Soil Surveying in Agriculture: Current Practices and Future Directions
A symposium organised jointly by the Australian Soil Science Society Inc. (Victorian branch) and the Department of Primary Industries (Tatura Centre). Tatura, 3 October 2003

Principles of soil surveying: Theoretical considerations

Robert van de Graaff, PhD

van de Graaff and Associates, Pty Ltd
Mitcham, Victoria

Introduction

For any soil survey it is necessary to detail the objective of the work so that the end result can be judged in terms of how well it meets its objective. For the purpose of this paper I shall consider the term "*soil*" as meaning the same thing as 'land resource', but an individual "*soil type*" will be a category of soil at some unspecified level of classification.

The purpose of the soil survey is intimately bound up with the selected scale of mapping. The scale of mapping determines the approach to fieldwork and to what extent use will be made of aerial photography or other forms of remote sensing. The scale also determines to what degree the presented information relies on chemical and physical analyses of soil samples, as well as any *in situ* testing of soil properties.

The purpose of a soil survey may be merely to develop a general inventory of soil, or it may have very specific purposes, such as assessing land suitability for irrigation or urban uses (Reid *et al.* 1988). The first type of survey usually covers large areas and is presented at a suitable small-scale map, while the latter may be restricted to small areas and be presented at a large scale, suitable for subsequent planning of an irrigation scheme or urban development. As a guide towards the appropriate survey scale, I shall combine the Tables from Reid (1988) and Gunn *et al.* (1988), with the guidelines from the Soil Survey Manual (Soil Survey Staff 1951) in Table 1.

Table 1 Guideline specifications for soil or land resource mapping

Orders of soil or land survey	Appropriate map scale	Minimum delineation[1] (ha)	Mapping units[2,3,4]	Component units[2,3,4] (Not mapped)	Survey objectives
Very high intensity (Very large scale)	1:5 000 1:10 000	0.05 – 0.07 0.20 – 0.27	Land facets, soil phases and soil types, PPF, PPF+	- soil phases	Agriculture research areas, irrigation implementation, urban development, highway planning, mine site rehabilitation, property planning
High intensity	1:20 000 1:25 000	0.8 – 1.1 1.2 – 1.7	Land facets, soil types, soil complexes, PPF	- soil types, PPF	Agriculture production, urban development, highway planning, mine site rehab., shire planning, catchment management
Medium intensity	1:50 000	5.0 – 6.7	Land systems, soil series, soil associations	Land facets Soil series, PPF	Agriculture production, irrigation feasibility, shire planning, catchment management
Low intensity	1:100 000	20 - 27	Land systems, soil associations,	Land facets Soil series, PPF, soil associations	Agriculture & irrigation feasibility, shire planning, large catchment management
Reconnaissance	1:250 000 1:500 000 1:1 000 000	120 – 170 500 - 675	Land systems Great Soil Groups	Land facets PPF, Soil associations	Land resource inventory, agriculture development potential, infrastructure planning
Synthesis (Very small scale)	1:2 000 000	8000 – 11000	Regions or provinces; no soil equivalent	Land systems Great Soil Groups	Natural resource inventory, continental scale mapping

[1] The size delineation depends on whether the area shown has uniform or elongated occurrence, such as a narrow floodplain following a river.
[2] Mapping units and component units are defined in Gunn *et al*. (1988)
[3] PPF, Primary Profile Form; PPF+, subdivisions of a Primary Profile Form (Northcote 1979)
[4] Great Soil Groups as described in Stace *et al.* (1972)

Structure, relationships and terminology in soil survey reports

It is essential that the information presented in the soil survey report be properly structured in every sense of the word, and that any important pedological and geomorphologic relationships are listed and explained so that the reader can more easily understand, remember and extend the information. It is also important to adhere to accepted terminology and definitions to prevent misunderstanding by the user of the information. Adhockery is blight on soil survey reports.

Hierarchy of soil mapping units

Soil mapping units are usually ordered into a hierarchy, traditionally comprising the *soil series*, *type* and *phase* designations.

Soil series

The 'soil series' is a group of soils having soil horizons similar in differentiating characteristics and arrangement in the soil profile, except for texture of the surface soil. The soil series has developed from a particular type of parent material. It is comparable to Northcote's Primary Profile Form, except that the latter does not specify an identical parentage, so that there are far fewer Primary Profile Forms than there can be soil series. The soil series is differentiated on the basis of significant morphological features, such as kind, thickness, and arrangement of horizons; horizon colour, structure, texture (except of the A horizon), reaction, carbonates, etc. These features are used by Northcote to subdivide his lower level Classes and Principal Profile Forms.

Soil type

The 'soil type' is a subdivision of the 'soil series', as explained above, on the basis of A-horizon soil texture. The series was given a local name and the soil type added a textural parameter, e.g., Plainfield sand.

Soil phases

'Soil phases' were used as a further mapping subdivision to indicate, for example, gravelly, eroded, complex slope, or shallow variants of the soil type.

Older Australian soil surveys (pre-World War and immediately post World War) tended to be large-scale surveys for a specific purpose, such as irrigation development and used the American system of *soil series* and *soil types*. For small-scale surveys, which tended to become more frequent at a later time, *soil associations* or *Great Soil Groups* would often have been the mapping units of choice to cope with the decreasing homogeneity within these units.

Hierarchy of land mapping units

Distinctions between morphological and genetic land mapping units

Landform description is very helpful as it helps the reader to readily identify or imagine the part of the terrain under discussion (Speight: *in* McDonald *et al.,* 1990). However, the use of landform descriptions must not allow confusion by mingling purely *morphological* descriptive terms with names that have a *genetic*, geomorphic connotation. One must never mix two classifications that have different aims, because this creates classes that double up. For example, peneplains and pediplains (pediments) are special kinds of plains defined by their geomorphic history, whereas the term 'plain' simply denotes a rather level and extensive landform of undefined origin. From the known or assumed geomorphic history one can draw additional inferences that may be useful for practical land use purposes. Thus peneplains and pediments are very old erosional and depositional land forms, but a flood plain is a very young one and, if contemporaneous, will still be subject to periodic inundation.

Landform patterns and elements

It is almost inevitable that mapping large areas at small scale involves complex mapping units, such as *landform patterns*. These will have a range of *landform elements* within them, and each landform is likely to have more than one distinct kind of soil. A landform element may be characterised by its slope and position in a toposequence, whereas relief and stream occurrence describe something wider, a landform pattern.

At larger scales of mapping it may be feasible to delineate single landforms using stereoscopic aerial photo interpretation to exploit boundaries that are easily observed on the basis of sharp slope changes, colour or tone or other such features.

Speight (*in* McDonald *et al.,* 1990) gives a key to landform element types, in which the names are related to the mode of geomorphic activity and the land-forming agent, as well as a glossary of landform patterns, most of which are defined by morphology as well as geomorphic process. These should be contrasted with the names used for erosional landform patterns characterised merely by relief and modal slope.

Mapping detail and information content of mapping units

Depending on what previous knowledge is available already prior to a soil survey, or the amount of time and resources available to carry it out, we can distinguish four broad cases of soil survey involving mapping (Table 2).

Table 2. General types of soil survey

Cartographically detailed Categorically detailed	Cartographically detailed Categorically cursory
Cartographically cursory Categorically detailed	Cartographically cursory Categorically cursory

Cartographically detailed and Categorically detailed soil surveys

This type of mapping is typical of many of the old, detailed soil maps produced in Victoria for the irrigation areas. The oldest of these maps were sometimes produced without the benefit of an accurate topographical base map and aerial photography, and therefore are spatially not accurate. These maps can be updated with the aid of highly accurate spatial and topographic information (that has become available in recent years), and using GIS techniques.

Many of these detailed surveys were carried out as *grid surveys*. My own experience is of the 1:10,000 survey of a Rhine River floodplain area near Utrecht, with parallel traverses 200 m apart following the main drainage ditch system. I used a cadastral map and soil borings every 50 m along each traverse.

By contrast, when I was soil series-slope mapping in Seneca County, New York (at a scale of 1:15,840) for the U.S.D.A. Soil Conservation Service (Hutton, 1972) over three summers, sampling was entirely based on a *free survey*, aided by large-scale black and white aerial photographs for navigation in the field.

Cartographically cursory and Categorically detailed soil surveys

This kind of survey fits the small-scale, land system mapping that has become a common activity in Australia in the post-war years. The boundaries of these surveys enclose large areas of internal complexity, but recurring constituent land units. Due to intensive field work at a few selected sites, it is possible to describe in reasonable detail the recurring pattern of soils that are likely to be found there, the ecosystem components in terms of native vegetation, and the kind of landforms and geomorphic processes currently active. The field method uses *free survey*. Aerial photography is used for extending mapping boundaries in areas not visited on the field.

Cartographically detailed and Categorically cursory

This kind of map is probably rather rare. It presupposes that boundaries of mapping units can be drawn very accurately at large scale, but little is discovered about the contents of the mapping unit. They are only possible where mapping units are evident from aerial photos.

Cartographically cursory and Categorically cursory

These are the sorts of maps one finds in atlases. They provide only a broad overview of the earth’s surface and have little practical value. They are mainly used for general education in geography.

Relation of map scale to intensity of fieldwork

Most soil surveying agencies in the world accept that the number of man-days in the field per square kilometre mapped will be a function of map scale. The larger the scale and the more detail presented, the more time will have to be devoted to fieldwork. Reid (*in*: Gunn *et al*., 1988) provides estimates of soil survey rates by full-time experienced soil surveyors (Table 3). Beattie and Gunn (*in* Gunn *et al*., 1988) derive similar relationships for land system surveys at different scales.

Table 3. Soil survey rates at different intensities and scales

Intensity example	Scale	Survey rate (km^2 / man-year) Without air-photo interpretation	With air-photo interpretation
Very high	1:10 000	7 – 14	14 – 28
High	1:25 000	30 – 60	85 – 170
Medium	1:50 000	85 – 170	260 – 520
Low	1:100 000	350 – 700	1000 – 2000

Bie and Beckett (1970, 1971) did an international survey of soil survey organisational practices and summarised their findings in the form of a logarithmic function:

$$\log_{10}E = 7.41 + 1.57 \log_{10}S \qquad (1)$$

where E is survey effort in man-days per km^2 in the field and S is map scale expressed as a fraction. This function can be portrayed on double logarithmic paper to facilitate reading off the value of E for any chosen scale S.

For example, assuming a map scale of 1:25 000, then:

$$\log E = 7.41 + 1.57 \log (1/25,000) \qquad (2)$$

Hence, the survey effort (E) on this scale is approximately 3.2 man-days per km^2.

Comparisons of fieldwork intensity in New York and Queensland

The required intensity of fieldwork also depends on whether there is prior knowledge of the common soils making up catenas in the landscape. In the examples mentioned above of soil survey in the Rhine River floodplain and in New York State, all the common soil types and their catenary sequences on specified glacial and alluvial or lacustrine parent materials were already well known and had been defined. The issues were simply to map them at the specified scales.

The daily survey rate in Seneca County (New York), required of us for mapping at a scale of 1:15,840, was no more than 2 days per square mile. This survey rate covers, at least 1.28 km^2 per day, equal to about 0.8 man-days/km. I found this a feasible minimum production rate. Rainy days were used for office work.

Australia, with its large landmass and brief history of establishment, has had to make compromises on this survey rate. For example, McDonald (1975) in Queensland suggested a “relaxed” survey rate of 1.7 to 1.5 man-days/km^2 at scale 1:25,000, twice the rate above.

Case Studies of insufficient time and no quality control in soil survey

Case 1 A rapid soil and land type survey around Melbourne

The following story illustrates what happens, if there are *no production criteria* and there is *no theoretical framework* in a soil survey. One group in the former Land Protection Service (LPS) of the Victorian Department of Conservation conducted one "detailed soil and land type survey" of 2300 km^2 of the non-urban and corridor zones of the Melbourne Metropolitan Planning Scheme (MMPS) at a scale of 1:25,000, published in 1985. They proceeded at an extremely fast rate of approximately 6 km^2/man-day (0.17 man-days/km^2), which included also all the time in the office and any rainy days. During this time, moreover, the same workers were simultaneously busy on another survey elsewhere: a 5,728 km^2 of land in the Wimmera and Rocklands Reservoir catchment, centring on the Grampians National Park (White et al., 1985). The MMPS survey was partly carried out by a fresh university graduate, without any previous experience. The survey was forced to rely almost exclusively on aerial photo interpretation and produced a poor quality map. (By comparison, and at the other extreme, some land systems mapping conducted by others in LPS took years to complete, but at least tended to result in reliable data and maps).

Case 2 "Cut and paste" soil surveys

Sheer lack of time for quality work, departmental chaos, absence of professional leadership and pressure from "above" for ever faster work, during the 1985-1990 period, brought about a culture of "cut and paste" from previous reports. This resulted in serious inconsistencies.

In many reports, mapping units were each being accompanied by quantitative statements on permeability classes of the soils in them. In MMPS report the glossary boasts that these permeability classes are "the most commonly recorded values determined by a constant head method." To the best of my knowledge, no permeability tests were ever carried out during that particular survey. However, a handful of permeability tests had been carried out for a previous survey (in another area, Berwick-Pakenham) and that report's glossary became the source of the glossary in the MMPS report.

The successor to this MMPS survey (White et al., 1985) contained the same glossary, but this time contradicted itself in one section on land capability with respect to the method said to have been used for measuring soil permeability, again without any measurements having been made. Of the four mappers who carried out this survey, two had no experience whatsoever, and one was fresh out of university.

A fourth survey report (White, 1990), however was more honest, and admitted that the soil permeability classes "were described" as a property of the soil profile in the field, as if this is as easy as noting a Munsell soil colour.

Case 3 "Short-cut" soil surveys

In the same 1985-1990 period there was so little time for fieldwork *and especially for thought*, that "shortcuts" were employed. A time-saving short-cut was to assume that the soils on a particular parent rock will always be the same. The survey strategy was to describe soils in a few spots, and then assume they won't vary when the geomorphic surface changes.

Situations where these assumptions were applied included:

- Describing the soils on a young dissected surface under 700-800 mm rainfall and those on an old plateau with 1200 mm rainfall as being identical. For example, Soil Type 34 on Silurian and Devonian sedimentary rocks are supposed to be the same, whether they occur on near level to gently inclined land near Diamond Creek, or on mountain slopes of 35% near Arthur's Creek or on the gently rolling Plateau around Kinglake. Clearly, these very large areas were never visited by anyone in the team.
- Describing soils (Soil Type 35) on near horizontal land, as well as on a 35+% sloping escarpment, and in the bottom of a wet valley (at the base of the escarpment) as being identical.

Five years after the MMPS report was published, the main author still had not discovered that the deep red friable soils on the Kinglake Plateau were wholly different from his Soil Type 34. In White (1990) these stone-free well drained highly arable red soils, once used for intensive potato growing, were described as belonging to Soil Association 2 and having yellow brown to brownish yellow clay subsoils incorporating large amounts of sandstone gravel, possessing a hardpan in the subsurface, and suffering from seasonal waterlogging.

Case 4 Use of confusing and inappropriate mapping units in survey reports

Mapping units, which are often as complex as a land system, have sometimes been described as "soil types" in some survey reports. Each of these "soil types" often occupies a whole range of unrelated landforms. In one of these reports (White et al., 1985), "Soil type 9" contains the following landforms and parent materials, as shown in the Table 4.

Table 4. Landforms, geological ages and parent materials as reported in "Soil type 9"

Landform & slope gradient	Geological age	Lithology	Northcote soil classification
Undulating low hills (3-10%) Foot hill (<15%) Foot slope (<10%) Fan (3-10%) Moderate slope (10-30%) Low rise (2-3%) High rise (<10%) Crest (0-1%) Peneplain (<3%) Open depression (4%)	Lower Carboniferous Late Pleistocene and Recent Quaternary Pleistocene and Quaternary Pliocene Tertiary	Quartzose sandstone, silt-stone, minor mudstone, sands and clay; Alluvial and colluvial sands, scree and outwash deposits; Sedimentary fluvial deposits of clay, sand and gravel; Shallow marine cross-bedded sand, sandstone and silt. Lateritic weathering.	Dy 4.1, Dy 4.4 Dy 5.4 Dd 3.2, Dd3.4 Db 3.2, Db 3.4

The landform names in Table 4 have been picked at random from Speight's Tables in McDonald *et al.* (1990) of geomorphologically defined and purely morphologically defined landforms. For convenience, the morphologically defined landforms have been stripped of their typical relief range by White et al., 1985.

The reader is asked to believe that a singe soil type, "Soil type 9", is a mapping unit that encompasses:

- young erosional landforms
- an ancient erosion surface (the peneplain)
- erosional as well as depositional landforms
- steeply sloping land, and
- land that is nearly flat.

The parent materials for "Soil type 9" span the enormous geological period from the Carboniferous to the Recent, and include materials that have undergone lateritic weathering, where other materials would be quite unweathered. Finally "Soil type 9" contains at least 7 Northcote soil classes.

When the White et al. (1985) report discusses land capability ratings, every component part bar one of "soil type 9", has a Class 5 (Ss) rating. This "Very Poor" rating, for "Grazing Hazard", is on account of stones and gravel in the soil. What does grazing hazard mean? Is the hazard related to the sheep's teeth or its digestive system, or does the stone content render the land susceptible to degradation under grazing? All of these duplex soils are apparently full of stones and gravel, but nevertheless the description of the mapping unit states also that gravel is rare in all the Dd and Db soils.

Case 5 Use of mapping units with "fantasy boundaries"

Elsewhere, in these 1985-1990 surveys one finds mapping units that cannot be delineated on the basis of easily distinguished features on black and white aerial photos. The mapping units have identical topography but possibly a few different soil types, delineated nevertheless with fantasy boundaries.

In the MMPS survey these *fantasy boundaries* may have arisen because one surveyor described a soil profile in one place and found a profile with dark brown heavy clay B-horizon on basalt. Another surveyor, working in an adjoining area found a similar profile, except that the heavy clay B was dark reddish brown. When the mapping had to be joined, instead of keeping a single mapping unit (comprising a single soil association), they decided to make two mapping units. They then had to invent a boundary between these because, obviously, on the black and white aerial photos one can't distinguish dark brown and dark reddish brown clay in the B horizon subsoil. Thus we see on Map 9 that mapping unit Up27 has an intricate boundary with mapping unit Up26, where on the surface of the land there is nothing to be seen that indicates this boundary separates two subsoils of barely differing colour. Similar fantasy boundaries occur elsewhere.

If Up26 and Up27 had distinctly different land capabilities, one could understand the need for the separation, but the report tells us the land capabilities are almost identical.

Conclusion

In soil surveying, if we throw out all theoretical and intellectual discipline, we welcome an unholy mess! In turn, if poor quality surveys are passed on to State and Local Government planning bodies we may wonder at what happens to their planning! However we also note that well-produced surveys continue to benefit the community long after their authors have retired or died. When it is decided that a soil data base is needed in the future, it is worth doing it properly.

References

Bie SW, Beckett PHT (1970). The costs of soil survey. Soils and Fertilisers **33**, .203-217

Bie SW, Beckett PHT (1971) Quality control in soil survey. II The costs of soil survey. Journal of Soil Science **22**, 453-465

Gunn RH, Beattie JA, Reid RE, van de Graaff RHM (Eds) (1988) 'Australian Soil and Land Survey Handbook: Guidelines for Conducting Surveys'. (Inkata Press, Melbourne)

Hutton FZ (1972) 'Soil Survey Seneca County, New York'. (U.S. Dept of Agriculture, Soil Conservation Service, in cooperation with Cornell University, Agricultural Experimentation Station)

McDonald RC (1975) 'Guidelines for soil survey in Queensland'. Agricultural Chemistry Branch, Technical Report No. 6.

McDonald RC, Isbell RF, Speight JG, Walker J, Hopkins MS (1990) Australian Soil and Land Survey: Field Handbook. (Inkata Press, Melbourne and Sydney)

Melbourne & Metropolitan Board of Works and Department of Conservation, Forest and Lands, (1985). Land Resource Data Atlas – Non-Urban Areas.

Northcote KH (1979) 'A Factual Key for the Recognition of Australian Soils.' 4th edition (Rellim Technical Publications, Adelaide, S.A.)

Reid RE, Gunn RH, Stackhouse KM, Galloway RW (1988) Chapter 2 'Framework for soil and land resource surveys'. In: Gunn *et al*. (1988) See above.

Soil Survey Staff (1951) 'Soil Survey Manual'. (U. S. Department of Agriculture, Soil Conservation Service)

Stace HCT, Hubble GD, Brewer R, Northcote KH, Sleeman JR, Mulcahy MJ, Hallsworth EG (1972) 'A Handbook of Australian Soils.' (Rellim Technical Publications, Adelaide, S.A.)

White, L.A., Kelynack, P.J., Gigliotti, F., and Cook, P.D., (1985). Land Inventory of the Wimmera Systems and Rocklands Water Supply Catchments - A Reconnaissance Survey

White, L.A., (Ed.) (1990). Reconnaissance Survey of the Middle Reaches of the Goulburn River Catchment. Section D: Land Inventory and Assessment; Section E: Associated Information.