) Choice of Stabilizers

Virtually all types of soils can be stabilized for almost any purpose. However, highly organic soils are susceptible to high volume changes and do not develop useful strengths without special treatment. Soils with a large, or very active clay content show extreme volume change characteristics and considerable loss of strength with

increase of moisture content. There is also difficulty in mixing additives with such soil.

Cement

Cement stabilization should not be used where there is appreciable sulphate matter in the soil (i.e. free sulphate greater than 0.2%) as strength cannot be developed. Sulphate resisting cement is of little value in treating sulphate-rich clay soils.

Rapid hardening cement containing calcium chloride can be effective in stabilizing organic rich soils.

The fineness of cement can also lead easily to segregation in sandy soils, especially when watering is necessary.

A further disadvantage is that compaction of soil cement work must be effected within a short time of mixing if serious loss of strength is to be avoided (due to the rapid cement hydration reaction) - See figure 7.6.

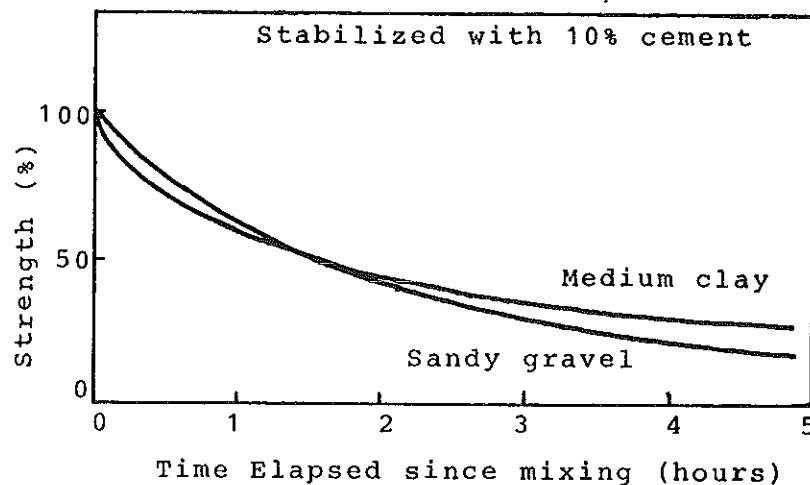


Figure 7.6 Loss in strength due to delay in compaction

Lime

Large additions of lime are not desirable in light clay soils, due to loss of cohesion.

For anti-erosion work the lime percentage should not be reduced below 2% by weight, so as to allow for inadequate distributive mixing (this leads to an allowable tolerance of $\pm \frac{1}{2} - 1\%$).

As with cement, lime is not recommended for highly organic soils.

Lime addition to the soil has the following influences:-

1. increases the optimum moisture content for compaction.
2. reduces the maximum dry density for a given compactive effort.
3. may or may not reduce the soil plasticity (may even increase it).

One positive advantage of lime stabilization is the easier construction afforded by the flatter compaction curves.

(f) Construction

The success of a stabilization programme depends upon the efficiency of the construction processes and recognition of easily stabilized soils. For instance, a red soil (e.g. Krasnozern, red earth, red podzolic soil) indicates the presence of iron and generally reacts exceptionally well with cement. Conversely, a black farmland soil (e.g. black earth, prairie soil, chernozem) may react rather poorly with cement because of the presence of organic material.

Moisture Content

The moisture content of a stabilized soil should be adjusted to the optimum for compaction. The water required for cement hydration is 22% of the weight of the cement; thus, usually the water added for compaction is more than adequate for hydration of cement - stabilized soils. The effect of moisture content is thus most marked in the manner in which it governs the compacted density achieved.

A second significant effect is that a higher initial moisture content reduces the loss in strength on soaking.

The moisture content at which a stabilized soil is placed is chosen as the optimum for compaction. This precludes the use of high moisture contents during placing.

Water, contaminated with salts and/or organic matter affects the properties of stabilized soils. It can affect the volume change characteristics, prevent hydration of cement and also interfere with cohesion.

Pulverisation

Depending on the type of soil and mixing equipment the soil may need to be scarified, pulverised or pre-wet. Silty and clayey soils may require extra effort to pulverise them, particularly if they are too wet or too dry.

There are two keys to easier pulverisation -

1. Proper moisture control
2. Proper equipment.

Soils that are difficult to pulverise when dry and brittle can be broken down readily if water is added and allowed to soak in, whereas sticky soils can be pulverised more easily when they are dried out a little.

Finer pulverisation offers considerable benefits but practically this approach is limited by the power required to process such soils. Common specifications are that 80% of the pulverised material shall pass through a 4.76 mm sieve (A.S.T.M. No. 4).

Mixing

In stabilized construction the additive is usually required to be mixed thoroughly with the soil, this degree of mixing being judged by the uniformity of colour of the mixture.

The use of secondary additives, particularly lime, improve pulverization. Lime-cement mixes can give higher strength than cements alone.

Cement blending must be watched for segregation in open sands, which may be accentuated by water additions. In heavy clays good blending requires good pulverization of the clay.

Lime blending (which occurs mostly with clayey soils, since lime is not a stabilizer for clean sands) has fewer problems than cement. For heavy clays, it is sometimes expedient to mix in two stages, the first stage consisting of a low percentage lime treatment which, if allowed to cure for one or two days, makes the subsequent pulverization of the soil easier and better for mixing in the final lime or cement addition.

(g) Compaction

Due to a stabilized soils increase in resistance to compaction with time, it is essential to have the full compactive effort brought to bear as soon as possible after mixing.

The strength of stabilized materials is usually related to density and if a particular density is to be used as a basis for predicting the probable field strength, that density is the minimum that should be achieved.

Roller Type

With granular materials, vibrating rollers and compactors are particularly effective, but where a high percentage of relatively coarse stone occurs, then heavy steel-wheeled rollers are usually required, particularly during finishing.

Where fine, cohesive materials are being treated, then pneumatic-tyred rollers are usually the most effective and convenient equipment. On these types of soils, there is

usually a marked tendency for the steel-wheeled rollers to pick up, particularly as it is often necessary to spray the surface with water to prevent drying out during compaction and finishing.

(h) Curing

Curing of stabilized pavements in the field usually entails keeping the pavement moist by watersprays for about 7 days or sealing the surface immediately after compaction.

High temperatures of curing (as often encountered in Australia) tend to develop greater strengths. This effect is greater with lime than cement.

(i) Wet Soils

Excessively wet soil is difficult to mix and pulverise. Cement can be mixed with sandy soils when the moisture content is as high as 2% above optimum for compaction. For clayey soils, the moisture content should be below optimum for efficient mixing.

(j) Testing and Control of Work

Quality control for construction is based on some essential property of the stabilized soil which can be readily measured in the field; preferably one which has a low coefficient of variation in the sampling and testing. Preferred choices might be compacted voids (calculated from density and moisture content) or a simple strength test, (as an unconfined compression test is suitable). Research Centres should be able to assist in this regard.

7.3 Soil Testing

Soil is a difficult material to deal with because of the complexity of its physical properties and because of the large number of properties that must be determined in order to obtain a reasonable complete description.

It is important to realise that few soil analyses give results of high accuracy and most of them give values which are only estimates. This is due partly to the fact that the values obtained are very much dependent on the way in which they are measured, but also due to the extreme variability of the soil material.

Soils vary both horizontally and vertically. Ideally, samples should be taken in such a way as to show the range in variation which exists in each soil, and the number of samples tested should be sufficient to permit determination of reasonably dependable values of average soil properties.

7.3.1 Standard Soil Tests carried out by Soil Conservation Service Laboratories.

The following tests are normally carried out on samples sent in by soil conservationists for determination of their suitability in earthworks.

1. Particle Size Analysis
2. Atterberg Limits
3. Dispersal Index
4. Linear Shrinkage
5. Volume Expansion
6. Emerson Aggregate Test

The first two are used to classify soil according to the Unified Soil Classification System as described in Section 7.1. Particle Size Analysis is also used to infer permeability.

The last four tests are used to identify particular soil problems.

(a) Particle Size Analysis

The method used is similar to that of the American Society for Testing and Materials (ASTM D422-63). The concentration of fine fraction is measured using a hydrometer and the coarse fraction is determined by wet sieving. The content of fine sand is determined by difference and therefore the sum of the percentage content of various fractions is always 100.

The results of the hydrometer and sieve analysis are plotted to give a particle size distribution curve and the amount of the following arbitrary groups of particle size is interpolated from the curve -

<0.002 mm	clay	0.2-2.0	coarse sand
0.002-0.02 mm	silt	> 2.0mm	gravel
0.02 -0.2 mm	fine sand		

Any attempt to characterize soil behaviour in terms of these groupings can be useful provided it is understood that:

1. There is no sharp change corresponding to the size limit for each group.
2. A relatively small content of one group may give a soil one particular trait of that group and yet have little effect on other characteristics.

The Relevance of Particle Size Analysis to the Design of Structures.

The presence of coarse materials such as sands, gravels and stones gives the soil stability against running water. However, a large amount of this coarse material relative to clays and silts means that the resulting structure will not hold water for any length of time.

Fines (silts and clays) behave in a manner considerably different from coarse particles. These finer particles frequently act together in aggregations rather than as single particles. When they do this the resulting structure again may not hold water satisfactorily.

Silts are materials of low plasticity; lumps of silts will break down readily in the presence of water. Soils made up primarily of this component are often quite susceptible to the erosive action of water, due to the combination of fine particles and the relatively weak attraction between particles.

Clays have a low resistance to deformation when wet, but when dry they offer much higher resistance than do silt particles. In contrast to silts, which may or may not be impervious to water, clay soils can be expected to be rather impervious to water, except where aggregated.

The electrochemical activity of clay minerals relative to the adsorption of water and dissolved ions is largely responsible for the properties of clays - sticky when wet, capacity to hold water, swelling and shrinking.

Montmorillonite clays (such as "bentonite") exhibit clay properties to a marked degree. The montmorillonite has a small crystal and a high density of negative charge per unit of surface area distributed over the crystal. The crystal structure of montmorillonite allows adsorption of water and ions between structural sheets, thus causing expansion of the crystal which in turn accounts for the high swell capacity of montmorillonite clays when wetted.

Kaolinite mineral has a much larger crystal size than montmorillonite. It has fewer charges per unit volume and hence much less water adsorption and much less swell. The activity of illite clay is intermediate between kaolinite and montmorillonite.

Ions adsorbed in a clay micelle can be replaced or exchanged, and the kind of adsorbed ions affect the thickness of the water layer and the properties of the clay. Montmorillonite clay is more plastic, swells more when wet, and shrinks more when dry with adsorbed sodium ions than with calcium ions. The ability to change clay characteristics by ion replacement provides many opportunities to alter natural soils for a particular engineering purpose.

(b) Atterberg Limits

Two Atterberg Limits and one Index are normally determined on the fine grained fraction of the soil.

The Liquid Limit is the water content at which the soil passes from the liquid state into the plastic state and is determined by ASTM method D423-66.

The Plastic Limit is the water content at which the soil passes from the plastic state into the solid state and is determined by ASTM method D424-59.

The numerical difference between the Liquid Limit and the Plastic Limit is the Plasticity Index and corresponds to the range of water contents within which the soil is plastic. Soil plasticity is an important property of fine-grained soils. Highly plastic soils have a high value for plasticity index whereas in non-plastic soils the plastic limits and the liquid limit are the same and the plasticity index is zero.

These limits of consistency are used in the Unified Soil Classification System already described in Section 7.1 as the basis for laboratory differentiation between materials of appreciable plasticity (clays) and slightly plastic or non-plastic materials (silts).

(c) Dispersal Index Test

This test was developed at Scone Research Centre during the early 60's. (Ritchie 1963). It is an adaptation of an old particle size analysis procedure and is the ratio between the amount of material in suspension obtained by mechanical and chemical dispersion for one hour and the amount of material obtained by mechanical dispersion for ten minutes.

The mechanical dispersion is achieved by end over end shaking and chemical dispersion is achieved by saturating the exchange complex of the clay using buffered sodium hexametaphosphate (Commonly known as 'Calgon').

Hydrometers are used to measure the amount of fine material remaining in suspension after settling for two hours in 1000 cc glass cylinders. It is accepted that there are limitations to the use of hydrometers, both with regard to their readability and accuracy in widely differing suspensions. For this reason the test is used only as an indicator of unstable soils and its interpretation is based on a combination with the results of other assessments where possible. The Dispersal Index value is generally abbreviated to D.I.

The test as used by the Service is defined as -

Mean hydrometer reading in 0.5% Calgon solution after 2 hours sedimentation following dispersion with Calgon and 1 hour shaking

D.I. = $\frac{\text{Mean hydrometer reading in 0.5\% Calgon solution after 2 hours sedimentation following dispersion with Calgon and 1 hour shaking}}{\text{Mean hydrometer reading in water after 2 hours sedimentation following dispersion by 10 minutes shaking. (The Hydrometer readings are corrected for temperature only).}}$

In the case of soils with a high exchangeable sodium content, the denominator would approach the numerator and the ratio would approach one. Hence, highly dispersible soils have a low Dispersal Index and slightly dispersible soils have a high Dispersal Index.

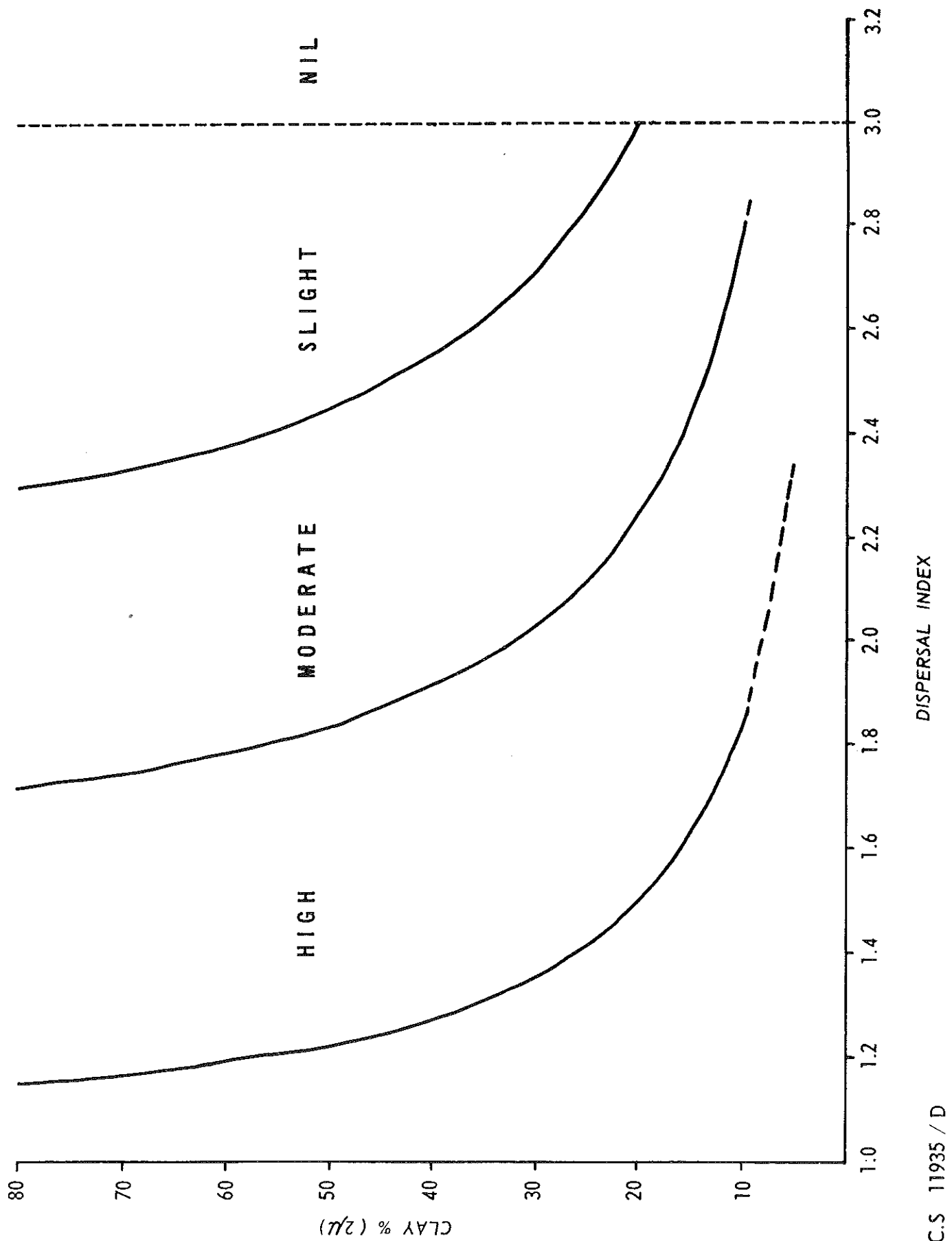
Interpretation of the Dispersal Index Test

This test was developed by Ritchie (op.cit). in order to identify soils which when used in earthworks are susceptible to failure by tunnelling. Failure due to tunnelling being a failure which results from postconstruction deflocculation (dispersion) and subsequent accelerative removal of the deflocculated material.

From an examination of the soils and case histories of some 60 earthworks throughout New South Wales, Ritchie set an arbitrary limit of 3.0 for the Dispersal Index such that those soils with a value less than 3.0 are susceptible to tunnelling failure. Subsequent experience with many hundreds of soils and case histories showed little reason to change this limit. Recent studies (Elliott 1976) have indicated additional support for this limit.

There are, however, a number of aspects which must be considered in respect to the interpretation of the Dispersal Index Test. Failure of earthworks by tunnelling is a complex process depending on variables such as the density and moisture content of the soil, soluble salt content of the stored water, and rate of filling as well as on the properties of the soil (Rosewell 1970). When limits are set, based on a Dispersal Index Test, on the soil, there must be a range of uncertainty in the prediction of earthwork performance as such limits are based on average conditions of construction and filling of the earthwork. In addition the majority of soils which have been tested and on which experience has been based have been clays of low plasticity with clay contents in the range of 25 to 50 percent.

A recent review of the test (Rosewell 1976) examined the precision of the test and has indicated that it can be interpreted for soils of a wide range of particle size analyses. The Dispersal Index test should be interpreted using Figure 7.7 where the soil is classified as being of high, moderate or slight tunnelling susceptibility (or none).

Figure 7.7 TUNNELLING SUSCEPTIBILITY

(d) Linear Shrinkage

This test determines the percentage decrease in length of a specimen of disturbed soil on drying from the liquid limit to oven dry. The method used is Australian Standard A89-1966 Test 5A.

Interpretation of the Linear Shrinkage Test

At this time the main use of the linear shrinkage test by this Service is in placing limitations on the use of soil as foundations for small buildings and roadways in urban areas. The following limitation classes are proposed for urban uses. (Department of Public Works 1977, also Section 5.3.2 and Mills et al 1977).

<u>Limitation Class</u>	<u>Linear Shrinkage</u> <u>%</u>
Low	0 - 12
Medium	12 - 17
High	17 - 22
Very High	>22

The test has not yet been applied to the prediction of instability in soil conservation earthworks but the above limits can be used as a guide. A high linear shrinkage indicates a large potential shrinkage of a soil mass on drying. Earthworks constructed with such material are susceptible to failure when water enters the shrinkage cracks developed following prolonged dry periods.

(e) Volume Expansion

This test is a free swell test on disturbed soil when wetted from air dry to saturation. The method used is that of Keen and Raczowski (1921) with a modified computational procedure (Wickham & Tregenza, 1973). As the test relies on the soil sample achieving saturation it can give erroneous results with some slow wetting dispersible soils (Mills et al 1977). Some soils may shrink in volume in this test.

Interpretation of the Volume Expansion Test

The test probably has no quantitative value, however it does provide for simple identification of potentially expansive soils. A large volume expansion indicates a large potential expansion on wetting and subsequent shrinkage on drying. Earthworks constructed with such material are susceptible to failure when water enters the shrinkage cracks developed following prolonged dry periods.

Experience with soils used in soil conservation earthworks has yielded the following categories based on value judgements:

<u>Category</u>	<u>Volume Expansion %</u>
Low	0 - 10
Moderate	10 - 20
High	20 - 40
Very High	> 40

A soil containing greater than 40% clay and with a volume expansion greater than 40% will be susceptible to extensive cracking to the extent that it would not be suitable in the critical parts of an earthwork.

Soils with a volume expansion of 20-40% are prone to cracking but are amenable to suitable control measures.

Soils with a volume expansion of 0-20% are generally considered stable for use in earthworks.

Those soils which shrink are soils which deflocculate on wetting. Such behaviour is associated with low Dispersal Indices and/or silty materials (ML, SM). When used in earthworks the compacted soil may exhibit a settlement on saturation by seepage flow when the structure fills. The settlement on saturation will lead to settlement of the compacted fill below the phreatic (seepage) line. The gap remaining between the settled saturated zone and the unsettled unsaturated zone may induce tunnelling failure particularly in high tunnelling susceptible soils. The settlement may also induce cracking.

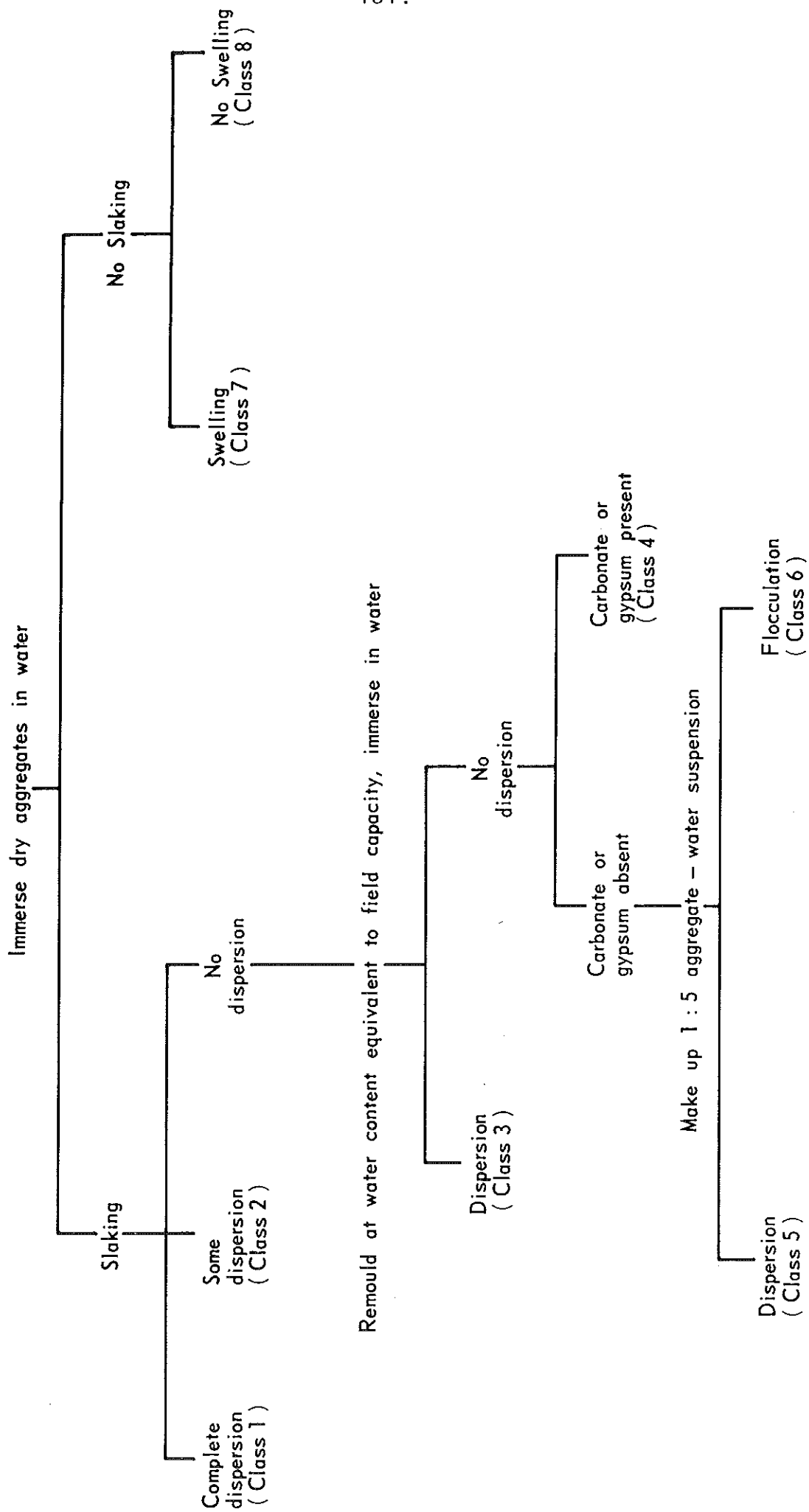
A good correlation between Linear Shrinkage and Volume Expansion has been found for non-dispersible soils (Mills et al 1977). The former test is now favoured.

(f) The Emerson Aggregate Test

This test, developed by Emerson (1967), is basically a classification of soil aggregates based on their coherence in water. The interaction in water of clay-sized particles in aggregates may largely determine the structural stability of a soil. The Emerson Aggregate Test is a simple physical test for dividing aggregates into 8 main classes (See Figure 7.8).

The first separation of aggregates is made according to whether the dry aggregates break up (slake) when immersed in distilled water in a beaker. Most aggregates will probably slake due to the stresses induced by entrapped air and by swelling. These aggregates are placed in Classes 1-6. Those that do not slake are divided into two classes, class 8 aggregates are unchanged, whereas class 7 aggregates swell but remain coherent.

Figure 7.8 Emerson's Aggregate Classes



Once aggregates are immersed in water, an osmotic stress arises between the negatively-charged clay particles. The stress increases as the soluble salts initially present in the aggregates diffuse out. The increase may be sufficient to cause dispersion of the clay.

Class 1 aggregates disperse completely, leaving only sand grains in a cloud of clay. Those of class 2 show only partial dispersion. The dispersion of aggregates can be checked rapidly if the finest slaked fragments are observed.

Clay aggregates which are saturated with calcium and magnesium do not disperse when initially placed in water. However, clays that are saturated with these two ions and are also capable of swelling significantly will "disperse" when shaken in a suspension of water. Under similar treatment calcium kaolinite (a non-swelling clay) will remain aggregated or flocculated in a suspension of water. When a clay has been shaken in a suspension, energy has been applied to the system to aid in dispersion. There is also a certain water content at which dispersion will take place. This water content will be intermediate between the maximum water uptake of an initial dry clay and that corresponding to a suspension.

These principles are the basis for separating classes 3, 4, 5 and 6.

Class 3 aggregates are defined as aggregates that, after remoulding at a water content equivalent to field capacity, show dispersion when immersed in water.

The clay present in the aggregates may still not disperse if there are minerals in the aggregates that dissolve rapidly enough to maintain the divalent ion concentration above the flocculating or aggregating threshold. Thus aggregates that do not disperse after remoulding at field capacity, but contain such minerals as calcite or gypsum are placed in class 4. Aggregates that disperse at a water content intermediate between field capacity and that of a suspension (1:5 aggregate-water ratio, 10 minute shaking) form class 5. If a suspension of aggregates flocculates completely after five minutes standing, the aggregates are placed in class 6.

Because of the Service's concern with dispersible soils, and the use of the Emerson test by both extension and research staff, the need has been felt to further subdivide classes 2 and 3. This subdivision has been aimed at a more objective assessment of aggregate behaviour, together with a tightening up of the guidelines for carrying out the test. These guidelines are summarized as follows.

The test should be carried out on an air-dry aggregate 5-10 mm in size. The aggregate should be placed in 75 ml of distilled water contained in a 250 ml beaker. Sub-samples should be tested in triplicate for classes 1 and 2,

and singly from each reworked sample for class 3. Dispersion should normally be rated after two hours and twenty hours, with the latter being used for interpretative purposes.

Reworking (class 3) of a sample is carried out by mixing about 40g of soil in an evaporating dish, using a spatula, and working for 30 seconds at a moisture content in the plastic range. The wet sample should not be touched by hand - a piece of 5mm glass tube and perspex plunger is useful to extrude a suitable sample.

Subdivision of classes 2 and 3 is as follows, giving three subclasses for class 2 and four subclasses for class 3.

- (1) slight milkiness, immediately adjacent to the aggregate.
- (2) obvious milkiness, less than 50% of the aggregate affected.
- (3) obvious milkiness, more than 50% of the aggregate affected.
- (4) total dispersion, leaving only sand grains.

Thus, examples of the groupings might be:

Class 1 - total dispersion of natural aggregate.

Class 2 (2) - partial dispersion, less than 50% affected.

Class 3 (4) - total dispersion, after reworking wet.

Classes 4-8 - remain as in Emerson (1967).

Application of the Emerson Aggregate Test to Farming Practices.

In the field, surface soil aggregates are mechanically stressed during cultivation and also under intense rainfall. If surface soils containing class 3 aggregates are cultivated wet, then the clay present is liable to disperse when water is applied to the surface resulting in crusting and possibly reduced germination of crops.

By applying gypsum to these soils, so as to maintain an appropriate calcium ion concentration in the soil solution, crusting can be reduced. The amount of gypsum required would be the amount sufficient to make the aggregates behave as class 4 aggregates.

In neutral to acid soils, the application of excess calcium carbonate could also be effective as a long-term treatment, if the applied carbonate is subsequently re-precipitated throughout the aggregates.

The recommendations given in Table 7.7 should always be read in conjunction with the general remarks below.

The criteria used are:

1. Unified Soil Classification (and related Proctor compaction data)
2. Particle Size Analysis
3. Tunnelling susceptibility based on the Dispersal Index and/or the Emerson Aggregate Test. There is a broad correlation between these two.
4. Emerson Aggregate Test
5. Shrink Swell Potential

7.4.1 Unified Soil Classification System

Reference should be made to Table 7.2 for a qualitative comparison of engineering properties and suitability of the various groups. It should be noted that this table refers to the characteristics of soil compacted to 95% of the Proctor Maximum Dry Density at optimum moisture content, conditions which do not often apply in soil conservation earthworks.

The Proctor compaction test is a widely used standard for expressing soil compaction data. The test may be considered as a procedure designed to bring soils to approximately the same state of density as is obtained when earth dams are compacted by rolling equipment. The procedure involves tamping soil samples in layers in a standard mould, at a series of different moisture contents. The unit dry weights of the different samples are then plotted against moisture content, and the maximum density and optimum moisture content for each soil determined. Proctor data for the different classes of the Unified system are shown in Table 7.1.

The recommended batter grades for each group are given in Tables 7.3 and 7.4 and should be adhered to particularly for soils which may be tunnelling or cracking susceptible.

GC and SC materials are stable and are generally suitable for water holding structures if well compacted at the optimum moisture content. If compacted dry they will be pervious. Tunnelling susceptible GC and SC material should never be used for earthworks when very dry.

GM and SM materials should not be used for the core of zoned embankments. They should be protected from erosion if used on exposed batters.

Application of the Emerson Aggregate Test to Earthworks

Class 1 aggregates most certainly indicate high tunnelling susceptibility. Detection is difficult in acid soils where there are usually local variations in the percentage composition of the exchangeable cations.

Class 2 aggregates indicate some degree of tunnelling susceptibility, the actual amount depending on other factors such as permeability and resistance to cracking and slumping. Subclass 2(1) material (showing slight dispersion) is desirable for water storage structures. Sub-classes 2(2) and 2(3) aggregates should be treated as being unstable, and further laboratory tests carried out to determine suitability for earthworks, requirements for ameliorants etc.

Class 3 aggregates are generally stable and indicate a more desirable material for soil conservation earthworks. It is unlikely that structures built from class 3 material will leak, but if they do, they can be readily sealed after construction by compacting when wet with a roller or stock. Subclasses 3(1) and 3(2) are the most satisfactory materials within this class. Subclasses 3(3) and 3(4) are more subject to dispersion failure following construction and/or working at high moisture content and should therefore be used with care. Laboratory tests should be carried out to clarify the use of these soils in earthworks.

Classes 4, 5 and particularly class 6 aggregates indicate more highly aggregated materials less likely to hold water. Special compactive effort using high-contact-pressure compaction plant such as a vibrating sheepsfoot roller with the soil at optimum moisture content for the plant or wetter, would be required to construct a water-tight structure. It may be necessary to use a suitable dispersant to cause dispersion and sealing.

Soils with a Dispersal Index greater than 15 will generally fall into class 6 and are unlikely to hold water unless treated with a dispersant. Classes 4 and 5 materials can be sealed given good construction conditions as indicated above. A useful criteria is that if total dispersed clay (Clay content) falls below 5% then the material is likely to D.I.

leak. Laboratory testing of such soils is desirable to determine requirements in this regard.

7.4 Recommendations from Soil Test Data

Table 7.7 is a simplification of the processes involved in making a recommendation on a soil sample. The remarks and recommendations given in this section and in Table 7.7 are approximate only and are based on the best available knowledge and experience with special emphasis on the use of the soils in soil conservation earthworks constructed at what can be considered normal conditions.

GW, GP, SW and SP materials are not suitable for inclusion in soil conservation earthworks designed to retain water. They may be used in the shell of zoned embankments.

CL and CH materials will retain water. They may be tunnelling or cracking susceptible and other test results need to be considered. CH materials with a high content of expansive clay will crack extensively on drying out and also have extremely low wet strengths.

ML and MH materials are semi-pervious. They are subject to settlement on wetting and are generally erodible.

OL and OH materials are generally not suitable for soil conservation earthworks.

7.4.2 Particle Size Analysis

This test is used primarily for classification of soils by the Unified Soil Classification System, but also provides some limits on the suitability of soils for earthworks. The following five categories are suggested for use in addition to the Unified Soil Classification System group.

- (a) Clay percentage less than 10%, silt + clay less than 20%. These coarse-grained soils are considered to be pervious and are not recommended for general use in homogeneous or the impervious zones of water storage structures. Soils with a Unified Classification of GC or SC may be suitable for water storage when well compacted at the optimum moisture content. A filter zone would be required.
- (b) Clay percentage 10 to 25%, silt + clay 20 to 40%. These are coarse-grained soils which are generally suitable for use in earthworks. Such soils with a classification of GM or SM are not suitable for homogeneous or the impervious zones of water storage structures. Particular care must be taken with soils of this category which are tunnelling susceptible.
- (c) Clay percentage 10 to 25%, silt + clay greater than 45%. These are fine-grained silty soils which have variable permeability and are likely to be erodible. Generally only suitable for upstream and downstream zones of a zoned embankment or in a modified homogeneous embankment with filter zone.

- (d) Clay percentage 25 to 40%. These are generally fine-grained soils and are suitable for most soil conservation earthworks. Attention should be paid to tunnelling and cracking susceptibility.
- (e) Clay percentage greater than 40%. These fine-grained soils may leak if well aggregated or crack on drying if they have high volume expansion or linear shrinkage values.

7.4.3 Tunnelling Susceptibility

The categories used are High, Moderate, Slight and Nil tunnelling susceptibility based on the Dispersal Index and Figure 7.7. The Emerson Aggregate Test can also be used. Class 1 soils have high tunnelling susceptibility. Class 2 soils have moderate tunnelling susceptibility. Class 3 soils have slight tunnelling susceptibility. Class 4 to 6 soils are non tunnelling.

7.4.4 Emerson Aggregate Test

The results of this test provide information on tunnelling susceptibility and on the degree of aggregation of the soil. Class 4 to 6 are aggregated soils which may leak unless well compacted when wet, or unless sodium salts are added to the soil. Classes 7 and 8 are uncommon, and are likely to be stable.

7.4.5 Shrink-Swell Potential

Four categories are suggested:

Limitation Class	Linear Shrinkage %	Description
Low	0 - 12	Stable soils suitable for soil conservation earthworks.
Medium	12 - 17	Soils susceptible to minor shrinkage on drying/swelling on wetting.
High	17-22	Soils susceptible to moderate shrinkage and swelling. Increased hazard in tunnelling-susceptible soils. Swelling of otherwise stable soils will decrease permeability.
Very high	>22	Soils susceptible to extensive shrinkage cracking on drying and which swell considerably when wetted.

(See section 7.3.1 d & e)

7.4.6 Recommendations for Homogenous Structures (See table 7.7)

Recommendations for Table 7.7

- A Suitable for normal use. Use the recommended batter grades. If the material is very dry reduce the thickness of the layers and roll more frequently.
- B Use the recommended batter grades. Take care to achieve good compaction preferably with moist soil.
- C The structure should be built with the recommended batter grades. The soil should be close to the optimum moisture content for the compaction plant available and should be rolled with at least 4 complete passes of the compaction plant. A density of at least 85% of Proctor Maximum should be achieved.
- D This material is stable and impervious when compacted to at least 85% of Proctor Maximum dry density at a moisture content close to optimum. This may be achieved by compacting with 4 complete passes of a crawler tractor or a flat roller. Use a vibrating roller on soils up to 5% drier than optimum.
- E Aggregated material which might not hold water. Compact when wet of optimum using 4 to 6 complete passes of a crawler tractor or flat roller. Use a vibrating roller on soils at optimum moisture content. An ameliorant may be required. (Reynolds and Rosewell, (1975) pp 16-19). As a general rule, soils with $pH > 7.5$ should be sealed with sodium carbonate and those with $pH < 7.5$ with S.T.P.P.
- F Aggregated material which may not hold water. Compact when wet of optimum using 4 to 6 passes of a sheepsfoot roller on soil layers up to 20cm loose thickness. Use a vibrating roller for drier soils or for increased output. An ameliorant is probably required. (Reynolds and Rosewell, (1975) pp 16-19) As a general rule, soils with $pH > 7.5$ should be sealed with sodium carbonate and those with $pH < 7.5$ with S.T.P.P.
- G The structure should be built with the recommended batter grades and should be designed to store a minimum head of water above ground level. The soil must be close to the optimum moisture content for the compaction plant available and should be rolled with at least 4 complete passes of the plant. A density of at least 85% of Proctor Maximum should be achieved. If the soil is more than (10% for CH, 5% for CL or 3% for GC, SC) dry of the optimum moisture content for the compaction plant, then hydrated lime or a fine grained gypsum should be applied to the upstream face at the rate of 1 tonne/1000m³ and mixed in to a depth of 20-30 cm.*

- H The structure must be built to the recommended batter grades and must be designed to store a minimum head of water above ground level. The soil must be close to the optimum moisture content for the compaction plant available and should be rolled with at least 4 complete passes of the plant. The soil must be spread in layers not exceeding 20cm loose thickness before rolling. Thinner layers should be used for drier soils. If the soil is more than (5% for CH, 3% for CL and 2% for GC, SC) dry of the optimum moisture content for the compaction plant, then hydrated lime or fine grained gypsum must be applied to the upstream face at the rate of 1 tonne/1000m³ * and mixed in to a depth of 20 to 30 cm.
- I As for H above but hydrated lime or gypsum must always be used and at rates determined in the laboratory.
- J The recommended batter grades should be adhered to. Every effort should be made to achieve a central core compacted to at least 85% of Proctor Maximum at a moisture content equal to the expected long term average moisture content. The freeboard should be increased to prevent surface cracks extending below the water line.
- K Not recommended for use unless all of the following precautions can be undertaken. The recommended batter grades must be used. The moisture content must be within 5% of the optimum for the compaction plant available. A vibrating sheepsfoot roller is the preferred plant. The central core of the embankment must be compacted to at least 85% of Proctor Maximum. The settled freeboard must be increased to at least 1 metre above surcharge level. In extreme and critical cases the batter grades should be increased by 0.5:1.
- L Pervious. Not recommended for general use. SC and GC may be suitable in the core of zoned embankments and for homogeneous embankments if compacted to at least 85% of Proctor Maximum dry density at a moisture content within $\pm 2\%$ of optimum. Material can be sealed with bentonite or plastic liner. (Reynolds and Rosewell, (1975) pp 14-16 and pp 21-30).
- M Not recommended.

* 1 tonne/1000m³ means 1 tonne of ameliorant applied to the upstream face of the wall for every 1000 cubic metres of dam capacity. Mixing with the surface soil layers is essential.

Table 7.7 Generally Appropriate Recommendations
(A to M) for Gully Control Structures

USCS	Clay %	Clay + Silt %	Tunnelling Susceptibility	Emerson Aggregate Class	Linear Shrinkage (Volume Expansion)			Remarks
					0-12% (0-20)	12-22% (20-40)	>22% (>40)	
-	<10	<20	-	-	L	-	-	
GM			Yes	1-3	M	-	-	Shell of zoned embankment only.
			No	3	C	-	-	Shell of zoned embankment only.
			No	4-6	B	-	-	Shell of zoned embankment only.
SM			Yes	1-3	M	-	-	Shell of zoned embankment only Erodible
			No	3	C	-	-	Shell of zoned embankment only Erodible
			No	4-6	B	-	-	Shell of zoned embankment only Erodible.
GC			High	1	H	M	-	
			Moderate	1-2	G	G	-	
			Slight	2-3	C	G	-	
			Non	3	D	A	-	
			Non	4-6	E	B	-	
SC			High	1	G	H	-	
			Moderate	1-2	C	G	-	
			Slight	2-3	B	A	J	
			Non	3	D	A	J	
			Non	4-6	E	B	-	

USCS	Clay %	Clay + silt %	Tunnelling Susceptibility	Emerson Aggregate Class	Linear Shrinkage (Volume Expansion)			Remarks
					0-12% (0-20)	12-22% (20-40)	>22% (>40)	
ML			High	1	H	H	-	Shell only. Erodible.
			Moderate	1-2	C	G	-	
			Slight	2-3	B	C	-	
			Non	3	A	A	-	
			Non	4-6	E	A	-	
CL	<25		High	1	G	H	-	
			Moderate	1-2	C	G	-	
			Slight	2-3	B	C	-	
			Non	3	A	A	-	
			Non	4-6	E	A	-	
	>25		High	1	G	H	I	
			Moderate	1-2	C	G	H	
			Slight	2-3	B	C	G	
			Non	3	A	J	K	
			Non	4-6	F	J	K	
MH			High	1	H	H	I	Erodible Erodible Shell of zoned embankment only. Erodible.
			Moderate	1-2	G	G	I	
			Slight	2-3	C	G	H	
			Non	3	A	A	K	
			Non	4-6	F	F	K	
CH	<40		High	1	G	H	I	
			Moderate	1-2	C	G	I	
			Slight	2-3	C	G	H	
			Non	3	E	J	K	
			Non	4-6	F	F	K	
	>40		High	1	G	I	K, I	
			Moderate	1-2	C	G	J, I	
			Slight	2-3	C	G	I	
			Non	3	B	J	K	
			Non	4-6	F	F	K	

7.4.7 Recommendations when more than one Type of Soil has to be used in a Structure .

At any proposed earthwork site, it is possible to get varying soil materials, both with depth and in area. Very often these different soils have vastly different suitabilities as construction materials.

The major considerations are for the compacted earthwork to have sufficient strength and for permeability to be sufficiently low to retain the stored water under all conditions of operation. All soil materials are pervious to water and the through-seepage flow has to be considered in the ultimate stability of the embankment.

The through-seepage in small structures does not usually represent a major loss from the stored water. Compared to evaporation losses, for example, it is usually insignificant. Through-seepage results in saturation of part of the embankment. This saturation has two undesirable effects on the stability of the downstream portion of the embankment. Firstly the total weight of the soil is greater when saturated than when unsaturated. Secondly the water pressure in the soil pores reduces the shear strength of the soil. If the downstream batter is too steep, a failure, in the form of a slide or slip, may occur. This is more likely the higher the permeability of the soil, because the steady state seepage, or phreatic line, reaches the downstream batter at a higher level. This problem may be also greater in soils of high clay content due to their lower shear strength. Similarly a slip failure of the upstream batter may occur when the water level is reduced quickly after being held at a high level for a long period. This 'drawdown' type of failure is the result of the combined effect of the removal of the water load on the upstream face together with the residual water pressure remaining in the pores of the 'impervious' fill.

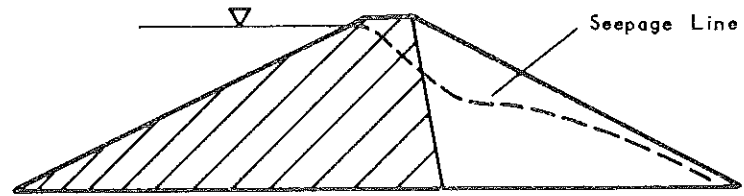
In a homogeneous embankment constructed from uniform soil material the usual protective measure is to have a relatively flat downstream batter and to cover it with a layer of fertile, organic topsoil, and to maintain a dense vegetative cover. The topsoil is normally pervious and allows drainage of the seepage water down to the toe of the embankment and, in addition, the root system of the vegetation helps to resist piping and uses some of the seepage water for transpiration.

Where different soil materials are present at the site then it is advantageous to design and construct an embankment with a zoned cross section. A zoned cross section makes best use of the available material and permits the use of steeper batter grades (Table 7.4).

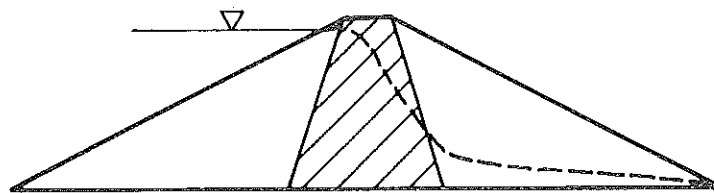
Examples of zoned embankments are shown in Figure 7.9 .

Figure 7.9

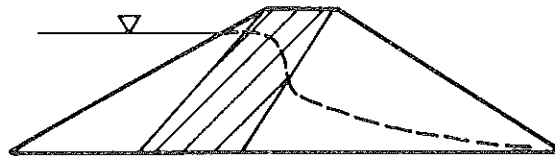
ZONED CROSS SECTION EMBANKMENTS



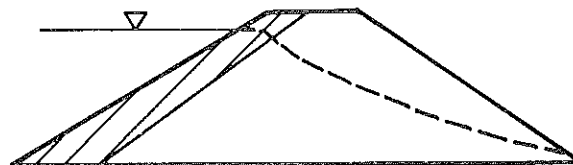
(a) Double Zoned



(b) Central Core



(c) Sloping Core



(d) Upstream Blanket



Impervious Material

Pervious or Semi Pervious
Material

In all cases the best (least pervious) material is placed in the impervious core and this is supported by a well compacted more pervious material. The pervious zones must be equally as well compacted as the impervious zone as settlement of the former will cause cracking of the latter. Ideally the material should grade from one zone to another.

The type of zoning used will depend on the amount, and location of the soil material. The central core Figure 7.9 (b) is the most versatile of all embankment cross sections. The low strength impervious core material is supported by the stronger shells, which, in addition provide drainage on the downstream side, and resists the effects of sudden drawdown of the stored water on the upstream side. The sloping central core Figure 7.9 (c) is perhaps more easily constructed with dozers.

The upstream blanket zoned cross section shown in Figure 7.9 (d) can be used on embankments where the quantity of impervious material is limited. This impervious layer can be added later as a repair measure when through-seepage of a homogeneous cross section is excessive. (Reynolds and Rosewell (1975) pp 9 and 14).

7.4.8 Embankment Settlement

Embankment settlement may be due to dry settlement (consolidation) or settlement on saturation.

Dry settlement of the compacted soil in an embankment proceeds during construction due to the weight of the superimposed fill. It may possibly continue after completion of construction up until the filling of the storage when seepage flow commences through the embankment. Following the onset of seepage flow (or saturation of small embankments by prolonged rainfall) dry settlement is likely to assume an insignificant role in the embankment settlement compared to that due to other volume changes such as settlement on saturation or swelling of clay soils (Fietz 1969).

Settlement of the foundation beneath an embankment will also occur, particularly in plastic clays, due to the overburden pressure. Normally such settlement occurs during construction and is not normally allowed for in the finished height of the embankment.

The practical importance of dry settlement in small earth dams hinges on the rate of settlement rather than on the amount. If dry settlement proceeds at a rate equal to that of construction then settlement subsequent to completion will be negligible, and no allowance for subsequent dry settlement need be made in the height of the embankment. This is probably the case with coarse grained soils where rapid dissipation of pore pressure allows settlement to proceed apace with construction (Fietz op cit).

On the other hand embankments built with a large proportion of plastic clay may have excess pore pressure at the end of construction, particularly if placed wet. As the pore pressure dissipates dry settlement due to primary consolidation may occur. The rate of pore pressure dissipation depends on the hydraulic conductivity and the length of the drainage path.

The allowance for dry settlement can be estimated from the compressibility data of Table 7.1 using the method suggested by Fietz. The method assumes that no settlement occurred during construction. Allowance for dry settlement as a percentage of embankment height for soil materials commonly used in soil conservation earthworks is shown below.

Allowance for dry settlement for material compacted to Proctor Maximum Density at optimum moisture content.

CH	MH	CL	ML	SC	SM
1.7%	1.0%	1.0%	0.7%	0.7%	0.3%

Allowance for dry settlement for material compacted wet of the optimum moisture content.

CH	MH	CL	ML	SC	SM
3.4%	1.0%	2.0%	0.7%	0.7%	0.3%

Allowance for dry settlement for material compacted to less than Proctor Maximum Density.

CH	MH	CL	ML	SC	SM
2.5%	1.5%	1.5%	1.0%	1.0%	0.5%

Compacted soil in an embankment may exhibit a sudden settlement on saturation by seepage flow when the storage fills, or by percolation of rain water in the case of very small embankments.

Settlement on saturation by seepage flow may lead to settlement of the compacted fill in an earth embankment in the affected zone below the seepage line. The void remaining between the settled saturated zone and the unsettled saturated zone may induce tunnelling failure particularly in tunnelling susceptible soils. Also settlement on saturation below the seepage line is a case of differential settlement which induces tensile strains in the unsaturated soil arch above. If the unsaturated soil is unable to conform to these strains then transverse cracking may occur (Sherard 1953).

There is no simple method of predicting the amount of saturation settlement which will occur in any given material. However, saturation settlement is greatest in clay soils, less in silts and silty clays and least in sandy soils. Tunnelling failure and loss of freeboard are thus most likely in poorly compacted dry clays. Cracking by differential settlement produced by saturation is more likely in silts and silty clays (Fietz 1969). It is

generally assumed that if shrinkage is observed in the Volume Expansion test then greater saturation settlement can be expected.

Recommended Allowance for Settlement

For small earth embankments which are usually poorly compacted dry of the optimum moisture content a gross allowance is made for settlement including both dry settlement and saturation settlement. Because of the great influence of compaction on both phenomenon any recommendation should vary according to the compactive effort.

Edwards (1964) makes the following recommendations:-

Rolled fill	5%
Scraper placed without rolling	8%
Dozer placed without rolling	10%

7.5 Soil Sampling

The detail required to investigate an earthwork site will depend greatly on existing knowledge of the variability both in area and depth of the soil, the relative importance of the structure and the likely occurrence of problem soils.

7.5.1 Soil Sampling Methods

Ideally, samples should be taken on an intensive grid basis, but this is usually impracticable. As a general rule, if two or three holes reveal a relatively uniform soil type, then only one site need be chosen for sampling. However, if three holes reveal three different soil materials then further holes should be dug until the diversity of the soil is known.

Soil characteristics also vary with depth. The upper and lower B horizons, and C horizons are used as construction materials. If the soil is uniform with depth only one sample per hole need be taken - if there are obvious layers, then each layer should be sampled.

At least 2 kg of soil should be collected per sample. Calico bags are generally preferred for collecting soil samples. A label should be tied to the bag before the ties are used to close the bag. Complete all details on the label. The depth shown should be the depth below the surface unless it is a sample from an embankment in which case it would be the depth below top water level.

(a) Sampling for Proposed Gully Control Structures

Where a gully is present the profile exposed can be used to examine soil variability both in area and with depth. Soil samples should not however, be taken from the exposed surfaces of the gully. A hole can be bored or excavated into the face of the gully to take samples at least 20 cm in from the exposed surface.

In normal situations the minimum number of test holes recommended is one hole in the middle of the proposed embankment site (using a gully, if present to gain extra depth) and one at either end of the proposed wall. At least one and preferably all test holes should go to the full depth of the proposed structure. For large structures or for variable soils, further test holes should be bored upstream of the proposed embankment site.

Soil samples should be taken that represent the range of soils found in the test holes.

(b) Sampling Areas of Failed Banks and Gully Control Structures

An examination should be made of the bank or wall adjacent to the failed area, from the channel and uphill batter above the failure, and from the borrow area from which repair material is to be taken. In all cases at least one sample should be of undisturbed soil.

(c) Sampling for Leaking Gully Control Structures

It is very important to determine as precisely as possible where the leak is. If the structure drains only to a certain level then the leak is obviously above this level. The place of exit of the water downstream of the structure will also give a clue to the location of the leak.

The inside of the structure should be carefully examined for holes, soft spots, gravel or sand seams, layers of flocculated soils or layers of calcium carbonate. If it is a general leak then test holes should be made into the upstream and downstream batters as well as the bottom. The test holes in the bottom of the structure should go down at least 1 m to determine whether gravel seams are present.

Samples should be taken from any unusual material. Samples from the upstream batter and the bottom should be from undisturbed material.

Chapter 8

GENERAL SUMMARY AND CONCLUSIONS

In this handbook an attempt has been made to put together in a coherent and logical way information on soils relevant to their conservation in New South Wales. It is not meant to be a descriptive text about all the different soils occurring in the State, nor a soil science text for the more academically-minded soil conservationist. The handbook has been written as a compendium of useful technical information on soils, their formation, classification, erosion characteristics and properties relevant to different soil conservation methods, including structural earthworks for erosion control. The intention has been to produce a readable reference text for the practical use of soil conservationists, students, land use planners, engineers and researchers who are interested in the conservation of the wide range of soils we have.

The complexity of soils and soil materials, and the multi-disciplinary nature of soil conservation, mean that the soil conservationist must be something of a chemist, physicist, pedologist, agronomist and engineer before he can hope to understand soils as they affect his work. In planning land use it is important for him to take account of the intrinsic factors which enable a soil to resist degradation by erosive forces, and those which make it susceptible to them in an erosive situation. In restoring eroded land he may be more interested in those soil properties which help determine the form and extent of the rehabilitation programme, but he should not lose sight of the longer term use of the land when restored, and the soil factors controlling that use.

The most significant soil factors in an erosion/conservation situation can be summarized as soil texture, structure, infiltration characteristics and dispersibility. These are all inter-related in a rather complex way, but will determine to a large extent the intrinsic susceptibility of a soil to erosion - its erodibility. Information on these properties should thus be used to modify decisions on land use, bank designs, bank spacing, runoff assessments etc. The external factors such as land slope, rainfall intensities, rainfall duration and more specific limitations will then come into play to decide what measures are required to protect the soil and how intensive they must be for a particular use.

The soil's fertility does not directly affect its erodibility, but clearly the chemical status of a soil is likely to affect the way the soil is used and the sort of crops grown. The amount and type of plants which will grow in it, their protective effect, and the amount of organic matter which will accrue from their breakdown and assist soil stability, are also of tremendous importance.

Fertility in this sense does not merely mean the amount of nutrients available to the plant, but also the suitability of the pH and salinity levels which indirectly affect this. Suitable physical fertility is also vital to allow plant roots aeration, penetration and access to soil moisture and nutrients. Both chemical and physical fertility become a particular problem where erosion has already occurred, and the normally more fertile topsoil removed. Revegetation of the remaining soil surface then requires special measures which will depend on the characteristics of the subsoil exposed.

The third important aspect of soils from the soil conservation viewpoint is their ability to absorb rainfall. If soil could absorb all rainfall as it fell, then soil erosion by water would be virtually non-existent. The situation in many northern European countries approaches this ideal because rainfall is generally far less intense than here, and more evenly distributed throughout the year. Soil erosion as we know it is therefore not a serious problem in those countries.

A soil's absorption of rainfall depends on the rate at which water can infiltrate the surface, the capacity of the soil profile to retain water, and its drainage characteristics. The stability of the surface structure is vital to any infiltration, and all these properties are in fact dependent on the texture and structure of the different horizons in the soil, the depth of individual horizons and the overall depth of soil involved.

In New South Wales the use of structural earthworks is an important factor in the control of accelerated soil erosion, particularly on arable land. The soil conservationist is therefore concerned with soil as an engineering material for use in building earthen banks to hold and divert runoff safely. These may comprise gully control structures, contour or graded banks, waterways or earth flumes. The soil material for these structures is removed from its normal situation and placed and compacted mechanically in a surveyed location, and thus a wider set of properties come into play. These affect how it can be compacted, to what angle it can safely be built up, what type of machinery is best used, and how the soil is likely to behave after repeated wetting and drying or under the effect of a substantial hydrostatic head. The texture, plasticity, shear strength, compaction characteristics and shrink/swell potential of the soil then assume a special significance.

These engineering properties of soil material are also important in urban soil conservation planning. This is because they affect the soil's use for supporting foundations of buildings, roads and other urban structures. They also relate strongly to the soil's behaviour in a landslip situation which is of increasing concern in many urban areas.

Soil conservation is thus concerned with four broad aspects of soil technology which can be summarized as:

- S (i) Their resistance to erosive forces.
- O (ii) Their chemical and physical fertility.
- I (iii) Their ability to absorb rainfall.
- L (iv) The engineering properties of the materials
- S that comprise them.

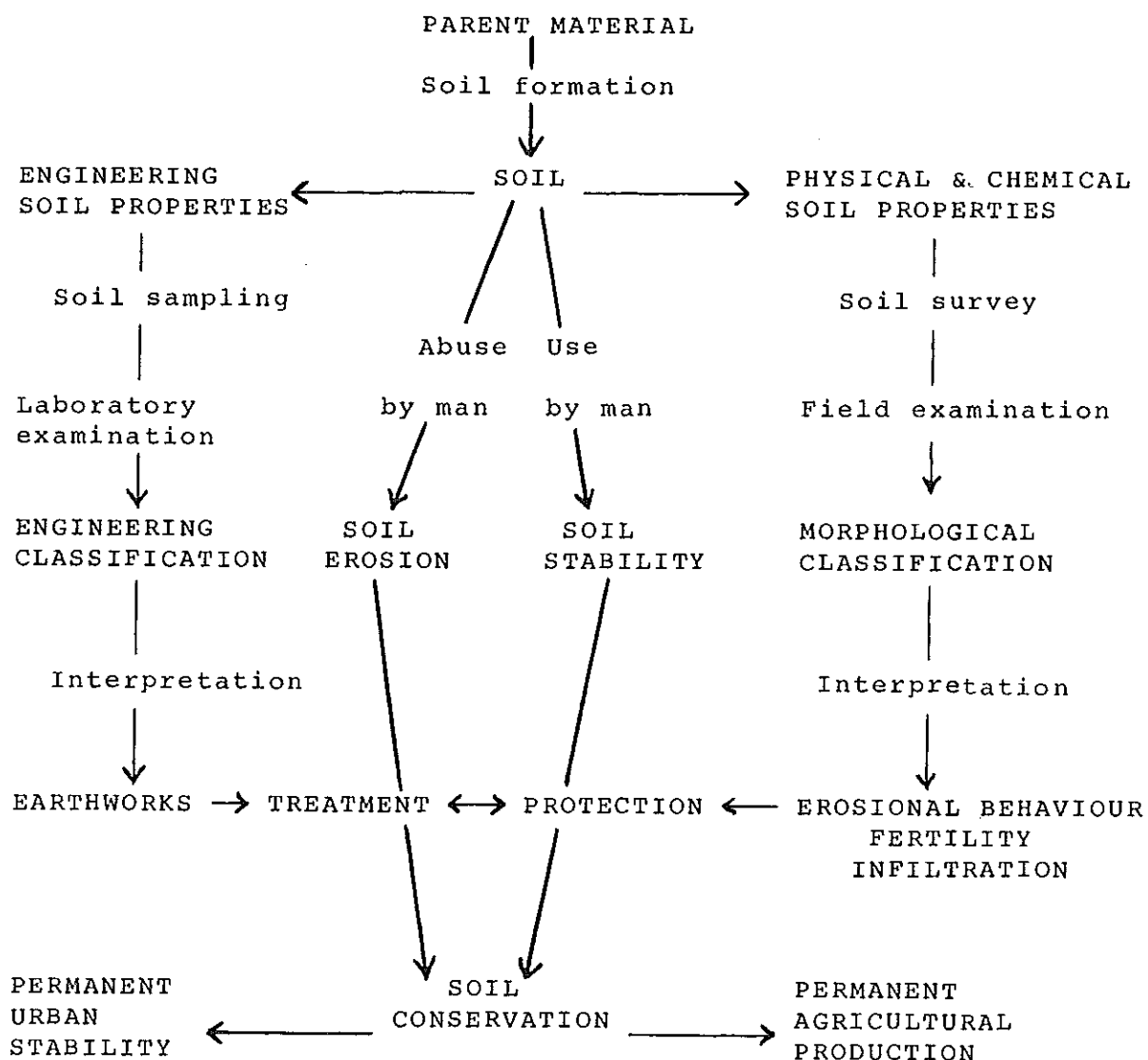
One way to gain an insight into these four aspects is to study how soils are formed. Obviously a soil's present characteristics are strongly related to the origin of the soil material, and how it has been affected during the soil's formation. For this reason a section on soil formation has been included in this handbook.

The morphology of the soil, or its form in the field, is a result of the interaction of many formative processes. It is therefore the key to many of that soil's current behaviour patterns and properties - the way it erodes, whether it absorbs water rapidly, how it reacts to cultivation and so on. An understanding of soil profiles and their examination is thus of great value in this context. It is also important to comprehend the lateral variation in soils, particularly those associated with topographic changes. These are relevant to soil conservation practice, because they account for soil changes on slopes where we are naturally more concerned with erosion. A knowledge of such changes can always be put to good use in soil conservation design work.

The pattern of soils over the land surface has to be studied and recorded for many purposes. In soil conservation work we are currently becoming more conscious of the need for soil mapping - not only for the implementation of the more traditional soil conservation works but also in a broadening field of land use work in which we are becoming involved. Whilst it is conceded that soil surveying and mapping is very much a matter of individual approach and interpretation, it is hoped that a reasonably uniform method can be developed for soil conservation purposes. To this end guidelines have been set out for soil observation, description, survey, sampling and mapping.

The subject of soil classification, as it relates to soil conservation, has become of increasing interest in recent years. This is not only because of the Service's wider involvement in soil survey and mapping, but also due to the belief that with appropriate classification methods we can infer much soil information of value which is pertinent to the conservation of soils in New South Wales. We believe that appropriate soil classification provides the all-important link between soil formation and properties on the one hand and conservation of the productive resource on the other, as shown in figure 8.1.

Figure 8.1 Soils of New South Wales - Characterization, Classification and Conservation.



The figure aims to relate, on the one side, accelerated erosion caused by man's abuse of the land, and treatment to achieve soil conservation and stability using, to a large extent, earthworks based on the engineering properties of soils. On the other side, emphasis is on use of soil physical and chemical properties and morphological classification to infer the erosional behaviour, fertility and infiltration properties of soils in order to make land use and protection decisions to achieve permanent soil stability. There is a central interchange between "earthwork treatment" and "protection" concepts, as both are used to achieve long term stability. Earthwork-treated (eroded) areas generally use conservative agronomic measures as an essential adjunct to the earthworks, and frequently, uneroded land is protected by earthworks to ensure stability under continuing (and often more intensive) use.

The vital theme of this handbook relates to the use of soil classification and characterization to infer the properties of soils which directly affect their erosional behaviour, and their treatment and use in the application of soil conservation measures. It is to be hoped that the book will be used in just that way. We can then suit our design decisions, revegetation programmes, soil conservation techniques and land use recommendations to the nature of the soils our job it is to conserve for the future prosperity and well-being of this State and its people.

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Sections 2.1.5, 3.5, 4.9	Mr. K. Styles
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Section 7.2	Mr. J. Dixon
Sections 7.1, 7.3, 7.4, 7.5	Mrs. C. Hird and Mr. C. Rosewell

APPENDIX ISOIL IDENTIFICATION

List of approximate correlations between Principal Profile Forms and Great Soil Groups. All forms for which soils have been recorded in editions 3 and 4 of the Factual Key are included. Those acknowledged in "Atlas of Australian Soils" (Sheet 3 for N.S.W.) are marked *. Certain group names have been proposed for forms without clear correlations with acknowledged groups. A similar table appears in "A Description of Australian Soils" (Northcote et al 1975) on pages 158 to 162. Correlations with the FAO World Soil Map are also given in that table.

Uniform Soils

*	Uc1.11	Calcareous sands
	.12	" "
	.13	" "
	.14	" "
*	.21	Lithosols/ siliceous Sands/Alluvial Soils
*	.22	" " " "
*	.23	" " " "
	.31	Calcareous sands
	.41	Sands/Lithosols
	.42	" "
*	.43	" "
	.44	" "
	Uc2.11	Leached sands
*	.12	" "
	.20	Leached sands/Podzols
*	.21	" " "
*	.22	" " "
	.23	" " "
*	.31	Podzols
*	.32	"
*	.33	"
*	.34	"
	.35	Humic podzols
	.36	" "
	Uc3.12	Leached sands
*	.21	" "
	.31	Podzols
*	.32	"
	.33	"
*	Uc4.11	Sands/Lithosols
	.12	" "

*	Uc4.21	Sands/Earthy sands
	.22	" " "
	.23	" " "
	.24	" " "
	.31	Sands/Earthy sands
	.32	Podzols/Sands/Earthy sands
	.33	Podzols
	Uc5.11	Sands
	.12	"
*	.13	"
*	.21	Earthy sands
	.22	" "
	.23	" "
	.31	Dense sands
	.32	" "
	Uc6.11	Structured sands/Lithosols
	.12	Structured sands/Rendzina (sandy)
	.13	Structured sands/Terra rossa
	.14	Structured sands
	Um1.13	Alluvial soils/Solonchaks
	.21	Alluvial soils/Solonchaks
	.23	" " "
	.32	Calcareous desert soils
	.33	" " "
	.41	Lithosols
*	.42	"
*	.43	"
	.44	"
	Um2.11	Leached loams
*	.12	" "
	.21	" "
	.22	" "
	.23	" "
	.32	Podzols
	Um3.12	Leached loams
	.21	" "
*	Um4.11	Lithosols
	.12	"
	.13	"
*	.21	Leached loams/Lithosols
	.22	" " "
	.23	" " "
	.25	" " "

*	Um4.31	Leached loams
	.41	" "
	.43	" "
	Um5.11	Calcareous desert soils
	.12	" " "
*	.21	Lithosols
	.22	Alluvial soils
	.31	Hardpan soils
*	.41	Lithosols
	.42	Alluvial soils
*	.51	Lithosols
	.52	Alluvial soils
	.61	Calcareous desert soils
*	Um6.11	Chernozems
*	.12	Structured loams
*	.13	" "
	.14	" "
*	.21	Calcareous desert soils/Rendzina
	.22	Calcareous desert soils
	.23	" " "
	.24	Calcareous desert soils/Terra rossa
	.31	Structured loams
	.32	" "
	.33	Structured loams/Terra rossa
	.34	Structured loams
	.41	Structured loams
	.42	" "
*	.43	Structured loams/Terra rossa
*	Um7.11	Alpine humus soils
	.12	" " "
	Uf1.13	Lithosols
	.23	"
	.41	Solonchaks/Lithosols
	.42	" "
*	.43	" "
	Uf4.41	Leached clays
	.43	" "
*	Uf5.11	Structured subplastic clays
	.12	" " "
	.21	Structured subplastic clays/Krasnozems
	.22	" " "
	.23	Structured subplastic clays/Xanthozems
	.31	Structured subplastic clays
*	Uf6.11	Rendzina/Structured plastic clays

*	Uf6.12	Structured plastic clays
	.13	Structured plastic clays
*	.21	Euchrozems/Structured plastic clays
	.22	Prairie soils/ Rendzina
	.23	Structured plastic clays
*	.31	Euchrozems/Structured plastic clays
	.32	Prairie soils/Structured plastic clays
	.33	Structured plastic clays
	.34	" " "
*	.41	Humic gleys/Structured plastic clays
	.42	" " " " "
*	.51	Solonchaks/Dense clays
*	.61	Humic gleys/Dense clays
	.62	" " " "
	.71	Massive earthy clays
*	Ug3.2	Grey clays
*	Ug5.11	Black earths/Rendzina
*	.12	Black earths
*	.13	" "
*	.14	" "
*	.15	" "
*	.16	Black earths/Weisenboden
	.17	" " "
*	.22	Grey clays
*	.23	" "
*	.24	" "
*	.25	" "
	.26	" "
	.27	" "
*	.28	" "
	.29	" "
*	.32	Brown clays
	.33	" "
*	.34	" "
*	.35	" "
*	.37	Red clays
	.38	" "
	.39	" "
*	.4	Black earths
*	.5	Grey clays
*	.6	Brown clays
	Ug6.1	Black earths
	.2	Grey clays

	*	Ug6.3	Brown clays
		.4	Black earths
	*	.5	Grey clays
		.6	Brown clays
<u>Gradational Soils</u>			
		Gc1.11	Solonized brown soils/Calcareous desert soils
		.12	Solonized brown soils/Calcareous desert soils
		.21	Solonized brown soils
	*	.22	" " "
		Gc2.11	Solonized brown soils/Calcareous desert soils
	*	.12	Solonized brown soils/Calcareous desert soils
		.21	Solonized brown soils/Calcareous desert soils
		.22	Solonized brown soils/Calcareous desert soils
		Gn1.12	Sandy earths
	*	.13	Sandy earth/Solonized brown soils
		.19	Sandy leached earths
		.23	Sandy earths
		.46	Sandy leached earths
		.83	Sandy earths
	*	.84	Sandy leached earths
	*	Gn2.11	Red earths
	*	.12	" "
	*	.13	Calcareous red earths
	*	.14	Red earths
	*	.15	" "
	*	.16	Calcareous red earths
	*	.17	Red leached earths
	*	.18	" " "
	*	.19	" " "
		.111	" " "
		.112	" " "
		.113	" " "
	*	.21	Yellow earths
	*	.22	" "
	*	.23	" "
	*	.24	" "
	*	.25	" "
		.31	Yellow leached earths
		.32	" " "
	*	.34	" " "
	*	.35	" " "
		.41	Yellow-brown earths
		.42	" " "

*	Gn2.43	Yellow-brown earths
*	.44	" " "
	.45	" " "
*	.46	" " "
	.51	Yellow-brown leached earths
	.52	" " " "
	.53	" " " "
	.54	" " " "
*	.55	" " " "
	.61	Yellow earths
	.62	" "
	.63	" "
	.64	" "
	.65	" "
	.71	Yellow leached earths
	.72	" " "
*	.74	" " "
*	.75	" " "
*	.81	Grey earths
	.82	" "
*	.83	" "
	.84	" "
	.85	" "
*	.91	Grey leached earths
	.92	" " "
	.93	" " "
*	.94	" " "
*	.95	" " "
	.96	" " "
	.02	Dark earths
	Gn3.10	Krasnozems
*	.11	"
*	.12	Euchrozems
*	.13	"
*	.14	Krasnozems
	.15	Euchrozems
*	.16	"
	.17	"
*	.21	Prairie soils
	.22	" "
	.23	" "
	.24	" "
	.25	" "
	.32	Prairie soils
	.34	Prairie soils
	.41	Prairie soils
*	.42	" "
*	.43	" "
	.44	" "
	.45	" "

	Gn3.46	Prairie soils
	.47	" "
	.48	" "
	.49	" "
	.51	Xanthozems
	.52	"
	.53	"
*	.54	"
	.56	"
*	.64	Xanthozems
	.71	Xanthozems
	.72	"
	.73	"
*	.74	"
	.75	"
	.76	"
	.81	Xanthozems
	.82	"
	.83	"
*	.84	"
	.85	"
	.90	Prairie soils (Minimal)
*	.91	" "
*	.92	" "
	.93	" "
*	.94	" "
	.95	" "
	.96	" "
	.01	Prairie soils (Minimal)
	.02	" "
	.03	" "
	.04	" "
	.05	" "
	.06	" "
*	Gn4.11	Krasnozems
*	.12	Euchrozems
	.13	"
*	.14	Krasnozems
*	.31	Prairie soils
*	.32	" "
	.33	" "
*	.34	" "
*	.41	Prairie soils
*	.42	" "
	.50	Krasnozems (Minimal)
	.51	"
	.52	"
	.54	"
	.64	Krasnozems (Minimal)

Duplex Soils

	Dr1.12	Desert loams
*	.13	" "
	.16	Hardpan soils
*	.32	Desert loams
*	.33	" "
	.42	Desert loams
*	.43	" "
	.73	Desert loams
	.82	Desert loams
	.83	" "
*	Dr2.11	Red podzolic soils
*	.12	Non-calcic brown soils
*	.13	Red-brown earths
*	.21	Red podzolic soils
*	.22	Red-brown earths/Non-calcic brown soils
*	.23	Red-brown earth
	.31	Red podzolic soils
*	.32	Red solodic soils
*	.33	Red solodic soils
*	.41	Solods
*	.42	Red solodic soils
*	.43	Red solonetzic soils
	.51	Red podzolic soils
	.52	" " "
	.53	Red solodic soils
*	.61	Red podzolic soils
*	.62	Red solodic soils
*	.63	Red-brown earths
	.71	Red podzolic soils
	.72	Red solodic soils
	.73	" " "
	.81	Solods
	.82	Red solodic soils
	Dr3.11	Red podzolic soils
	.12	Non-calcic brown soils
	.13	Red-brown earths
*	.21	Red podzolic soils
	.22	Red-brown earths
*	.23	" " "
*	.31	Solods
	.32	Red solodic soils
	.33	Red solonetzic soils

*	Dr3.	.41	Solods
		.42	Red solonetzic soils
		.43	Red solonetzic soils
		.51	Red podzolic soils
		.61	Red podzolic soils
		.62	Red solodic soils
		.71	Solods
		.81	Solods
		.83	Red solonetzic soils
*	Dr4.	.11	Chocolate soils
		.12	" "
		.13	" "
*		.21	Chocolate soils
		.22	" "
		.23	" "
		.33	Red-brown earths
		.41	Solods
		.42	Red solodic soils
		.43	Red solonetzic soils
		.53	Chocolate soils

*	Dr4.61	Chocolate soils
	.63	" "
	.72	Red solodic soils
	.73	Red-brown earths
	.81	Solods
	.82	Red solodic soils
*	Dr5.11	Red podzolic soils
*	.12	" " "
*	.21	Red podzolic soils
	.23	Red solodic soils
	.32	Red solonetzic soils
*	.33	" " "
	.41	Solods
	.42	Red solonetzic soils
*	.43	" " "
*	.62	Red solodic soils
	.81	Solods
	Db0.13	Solonchaks (Secondary)
	.23	Solonchaks (Secondary)
*	.33	Solonchaks (Secondary)
*	.43	Solonchaks (Secondary)
*	Db1.11	Brown podzolic soils
*	.12	Non-calcic brown soils
*	.13	Red-brown earths
*	.21	Grey-brown podzolic soils
*	.22	Red-brown earths/Non calcic brown soils
*	.23	Red-brown earths
	.31	Grey-brown podzolic soils
*	.32	Brown solodic soils
*	.33	Red-brown earths
	.41	Solods
*	.42	Brown solodic soils
*	.43	Brown solonetzic soils
	.52	Non-calcic brown soils
	.61	Grey-brown podzolic soils
	.62	Red-brown earths
	.81	Solods

	Db2.12	Non-calcic brown soils
	.13	Red-brown earths
	.21	Grey-brown podzolic soils
	.22	Red-brown earths
	.23	Red-brown earths
	.31	Solods
*	.32	Brown solonetzic soils
*	.33	Brown solonetzic soils
	.41	Solods
*	.42	Brown solonetzic soils
*	.43	" " "
	Db3.11	Chocolate soils
*	.12	" "
*	.13	" "
	.21	Chocolate soils
	.22	Red-brown earths
*	.23	Red-brown earths
*	.32	Brown solodic soils
	.40	Solods
	.41	"
	.42	Brown solodic soils
	.43	Brown solonetzic soils
*	Db4.11	Brown podzolic soils
	.13	Red-brown earths
	.21	Grey-brown podzolic soils
*	Dy1.13	Solonchaks (Secondary)
	.32	Solonchaks (Secondary)
*	.33	"
*	.43	Solonchaks (Secondary)
	.63	Solonchaks (Secondary)
	Dy2.11	Yellow podzolic soils
	.12	" " "
	.13	Yellow solodic soils
*	.21	Yellow podsolic soils
*	.22	" " "
*	.23	Yellow solodic soils
	.31	Yellow podzolic soils
	.32	Yellow solodic soils
*	.33	Yellow solonetzic soils
*	.41	Solods
*	.42	Yellow solodic soils
*	.43	Yellow solonetzic soils

*	Dy2.51	Yellow podzolic soils
	.52	" " "
*	.61	Yellow podzolic soils
	.62	" " "
*	.71	Yellow podzolic soils
	.73	Yellow solonetzic soils
	.81	Solods
	.82	Yellow solonetzic soils
	.83	" " "
	.84	Lateritic podzolic soils
*	Dy3.11	Yellow podzolic soils
	.12	" " "
	.13	Yellow solodic soils
*	.21	Yellow podzolic soils
*	.22	" " "
	.23	Yellow solodic soils
	.31	Solods
*	.32	Yellow solonetzic soils
*	.33	" " "
*	.41	Solods
*	.42	Yellow solonetzic soils
*	.43	" " "
	.51	Yellow podzolic soils
	.53	Yellow solodic soils
*	.61	Yellow podzolic soils/Lateritic podzolic soils
*	.62	Yellow podzolic soils
	.63	Yellow solodic soils
	.71	Solods
	.73	Yellow solonetzic soils
*	.81	Solods
*	.82	Yellow solodic soils
	.83	Yellow solonetzic soils
	.84	Lateritic podzolic soils
	.85	" " "
*	Dy4.11	Yellow podzolic soils
	.12	" " "
	.13	Yellow solodic soils
	.21	Yellow podzolic soils
	.22	Yellow podzolic soils
	.23	Yellow solodic soils
	.32	Yellow solodic soils
	.33	Yellow solonetzic soils

*	Dy4.41	Solods
	.42	Yellow solodic soils
	.43	Yellow solonetzic soils
	.51	Yellow podzolic soils
	.81	Solods
	.83	Yellow solonetzic soils
*	Dy5.11	Yellow podzolic soils
	.12	" " "
	.13	Yellow solodic soils
*	.21	Yellow podzolic soils
	.22	Yellow podzolic soils
	.23	Yellow solodic soils
	.31	Solods
	.32	Yellow solonetzic soils
*	.33	Yellow solonetzic soils
*	.41	Solods/Lateritic podzolic soils
*	.42	Yellow solodic soils
*	.43	Yellow solonetzic soils
*	.51	Yellow podzolic soils
*	.61	Yellow podzolic soils/Lateritic podzolic soils
*	.62	Yellow podzolic soils/Lateritic podzolic soils
	.63	Yellow solodic soils
	.71	Solods
*	.81	Solods
*	.82	Yellow solodic soils
	.83	Yellow solonetzic soils
	.84	Lateritic podzolic soils
	Dd1.11	Dark podzolic soils
	.12	" " "
	.13	Dark solodic soils
	.21	Dark podzolic soils
*	.22	Dark podzolic soils
*	.23	Dark solodic soils
	.31	Solods
	.32	Dark solonetzic soils
*	.33	" " "
*	.41	Solods
*	.42	Dark solodic soils
	.43	Dark solonetzic soils
	.52	Dark podzolic soils
	.81	Solods

	Dd2.11	Dark podzolic soils
	.12	Dark solodic soils
	.13	" " "
	.22	Dark solodic soils
	.31	Solods
	.32	Dark solodic soils
	.33	Dark solonetzic soils
*	.41	Solods
*	.42	Dark solonetzic soils
	.43	" " "
*	Dd3.11	Dark podzolic soils
*	.12	" " "
*	.13	Dark solodic soils
*	.21	Dark podzolic soils
	.23	Dark solodic soils
*	.32	Dark solodic soils
	.33	Dark solonetzic soils
	.41	Solods
	.42	Dark solonetzic soils
	.43	" " "
	.51	Dark podzolic soils
	Dd4.11	Dark podzolic soils
	.13	Dark solodic soils
	.23	Dark solodic soils
	.32	Dark solodic soils
	.43	Dark solonetzic soils
	.63	Dark solodic soils
*	Dg1.41	Gleyed podzolic soils
	.43	Gleyed podzolic soils (Humic gleys)
	.81	Gleyed podzolic soils
	Dg2.21	Gleyed podzolic soils
	.23	Gleyed podzolic soils (Humic gleys)
	.31	Gleyed podzolic soils
	.41	Gleyed podzolic soils
	.42	" " "
	.43	" " " (Humic gleys)
	.63	Gleyed podzolic soils (Humic gleys)
	.81	Gleyed podzolic soils
	.82	Gleyed podzolic soils
	.83	Gleyed podzolic soils (Humic gleys)

	Dg3.	.41	Gleyed podzolic soils
		.43	Gleyed podzolic soils (Humic gleys)
*		.81	Gleyed podzolic soils
*	Dg4.	.11	Gleyed podzolic soils
		.13	Gleyed podzolic soils (Humic gleys)
		.21	Gleyed podzolic soils
	Dg4.	.31	Gleyed podzolic soils
		32	" " "
		.33	Gleyed podzolic soils (Humic gleys)
*		.41	Gleyed podzolic soils
		.42	" " "
		.43	Gleyed podzolic soils (Humic gleys)
*		.81	Gleyed podzolic soils

Organic Soils

*	O	Peat soils (Acid and neutral)
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APPENDIX II

IDENTIFICATION OF SOIL GROUPS

Great Soil Group	Northcote codings	Further Diagnostic Features.	Notes
Solonchaks	Some Um1 and Uf1 soils Some Uf6 e.g. Uf6.51 Db0 and Dy1 soils ending in 3.	Soils dominated by salt accumulation with one or more the following features: a. Salty encrustations b. Surface flaking of clay crusts. c. Polygonal cracking of surface. d. Powdery structure e. Lack of normal plant growth except for salt-tolerant species	Primary solonchaks show little pedologic organisation, and are uncommon. Secondary solonchaks may show features of other soil groups, and are best described as saline forms of those groups (e.g. Dyl.43). These soils form when climatic and/or topographic conditions allow the accumulation of free salt in the soil profile. Soil salinity leads to revegetation problems and erosion hazard.
Alluvial soils	Some Um1 and Uf1 soils Um5.2 soils	Juvenile soils formed by deposition from still or moving water. Little pedologic organisation, beyond some accumulation of organic matter at the surface and sometimes minor changes in colour, consistence, texture and structure throughout the profiles.	Extreme variation. Soils may show differential layering of sedimentary material, but no well-developed pedogenic horizons. (N.B. The majority of soils are alluvial or colluvial to a certain extent). Generally no erosion problems.
Lithosols	Some Uc4, Uc6 Um1 and Uc1 soils Some Uf1, Um2, Um4, Um5.41, Um5.51 Um5.21	Shallow stony soils dominated by presence of underlying rock material. Little pedologic organisation.	Characteristic of steeper exposed slopes where natural erosion restricts profile development. Some have minimal A ₂ horizons (Um2 and Um4). Erosion hazard due to slope and low fertility.

APPENDIX II Cont'd.

Great Soil Group	Northcote Codings	Further Diagnostic Features	Notes
Sands	Some Uc1 and Uc5 soils. Uc2.1, 2.2, Uc3 and Uc4. Uc6 soils	Soils with little or no pedologic organization, generally deep, characteristic of coastal dune areas and inland deserts.	Calcareous, siliceous, ferruginous, dense, leached and earthy variants occur. Leached sands - Uc3 and Uc4, Uc2.1. Structured sands - Uc6. Generally erodible because of poor structure and low fertility.
Calcareous Desert soils	Um1.3 Um5.1 and Um6.2 soils. Gc1.1 soils Gc2.1. Some Um6.4, Um5.6	Shallow soils of arid areas, on calcareous sedimentary rocks, with finely divided CaCO ₃ throughout the solum.	Grey-brown and red variants occur, also more clayey types. (Gc1.1).
Hardpan soils	Um5.3 soils		See also Dr1 soils.
Grey clays	Ug3.2 Ug5.2 and Ug5.5 Ug6.2 and Ug6.5 soils		Cracking soils with high volume expansion coefficients. Prone to gilgai formation. Formed on fine-textured alluvium associated with inland river systems, as are brown clays also. Ug5.2 typical
Brown clays	Ug5.3 and Ug5.6 Ug6.3 soils Ug5.32-35. Brown Ug5.37-39. Red		Cracking soils with high volume expansion coefficients. Includes red variants (hue of clay horizon as red or redder than 5YR). Prone to gilgai formation. Ug5.3 typical. Parent material as above and probable aeolian influence.

APPENDIX II Cont'd

Great Soil Group	Northcote Codings	Further Diagnostic Features	Notes
Black earths	Ug5.1 and Ug5.4 Ug6.1 soils		Includes Weisenboden (hydro-morphic variant). Ug5.16, 5.17 Prone to gilgai formation and cracking. Often basaltic in origin. High volume expansion coefficients. Ug5.1 typical. *
Rendzina	Uf6.11, possibly Uf6.22. Some Uc6.12 (Sandy) Some Um6.21 Some Ug5.11	Calcareous parent materials present. Soils rest directly on fresh rock. Usually well-structured.	Similar to shallow friable black earths on calcareous parent material. Uf6.11 typical. More stable than black earths due to less cracking.
Chernozems	Um6.11		Occurrences generally isolated, and restricted to alluvial parent materials with basic constituents. Few erosion problems. Similar to coarser-textured, friable and porous black earths. Um6.11 typical. Organic soils normally very fertile.
Terra Rossa	Um6.24, .33. .43, Uc6.13	Calcareous parent materials present. Soil rests directly on fresh rock.	Normally shallow, structured, red soils on calcareous parent material. Texture varies with texture of parent material.

* Unstable when wet. Erodible under cultivation on long slopes.

APPENDIX II Cont'd

Great Soil Group	Northcote Codings	Further Diagnostic Features	Notes
Podzols	Uc2.3, Uc3.3 soils Some Uc4.3 soils Um2.32 Some Uc2.2	Acid soils with organic A ₁ horizons and accumulation of humus and/or sesquioxides in the B horizon.	Peaty and humic variants occur. There is sometimes minor clay accumulation in the B horizon. These soils occur mainly in cool wet climates and on siliceous parent materials - particularly unconsolidated sands. Uc2.36 is the most typical podzol in the true sense. Low fertility - erodible when exploited.
Alpine Humus Soils	Um7 soils ending in .11, .12.		Shallow organic soils which are acid throughout - typical of cold, wet situations of the S.E. highlands. Erosion likely when native vegetation destroyed.
Humic gleys	Possibly Uf6.4 Uf6.6	Organic soils with evidence of gleying in subsoil.	Vary variable - occur in low lying areas subject to periodic inundation. May be subject to gullying on lower slopes. See also gleyed podzolic soils.
Peat soils	O Acid O Neutral		Soils dominated by plant remains for at least the top 30 cm. Few erosion problems due to situation.
Other Groups			
Leached loams	Um4 soils	Deeper types with stronger pedologic organization. (cf. Lithosols)	

APPENDIX II Cont'd.

Other Groups	Northcote Codings	Further Diagnostic Features	Notes
Structured loams	Um6 soils		Chernozem (Um6.11) is included
Structured subplastic clays	Uf5 soils		Generally stable soils
Structured plastic clays	Uf6 soils		Generally stable soils. Rendzina (Uf6.11) is included.
Dense Clays	Uf6.5, 6.6		Stable soils due to massive structure.
Massive earthy clays	Uf6.71		Stable soils due to massive structure.
Leached clays	Uf4		

APPENDIX II Cont'd

Great Soil Group	Northcote Codings	Further Diagnostic Features	Notes
Prairie soils	Gn3.2, Gn3.3 Gn3.4, Gn3.9 and Gn3.0, Gn4.3 soils Gn4.4. Possibly Uf6.22	Thick dark well-structured A horizon. No free carbonates in solum.	Gn3.42 is modal profile code. These are dark soils, often associated with black earths or krasnozems in higher rainfall areas. Form on basic parent materials usually. Some browner soils are included (Gn3.2). Bleached prairie soils - Gn3.3 Minimal prairie soils - Gn3.9 Gn3.0. Erodible under intensive usage.
Solonized brown soils	Gc1 and Gc2 soils Possibly Gn1.13	Soils dominated by calcareous material throughout the profile.	Mallee soils. These develop from calcareous parent material of transported origin, in semi-arid regions. Gc1.12 typical. Subject to wind erosion when native vegetation removed.
Red earths	Gn2.1 soils	Dark A ₁ horizon normally deep and sandy textured.	Calcareous red earths (normally Gn2.13) also occur. Lateritic or podzolic variants occur but less frequently. Gn2.11 is modal profile code. Gn2.17, .18, .19 - Red leached earths also Gn2.111, .112, .113. Stable soils, especially under pasture.

APPENDIX II Cont'd

Great Soil Group	Northcote Codings	Further Diagnostic Features	Notes
Yellow earths	Gn2.2, Gn2.3, Gn2.4, Gn2.5, Gn2.6, Gn2.7 soils		Similar to red earths except for colour. Red and yellow earths are typically deep soils developed from siliceous parent materials. Gn2.3, 2.7, - Yellow leached earths. Gn2.4 - Yellow-brown earths. Gn2.5 - yellow-brown leached earths.
Euchrozems	Gn3.12 and .13 soils. Gn3.15-.17 Gn4.12, .13. Possibly Uf6.21, Uf6.31	Types with A ₂ horizons (sometimes bleached) are included, but are not typical.	Gn3.12 is the modal profile code. These are the less acid and less friable equivalent of the krasnozems (see below), generally found on basic rocks or colluvium. *
Xanthozems	Gn3.5, Gn3.6, Gn3.7 soils. Gn3.8 Possibly Uf5.23	Types with A ₂ horizons (sometimes bleached) are included, but are not typical.	These soils are essentially yellow krasnozems, which have been formed under less well-drained conditions (see below). Gn3.71 typical. Not common in N.S.W.

* Erosion likely under cultivation on slopes - such soils are highly detachable under saturation and heavy rainfall conditions.

APPENDIX II Cont'd

Great Soil Group	Northcote Codings	Further Diagnostic Features	Notes
Krasnozems	Gn3.10, .11, .14, Gn4.11, .14, Gn4.5 Gn4.6. Possibly Uf5.21	Types with A ₂ horizons (some- times bleached) are included, but are not typical.	Gn4.11 is the modal profile code. Outside the tropics these soils are found mainly on basic parent materials, where annual rainfall is over 1200 mm. Typically they are red, deep, well structured, acid and porous clay soils. Gn4.5 Minimal Krasnozems Gn4.6 Minimal Krasnozems. *
Other Groups	Northcote Codings	Further Diagnostic Features	Notes
Sandy Earths	Gn1 soils		Gn1.13 (possibly solonized brown soil) Gn1.19, .46, .84 - Sandy leached earths
Grey Earths	Gn2.8, Gn2.9 soils		Gn2.9 - Grey leached earths
Dark Earths	Gn2.0		

* Erosion likely under cultivation on slopes - such soils are highly detachable
under saturation and heavy rainfall conditions.

APPENDIX II Cont'd

Great Soil Group	Northcote Codings	Further Diagnostic Features	Notes
Solonetzic Soils	<p>Dr soils ending: 2.43, 2.83, 3.33, 3.42, 3.43, 3.83, 4.43, 5.32, 5.33, 5.42, 5.43.</p> <p>Dy soils ending: 2.33, 2.43, 2.73, 2.82, 2.83, 3.32, 3.33, 3.42, 3.43, 3.73, 3.82, 3.83, 4.33, 4.43, 4.83, 5.32, 5.33, 5.43, 5.82, 5.83.</p> <p>Db and Dd soils ending: 1.33, 1.43, 2.32, 2.33, 2.42, 2.43, 3.33, 3.42, 3.43, 4.43.</p>	<p>A₂ horizon: poorly developed, less than 3 cm thick (solonetz) well developed, more than 3 cm thick solonetzic.</p> <p>A/B boundary abrupt (all soils) B horizon: v. hard/tough consistence (all soils). Prismatic to columnar structure (solonetzic). Columnar or blocky structure with doming (solodized solonetz).</p>	<p>Solonetz soils are normally formed on medium-textured colluvium or alluvium associated with sedimentary parent materials. Solodized solonetz soils are characterized by the domed columnar structure of the B horizon. The whole solonetzic group is typically poor in both chemical and physical fertility, erodibility is extreme dispersibility moderate to high and tunnelling common. Soils with an acid reaction trend are excluded. The group intergrades closely with solodic soils (see below) Individual members are named according to the colour of the B horizon. (e.g. Red solonetzic soil).</p>

APPENDIX II Cont'd

Great Soil Group	Northcote Codings	Further Diagnostic Features	Notes
Red-brown earths	<p>Dr soils ending: 2.13, 2.22, 2.23, 2.63, 3.13, 3.22, 3.23, 4.33, 4.73, Db soils ending: 1.13, 1.22, 1.23, 1.33, 1.62, 2.13, 2.22, 2.23, 3.22, 3.23 Possibly Dd4.13</p>	<p>A₂ horizon: poorly developed A/B boundary abrupt to clear B horizon: Hard/firm to friable consistence. Blocky structure. Soils ending .33 or .73 tend to have solonetzic features, and could be regarded as intergrades.</p>	<p>Dr2.23 is the modal profile code. These soils should not be confused with red solodic soils. The important features are the character of the A₂ horizon, structure in the B horizon, and reaction trend. They form on a wide range of parent mater- ials, except for the most acid and most basic igneous rocks. Erosion is widespread on these soils, particu- larly under continuous cultivation or over grazing. Structural deterioration of the A₁ horizon can be very rapid.</p>
Solodic soils	<p>Dr soils ending: 2.32, 2.33, 2.42, 2.53, 2.62, 2.72, 2.73, 2.82, 2.83, 3.32, 3.62, 4.42, 4.72, 4.82, 5.22, 5.23, 5.62 Dy soils ending: 2.13, 2.23, 2.32, 2.42, 3.13, 3.23, 3.53, 3.63, 3.82, 4.13, 4.23, 4.32, 4.42, 5.13, 5.23, 5.42, 5.63, 5.82, Dd soils ending: 1.13, 1.23, 1.32, 1.33, 1.42, 2.12, 2.13, 2.22, 2.32, 3.13, 3.23, 3.32, 4.13, 4.23, 4.32, 4.63</p>	<p>A₂ horizon: well developed A/B boundary, abrupt B horizon: Hard/ v. tough consistence. Blocky structure but some- times massive.</p>	<p>These soils are similar to, and intergrade with, solodized solonetz soils. The structure of the B horizon tends to be less coarse. Sub soils are usually dispersible, giving rise to tunnelling and high erodibility. They form on a wide range of parent materials except the most basic. Individual members are named according to the colour of the B horizon (e.g. yellow solodic soil).</p>

APPENDIX II Cont'd

Great Soil Group	Northcote Codings	Further Diagnostic Features	Notes
Solods	<p>Dr soils ending: 2.41, 2.81, 3.31, 3.41, 3.71, 3.81, 4.41, 4.81, 5.41, 5.81</p> <p>Dy soils ending: 2.41, 2.81, 3.31, 3.41, 3.71, 3.81, 4.41, 4.81, 5.31, 5.41, 5.71, 5.81,</p> <p>Dδ soils ending: 1.41, 1.81, 2.31, 2.41, 3.40, 3.41,</p> <p>Dδ soils ending: 1.31, 1.41, 1.81, 2.31, 2.41, 3.41,</p>	A ₂ horizon: well developed A/B boundary abrupt. B horizon: Hard v. tough consistence. Blocky structure but sometimes massive.	Solods are the acid members of the solodic group, and have somewhat less abrupt A/B boundaries, and more friable consistence in the B horizon. These soils are less dispersible than solodic soils generally.
Desert loams	Dr 1 soils (excepting those below)	No pans. Alkaline.	Dr1.33 is the modal profile code. These soils are found on fine-textured sedimentary rocks and alluvium of the arid inland. Crusting surface can give rise to low infiltration and high run-off rates.
Hardpan soils	Dr1 soils ending: .14, .15, .16, .54, .55, .56		See also Um5.3. These soils are common in the central part of W.A. but not as common in N.S.W.

APPENDIX II Cont'd

Great Soil Group	Northcote Codings	Further Diagnostic Features	Notes
Non-calcareous brown soils	Dr2 or Db1 soils ending in .12, .52. Possibly Db1.22, Dr2.22		Dr2.12 is the modal profile code. Differ from red-brown earths in lack of A ₂ horizon, and less alkaline reaction trend. (In W.A. Dr2.22 is typical). Erodibility similar to that of red-brown earths.
Chocolate soils	Db3.1 soils. Dr4.1, .2, .5 and .6 soils also Db3.21		Shallow well-structured and friable reddish-brown soils on basalt and similar rocks. Some types are more uniform, tending towards Um6, or Uf6: A ₂ horizons are generally indistinct. Normal chocolate soils are clay-loam over clay soils with an acid reaction trend. Probably the most stable of the duplex soils.
Grey-brown podzolic soils	Db1 and Db2 soils ending .21, .61. Also Db1.31, Db4.21	A ₂ horizon well developed. A/B boundary abrupt to clear. B horizon has: Firm/plastic consistence. Blocky structure.	A ₂ horizon sometimes bleached. Drab colours predominate in these soils as compared with red and yellow podzolic soils. Are sometimes associated with brown podzolic soils in drier parts of the Eastern highlands. They are occasionally dispersible, and occur on a range of parent materials. Gully erosion is fairly common in these soils.

APPENDIX II Cont'd

Great Soil Group	Northcote Codings	Further Diagnostic Features	Notes
Red podzolic soils	Dr2, Dr3, Dr5 soils ending in .11, .21, .31, .61, also Dr2.51, .51, .71 excepting Dr3.31, Dr5.31 Dr3.51	A ₂ horizon well developed. A/B boundary clear to gradual. B horizon has: Firm/friable consistence. Fine angular blocky structure.	Dr2.21 is the modal profile code. These soils are typical of coastal and sub-coastal regions in N.S.W. often grading into red earths or krasnozems in wetter areas, into red solodic soils in drier areas, or into yellow podzolic soils in lower catenary positions. They are more stable than other podzolic soils, and occur on a wide range of parent materials.
Yellow podzolic soils	Dy2, Dy3, Dy4, Dy5 soils ending in .11, .12, .21, .22, .51, .52, .61 .71 Dy 2.31	A ₂ horizon well developed. A/B boundary clear to gradual. B horizon has: Firm/friable consistence. Fine polyhedral or blocky structure.	Dy2.21 or Dy3.21 is the modal profile code. These soils form in catenary association with red podzolic soils in poorly drained situations, and on a wide range of parent materials. A ₂ horizon is less bleached than that of the yellow solodic soil, often more so than in the red podzolic soil. Are sometimes dispersible especially in coastal areas.
Brown podzolic soils	Db soils ending in .11, .51 (except Db3)	A ₂ horizon not evident, A/B boundary gradual to diffuse. B horizon has: Friable consistence. Weak to blocky structure.	The A horizon has higher organic matter content than the other podzolic soils, which masks the strong horizonation typical of them. These soils are found on the eastern highlands in cool, moist situations (e.g. Monaro, New England plateau). The brown colouration applies to the whole of the profile. They tend to be more stable than other podzolic soils.

APPENDIX II Cont'd

Great Soil Group	Northcote Codings	Further Diagnostic Features	Notes
Lateritic podzolic soils	Dy2, Dy4, Dy3, and Dy5 soils ending in .84, .85, .86 Some Dy3.61, 5.61 5.41.	Ironstone layer at base of thick sandy A horizon. Mottled kaolin clay layer at base of B horizon, but this is sometimes absent.	Any podzolic soil with laterite included. Dy3.84 is the modal profile code. These are generally relict soils not common in N.S.W.
Gleyed podzolic soils	Dg soils	Gleying: Coarse mottling throughout B horizon. Evidence of high water table, (grey or blue colours).	Any podzolic soil showing gleyed features is included. The gleying may be due to prolonged seepage in the soil, or to high water table. See also Humic Gleys. May be gully eroded on lower lands.
Other Groups			
Dark Podzolic soils	Dd1 and Dd3 soils ending: .11, .12, .21, .22, .51. Also Dd2.11 Dd4.11		Intergrade with solods.

INDEX

- A horizon, 40, 42, 43, 44, 46, 88
 "A" line, 151
 abrasion, 12
 absorptive capacity, 30
 accelerated erosion, 15, 22
 acid bleached grey earths, 25
 acid grey earths, 25
 acid rocks, 39
 acrisols, 102
 aeration, 29
 aggregate stability, 12, 29
 aggregate stability assessment, 134, 135
 aggregation, 23
 agricultural production, 28
 air photograph interpretation (API), 58, 62
 alfisols, 98
 alkalinity, 29, 124
 alluvial soils, 37, 57, 64
 alpine humus soils, 24, 25, 54
 amelioration, 7
 andosols, 101
 apedal soil, 50
 arenosols, 101
 aridisols, 98
 Atterberg limits, 20, 176
 auger, 47, 84
 azonal soils, 37
- B horizon, 42, 43, 44, 46
 banks, 31, 35
 bank spacing, 30, 130, 143
 bank spacing factor, 144
 bank channels, 141
 bases, 41c
 basic rocks, 39
 batter gradients, 35
 bearing value, 125, 127
 black earths, 22, 23, 25, 26, 38, 41a
 blanket, 126
 bleaching, 40, 50
 brown calcareous soils, 25
 brown clay, 24, 25, 54
 brown gibber soils, 95
 brown mallee soils, 22
 buried soils, 42, 55
- C horizon, 43, 45, 46
 calcareous sands, 24, 25
 calcareous soils, 79
 calcium carbonate, 38, 52, 53, 79
 calcium sulphate, 38
 cambisols, 102
 castanozems, 101
 catena, 55, 67
 cathedralism, 17
 cation exchange, 27
 cation exchange capacity, 20
 central core embankment, 193
 channel scouring, 17
- chernozems, 25, 41a
 chlorides, 54
 chocolate soils, 24, 25
 chroma, 49
 class (Northcote), 78, 80, 86
 classification of fine-grained soils, 151
 clay, 21, 24, 48, 148, 149
 clay loams, 48, 49
 clay mineralogy, 20
 clay pans, 52
 clay particles, 12
 clay type, 12
 climate, 11, 37, 112
 coarse-grained sandy soils, 13
 coarse-textured soils, 48
 coding (Northcote), 78
 coefficient runoff, 30, 130, 136
 coherence, 51
 colluvial detritus, 19
 colour, 49
 compaction, 7, 32, 155, 156, 157, 160, 163
 compaction control, 164
 compaction equipment, 156, 157
 compactive force, 163
 compressibility, 33, 155, 156, 157
 conductivity, 26
 cone penetrometer, 20
 consistence, 29, 52, 85
 consolidation, 33
 conspicuously bleached, 50
 contour banks, 16
 contour furrows, 16
 correlations, 208
 cracking, 7, 14, 34, 79
 cracking soils, 64
 cracking (surface), 120
 critical velocities, 140
 cropping, 23
 cultural practices, 16
 cut and fill, 18
- D horizon, 43, 45, 46
 dams, 158, 159
 deep red friable loams, 25
 deflocculation, 12
 degradation, 6
 density and moisture content, 161
 depositional sites, 41
 depth, 29
 depth of A horizon, 88
 detachability, 131, 132
 detachment, 12, 23
 desert loam, 22, 54, 96
 desert sand plains, 22
 differential settlement, 34, 195
 dilatancy, 153
 Dispersal Index, 184
 Dispersal Index test, 122, 176, 177, 178

- dispersible soils, 7, 17, 33, 121
- dispersibility, 29, 30, 138
- dispersion, 11, 12
- division (Northcote), 78, 79, 86
- double-zoned embankment, 193
- drainage, 23, 29, 31
- drought, 22
- dry settlement, 195, 196
- dry strength, 153
- dryland agriculture, 109
- duplex soils, 38, 41a, 41c, 49, 79

- Earth structures, 29, 188, 189, 192
- earthworks, 11, 31, 146
- earthy fabric, 50
- electrolyte content, 33
- eluvial horizons, 43
- eluviation, 43
- embankments, 193
- embankment settlement, 194
- Emerson's aggregate classes, 181
- Emerson Aggregate Test, 20, 53, 122, 123, 180-184, 187
- engineering behaviour, 11
- engineering characteristics of soil groups, 155, 160
- engineering suitability, 29
- entisols, 98
- epimorphism, 41
- ermosols, 101
- erodibility, 12, 13-14, 29, 30, 113, 130, 131-132, 145
- erodibility index, 133, 138
- erosion, 6, 11, 29
- erosion-accelerated, 15, 22
- erosion-existing, 115
- erosion-gully, 15, 16
- erosion-headward, 17
- erosion-landslips, 18
- erosion-sheet, 15
- erosion-splash, 15
- erosion-tunnel, 15, 17, 18
- erosion-water, 11, 12, 15
- erosion-wind, 12, 15, 20-22
- euchrozems, 24, 25
- evaporation, 38
- exchangeable sodium, 7, 12, 18
- expansive soils, 120, 121

- F.A.O./UNESCO Soil Classification System 100
- fabric, 50
- fabric-contrast soil, 41a
- Factual Key, 8
- Factual Key operation, 80
- farm planning, 116
- ferralsols, 102
- ferric iron, 21, 56
- ferromagnesian minerals, 39
- fertility, 23-28, 30, 125
- field texturing procedure, 48
- fine-textured soils, 48
- flow rates, 30
- flows, 19

- flumes, 31
- fluvisols, 101
- foundation material, 30, 125
- free survey, 62, 63
- freezing/thawing, 12

- G horizon, 45
- geologic erosion, 15
- gilgai, 41a, 64, 120
- gleying, 45
- gleysols, 101
- gradation, 147
- gradational soils, 49, 79
- graded banks, 16
- granite soils, 95
- gravel and sand, 147
- Great Soil Groups, 8, 38, 66
- Great Soil Group Identification, 223
- Great Soil Group System, 72-77
- grey/brown soils of heavy texture, 22
- grey calcareous soils, 25
- grey clay, 24, 25, 54
- grid survey, 62, 63
- gullies, 16
- gully branching, 17
- gully control structures, 31, 57, 196, 197
- gully erosion, 15, 16
- gully filling, 17, 31
- gullying, 17
- gypsum, 7, 38

- Halosols, 101
- hard red soils, 91
- hardsetting surface, 51
- headward erosion, 17
- heavy clays, 48, 49, 94
- histosols, 98, 102
- horizon depth, 138, 139
- hue, 49
- humic gleys, 25
- humus, 52
- hydraulic conductivity, 12, 13, 142
- hydraulic gradient, 33
- hydraulic head, 32
- hydrostatic head, 33
- hydrology, 11, 30

- Identification of soil groups, 208, 223
- igneous rocks, 39
- illuvial horizons, 43
- illuviation, 43
- inceptisols, 98
- indurated horizon, 19
- infiltration, 12, 13, 27, 29, 130, 137
- infiltration capacity, 31, 137
- infiltration class, 142
- infiltration characteristics, 12, 31
- interparticle bonds, 12
- intrazonal soils, 36
- iron oxides, 52
- ironstone gravels, 25

- Kaolinite, 14
 krasnozems, 24, 25, 38, 41a, 41b
- Land capability, 8
 land capability assessment, 109
 land capability class definitions, 111
 landform, 11, 112, 117
 land slope, 112
 land use, 11, 27
 landslip, 15
 landslip erosion, 18
 lateral transport, 40
 lateritic podzolic soils, 25
 leaching, 38, 39, 41
 leaking gully control structures, 197
 light clays, 48, 49
 lime, 7, 38
 linear shrinkage, 121, 179, 187
 linear shrinkage test, 20, 179
 liquid limit, 121, 176
 lithosols, 25, 41a, 42, 102
 loams, 48, 49
 luvisols, 102
- Map scale, 58
 map unit quality, 105
 mapping classes, 65
 mass movement, 18, 30, 119
 massive surface horizon, 51
 maximum compaction, 163
 maximum dry density, 155
 maximum permissible velocity, 141
 medium texture soils, 48
 microbial population, 27
 minimum tillage, 29
 modal profile, 60
 moisture content, 161
 mollisols, 98
 montmorillonite, 7, 14, 34, 120
 mottling, 51
 multivariate (statistical) methods, 104, 106
 Munsell soil colour chart, 49
- New mineral formation, 40, 41
 non-calcic brown soils, 25
 Northcote codings, 8
 Northcote Factual Key, 68, 77
 nutrient supply, 29
- O horizon, 44
 optimum moisture content, 32, 155
 organic coatings, 13
 organic horizon, 44, 46
 organic matter, 12, 21, 23, 29, 54, 149
 organic (O) soils, 79
 organisms, 37
 overland flow, 15
 oxisols, 98
- Pans, 52
 paramosols, 102
 parent material, 19, 37, 39, 43, 46
- particle packing, 162
 particle size analysis, 123, 174, 175
 186
 particle size distribution, 20
 pasture improvement, 23
 pedal soil, 50
 pedalfers, 75
 pedality, 50
 pedocals, 75
 pedologic organization, 50
 peds, 50
 percolation, 32
 permanent storage structures, 126, 127
 permeability, 19, 29, 30, 32, 122, 137
 155, 156, 157
 pH, 23, 26, 29, 53
 phaeozems, 102
 phreatic line, 32
 physiographic survey, 62, 63
 planosols, 101
 plant growth, 11
 plant nutrient availability, 23
 plant residues, 16
 plastic limit, 176
 plasticity index, 121, 176
 podzolic soils, 38, 54
 podzols, 22, 24, 25, 38, 41a, 102
 pore size, 13
 pores, 13
 porosity, 31
 prairie soils, 25, 38, 41a, 41b
 precipitation, 38
 primary profile form, 66
 principal profile form, 66, 78, 80, 86
 principal components analysis, 107
 Proctor compaction test, 20, 155, 185
 projects, 8
- Raindrop splash, 15
 rainfall amount, 11, 113
 rainfall duration, 11
 rainfall intensity, 11, 113
 rankers, 101
 rates of flow, 30
 Raupach's Solution, 51
 recommendations for earth structures, 188, 192
 red-brown earths, 22, 25, 38
 red calcareous soils, 25
 red clays, 24, 25, 54
 red earths, 24, 25, 41a
 red podzolic soils, 24, 25, 42
 relief, 37
 rendzinas, 101
 residual sites, 41
 resistance to cracking, 156, 157
 resistance to piping, 156, 157
 retardance, 23
 revegetation, 26
 rhegosols, 101
 rills, 15, 16
 rockiness, 29
 rocks and stones, 115

- roller compaction, 163
- rough-ped fabric, 50
- runoff, 11, 12, 15, 30
- runoff coefficient, 30, 130, 136
- runoff index, 139
- Saline soils, 124
- salinity, 23, 26, 29, 30, 124
- salinity/alkalinity, 115
- saltation, 12, 21
- salting, 56
- sand, 48, 147
- sandy fabric, 50
- sandy loams, 48, 49
- saturated hydraulic conductivity, 13
- saturation settlement, 195, 196
- seasonal cracking, 79
- section (Northcote), 66, 78, 80, 86
- sedimentary rocks, 39
- seepage, 7, 32, 33
- seepage path, 33
- self-mulching soils, 14, 51
- septic tank, 127
- sesquioxides, 52
- settlement, 33, 34, 35
- sewerage, 127
- shear failure, 19
- shear strength, 20, 35, 155, 156, 157
- shear strength test, 20
- shearing resistance, 18
- shearing stress, 18
- sheet erosion, 15
- shrink/swell potential, 30, 121, 187
- signal enhancement seismograph, 19
- silica, 52
- siliceous sands, 25
- silt, 48, 148, 149
- site drainage, 19
- skeletal soils, 22, 37, 64, 93
- slides, 19
- slope, 11
- slope failure, 18, 19
- sloping core embankment, 193
- slumping, 17, 35
- small earthfill dams, 158-9
- smooth-ped fabric, 50
- sodic clay, 18
- sodicity, 124
- soft red soils, 90
- soil aggregates, 11
- soil auger, 84
- soil boundaries, 63, 68
- soil classification, 8, 70
- soil classification categories, 66
- soil classification systems:
 - FAO, 100
 - Great Soil Groups, 72
 - Northcote Factual Key, 77
 - Soil Conservation Service, 87
 - Unified, 152
 - United States, 97
- soil coding, 78
- soil colour, 19, 49
- soil compaction, 7, 32, 155, 156, 157, 160, 163, 164
- soil components, 146
- soil conservation earthworks, 31
- soil conservation farm planning, 8, 116
- soil conservation mapping, 68
- Soil Conservation Service of NSW, 6
- soil consistence, 29, 52, 85
- soil dendrogram, 108
- soil detachability, 131, 132
- soil dispersibility, 7, 13, 29, 30, 177
- soil distribution, 54, 64
- soil erodibility, 12, 13-14, 29, 30, 113, 130, 131-132, 145
- soil erosion, 6
- soil fertility, 23-28, 30, 125
- soil formation, 36-42
- soil gradation, 147
- soil horizons, 42, 44-46
- soil identification, 208, 223
- soil infiltration, 12-13, 27, 29, 130, 137
- soil map, 64, 65, 68
- soil mapping categories:
 - soil association, 55, 67
 - soil class, 66
 - soil complex, 67
 - soil family, 66, 67
 - soil order, 66
 - soil phase, 66
 - soil series, 66, 67
 - soil type, 66
 - soil variant, 66
- soil moisture relations, 27
- soil morphology, 42
- soil particle packing, 162
- soil permeability, 122
- soil pH, 23, 26, 29, 53
- soil profile, 9, 42, 43, 46
- soil profile examination, 47
- soil profile nomenclature, 46
- soil profile pit, 47
- soil properties (Northcote), 86
- soil reaction trend, 51, 52
- soil sampling, 196
- soil stabilization, 165
- soil structure, 13, 16, 29, 50, 137, 138, 139
- soil structure assessment, 134
- soil survey, 8, 57-58
- soil survey methodology, 60
- Soil Taxonomy, 97
- soil testing, 20, 173
- soil testing interpretation, 184
- soil testing kits, 53
- soil texture, 13, 21, 22, 29, 48, 137, 138, 139
- soil texture assessment, 133
- soil/water extract, 26
- solodic soils, 24, 25, 54
- solodized solonetz, 24, 25, 42
- solods, 25
- solonchaks, 24, 25
- solonetzic soils, 38
- solonized brown soils, 25, 54, 92
- soloths, 38
- soluble salts, 38

solum, 43, 46
 splash, 11, 12
 splash erosion, 15
 spodosols, 99
 sporadic bleaching, 50
 spring water, 33
 stability, 11
 stoniness, 29
 storage structures, 126, 127
 stubble mulching, 29
 subclass (Northcote), 78
 subdivision (Northcote), 78, 79, 86
 subsection (Northcote), 78
 subsoil, 28, 30
 subsurface drainage, 122
 sulphates, 54
 surface cracking, 120
 surface creep, 21
 surface crust, 51
 surface roughness, 11
 surface stability, 29
 surface structure, 87
 surface texture, 87
 suspension, 21

 Temporary storage structures, 126, 127
 terra rossa soils, 24, 25
 texture, 13, 21, 22, 29, 48, 137
 texture assessment, 133
 texture-contrast soil, 41a-c, 49, 93
 time (weathering duration), 37
 time of concentration, 30, 130
 toe drains, 126
 topography, 11
 toposquence, 55, 67
 topsoil, 28, 30
 topsoiling, 34
 toughness, 154
 toxicity, 29
 transportation sites, 41
 truncation, 55
 tunnel erosion, 15, 17, 18
 tunnelling, 7, 33
 tunnelling susceptibility, 184, 187

 Ultisols, 99
 undercutting, 17
 Unified Soil Classification System,
 127-9, 142, 146-60, 185
 uniform soils, 49, 79
 univariate (statistical) methods, 104
 Universal Indicator, 51
 upstream blanket embankment, 193
 urban capability assessment, 116
 urban capability report, 117
 urban development, 29
 urban soil factors, 117
 urban soil survey technique, 118

 Value (soil colour), 49
 value/chroma rating, 50
 vegetated channel, 141
 vegetative cover, 11, 22-23

vegetation, 11, 22-23
 vertisols, 99, 101
 voids, 32
 volume expansion, 179

 Water erosion, 11, 12, 15-17
 water-holding capacity, 23, 29, 114
 water movement, 11
 water repellant sands, 13
 water table, 19
 water transmissivity, 131
 water transmitting properties, 132
 waterways, 31
 weathering, 37, 39, 41
 well, 126
 well-graded (texture), 14
 wet and dry strength, 29
 wetting/drying, 12
 wetness, 115
 wetness and drainage, 29
 wind erosion, 12, 20-22

 Xanthozems, 25
 xerosols, 101

 Yellow earths, 25, 41a
 yellow friable loams, 25
 yellow podzolic soils, 25

 Zonal soils, 36
 zoned embankments, 34, 193


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