

Manual for National Soils Database

R.H. Wilde (Editor)

Manual for National Soils Database

R.H. Wilde (Editor)

Landcare Research NZ Ltd
Private Bag 11052
Palmerston North
New Zealand

Date: July 2003

Reviewed by:

Approved for release by:

© Landcare Research New Zealand Ltd 2003

No part of this work covered by copyright may be reproduced or copied in any form or by any means (graphic, electronic or mechanical, including photocopying, recording, taping, information retrieval systems, or otherwise) with out the written permission of the publisher.

Contents

CHAPTER 1. Introduction and minimum requirements for descriptive and analytical work for the National Soils Database.....	5
1. Introduction.....	5
2. National Soils Database	5
3. Minimum requirements for descriptive and analytical work for gap-filling.....	7
3.1 Site and Profile Descriptions.....	7
3.2 Measuring stone content in the field.....	9
3.3 Physical and Chemical Analyses.....	11
3.3.1 Physical Analyses	11
3.3.2 Particle density.....	12
3.3.3 Chemical Analyses	12
3.3.4 Absolute minimum data set for both physics & chemistry.....	13
3.3.5 Sampling method for 'skeletal' data set for physics and chemistry	13
3.3.6 Correlation data set for physics and chemistry	13
3.3.7 Choice of laboratory analysis	14
3.3.8 Anaerobic mineralisable N	14
4. Acknowledgements.....	14
5. References.....	16
CHAPTER 2. Pedotransfer Functions for Soil Moisture, Porosity and Bulk Density	18
1. Introduction.....	18
2. Soil Properties Used in Pedotransfer Functions.....	18
2.1 Target Properties	18
2.2 Laboratory Predictor Properties	19
2.3 Field Predictor Properties	19
3. Data Sets for Pedotransfer functions.....	22
3.1 Full Data Set.....	22
3.2 Laboratory Properties Only	24
3.3 Allophanic Soils	27
3.4 Field Properties Only.....	27
4. Summary of Pedotransfer functions.....	30
4.1 Available Water Capacity.....	30
4.2 Readily Available Water Capacity	30
4.3 Total Porosity	31
4.4 Macroporosity	31
4.5 Fine Earth Dry Bulk Density.....	32
5. Acknowledgement.....	32
6. References.....	33
CHAPTER 3. Quality Control Procedures for the NSD.....	34
1. Introduction.....	34
2. QA/QC for site selection and field sampling	36
2.1 Filling data gaps	36

2.2	Historical QA/QC procedures	36
2.3	Current and future QA/QC procedures.....	36
3.	QA/QC for laboratory work	37
3.1	Environmental Chemistry Laboratory	37
3.2	Soil Physics Laboratory.....	37
3.3	Soil Mineralogy Laboratory	38
3.4	Machine calibration.....	39
3.5	Interpretation of results.....	39
3.6	Current and future aspects	39
4.	QA/QC for the electronic database	39
4.1	Historical aspects.....	39
4.2	Current and future aspects	39
4.3	Error detection and correction of the electronic data.....	40
5.	Acknowledgements	40
6.	References	43
CHAPTER 4. Sampling Strategy		46
1.	Introduction	46
1.1	Data gaps in the NSD	46
1.2	Selection of sites to fill data gaps	46
1.2.1	Identification of data gaps in the NSD.....	46
1.2.2	Future sampling methods for gap filling.....	48
1.2.3	Representativeness of the site.....	48
1.2.4	Using CMS samples to fill data gaps.....	48
2.	Field sampling procedure	49
2.1	Introduction	49
2.2	Methods of exposing the soil profile for description and sampling for analysis	49
2.2.1	Freshly dug profile pit.....	49
2.2.2	Mobile 200 mm diameter truck-mounted corer	49
2.2.3	Giddings light truck-mounted corer and Giddings hand-operated percussion corer	49
2.2.4	Road and railway cuttings and stream banks.....	50
2.3	Preferred sampling method.....	50
2.3.1	Sample increments and sampling procedure.....	50
2.3.2	Sample handling	50
3.	Acknowledgements	51
4.	References	51

CHAPTER 1. Introduction and minimum requirements for descriptive and analytical work for the National Soils Database

R.H. Wilde

1. Introduction

This chapter is written as a guide and reference to the procedures and operations (methods) we use to describe, sample, and analyse soil pedons, and to archive all descriptive and analytical data in the National Soils Database (NSD), after checking for accuracy. This will provide a quality management system and a basis for auditing and reviewing the quality of the National Soils Database data repository.

We briefly outline the NSD and discuss the data gaps in the database and how these should be filled. The chapter also deals with the minimum data sets necessary for filling these data gaps, and with the field sampling procedures. Field sampling relies on strictly following the Soil Description Handbook (Milne et al. 1995) where, apart from field sampling for analysis, all necessary procedures and methods are described.

2. National Soils Database

Landcare Research NZ Ltd operates and maintains the New Zealand National Soils Database (NSD) from its Palmerston North site. The database is a collection of soil profiles, site descriptions and chemical, physical and mineralogical characteristics for nearly 3000 soil profiles in New Zealand and the Pacific Islands (Wilde & Ross 1996; Willoughby et al. 1994, 2001). More than two-thirds of the data relate to New Zealand soils. The DSIR Soil Bureau and other predecessors of Landcare Research largely carried out the analyses. The NSD is currently funded from the Land Resource Information Systems Programme in the former PGSF Output Area 15.

Data from 1964 to 1992 was held in Paradox for Windows, a PC-based relational database. Pre-1964 data is held in a card filing system, in which analyses date back to 1938. Some pre-1938 analyses carried out by the Cawthron Institute are also available.

The database has been ported to Microsoft SQL Server (a structured query language database), and is currently accessible to all Landcare Research staff via the company intranet. It will eventually be publicly accessible via the World Wide Web.

Current Database Structure

The important data are contained in a series of tables within the NSD:

- Sites
 - Site data
 - topography and drainage, parent materials, climate, land management attributes vegetation cover, etc.
- Horizons

Soil profile descriptions

horizon depth and designation, colour/mottling, texture, structure, consistence, etc.

- **Chemistry**
Used principally for soil characterisation and classification but with some fertility measurements.
Analyses include: organic matter (C, N); pH, cation exchange properties, phosphorus fractions including an available P measurement; P retention, available sulphate & reserves of Mg and K; Al, Fe, and Si fractions, etc.
- **Physical analyses**
particle size distribution including stone contents; solid/void relationships (bulk density, total porosity, macro-porosity), water retention measurements (available and readily available water, etc).
- **Mineralogy**
sand, silt and clay mineralogy; amorphous constituents, heavy minerals.
- **XRF analyses**
analysis of total amounts of major elements (Ca, K, P, Mg, Na, Si, Al, Fe, etc); and minor elements (Mn, Cu, Zn, etc).
- **Methods**
analyst's name, method of analyses, date.

Soil chemical analyses from 1966 to mid-1987 follow the procedures in Blakemore et al. (1972, 1977, 1981). From the mid-1980s the procedures follow those described by Blakemore et al. (1987). Individual method codes are assigned to values.

Mineral analyses and interpretation of instrument data since 1980 follow Whitton and Churchman (1987). Method codes are given in parentheses. For mineral analyses carried out before 1980, Claridge (1969) was generally followed.

Chemical, physical and mineralogical information for the whole collection of recorded soil profiles are variable. Soils collected and analysed since the early 1980s generally have a more complete set of analytical data compiled for them compared with earlier collections. Before 1980 the emphasis was on soil chemistry and mineralogy. During the 1980s soil physical data became more highly valued and the analytical work carried out on the soil survey samples began to reflect this, so that from the middle of the decade full chemical, mineral and physical analyses were being carried out. Note that documented methods of analysis have changed over the years and this needs to be considered when interpreting data. Analytical data from soils collected before about 1960 should be treated with caution in comparison with data derived from more modern analytical techniques.

Soil profile descriptions use the method of Taylor and Pohlen from 1962 onwards, with the following modifications: FAO horizon designations for mineral horizons (FAO-UNESCO 1974), and the Canadian system of nomenclature for organic horizons (Canada Soil Survey Committee 1978) have both been in use since 1981. Slope classes follow the system used in the New Zealand Land Resource Inventory (NWASCO 1975–1979, 1979) and have been used in the NSD since 1981. Consistence terminology follows earlier drafts of US Department of Agriculture (1993) and has been used in the NSD since 1983. Penetration resistance classes are based on those of Griffiths (1985). Horizon designations since 1988 follow the system of Clayden and Hewitt (1989). From 1994 on, the method of soil profile description changed from the method of Taylor and Pohlen (1962) to the method of Milne et al. (1995).

3. Minimum requirements for descriptive and analytical work for gap-filling

Three levels of data are possible for NSD gap filling:

- Full, comprehensive site and profile description, with full chemical and physical analyses.
- Recommended minimum data sets (listed below).
- ‘Skeletal’ data. These are data ancillary to NSD but included because despite their brevity, the data sets could be useful for some purposes, rather than be lost.

A more complete discussion of NSD gap filling is given in Chapter 4.

3.1 Site and Profile Descriptions

Recommended minimum data set for the site description

We consider the minimum amount of site data we should collect for NSD gap filling should comprise the full description of the site as outlined in the Soil Description Handbook (Milne et al. 1995) and contained on the new soil description card compiled and made available towards the end of 2000.

Data set

Unique field identifier for the site and profile

Project name

Date

Author (both describing and sampling)

Soil name (distinguish between series or set). Topsoil texture (soil type) may be included here even though it is given in the soil profile description

Soil classification (down to soilform level)

Map Reference: NZMS number, with 7-figure grid reference from GPS. Give an accuracy reading if possible (either the uncertainty in metres or the PDOP reading).

Description of the site location (sufficient to allow someone to identify the approximate position of the site without using the grid reference)

Elevation (metres a.s.l)

Slope angle

Aspect

Contour shape

Profile shape

Rock outcrops (% depends on site size)

Boulders

Landscape and landform including landform element and microtopography, to define the site and profile position

Erosion/deposition

Vegetation (species and class for profile and site (where site is ± 10 m from profile) and % cover).

Land use (both current and historical)

Land management practice

Internal soil drainage

Depth of any slowly permeable or impeding layer to roots or water (potential rooting depth)

Parent material

Geological substrate (from geological map if not observable).

Absolute minimum data set for the site description ('skeletal' data set – not recommended)

Unique field identifier for the site and profile

Date

Author (both describing and sampling)

Grid reference

Soil classification (down to series level)

Vegetation (species and class for profile and site (where site is ± 10 m from profile).

Land management (current and historical)

Depth of any slowly permeable or impeding layer to roots or water (potential rooting depth).

Note: Slope, aspect and internal soil drainage would be a bonus but we are reluctant to include these within an absolute minimum data set (possibly collected by people not associated with filling the NSD data gaps) as we don't wish to disqualify otherwise useful data.

Recommended minimum data set for the soil profile description

This recommended minimum data set omits attributes such as voids and various descriptors for consistence and coatings. The 'full' data set for the profile description comprises the data set described in the Soil Description Handbook (Milne et al. 1995). It is more comprehensive and is represented on the new soil description card.

Note: When using class descriptors for abundance and size data, give also the actual percentage of the item and its size in millimetres. If the soil description card is being used, percentages and sizes can be recorded alongside the class code box. The profile should be described to a minimum depth of one metre, or to rock if this occurs at shallower depth.

It is important to take a photograph, preferably digital, of the soil profile, as well as of the site. Photographs are essential for checking and correlation, and are also useful for educational purposes. Digital images can be stored in the database.

General

Unique field identifier for the site and profile

Horizon designation,
top and base depths

Horizon number

Munsell matrix colour code

Mottles_1 abundance (%)

Mottles_1 size (mm)

Mottles_1 contrast

Mottles_1 Munsell colour code

Mottles_2 abundance (%)

Mottles_2 size (mm)

Mottles_2 contrast

Mottles_2 Munsell colour code

Concentrations abundance (%)

Concentrations size (mm)

Concentrations Munsell colour code

Concentrations type

Pan type if present

Texture

Texture class

Texture sand qualifier

PSD sand (%)

PSD clay (%)

Texture organic matter qualifier

Gravels (<200 mm) abundance
 Gravels (<200 mm) size (mm)
 Gravels (<200 mm) weathering
 Gravels (<200 mm) roundness
 Gravels (<200 mm) rock type
 Boulders (>200 mm) abundance
 Boulders (>200 mm) size (mm)
 Boulders (>200 mm) weathering
 Boulders (>200 mm) roundness
 Boulders (>200 mm) rock type

Note: For accurate measurement of gravels in the field, use sieves and a spring balance to calculate % coarse fragments. Ensure an adequately-sized sample is collected and sieved.

3.2 Measuring stone content in the field

Fine and medium stones (2–20 mm diameter)

Collect a representative volume of stony soils and weigh. Sieve through a nest of sieves (2–6 mm, 6–10 mm, 10–20 mm and 20–60 mm) and then weigh the stones. Collect a small representative amount of both the fine earth and the stones for subsequent soil moisture analysis and conversion of the moist weights to dry weights. To convert stone weight to volume, this sample can also be used in the calculation of stone-particle density. If time in the field is limited, collect a representative sample of the stony soil for laboratory sieving and weighing. Do not rely on laboratory staff to assess the stone content from undisturbed cores or from the chemical samples because, unless the stones are very small, these samples will not be representative of the whole site. Moreover, large stones may have been discarded before sampling.

Coarse and very coarse stones (20–200 mm diameter)

It is difficult to obtain a representative sample of stony soils with coarse or very coarse stones because large sample volumes are necessary. When samples are sufficiently large and representative, however, the field measurement of stone content will enhance the pedological description of stones to provide a good overall estimate of the volume of stones and fine earth within the sampled pedon. The number of stones in a given sample depends on stone size. We require a sample size large enough to avoid having only one or two large stones dominating the sample. If, for example, the sample is large enough to contain 100 stones, then an adequate proportion of fine material is assured. It is also desirable to have the proportion of fine material to stones more or less constant between samples.

A proposed rule of thumb is to collect a sample whose volume is one hundred times the volume of the largest particle in that sample. Having a constant multiplier increases the probability of a given sample containing close to the average volume of stones for that soil.

Table 1 gives suggested sample volumes required for coarse spherical particles ranging in diameter from 10 to 200 mm. It also shows that it is not feasible when sampling individual horizons for one to two-person field parties without access to mechanical equipment to excavate and sieve coarse fractions where the stone diameters are greater than 50 or 60 mm. Where the diameter of the stones exceeds 60 mm, the recommended size of a representative sample is too large to handle. In these situations a visual estimate of stone contents, horizon by horizon, using visual estimate charts, is practical.

Table 1. Suggested sample volumes for coarse spherical particles that range in diameter from 10 to 200 mm, where the minimum sample volume is at least 100 times the volume of the largest particle in that sample.

Diameter of largest stone in sample (mm)	Volume of largest stone (ml)	Suggested minimum sample size (100*volume of largest stone in sample) (litres)
10	0.5	0.05
20	4	0.4
40	34	3.4
50	65	6.5
60	113	11
100	524	52
200	4189	419

Consistence:

Soil strength
Failure
Sensitivity
Induration
Stickiness.

Macrofabric (structure):

Pedality type
Apedal materials (where present)
Pedality degree
Primary pedality size description
Primary pedality shape
Secondary pedality size description
Secondary pedality shape.

Other:

Root abundance (%)
Root size (mm)
Root location
Parent material determination
Parent material origin
Parent material alteration
Parent material induration
Surface features kind
Surface features location
Surface features abundance (%)
Surface features distinctiveness
Surface features roughness
NaF test result
Boundary distinctness
Boundary shape.

Absolute minimum data set for the soil profile description ('skeletal' data set)

(For example, in an auger description for which the minimum data set requirements are waived). Such data sets may become available from other projects or from other organisations and still be

useful to Landcare Research for data gap filling.

Unique field identifier for the site and profile

Horizon designation

Horizon depths

Matrix Munsell colour

Mottles abundance (%), size, contrast & Munsell colour

Texture including stone content

Note: The profile should be described to a minimum depth of one metre, or to rock if this occurs at lesser depth.

Correlation data set for the site and soil profile description

We consider the recommended minimum data set for both the site and soil profile description (Sections 1.3.1.1. and 1.3.1.3) should be followed for soil correlation purposes. There seems little point in shortening the site and soil profile description when soil correlation is the main use of this work. Much time and effort involved in soil characterisation work is spent getting to and from the site, and shortening the description will have little impact on the overall time and costs.

3.3 Physical and Chemical Analyses

3.3.1 Physical Analyses

a) Full data set for physics

Particle size: (fine earth)

Moisture release: (total available water (TAW) and readily available water (RAW))

5 kPa (macropores)

10 kPa (field capacity) (used for both RAW & TAW)

33 kPa (may need to use 20 & 40 kPa to help in curve plotting).

100 kPa (used for RAW)

300 kPa (completes the pF curve)

1500 kPa. (used for TAW).

Dry bulk density

Particle density

Hydraulic conductivity:

K_s (and water content)

K₄₀

Note: Hydraulic conductivity measurements need many replicates to be meaningful. Current thinking recommends 9 replicates as a minimum number for topsoils, with almost as many for subsoils. Fewer replicates will be needed with K₄₀ measurements than for K_s measurements.

Liquid limit

Plastic limit

Oxygen diffusion rate (Field determination usually but can be done in laboratory).

Penetration resistance

Sheer strength (Equipment available but not set up. Measurements can take up to ½ day each).

Coefficient of linear extensibility (COLE)

b) Recommended minimum data set for physics

Dry bulk density

Note: For profiles where moisture release samples are not carried out on all horizons, the omitted horizons should be sampled for BD, providing bulk density measurements for all horizons.

Particle size: (fine earth)

Moisture release:

5 kPa (macropores)

10 kPa (field capacity) (used for both RAW & TAW)

100 kPa (used for RAW)

1500 kPa (used for TAW)

3.3.2 Particle density

Note 1: To minimise damage to undisturbed samples by soil animals, apply 4% formalin to the sample immediately after sampling, before wrapping in cling film and placing in a plastic bag. Place samples in cooler as soon as possible to further slow faunal activity.

Note 2: For profiles where only three horizons are to be sampled for moisture release, additional important horizons should be sampled for bulk density using one large-diameter (98 mm) ring per horizon with no replicates. This would be cost effective, and would provide an acceptable minimum data set for soil physics. If it is considered necessary to obtain K_{40} determinations, additional funds will be required to accommodate the necessary replicates, and all samples would need to be collected using large-diameter rings. This would significantly increase the costs per profile.

c) Recommended Field Sampling Procedure for Physics

We currently favour a sampling regime for soil physics in which a minimum physics data set of two replicates is provided. This is similar to the soil physics sampling methods used by the former DSIR Soil Bureau for the National Soils Database collection in which moisture release samples were collected in 2 small brass rings positioned one above the other. (Figure 1 gives a diagrammatic representation of where to position the sampling rings). There is an issue here of replicate samples. Given that we are concerned with obtaining good measurements for single profiles to add to the National Soils Database, it is arguable whether 3 replicates are much better than 2, and our budget does not extend to analysing large numbers of replicates (e.g., 6 or more) for individual soil horizons. A better tactic is to take the minimum number of replicates per horizon to satisfy QA/QC requirements, and increase the total number of profiles analysed. When considering the costs of analysis it should be noted that for an annual amount of \$30,000 per year set aside for analyses, we can afford to analyse about 25 profiles per year.

3.3.3 Chemical Analyses

a) Full data set for chemistry

Sample preparation and moisture factor

pH

C & N (Leco)

Olsen P (topsoil only)

0.5 M H_2SO_4 -soluble P

Organic & total P

P retention

CEC

Exch. Bases

Acid-soluble K & Mg

Extractable sulphate S

Dithionate extractable (Al & Fe)

Oxalate extractable (Al, Fe & Si)

Pyrophosphate extractable Fe & Al

Electrical conductivity

Anaerobic mineralisable N (A horizons only)

KCl-extractable Al (if pH<5.6)

Carbonate (if BS>100 or pH>7.0)

Mineralogy of clay, silt and sand.

b) Recommended minimum data set for chemistry

Sample preparation and moisture factor

pH

C & N (Leco)

CEC

Exchangeable bases

Olsen P (topsoil only)

0.5 M H₂SO₄-soluble P

Organic & total P

P retention

Acid-soluble K & Mg

Extractable sulphate S

Anaerobic mineralisable N (A horizons only)

c) Recommended Field Sampling Procedure for Chemistry

Owing to soil variability within short distances, even across a single pit face, it is recommended that chemical samples are collected from at least two sides of the sample pit to ensure a representative sample. On each pit face, sample along a narrow channel excavated from top to bottom of each horizon, leaving no gaps down the pit face. Collect between 300 g and 400 g of fine earth (more from stony soils and wet organic soils), to ensure 150–200 g of dry sample is obtained, enough for all analyses as well as for sample archiving—the volume of a softball is suggested as a suitable amount. If necessary, quarter down larger samples to obtain the required amount: spread the sample out on a clean plastic sheet, divide it into quarters and discard one of the quarters. Repeat the process until the required amount of sample is obtained.

3.3.4 Absolute minimum data set for both physics & chemistry ('Skeletal' data set – not recommended).**Physics**

Dry bulk density

Chemistry

Preparation and moisture factor

pH

C & N (Leco)

Olsen P (topsoil only)

0.5 M H₂SO₄-soluble P

P retention

3.3.5 Sampling method for 'skeletal' data set for physics and chemistry

Collect 20 samples over the sample site to a depth of 10 cm and bulk them. Then sample the next two most important horizons of the profile. This would make a total of 3 horizons sampled. In addition, collect dry bulk density rings (98 mm diameter) for all remaining horizons. Dry bulk density will be the only physics analysis carried out for skeletal datasets.

Where only minimum or skeletal datasets are obtained from analyses, pedotransfer functions will be needed to predict the full datasets. For example, the prediction of available water capacity from other data remains a high priority.

3.3.6 Correlation data set for physics and chemistry

The correlation data set for physics is closely similar to the 'skeletal' data sets, with the addition of particle size. The correlation data set for chemistry is similar to the 'skeletal' data set for chemistry,

with the addition of CEC, exchangeable bases, organic and total P, and without Olsen P. In addition to the 'skeletal' data sets, it is important to have accurate particle size, exchangeable bases, and phosphorus data for soil correlation purposes.

Physics

Dry bulk density

Particle size analysis (fine earth)

Chemistry

Preparation and moisture factor

pH

C & N (Leco)

0.5 M H₂SO₄-soluble P

Organic & total P

P retention

CEC and exchangeable bases

3.3.7 Choice of laboratory analysis

With limited funding, there is an inevitable tension between carrying out limited analysis on a large number of profiles or to carry out more detailed analysis on a few profiles. It costs at least \$800.00 for 3 horizons for full chemical analyses (on the basis of year 2000 prices) and at least \$400.00 for full physics analyses. If we undertake full analysis of profiles for the filling of data gaps we can afford to analyse only a few profiles per annum. However, if by accepting lesser (minimum) data sets for physics and chemistry (or possibly even 'skeletal' data sets) we can afford to analyse many more profiles.

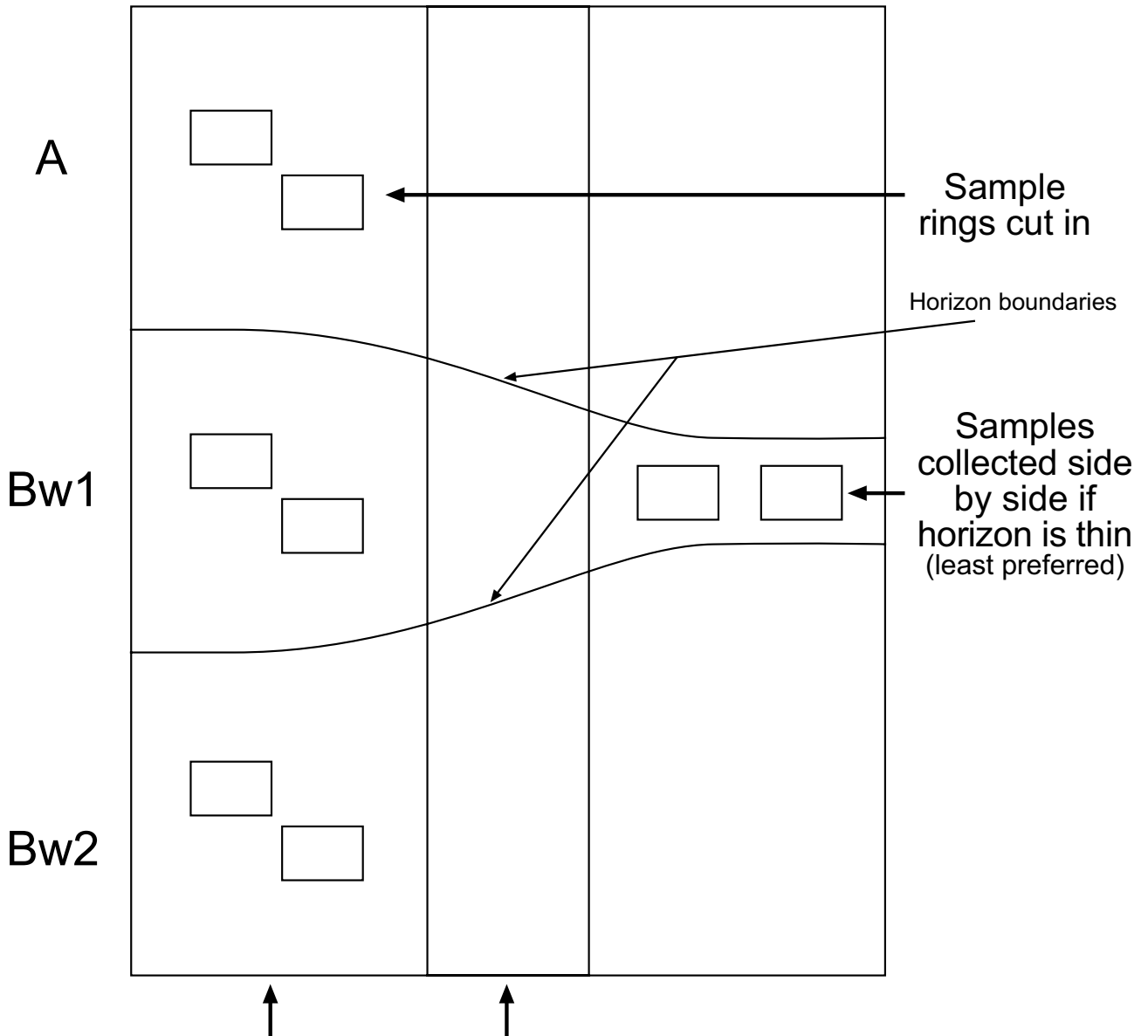
3.3.8 Anaerobic mineralisable N

There is an issue with the anaerobic mineralisable N sampling (AMN) as the most efficient way to analyse these samples is in batches of 40 samples or more. Samples should be in the laboratory within 3 days of sampling and analysed within 1 week. It is doubtful whether the data gaps sampling programme can produce sufficiently large numbers of samples for efficient analysis of AMN. Another issue is that as soil characterisation samples collected before 2001 were not analysed for AMN, it is not possible to compare the newer analyses with historical data.

4. Acknowledgements

Trevor. Webb, Landcare Research, Lincoln, provided valuable advice and comments on this chapter. Funds for this work were provided by the Foundation for Research Science and Technology through contract CO9X0215.

e.g. Brown soil



Physics samples

Preferred method where samples are collected at different depths and offset to allow sample ring to be cut in

Chemistry samples

Collected from a vertical channel cut through all horizons to be sampled, with no gaps, and from at least two pit faces



Ring samples to be cut carefully into the soil and not trimmed top or bottom; rather keep proud. Samples to be immediately wrapped in clingfilm.

5. References

- Blakemore, L.C.; Searle, P.L.; Daly, B.K. 1972, 1977 & 1981: Methods for chemical analysis of soils. Part A. Soil Bureau Laboratory Methods. *New Zealand Soil Bureau Scientific Report 10*.
- Blakemore, L.C.; Searle, P.L.; Daly, B.K. 1987: Methods for chemical analysis of soils. *New Zealand Soil Bureau Scientific Report 80*. 103 p.
- Canada Soil Survey Subcommittee, Subcommittee on Soil Classification 1978: The Canadian system of soil classification. *Canadian Department of Agriculture Publication 1646*. Supply and Services Ottawa, Ontario, Canada. 164 p.
- Claridge, G.G.C. 1969: Physico-chemical methods for soil analysis. *New Zealand Soil Bureau Information Series 23*. 39 p.
- Clayden, B.; Hewitt, A.E. 1989: Horizon notation for New Zealand soils. *DSIR Division of Land and Soil Sciences Scientific Report 1*. 30 p.
- FAO-Unesco 1974: Soil Map of the World. 1:5 000 000. Vol. 1 Legend. Unesco, Paris. 59 p.
- Griffiths, E. 1985: Interpretation of soil morphology for assessing moisture movement and storage. *NZ Soil Bureau Scientific Report 74*. 20 p.
- Milne, J.D.G.; Clayden, B.; Singleton, P.L.; Wilson, A.D. 1995: Soil Description Handbook Revised Edition. Published by Manaaki Whenua Press, Landcare Research, P.O. Box 40 Lincoln 8152, New Zealand. 156 p.
- NWASCO 1975–1979: New Zealand Land Resource Inventory Survey, 1:63 360. Wellington, New Zealand. National Water and Soil Conservation Organisation.
- NWASCO 1979: Our Land Resources. Wellington, New Zealand. National Water and Soil Conservation Organisation. 79 p.
- Taylor, N.H.; Pohlen, I.J. 1962: Soil Survey Method. A New Zealand handbook for the field study of soils. *New Zealand Soil Bureau Bulletin 25*. 242 p.
- United States Department of Agriculture 1993: Soil Survey Manual. *Agriculture Handbook No 18*. 437 p.
- Whitton, J.S.; Churchman, J.G. 1987: Standard methods for mineral analysis of soil survey samples for characterisation and classification in New Zealand Soil Bureau. *New Zealand Soil Bureau Scientific Report 79*. 27 p.
- Wilde, R.H.; Ross, C.W. 1996: New Zealand Reference Soil Collection and the National Soils Database. *New Zealand Soil News 44*, 6 December 1996 224–227.
- Willoughby, E.J.; Baker, I.R. 1994: *Standard Input/Output Procedures for the National Soils Database Using Paradox and Windows*. Unpublished Landcare Research Report. 21 p + appendix.

Willoughby, E.J.; Wilde, R.H.; McLeod, M.; Hewitt, A.E. and Webb, T.H. 2001: National Soils Database Audit: A document describing Landcare Research soils data. Landcare Research Unpublished Report.

CHAPTER 2. Pedotransfer Functions for Soil Moisture, Porosity and Bulk Density

D.J. Giltrap¹ & A.E. Hewitt

1. Introduction

Pedotransfer functions allow estimation of properties that are difficult or expensive to measure (or which are not included in historic datasets) from other properties, which are available or can be more easily measured. One way of constructing pedotransfer functions is to use multiple regression analysis on comprehensive datasets to explore relationships between the "target" properties and other readily available properties. If relationships are found that explain a sufficiently high proportion of the original variance (or which have a sufficiently low residual variance) then these relationships may be used as pedotransfer functions.

Earlier unpublished work (Wilson and Giltrap *c.* 1985) suggests that useful pedotransfer functions could be established for available water capacity (AWC), readily available water capacity (RAWC) and fine earth dry bulk density (FEDBD). Similar relationships functions could also be developed for macroporosity (large pore volume), but the accuracy of the relationship appeared to be inadequate for useful pedotransfer functions. Since this work, the National Soils Database has been significantly extended and, more importantly, much of the particle size data has been revised due to a technical problem with an earlier method. This report uses the latest data available from the National Soils Database to investigate and/or construct new pedotransfer functions for these properties from

1. Profiles with field descriptions only,
 2. Profiles with field descriptions and basic laboratory data
-

2. Soil Properties Used in Pedotransfer Functions

2.1 Target Properties

These properties were the targets (Y variables) of the multiple regressions used to construct pedotransfer functions.

1. Available Water Capacity (AWC).
2. Readily Available Water Capacity (RAWC).
3. Total Porosity (TP)
4. Macroporosity (Large Pore Volume, MP)
5. Fine Earth Dry Bulk Density (FEDBD)

The first four of these properties are reasonably expensive to measure and are required for water balance and water movement models. Fine earth dry bulk density is quite easy to measure but is missing from a large number of samples in the National Soils Database. Fine earth bulk density is required to convert gravimetric soil data (eg % Soil Carbon) to the volumetric form required by, for

¹ Small Office Systems Ltd, P.O. Box 46024, Lower Hutt

example, the national soil carbon inventory. A suitable pedotransfer function for bulk density would substantially extend the number of data points available from the National Soils Database for such inventories.

2.2 Laboratory Predictor Properties

These properties are used as numeric predictors (X variables) in the Pedotransfer functions.

1. Fine Earth Dry Bulk Density (DBD)
2. % Carbon (C)
3. Oxalate-extractable Al (Al)
4. % Sand (S)
5. % Silt (Z)
6. % Clay (Cl)
7. %Sand² (S²)
8. %Sand × %silt (S.Z)
9. %Sand × %clay (S.Cl)
10. %Silt² (Z²)
11. %Silt × %clay (Z.Cl)
12. %Clay² (Cl²)

Note that bulk density is used as both a target and predictor variable. It is used as a predictor variable for AWC, RAWC, MP and (somewhat trivially) TP for samples for which DBD is known. It is used as a target variable for its own pedotransfer function(s) for samples for which DBD is not known.

The quadratic terms in Sand, Silt and Clay are included as the relationship between (in particular) AWC and particle size appears to be markedly non-linear. The particle-size terms are subject to the constraint that $S+Z+C = 100\%$, and hence that (eg) $S^2+S.Z+S.Cl = S$. No one regression model will include all the terms S through Cl² as this would lead to a singular matrix.

2.3 Field Predictor Properties

These properties are derived from the field observations recorded against soil horizons. The original observations are categoric and are converted to numeric values by applying the "rating" systems described. The derived ratings are used as predictors (X variables) in the regression analyses.

The field properties are all based on soil morphological classes of Soil Survey Method (Taylor and Pohlen, 1979) because pedons in the National Soil Database pedons are predominantly described according to that system.

1. *Soil Strength (St)*

The descriptive soil strength term is converted to a numeric rating as in Table 1.

Table 1. Soil Strength Ratings

Descriptive Term	Rating
loose	0
very weak	1
weak	2
moderately weak	3
slightly firm	4
moderately firm	5
firm	6
very firm	7
moderately strong	8
very strong	9
rigid	10

2. Structure Grade (*G*)

The descriptive grade term of the primary structure is converted to a numeric rating as in Table 2.

Table 2. Structure Grade Rating

Descriptive Structure Grade	Rating
apedal (single grain or massive)	0
weakly developed	1
moderately developed	2
strongly developed	3

3. Structure Size (*Sz*)

The descriptive primary structure size is converted to a rating as in Table 3.

Table 3. Structure Size Ratings

Structure Descriptive Term(s)	Size Range (mm)	Rating
Single grain		0
fine crumb, very fine crumb, fine granular, very fine granular, fine platy	< 2	1
medium crumb, medium granular, very fine blocky, very fine nut, medium platy	2 - 5	2
coarse crumb, coarse granular, fine blocky, fine nut, coarse platy	5 - 10	3
medium nut, medium blocky, fine columnar, fine prismatic, very coarse platy	10 - 20	4
coarse nut, coarse blocky, medium columnar, medium prismatic	20 - 50	5
very coarse nut, very coarse blocky, coarse columnar, coarse prismatic	50 - 100	6
very coarse blocky, very coarse prismatic	> 100	7
massive		8

4. Structure Shape (*Sh*)

The structure type descriptive term was converted to a "shape" rating as in Table 4.

Table 4. Structure Shape Ratings

Structure Type Descriptive	Rating
Blocky	-1
Prismatic	-1
Nut	0
Columnar	0
Massive	0
Single grain	0
Granular	1
Crumb	2

Apedal structures or structures with partially rounded shapes are given a rating of zero. Angular (accommodating) structures are given a rating of -1. Porous (crumb) and non-porous (granular) spheroidal structures are given ratings of 2 and 1 respectively. The shape rating should roughly reflect the overall porosity of a soil formed from the specified ped shapes.

5. Texture (*S', Z', Cl'*)

The descriptive texture class was converted to the % sand, % silt and % clay ratings given in Table 5. These "ratings" are the mean values of the measured % sand, % silt and % clay in the samples ascribed to each texture class in the database. The primed notation (*S', Z', Cl'*) is used to distinguish these values from the actual measured values (*S, Z, Cl*) for each sample.

Table 5. Sand, Silt and Clay Estimates by Texture Class

Descriptive Texture Class	Rating (Mean Value)		
	Sand (<i>S'</i>)	Silt (<i>Z'</i>)	Clay (<i>Cl'</i>)
Sand	86.9	8.3	4.8
Loamy sand	69.5	21.5	9.0
Sandy loam	50.4	37.3	12.3
Sandy clay loam	35.7	45.2	19.1
Sandy clay	23.9	35.5	40.6
silt loam	18.8	53.6	27.6
Loam	50.0	35.0	15.0
loamy silt	42.4	46.6	11.0
heavy silt loam	13.1	57.9	29.0
silty clay loam	11.8	53.6	34.6
clay loam	18.2	48.2	33.6
silty clay	10.5	32.4	57.1
Clay	10.1	43.9	46.0
Peat	10.7	66.3	23.0

6. Product terms

The following product (or quadratic) terms are calculated from the above ratings -

$$G \times Sz, G \times Sh, S'^2, S' \times Z', S' \times Cl', Z'^2, Z' \times Cl', Cl'^2$$

3 Data Sets for Pedotransfer functions

Different pedotransfer functions are derived for a number of situations depending on the amount of data expected to be available.

3.1 Full Data Set

These pedotransfer functions are designed for samples with values available for all the listed laboratory and field predictor properties. Stepwise multiple regressions were used to construct pedotransfer functions for AWC, RAWC, TP and MP from the following candidate predictors:

DBD, C, Al, S, Z, Cl, S², S.Z, S.Cl, Z², Z.Cl, Cl², St, G, Sz, Sh, G.Sz and G.Sh

A similar multiple regression was used to predict DBD from the above candidate predictors other than DBD.

There were a total of 355 data points with all the required data.

Table 6. Stepwise Regression for AWC, Full Data

Model	Cumulative		Incremental			F Ratio	P
	SS	DF	SS	DF	MS		
Carbon	10138	1	10138	1	10137.80	463.843	0.0000
+Oxalate Al	11237	2	1100	1	1099.50	50.306	0.0000
+Silt	12563	3	1326	1	1325.98	60.669	0.0000
+Silt × Clay	13593	4	1030	1	1030.21	47.136	0.0000
+DBD	14166	5	572	1	572.31	26.185	0.0000
+Structure Shape	14321	6	155	1	154.88	7.086	0.0081
Full Model	14648	14	327	8	40.87	1.870	0.0638
+Residual	22079	354	7431	340	21.86		

Term	Coefficient	Std Error	t Value	P
DBD	-9.41662	1.69327	-5.561	0.00053
Carbon	0.80721	0.11326	7.127	0.00010
Oxalate Al	0.71222	0.29355	2.426	0.04145
Silt	0.25723	0.02245	11.456	0.00000
Silt × Clay	-0.00549	0.00063	-8.666	0.00002
Structure Shape	-1.13232	0.42958	-2.636	0.02990
Constant	21.24360	2.48784		
Error SD	4.72156			
Adj. R ²	0.64256			

Table 7. Stepwise Multiple Regression for RAWC, Full Data

Model	Cumulative		Incremental			F Ratio	P
	SS	DF	SS	DF	MS		
Carbon	996.6	1	996.6	1	996.64	150.877	0.0000
+Clay	1382.9	2	386.3	1	386.29	58.479	0.0000
+DBD	1533.6	3	150.7	1	150.66	22.808	0.0000
+Silt	1641.1	4	107.5	1	107.53	16.278	0.0001
+Silt × Clay	1734.6	5	93.5	1	93.45	14.147	0.0002
Full Model	1787.1	14	52.5	9	5.84	0.884	0.5398
+Residual	4033.0	354	2245.9	340	6.61		

Term	Coefficient	Std Error	t Value	P
FEDBD	-3.92737	0.68969	-5.694	0.00046
Carbon	0.21588	0.05614	3.845	0.00491
Sand	0.11411	0.00935	12.202	0.00000
Silt	0.19897	0.01731	11.491	0.00000
Clay	0.08588	0.02222	3.865	0.00477
Silt × Clay	-0.00266	0.00071	-3.767	0.00549
Error	2.56630			
Adj. R ²	0.42193			

Table 8. Stepwise Regression for Total Porosity, Full Data

Model	Cumulative		Incremental			F Ratio	P
	SS	DF	SS	DF	MS		
DBD	35071	1	35071.1	1	35071.07	3158.786	0.0000
+Full Model	35799	14	728.4	13	56.03	5.047	0.0000
+Residual	39574	354	3774.9	340	11.10		

Term	Coefficient	Std Error	t Value	P
DBD	-33.07470	0.63105	-52.412	0.00000
Constant	93.85670	0.81598		
Error SD	3.57174			
Adj R ²	0.88588			

Table 9. Stepwise Regression for Macroporosity, Full Data

Model	Cumulative		Incremental			F Ratio	P
	SS	DF	SS	DF	MS		
Sand	7640	1	7640.3	1	7640.30	216.349	0.0000
+DBD	10078	2	2438.1	1	2438.10	69.039	0.0000
+Structure size	11752	3	1673.6	1	1673.60	47.391	0.0000
+Oxalate Al	12684	4	932.1	1	932.10	26.394	0.0000
+Carbon	13295	5	610.7	1	610.70	17.293	0.0000
+Sand × Clay	13905	6	610.1	1	610.10	17.276	0.0000
+Structure shape	14229	7	324.3	1	324.30	9.183	0.0026
Full Model	14689	14	459.9	7	65.70	1.860	0.0753
+Residual	26696	354	12007.0	340	35.31		

Term	Coefficient	Std Error	t Value	P
DBD	-18.24770	2.09160	-8.724	0.00002
Carbon	-0.59872	0.13591	-4.405	0.00227
Oxalate Al	-1.88621	0.38556	-4.892	0.00121
Sand	0.17300	0.01484	11.655	0.00000
Sand × Clay	-0.00489	0.00122	-4.006	0.00392
Structure size	-0.59936	0.15460	-3.877	0.00470
Structure shape	1.62602	0.54128	3.004	0.01697
Constant	38.67420	2.90381	13.318	0.00000
Error SD	5.99397			
Adj. R ²	0.52359			

Table 10. Multiple Regression for Dry Bulk Density, Full Data

Model	Cumulative		Incremental			F Ratio	P
	SS	DF	SS	DF	MS		
Carbon	15.3755	1	15.3755	1	15.375500	799.459	0.0000
+Oxalate Al	22.0140	2	6.6385	1	6.638500	345.173	0.0000
+Clay	23.2058	3	1.1918	1	1.191850	61.971	0.0000
+Strength	24.6310	4	1.4252	1	1.425180	74.103	0.0000
+Structure shape	24.9541	5	0.3231	1	0.323060	16.798	0.0001
+Size	25.2553	6	0.3012	1	0.301250	15.664	0.0001
+Full Model	25.4768	13	0.2214	7	0.031631	1.645	0.1219
+Residual	32.0350	354	6.5582	341	0.019232		

Term	Coefficient	Std Error	t Value	P
Carbon	-0.004704	0.002163	-2.175	0.06133
Oxalate Al	-0.114601	0.006467	-17.720	0.00000
Clay	-0.006898	0.000606	-11.369	0.00000
Strength	0.021976	0.004543	4.838	0.00129
Structure size	0.014198	0.003610	3.932	0.00434
Structure shape	-0.049906	0.012435	-4.013	0.00388
Constant	1.472010	0.018540		
Error SD	0.139577			
Adj R ²	0.78472			

The stepwise regressions were developed by adding the candidate term giving the best improvement in adjusted R² subject to the constraints that

1. Redundant combinations of particle size terms (eg S, S², S.Z, and S.Cl) were avoided
2. Quadratic particle size terms were added to the model only if (one of) the component first-order terms was already included.

The process of adding terms was continued until no further addition would produce a significant improvement except for the total porosity model. Total porosity shows a very high negative correlation with dry bulk density, and the residual error from the DBD model (see Table 10) is only marginally improved by adding all the other terms (although the improvement is statistically significant). The relationship between total porosity and DBD is already well known and the simple linear DBD model is consistent with this relationship.

The AWC (Table 6) and RAWC (Table 7) models provide useful pedotransfer functions and account for 65% and 42% of the total variances respectively. These models depend very largely (AWC) or wholly (RAWC) on laboratory properties are similar to the models presented in Tables 11 and 12.

3.2 Laboratory Properties Only

The full dataset described in the previous section may not always be available. While it is likely that most soil samples subjected to laboratory analyses will have been described in the field, this will not always be the case (e.g. grab samples), and even where they are described in the field different descriptive methodologies or terminology may be used. The process by which structure and soil strength terms have been converted to numeric predictors are applicable only to the specific descriptive terms used here and not applicable to other systems of terminology. Restricting the analysis to the laboratory properties gives more generally applicable pedotransfer functions.

Stepwise multiple regressions were developed for AWC, RAWC, TP and MP using the following candidate predictors -

DBD, C, Al, S, Z, Cl, S², S.Z, S.Cl, Z², Z.Cl, Cl²

A similar regression was developed for DBD from the other candidate predictors. There were a total of 479 data points with the required data.

Table 11. Stepwise Regression for AWC, Laboratory Data

Model	Cumulative		Incremental			F Ratio	P
	SS	DF	SS	DF	MS		
Carbon	14826	1	14826	1	14825.70	538.850	0.0000
+Silt	17059	2	2233	1	2232.90	81.156	0.0000
+Clay	18874	3	1816	1	1815.50	65.986	0.0000
+DBD	22514	4	3640	1	3639.50	132.280	0.0000
+Silt × Clay	24782	5	2269	1	2268.80	82.461	0.0000
Full Model	25015	8	233	3	77.50	2.817	0.0387
+Residual	37946	478	12931	470	27.51		

Term	Coefficient	Std Error	t Value	P
Carbon	0.64124	0.10314	6.217	0.00000
DBD	-12.50730	1.16050	-10.778	0.00000
Sand	0.24881	0.01915	12.993	0.00000
Silt	0.60145	0.02568	23.421	0.00000
Clay	0.39157	0.03981	9.836	0.00000
Silt × Clay	-0.01043	0.00114	-9.187	0.00000
Error SD	5.27548			
Adj. R ²	0.64942			

Table 12. Stepwise Multiple Regression for RAWC, Laboratory Data

Model	Cumulative		Incremental			F Ratio	P
	SS	DF	SS	DF	MS		
Carbon	1156.2	1	1156.2	1	1156.18	176.367	0.0000
+Clay	1651.9	2	495.7	1	495.67	75.611	0.0000
+DBD	1827.8	3	176.0	1	175.98	26.845	0.0000
+Silt	1989.5	4	161.6	1	161.63	24.656	0.0000
+Silt × Clay	2113.2	5	123.8	1	123.76	18.879	0.0000
+Full Model	2169.6	8	56.4	3	18.80	2.867	0.0362
+Residual	5250.7	478	3081.1	470	6.56		

Term	Coefficient	Std Error	t Value	P
FEDBD	0.22474	0.05035	4.463	0.00001
Carbon	-3.20571	0.56656	-5.658	0.00000
Sand	0.10342	0.00935	11.059	0.00000
Silt	0.17771	0.01254	14.173	0.00000
Clay	0.08505	0.01944	4.376	0.00001
Silt × Clay	-0.00244	0.00056	-4.320	0.00002
Error SD	2.57549			
Adj. R ²	0.39615			

Table 13. Stepwise Regression for Total Porosity, Laboratory Data

Model	Cumulative		Incremental			F Ratio	P
	SS	DF	SS	DF	MS		
DBD	51722	1	51722	1	51721.90	5584.865	0.0000
+Full Model	52047	8	325	7	46.42	5.012	0.0000
+Residual	56409	479	4362	471	9.26		

Term	Coefficient	Std Error	t Value	P
DBD	-33.46540	0.46072	-72.637	0.00000
Constant	94.40150	0.59495		
Error SD	3.13133			
Adj. R ²	0.91674			

Table 14. Stepwise Regression for Macroporosity, Laboratory Data

Model	Cumulative		Incremental			F Ratio	P
	SS	DF	SS	DF	MS		
Sand	8747	1	8747	1	8746.60	219.875	0.0000
+DBD	12668	2	3921	1	3921.20	98.573	0.0000
+Sand ²	14618	3	1950	1	1949.70	49.012	0.0000
+Oxalate Al	15451	4	834	1	833.80	20.960	0.0000
+Carbon	16387	5	936	1	935.90	23.527	0.0000
+Full Model	17498	8	1111	3	370.30	9.309	0.0000
+Residual	36234	479	18736	471	39.78		

Term	Coefficient	Std Error	t Value	P
DBD	-18.55220	1.66375	-11.151	0.00000
Carbon	-0.60793	0.12859	-4.728	0.00000
Oxalate Al	-2.02772	0.34853	-5.818	0.00000
Sand	-0.03032	0.04315	-0.703	0.48261
Sand ²	0.00241	0.00046	5.258	0.00000
Constant	35.67120	2.42065		
Error SD	6.47084			
Adj R ²	0.44648			

Table 15. Multiple Regression for Dry Bulk Density, Laboratory Data

Model	Cumulative		Incremental			F Ratio	P
	SS	DF	SS	DF	MS		
Carbon	22.6159	1	22.6159	1	22.62	764.237	0.0000
+Oxalate Al	30.5413	2	7.9254	1	7.93	267.815	0.0000
+Clay	32.0170	3	1.4757	1	1.48	49.867	0.0000
Full Model	32.2151	7	0.1981	4	0.05	1.674	0.1549
+Residual	46.1829	479	13.9678	472	0.03		

Term	Coefficient	Std Error	t Value	P
Carbon	-0.056504	0.0023230	-24.254	0.00000
Oxalate Al	-0.113980	0.0073520	-15.503	0.00000
Clay	-0.004086	0.0005802	-7.042	0.00000
Constant	1.545360	0.0167428		
Error SD	0.172512			
Adj. R ²	0.69133			

The models for AWC, RAWC and Total Porosity are very similar to those in the previous section (Full Data). The set of predictor variables selected differs only for AWC (Clay included, Oxalate Al and Structure Shape excluded). The other differences reflect only the larger number of data points included. The models for AWC and RAWC account for a substantial fraction of the total variance (65% and 40%). These models require only Carbon, Particle Size and Bulk Density information, which makes them widely applicable as pedotransfer functions. The multiple regression model for AWC using the full dataset (Table 6) gives only a very slight improvement in prediction (error Std Dev 4.72 versus 4.81 if the model used in Table 11 is applied to the same data points). This improvement is outweighed by the greater complexity of the model and the requirement for a structure description (using the appropriate terminology) and Oxalate Al.

The models for macroporosity (Table 14, adjusted R^2 0.45) and bulk density (Table 15, adjusted R^2 0.69) are materially inferior to those in the previous section (Table 9, adjusted R^2 0.52 and Table 10, adjusted R^2 0.78 respectively). The full data models should therefore be used whenever the required predictor data is available.

3.3 Allophanic Soils

It is often difficult to get reliable silt and clay measurements from volcanic soils as the apparent values measured may be markedly sensitive to the amount of energy applied to disperse particle aggregates. A separate analysis was therefore performed on Allophanic Soils (*Suborder code starting with LO*) omitting Silt and Clay (but retaining Sand) as predictor variables. There were, however, only 32 samples from 11 volcanic soils and these covered only a narrow range of values (comparable to the *error* standard deviations from the full dataset) of the target properties.

Table 16. Target Property Statistics for Volcanic Soils

Property	Allophanic Soils		Error Std Dev	
	Mean	Std Dev	Full Data	Allophanic
AWC	22.86	6.27	4.72	1.06
RAWC	8.02	1.74	2.57	0.24
Total Porosity	71.34	5.70	3.57	0.10
Macroporosity	16.68	4.49	5.99	0.26
Dry Bulk Density	0.744	0.158	0.140	0.012

The fourth and fifth columns of Table 16 show the error standard deviations for the full dataset models given in Table 6 to Table 10 and the full models (all predictor variables) for the 32 volcanic soil samples. The very low errors in the last column probably reflect over definition of the models on a small dataset. Any regression model based on this dataset would be questionable if extrapolated to other volcanic soils. The means given in Table 16 are probably a more robust estimator than any of the regression models for volcanic soils.

The "full data" pedotransfer functions can be used for volcanic soils where reasonable particle size data is available.

3.4 Field Properties Only

The full dataset will not be available for soils which are described but not sampled for laboratory analysis. Multiple regression analyses were developed for AWC, RAWC, TP, MP and DBD using the "field predictors" S', Z', Cl', S'², S'.Z', S'.Cl', Z'², Z'.Cl', Cl'², St, G, Sz, Sh, G.Sz, G.Sh as candidate predictors.

Table 17. Stepwise Regression for AWC, Field Data

Model	Cumulative		Incremental			F Ratio	P
	SS	DF	SS	DF	MS		
Silt	2230	1	2230	1	2229.60	43.747	0.0000
+Silt.Clay	5221	2	2991	1	2991.20	58.691	0.0000
+Strength	5906	3	685	1	684.90	13.439	0.0003
+Ssize	6239	4	333	1	333.20	6.538	0.0110
+Silt2	6537	5	298	1	298.30	5.853	0.0160
+Clay	7630	6	1093	1	1092.60	21.438	0.0000
Full Model	7984	11	354	5	70.74	1.388	0.2279
+Residual	26892	382	18908	371	50.97		

Term	Coefficient	Std Error	t Value	P
Silt	0.48433	0.05454	8.881	0.00030
Silt.Clay	-0.00760	0.00131	-5.791	0.00216
Strength	-1.00857	0.23945	-4.212	0.00839
Ssize	0.46541	0.18846	2.470	0.05656
Constant	5.85797	1.30059	4.504	0.00638
Error	7.39167			
R*	0.22387			

Table 18. Stepwise Multiple Regression for RAWC, Field Data

Model	Cumulative		Incremental			F Ratio	P
	SS	DF	SS	DF	MS		
Clay	275.3	1	275.3	1	275.30	29.852	0.0000
+Sand (Silt)	688.7	2	413.4	1	413.44	44.831	0.0000
+Strength	818.6	3	129.9	1	129.90	14.086	0.0002
+Clay2	912.0	4	93.4	1	93.39	10.127	0.0016
+Full Model	1047.8	11	135.7	7	19.39	2.103	0.0425
+Residual	4469.2	382	3421.4	371	9.22		

Term	Coefficient	Std Error	t Value	P
Sand	0.06614	0.00502	13.176	0.00004
Silt	0.18776	0.01468	12.789	0.00005
Clay	-0.10131	0.02472	-4.098	0.00937
Strength	-0.34687	0.09446	-3.672	0.01441
Error	3.10356			
R2*	0.17671			

Note that the Sand, Silt and Clay terms in these models are the texture class means given in Table 5, NOT the actual measured values.

The stepwise ANOVAs included more terms than were adopted in the models, whose coefficients are shown. This is because additional terms (Z^2 , CI^2 , etc) made statistically significant but not particularly large improvements to the error standard deviation. The use of categorical rather than continuous data restricts the data range and increases the risk that isolated points may exercise excessive influence. For this reason simpler models (and particularly models that avoid too many texture-related terms) are preferred. Note that the full models would only reduce the error standard deviation from 7.39 to 7.14 for AWC and from 3.10 to 3.04 for RAWC.

These models may be used as Pedotransfer functions where laboratory data is not available but they are considerably less accurate than the full (or laboratory) dataset function in Table 6, Table 7, Table 11 and Table 12. The adjusted R^2 values (0.22 and 0.18) would indicate that the pedotransfer functions are, at best, of only marginal utility.

Table 19. Stepwise Regression for Total Porosity, Field Data

Model	Cumulative		Incremental			F Ratio	P
	SS	DF	SS	DF	MS		
Strength	2840	1	2840	1	2839.80	31.283	0.0000
+Silt	8433	2	5594	1	5593.50	61.618	0.0000
+Shape	9079	3	646	1	645.70	7.113	0.0080
+Grade	9318	4	239	1	238.60	2.628	0.1058
+Grade x Size	9862	5	545	1	544.50	5.998	0.0148
+Full Model	12854	11	2992	6	498.58	5.492	0.0000
+Residual	46532	382	33678	371	90.78		

Term	Coefficient	Std Error	t Value	P
Silt	0.31030	0.04085	7.596	0.00063
Strength	-2.29920	0.29466	-7.803	0.00055
Shape	2.11816	0.82861	2.556	0.05088
Const	46.89500	1.61000		
Error SD	9.94084			
Adj. R ²	0.18874			

The model presented includes only three terms (Z', St, Sh). The stepwise regression indicates that no one term gave a significant improvement, but that the remaining terms cumulatively did make a significant difference. The full model would, however, only reduce the error SD from 9.94 to 9.54. The adjusted R² value of 0.19 again indicates that a pedotransfer function based on this model would be of only marginal utility.

Table 20. Stepwise Regression for Macroporosity, Field Data

Model	Cumulative		Incremental			F Ratio	P
	SS	DF	SS	DF	MS		
Clay	8294	1	8293.7	1	8293.70	214.422	0.0000
+Size	10996	2	2702.2	1	2702.20	69.862	0.0000
+Shape	11905	3	908.9	1	908.90	23.498	0.0000
+Strength	12315	4	410.6	1	410.60	10.616	0.0012
+Grade x Size	12601	5	285.4	1	285.40	7.379	0.0069
+Full Model	13083	11	482.3	6	80.38	2.078	0.0550
+Residual	27433	382	14350.0	371	38.68		

Term	Coefficient	Std Error	t Value	P
Clay	-0.21360	0.03439	-6.211	0.00158
Strength	-0.72797	0.20832	-3.494	0.01739
Size	-0.98796	0.15621	-6.325	0.00146
Shape	1.85796	0.54859	3.387	0.01953
Grade x Size	-0.27866	0.10347	-2.693	0.04314
Constant	26.42150	0.88231		
Error SD	6.27240			
Adj. R ²	0.45216			

The adjusted R² value (0.45) for the macroporosity model is not much lower than that for the full dataset (0.52 see Table 9). A pedotransfer function based on this model will be a useful predictor. The error standard deviation (6.27) may not, however, meet the fairly demanding requirements of hydrological modelling at the low hydraulic conductivity end of the scale.

Table 21. Multiple Regression for Dry Bulk Density, Field Data

Model	Cumulative		Incremental			F Ratio	P
	SS	DF	SS	DF	MS		
Strength	1.8073	1	1.8073	1	1.80730	24.180	0.0000
+Silt	6.6268	2	4.8195	1	4.81950	64.481	0.0000
+Shape	7.3284	3	0.7016	1	0.70160	9.387	0.0023
+Grade	7.5371	4	0.2087	1	0.20870	2.792	0.0956
+Grade x Size	8.0995	5	0.5624	1	0.56240	7.524	0.0064
+Full Model	10.3482	11	2.2487	6	0.37478	5.014	0.0001
+Residual	38.0780	382	27.7298	371	0.07474		

Term	Coefficient	Std Error	t Value	P
Strength	-0.0091196	0.0017051	-5.348	0.00307
Silt	0.0615173	0.0084431	7.286	0.00076
Shape	-0.0698178	0.0237424	-2.941	0.03223
Const	1.4330400	0.0461330		
Error SD	0.2848394			
Adj. R ²	0.18607			

The regression for bulk density closely follows that for total porosity. These two properties are strongly correlated so the similarity is to be expected. The adjusted R² of 0.19 is much lower than that for the full dataset (0.78, see Table 10) and indicates that the pedotransfer function based on this model would be of only marginal utility.

4. Summary of Pedotransfer functions

4.1 Available Water Capacity

Where the required laboratory data (Sand, Silt, Carbon, DBD, Oxalate Al) is available water capacity (AWC) may be estimated by the pedotransfer function

$$AWC = 0.641C - 12.51DBD + 0.249Sand + 0.601Silt + 0.392Clay - 0.0104Silt.Clay$$

$$Adjusted R^2 = 0.649, \quad s = 5.28$$

No satisfactory pedotransfer function has been found based on field data only but the best of those tested was

$$AWC = 0.484Silt' - 0.0076Silt'.Clay' - 1.01Strength + 0.465Size + 5.86$$

$$Adjusted R^2 = 0.224, \quad s = 7.39$$

Where the predictor terms are the ratings derived from field observations as described in Table 1, Table 3 and Table 5.

There was insufficient data to construct safely robust separate pedotransfer functions for volcanic soils that did not have reliable %silt or %clay data. But on the basis of the volcanic soils in this dataset a constant value of

$$AWC = 22.9 \pm 6.3$$

might be acceptable for such soils.

4.2 Readily Available Water Capacity

Where the appropriate laboratory data (particle size, Carbon and bulk density) is available the

$$RAWC = 0.225Carbon - 3.21DBD + 0.103Sand + 0.178Silt + 0.085Clay - 0.0024Silt.Clay$$

$$Adjusted R^2 = 0.396, \quad s = 2.58$$

readily available water capacity (RAWC) may be estimated by the pedotransfer function.

No satisfactory pedotransfer function has been found based on field data only but the best of those tested was

$$RAWC = 0.066Sand' + 0.188Silt' - 0.101Clay' - 0.35Strength$$

$$Adjusted R^2 = 0.177, \quad s = 3.10$$

Where the predictor terms are the ratings derived from field observations as described in Table 1 and Table 5.

There was insufficient data to construct safely robust separate pedotransfer functions for volcanic soils that did not have reliable %silt or %clay data. But on the basis of the volcanic soils in this dataset a constant value of

$$RAWC = 8.0 \pm 1.7$$

might be acceptable for such soils.

4.3 Total Porosity

Where bulk density is available, total porosity may be estimated by the (empirically derived) pedotransfer function

$$TP = 94.40 - 33.47DBD$$

$$adjusted R^2 = 0.917, \quad s = 3.13$$

This is not materially different to the known non-empirical relationship

$$TP = 0.310Silt' - 2.30Strength + 2.12Shape + 46.89$$

$$adjusted R^2 = 0.189, \quad s = 9.94$$

$$TP = \left(1 - \frac{DBD}{PD}\right) \times 100\%$$

$$PD \approx 2.8$$

No satisfactory pedotransfer function was found for total porosity for soils without laboratory data. The best of the functions tested was where the variables on the right hand side of the equation are the ratings derived from field observations using Table 1, Table 4 and Table 5.

4.4 Macroporosity

Where the appropriate predictor variables are available macroporosity may be estimated by the pedotransfer function

$$MP = 38.67 - 18.25DBD - 0.60Carbon - 1.89Alox + 0.173Sand - 0.0049Sand.Clay - 0.60Size$$

$$Adjusted R^2 = 0.524, \quad s = 5.99$$

Where field data is not available (or has not been described compatibly with the terminology in

Table 3) macroporosity may be estimated from the (laboratory only) pedotransfer function

$$MP = 35.67 - 18.55DBD - 0.61Carbon - 2.03Alox - 0.030Sand + 0.0024Sand^2$$

$$Adjusted R^2 = 0.446, \quad s = 6.47$$

Where laboratory data is not available macroporosity may be estimated from the (field only) pedotransfer function

$$MP = 26.4 - 0.214Clay' - 0.73Strength - 0.99Size + 1.86Shape - 0.28Grade.Size$$

$$Adjusted R^2 = 0.452, \quad 6.27$$

Where the variables on the right hand side of the equation are ratings derived from field properties as in, Table 2, Table 3, Table 4 and Table 5.

4.5 Fine Earth Dry Bulk Density

Where the appropriate predictor properties are available Dry Bulk Density may be estimated by the pedotransfer function

$$DBD = 1.472 - 0.0047Carbon - 0.1146Alox - 0.00690Clay + 0.0220Strength + 0.0142Size - 0.0499Shape$$

$$Adjusted R^2 = 0.785, \quad s = 0.140$$

Where field data is not available (or has not been described compatibly with the terminology in Table 1, Table 3 and Table 4) bulk density may be estimated by the (laboratory only) pedotransfer function

$$DBD = 1.544 - 0.0565Carbon - 0.1140Alox - 0.0049Clay$$

$$Adjusted R^2 = 0.691, \quad s = 0.172$$

No satisfactory pedotransfer function was found for soils with no laboratory data. The best of the functions tested was

$$DBD = 1.433 - 0.0091Strength + 0.06152Silt' - 0.0698Shape$$

$$Adjusted R^2 = 0.186, \quad s = 0.284$$

Where the variables on the Right Hand Side of the equation are the ratings derived from field observations as shown in Table 1, Table 4 and Table 5.

5. Acknowledgement

Funding was provided by the Foundation for Research, Science and Technology through contract CO9X0215.

6. References

Taylor, N.H. and Pohlen, I. J. (1979). Soil survey method. Soil Bureau Bulletin 25. DSIR. Wellington. NZ.

CHAPTER 3. Quality Control Procedures for the NSD

R.H. Wilde

1. Introduction

This section describes the application of quality assurance and quality control to the entire sequence of National Soils Database (NSD) work in relation to:

- field procedures
- laboratory work, referring to existing laboratory QA/QC manuals
- archiving of data within the electronic database
- continued monitoring of the correctness of the database in relation to QA/QC issues.

The reporting of QA/QC issues relating to the archiving of electronic data, and to the ongoing monitoring of the database, will need to wait until the NSD is ported to MS SQL Server, when the underlying issues relating to QA/QC procedures will become clearer.

The contract brief to develop QA/QC procedures for the NSD is:

- to develop a QA/QC procedure for each step and component related to getting soils data into the NSD This includes selection of sample sites, sample collection and analysis, data processing and sample archiving.
- to provide internal documentation, archiving and reporting these procedures and supporting information.

How QA/QC relates to the NSD

Quality assurance (QA) and quality control (QC) procedures are required to ensure the integrity of the New Zealand National Soils Database (NSD) and its acceptability to users. This chapter records the processes, steps and procedures necessary to establish and maintain the NSD. This ensures that reviews and audits will find the key processes well documented and makes issues of quality assurance as transparent as possible to users.

Definitions of QA/QC terms used in this document

Quality assurance

Quality assurance comprises all the direct and indirect activities necessary to provide users with information about the quality of the data, to enable them to use it appropriately (Telarc 1994, Clesceri et al. 1998). Direct activities include:

- Selection of methods.
- Development and validation of methods, and their documentation in field and laboratory manuals.
- Documentation and maintenance of good records for site and soil profile descriptions, analytical methods, and data repositories.
- Provision of all necessary equipment including field and laboratory equipment, as well as computer hardware and software necessary for data storage and manipulation.
- Direct activities also include the maintenance of equipment, computer hardware and software, and ensuring that all equipment and software is used appropriately.
- Recording and reporting, including compiling the analytical data, entering it into the NSD, and associated reporting of the data to clients.
- Staff training.

Indirect activities include:

- Advertising, promoting and marketing the NSD to make it widely available to users, for example advertising and making it available to users through the Internet.
- Providing technical literature associated with the database including metadata.
- Acquiring the customer service and management skills necessary for dealing with database users.

An integral part of quality assurance is the provision of field and laboratory manuals that describe in detail the methods to be used. Such manuals need to be periodically updated and supplemented by published work. Many field and laboratory methods used by Landcare Research are already fully documented, for example, field descriptions of the site and soil profile (Taylor & Pohlen, 1962, Milne et al., 1995) and analytical procedures for chemical, physical and mineralogical analyses. (Daly & Hill (2001a, b, c); Hill and Daly 2001). Methods and QA/QC procedures for the Environmental Chemistry Laboratory are well documented, but methods for the mineralogical and soil physical laboratories, although adequate, are not as well documented.

Quality Control:

Quality control activities are the methods used to put quality assurance into practice and make it work (Telarc 1994; Clesceri et al.1998). They comprise the methods and procedures necessary to provide high quality data that will satisfy users' requirements. A QC system will typically contain routine and consistent activities and actions that are necessary to ensure data integrity, correctness and completeness. These will include:

- Checking accuracy of data acquisition and calculations.
- Identifying and correcting errors and omissions, and ensure the use of approved standardised measurement methods.
- Estimating uncertainty.
- Reporting, including the documentation of all QA/QC activities.

Before a QC system can be implemented, however, the methods to assess and maintain data quality must be developed.

The improved accuracy and reduced uncertainty resulting from QC activities, as well as the ongoing QC requirements, need to be balanced against time and cost effectiveness. The proposed system outlined here attempts to achieve this balance.

QA/QC activities should include a planned system of review procedures conducted by personnel not directly involved with the fieldwork and data acquisition, analytical work, data processing and data archiving process. Reviews should be performed by an independent third party to assess the effectiveness of the QA/QC program, to verify that data quality objectives are met, and to ensure that the database represents the best possible repository of New Zealand soils data.

2. QA/QC for site selection and field sampling

2.1 Filling data gaps

There are QA/QC issues relating to assessing the representativeness of deliberately-selected sample sites without carrying out a mini soil survey. For example, at least 25 to 30 auger observations should be made to develop the modal definition (McKenzie et al. 2000). Whatever QA/QC procedures are adopted, however, there needs to be independent verification and documentation that appropriate QA/QC procedures have been followed.

2.2 Historical QA/QC procedures

When soil surveys were being carried out in New Zealand before 1990, QA/QC issues relating to the conduct of fieldwork were handled through supervision of field personnel by senior Soil Bureau DSIR staff. A procedure of field soil correlation was carried out by designated staff, including field visits, and supervising staff frequently made random observations to check that map units were consistent and concepts were sound. When soil characterisation was a part of soil surveying it was usually possible to obtain an estimate of the appropriateness of the choice of sample site for the characterisation of a pedon, because considerable descriptive work to characterise map units was carried out and documented, and colleagues and supervisors could check this documentation against their observations in the soil profiles during correlation field trips, and their own knowledge.

2.3 Current and future QA/QC procedures

The selection of sites for filling data gaps relies entirely on the personal judgement of the pedologist, particularly when the site selection, sampling and laboratory analysis is not carried out during soil survey operations. There are always difficulties in estimating how good the pedologist's judgement is or how much bias has influenced the choice of site. If, however, the selection of sites for filling data gaps falls within the area of an existing soil survey made at a scale of 1:50 000 or larger scale, it is possible for some independent person to randomly select sites within the soil unit in question and compare the soil profile descriptions made from this random selection with the soil profile description made at the sample site. Otherwise it is impossible to gauge the "goodness" of the choice of site.

One method of QA/QC for data-gap filling is to provide adequate documentation of how the site was selected and where. This might include providing notes on typical and atypical features of the proposed site and profile, for example a brief description of the landform and position of the sample pit, and notes about the variability of horizon thicknesses relating to slope and aspect, the variability of overall profile thickness, and any subtle changes of horizon mottling and colour patterns that might indicate differences in internal soil drainage.

A good QA/QC system would also have an independent party examine one in ten sampled sites, for example, together with all documentation, to enable judgment of whether prescribed field sampling methods and QA/QC procedures have been followed. Above all, the best way to ensure good quality is to have well-trained and well-motivated field staff carrying out well-documented fieldwork procedures.

3. QA/QC for laboratory work

The three factors that ensure that high-quality analyses are carried out within the laboratory are:

- staff training and proficiency
- systems in place to ensure QA/QC requirements are met, and
- laboratory performance.

Success is ensured by having well-trained and well-motivated staff using well-documented techniques. Quality assurance is then made possible by putting quality control systems in place to oversee the methods used, detect and overcome problems, and monitor outputs.

3.1 Environmental Chemistry Laboratory

Historical aspects

Most of the NSD chemistry analyses were carried out before QA/QC issues reached New Zealand in the late 1980s. Early analyses used standard methods (Blakemore et al. 1972, 1977, 1981, 1987; Metson 1961), and replicated data to detect errors. These analyses were carried out with high precision but of unknown accuracy (B K Daly pers. comm.). Early work relied on the integrity and skill of managers to ensure correct results.

Current and future aspects

In recent years chemical analyses have become more accurate but less precise. Laboratory methods and QA/QC manuals have been extensively rewritten (Daly & Hill, 2001a, b, c; Hill & Daly 2001), and periodic sample exchange with other laboratories ensures accuracy is maintained. Currently, the Landcare Research Environmental Chemistry Laboratory exchanges two samples with five other laboratories, once each month, and also takes part in an international sample exchange scheme (ASPAC). Specific QA/QC procedures for the laboratory are described by Daly and Hill (2001b).

The Landcare Research Environmental Chemistry Laboratory is now accredited to the Institute of Accreditation New Zealand (IANZ).

3.2 Soil Physics Laboratory

Historical Aspects

Apart from particle-size analyses that began about 1959, routine physical analyses for soils involving measurement of bulk density and soil moisture storage did not occur until 1973. QA/QC was not an issue, and well-trained staff did their best. Moreover, apart from some early United States Department of Agriculture and United States Bureau of Reclamation publications, there were few methods available describing methods of physical analysis of soils until in 1979 the New Zealand Soil Bureau published their own methods (Gradwell & Birrell 1979).

Current and future aspects

The Landcare Research soil physics laboratories at Palmerston North and Hamilton rely on well-trained staff competently carrying out physical analyses. Apart from particle-size analyses, it is difficult to see how exchanging samples between laboratories would work, because if sufficient replicates are taken to share out among several laboratories (assuming there were several laboratories available to take part) a large volume of soil would be required, and natural soil variability would make comparisons of results between laboratories meaningless. Furthermore, physical analyses destroy the samples, so repeat analyses cannot be carried out on the same sample.

Landcare Research physical laboratories have relied on analysing two or three replicate samples. If one of these differs from the other two, all three are examined for differences in organic matter or stone content that can affect the results.

Staff at the Soil Physics Laboratories at Palmerston North and Hamilton have prepared the following notes detailing laboratory methods.

- Unsaturated Hydraulic Conductivity 1997.
- Permeameter Calibration Appendix January 1998.
- Saturated Hydraulic Conductivity 1988.
- Water-stability of Soil Aggregates.
- Eijkelkamp Penetrometer ('Penetrologger') Field Operation Manual 2000.
- Water retention 1997.

In addition to the unpublished laboratory methods manuals, published work relating to particle-size determination (Claydon 1989) and unsaturated hydraulic conductivity (Cook et al. 1993) is available.

3.3 Soil Mineralogy Laboratory

Historical Aspects

The Soil Mineralogical Laboratory of the New Zealand Soil Bureau used well-documented procedures for carrying out mineral analyses (Claridge 1969, 1978a, 1978b; Claridge and Weatherhead 1978; Farmer and Russell 1967; Farmer, 1974; Fieldes et al. 1956, 1972; Fieldes 1957, 1968; Mackenzie, 1970; Norrish and Hutton 1969, Wells and Smidt 1978, Whitton and Churchman 1987 and Whitton 1995). Staff who carried out mineralogical analyses were well-trained, competent and well-motivated.

In addition, the accuracy of the laboratory's work relied on an experienced senior scientist or technical officer supervising the work of junior staff, examining their analytical results and detecting any mistakes and anomalies before the results were delivered to the client.

A common method of quality control used was to divide a number of the mineralogical samples sent to the lab, and using several different methods to analyse them: X-ray diffraction, heavy mineral analysis, microscopy and spectroscopy; and then correlate the results. This multi-method approach allowed periodic checks to be made of the analytical techniques.

At one time, standard mineralogical samples were made available from the US Geological Survey to various laboratories throughout the world to detect operator bias. The Soil Bureau, DSIR, was one of the laboratories taking part in these inter-lab comparisons. Some variation occurred between laboratories analysing these standard samples owing to the different pre-treatments used. For example, the NZ Soil Bureau obtained more expansion of clay layers because they were more scrupulous in their sample preparation.

Sample cleaning procedures were limiting in some laboratories. This reduced the effectiveness of exchanging samples between different laboratories to reduce operator bias. Whole soil analyses without pre-treatment would give a different result to treated samples. For example, more interlayered hydrous micas (IHM), more vermiculite but less smectite was detected during analysis if shortcuts were made during pre-treatment (J.S. Whitton pers. comm.). Adequate pre-treatment was essential to separate smectite from IHM and from vermiculite. For example, the clay particles needed to be cleaned off sand and silt particles using ultrasonic vibration. Otherwise the clay mineralogy would bias the sand and silt mineralogy and produce errors.

3.4 Machine calibration

For XRD machines, every six months theta angles were checked with quartz contained in samples, during routine servicing and calibration by the agents of the supplier.

3.5 Interpretation of results

This was usually carried out by senior laboratory staff using well-documented procedures (Brindley & Brown 1980; Farmer & Russell 1967; and Norrish & Hutton 1969). Results for particular soils were checked between laboratory staff.

3.6 Current and future aspects

The most efficient way to carry out QC procedures for the Mineralogical Laboratory is to set up a sample exchange network between several laboratories for mineralogical samples, and exchange samples every six months or so, depending on the number of samples being processed in the laboratory. Laboratories that could take part in sample exchange are the Institute of Geological and Nuclear Sciences, and possibly some overseas laboratories (e.g. Macaulay Institute). Care is needed, however, to ensure that sample pre-treatments are standardised between laboratories.

4. QA/QC for the electronic database

4.1 Historical aspects

Before the establishment of an electronic database for the NSD, all data were held in a card filing system in which typed or handwritten cards were compiled for the site and soil profile descriptions, and for analytical data produced by each of the analytical laboratories. The card file is still preserved and forms part of the NSD archive. Strict procedures (not always adhered to) were set down for completion before analytical work could proceed. For example, the site and profile cards were to be filled out to an acceptable standard before samples could be registered with the analytical laboratories. After the analyses were completed, the results were checked by the laboratory manager and verified as correct. Likewise, the field descriptions of site and soil profile were checked by senior field staff and verified as correct. As soon as the data were verified by the relevant managers, the data cards were transferred to the card filing system. Responsibility for the system was given to the manager of the Soil Chemistry Analytical Laboratory.

This system survived into the electronic data processing era with few changes except that once the descriptions and analytical data were verified as complete and correct, the data were passed to a database manager who supervised the data entry into the electronic database.

Very few extra QA/QC procedures were implemented when the first electronic database was compiled in VMS Datatrieve, although various electronic data instruction manuals were produced and the greatest care was taken with data input, being all work thoroughly checked by another data input operator. Likewise, when the NSD in Datatrieve was ported to Paradox, care was taken to preserve the original table structures (Willoughby & Baker, 1994), although at the time few QA/QC procedures were implemented.

4.2 Current and future aspects

Soil sample and document archiving

Once soil samples have been analysed, 125 g of the dried, ground and sieved sample from the soil

chemistry samples is archived in safe and secure storage. It is not possible to archive soil physical samples apart from particle-size samples, because faunal and microbiological activity destroy undisturbed cores.

All information required to produce the database should be documented and archived. This includes:

- Information on the uncertainty associated with measurements of chemical and physical attributes and uncertainty related to soil variability within map units, mis-classification and mis-correlation of soils, and hence uncertainty carried through to the analytical database.
- Methods used, including those used to estimate uncertainty.
- Rationale for the choice of methods used.
- Changes in data inputs or methods from previous years.
- Identification of individuals providing expert judgement for any uncertainty estimates, e.g. for estimating uncertainty in correlation of soil map units and soil unit variability, and their qualifications and experience.
- Details of other electronic databases or software used in production of the database, including versions, operating manuals, hardware requirements, operating systems, and any other information required to enable their later use.
- Worksheets and interim calculations and any re-calculations carried on previous measurements.
- QA/QC plans, and outcomes of QA/QC procedures.
- Definitions of non-Landcare Research data inputs into the NSD.

Data input to database (data archiving)

This section cannot be completed until the NSD is fully ported to MS SQL Server and is stable (i.e. not continually being modified).

4.3 Error detection and correction of the electronic data

These sections will describe the QA/QC procedures built into the electronic database. They cannot be completed until the NSD is fully ported to MS SQL Server and is stable, and the QA/QC requirements become better understood.

Activities and procedures of the QA/QC system to be carried out after analyses are completed

General QC procedures relating to components of the NSD are given in Table 1. A sample transit sheet outlining the steps taken to verify and record site and profile descriptions, and to provide documentation confirming the completion of chemical and physical analyses, is given in Figure 1.

5. Acknowledgements

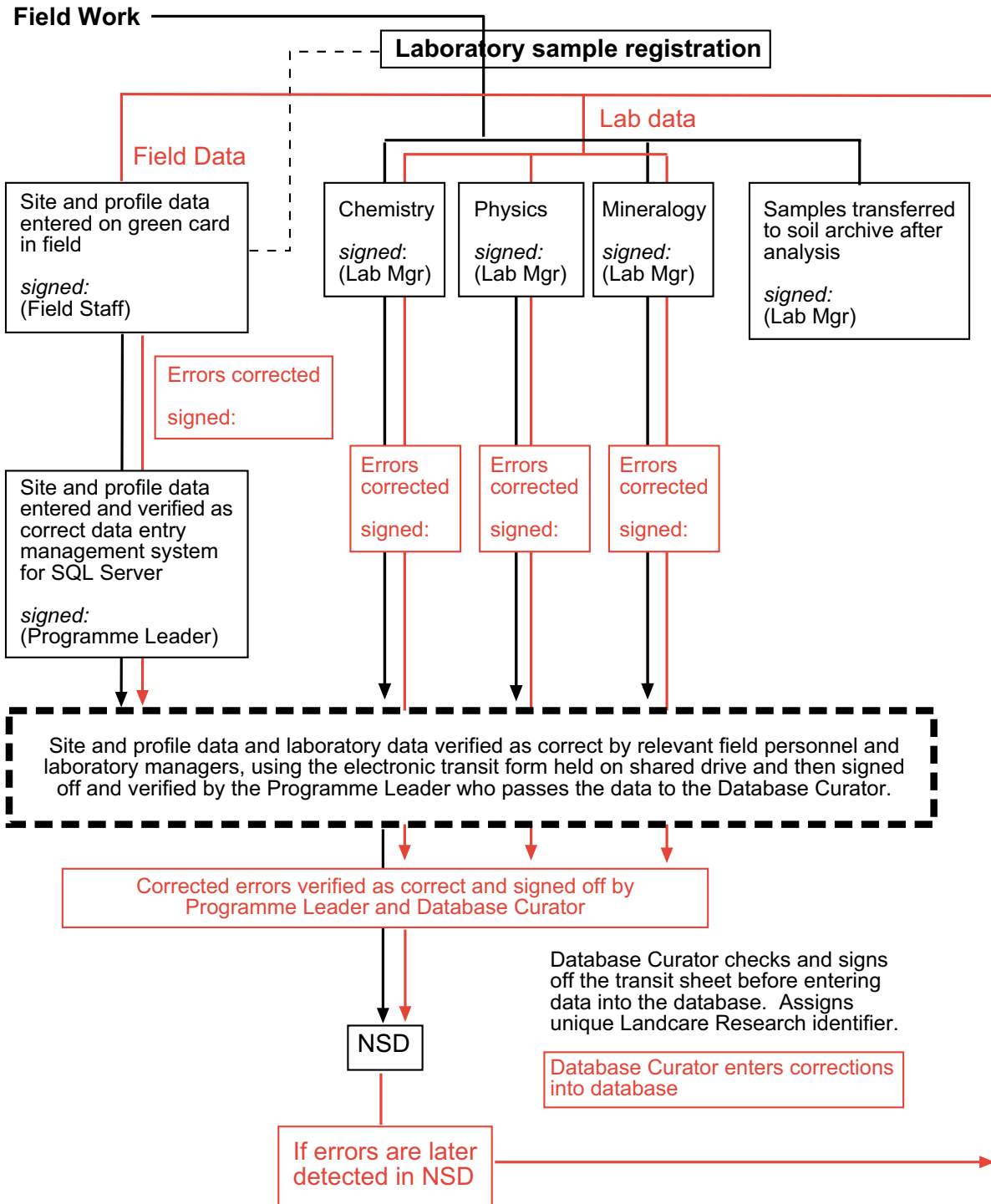
Joe Whitton, John Dando and Stephen Campbell, Landcare Research, Palmerston North, all provided information and advice about material that went into this chapter. Trevor Webb, Landcare Research, Lincoln, read through the chapter and provided valuable advice and criticism. Funds for this work were provided by the Foundation for Research Science and Technology through contract CO9X0215.

Table 1. Activities and Procedures of the QA/QC System to be carried out after analyses are completed.

General Inventory Level QC Procedures	
QC Activity	Procedures
Check for transcription errors in data input and references.	<p>Confirm bibliographic data references are correctly cited.</p> <p>Crosscheck a sample of input data from each laboratory (chemistry, physics and mineralogy) for transcription errors.</p> <p>Where possible, devise and introduce automated range checking for all input values recorded in the database.</p>
Check the integrity of the database files.	<p>Confirm appropriate data processing steps are correctly represented in the database.</p> <p>Confirm data relationships are correctly represented in the database.</p> <p>Ensure data fields are properly labelled and have correct design specifications.</p> <p>Ensure that adequate documentation of the database structure and operation is provided.</p>
Check for consistency in data between the NSD and associated spatial data (e.g. NZLRI).	Compare the soil identified at a sample sites with what the NZLRI shows. Ensure consistency.
<p>Check parameters are correctly recorded, and appropriate conversion factors are used (relates to the integrity of the database)</p> <p>Note: Some of these steps need be done only once, i.e. when the database is established. Thereafter, all that is required is to check that the initial database entries are correct. Thereafter, the procedures are automatic.</p>	<p>Check that units of measurement are appropriate and correctly labelled in calculation sheets.</p> <p>Check that units are correctly carried through from the beginning to end of calculations.</p> <p>Check that conversion factors are correct. Devise a computer-based method to check calculations.</p>
Reduce uncertainties in the data.	<p>Verify qualifications of individuals who provide expert judgements or estimates, and record these.</p> <p>Check that uncertainty errors are calculated correctly.</p> <p>Determine whether there are other sources of error we cannot account for. Test.</p>
Check methodological and data changes resulting in recalculations.	Check for consistency.
Review internal documentation.	Most of this is held in Rawa-Taiao (The metadatabase for information sources in Landcare Research).
Carry out completeness checks.	<p>Annually review geographic and taxonomic gaps in the NSD data. Document these. Plan and document a strategy to fill the gaps.</p> <p>Check that the database records adequately represent each taxonomic class (subgroup) according to their national areal extent.</p> <p>Check that all analyses done fulfil the specifications of data-gap filling.</p>
Check the representativeness of the database.	Design sampling to test this.

QA TRANSIT SHEET FOR NEW SOILS DATA

WORKFLOW DIAGRAM and Error Correction



6. References

- Claydon, J.J. 1989: Determination of particle-size distribution in fine-grained soils – Pipette method. DSIR Division of Land & Soil Sciences Technical Record LH5.
- Cook, F.J.; Lilley, G.P.; Nunns, R.A. 1993: Unsaturated hydraulic conductivity and sorptivity: Laboratory measurement. *In* Carter, M.R. *ed.* Soil Sampling and Methods of Analysis. Canadian Society of Soil Science. Pp 615–624.
- Blakemore, L.C.; Searle, P.L.; Daly, B.K. 1972, 1977 & 1981: Methods for chemical analysis of soils. Part A. Soil Bureau Laboratory Methods. *New Zealand Soil Bureau Scientific Report 10*.
- Blakemore, L.C.; Searle, P.L.; Daly, B.K. 1987: Methods for chemical analysis of soils. *New Zealand Soil Bureau Scientific Report 80*. 103 p.
- Brindley, G.W.; Brown, G. 1980: Crystal structure of clay minerals and their x-ray identification. Mineralogical Society, London. 495 p.
- Claridge, G.G.C. 1969: Physico-chemical methods for soil analysis. *New Zealand Soil Bureau Information Series 23*. 39 p.
- Claridge, G.G.C. 1978a, Sample preparation by particle size separation. Chapter D1.A *in* Soil Bureau Laboratory Methods D. Methods for mineral and element analysis. *New Zealand Soil Bureau Scientific Report 10D*.
- Claridge, G.G.C. 1978b: Electron microscopy. Chapter D1.F *in* Soil Bureau laboratory methods. D. Methods for mineral and element analysis. *New Zealand Soil Bureau Scientific Report 10D*.
- Claridge, G.G.C.; Weatherhead, V. 1978: Optical microscopy. *In* Soil Bureau laboratory methods. D. Methods for mineral and element analysis, Chapter D1.B. *New Zealand Soil Bureau Scientific Report 10D*.
- Clesceri, L.S.; Greenberg, A.E. Eaton, A.D. *eds* 1998: Standard methods for the examination of water and wastewater. Prepared and published jointly by the American Public Health Association, American Water Works Association and the Water Environment Federation. In ten parts.
- Daly, B.K.; Hill, L.F. 2001a: Plant and Water Analysis Method Manual. Environmental Chemistry Laboratory, Landcare Research. 63 p.
- Daly, B.K.; Hill, L.F. 2001b: Quality Assurance Manual. Environmental Chemistry Laboratory, Landcare Research. 55 p.
- Daly, B.K.; Hill, L.F. 2001c. Soil Analysis Method Manual. Environmental Chemistry Laboratory, Landcare Research. 133 p.
- Farmer, V.C. 1974: Infrared spectra of minerals. London Mineralogical Society. 539 p.

- Farmer, V.C.; Russell, J.D. 1967: Infrared absorption spectrometry in clay studies. Proceedings of the 15th Conference on Clays and Clay Minerals: 121–142.
- Fieldes, M. 1957: Clay mineralogy of New Zealand soils. Part 4. Differential Thermal Analysis. *New Zealand Journal of Science and Technology B38*: 533–570.
- Fieldes, M. 1968: Clay Mineralogy. Chapter 6.2, pp. 22–39 in Soils of New Zealand. Part 2. *New Zealand Soil Bureau Bulletin 26 (2)*. 221 p.
- Fieldes, M.; Walker, I.K.; Williams, P.P. 1956: Clay mineralogy of New Zealand soils. Part 3. Infrared absorption spectra of soil clays. *New Zealand Journal of Science and Technology B38*: 31–43.
- Fieldes, M.; Furkert, R.J.; Wells, N. 1972: Rapid determination of constituents of whole soils using infrared absorption. *New Zealand Journal of Science 15*: 615–627.
- Gradwell, M.W.; Birrell, K.S. 1979: Methods for physical analysis of soils. *New Zealand Soil Bureau Scientific Report 10C*.
- Hill, L.F.; Daly, B.K. 2001: Laboratory Safety Manual. Environmental Chemistry Laboratory, Landcare Research. 19 p.
- Mackenzie, R.C. 1970: Differential Thermal Analysis. Vols. 1 and 2. London Academic Press.
- McKenzie, N.J.; McDonald, W.S.; Murtha, G.G. 2000: Network of Australian soil and land reference sites: Design and Specification. ACLEP Technical Report No. 1. 42 p.
- Metson, A.J. 1961: Methods of chemical analysis for soil survey samples. *New Zealand Soil Bureau Bulletin 12*. 208 p.
- Milne, J.D.G.; Clayden, B.; Singleton, P.L.; Wilson, A.D. 1995: Soil Description Handbook Revised Edition. Published by Manaaki Whenua Press, Landcare Research, P.O. Box 40 Lincoln 8152, New Zealand. 156 p.
- Norrish, K.; Hutton, J.T. 1969: An accurate x-ray spectrographic method for the analysis of a wide range of geological samples. *Geochimica et Cosmochimica Acta 33*: 431–453.
- Taylor, N.H.; Pohlen, I.J. 1962: Soil Survey Method. A New Zealand handbook for the field study of soils. *New Zealand Soil Bureau Bulletin 25*. 242 p.
- Telarc 1994: Good laboratory management practice: New Zealand Code of Laboratory Management Practice and background reading and supporting notes to the Code of Laboratory Management Practice. Auckland, New Zealand, New Zealand Quality College, a division of Telarc New Zealand, 98 p.
- Wells, N.; Smidt, R.E. 1978: Methods for mineral and element analysis. *New Zealand Soil Bureau Scientific Report 10D*.
- Whitton, J.S. 1995: Sample preparation and instrumental techniques used in mineralogical characterisation at Landcare Research New Zealand Ltd. Landcare Research Internal Report 27 pp.

- Whitton, J.S.; Churchman, J.G. 1987: Standard methods for mineral analysis of soil survey samples for characterisation and classification in New Zealand Soil Bureau. *New Zealand Soil Bureau Scientific Report 79*. 27 p.
- Willoughby, E.J.; Baker, I.R. 1994: *Standard Input/Output Procedures for the National Soils Database Using Paradox and Windows*. Unpublished Landcare Research Report. 21 p + appendix.

CHAPTER 4. Sampling Strategy

R.H. Wilde

1. Introduction

1.1 Data gaps in the NSD

The current NSD is an incomplete representation of soil series identified in New Zealand. As at 1 July, 2001 there were 1914 soil series recognised in New Zealand and contained within the ‘Soils’ table of the National Soils Database (NSD). There are, however, only 750 unique soil series contained in the NSD, from a total of 1449 pedons described and analysed, because the total includes multiple analyses of some soil series. As a result there are data gaps in the NSD. A full inventory of these is presented in the NSD Audit (Willoughby et al., 2001).

In general, profile data within the NSD have been derived from sites selected for soil characterisation, which was usually carried out as part of soil survey operations. The quality of data for each soil series on the NSD is variable with different numbers of analyses for profiles. Some may have only chemical data. Others may have a full set of chemical, physical and mineralogical analyses. As a result, there is a need to add new data to the NSD. This we term “gap filling”, and for gap filling to be effective, we need to ensure there are standards to define what profiles should be sampled and what analyses need to be done. Two necessary properties of soil characterisation sites are that they are representative, and that they can be sampled to provide maximum data for a fixed cost.

Gap filling will also entail adding data from profiles that have been analysed and are contained in files and reports, but have not been entered into the electronic database. In this regard there are 54 pedons known as Reference Sites (NZ Soil Bureau, 1968) that have a full range of chemical, mineralogical, physical and soil engineering determinations. These data are currently being entered into the electronic database. This report details the necessary standards required to govern the selection of sites and the conduct of field procedures for carrying out an effective gap-filling programme.

1.2 Selection of sites to fill data gaps

1.2.1 Identification of data gaps in the NSD

There are several useful methods to identify data gaps in the NSD:

- Identifying geographic gaps. The distribution of data points, and hence the distribution of gaps, are easily observed on a plot of the data points overlying a map of New Zealand. Geographic gaps in the NSD include Northland, the King Country, Wairoa–Northern Hawkes Bay, Southern Hawkes Bay–Wairarapa, South Island high country, North Otago, South Westland and Fiordland.
- Identifying classification gaps (for example, we have only 190 of 250 Subgroups of the New Zealand Soil Classification presently in the NSD).
- Identifying sites where the land cover or land use is poorly represented in the NSD.
- Identifying thematic data gaps, for example, identifying sites from which the data will minimise errors in nationally modelled surfaces. Using the standard error of the mean from a

model developed to predict total soil P nationally, we prioritised sample sites that would supply data to best reduce the total error of prediction. Potential sample sites were identified in areas of high elevation (high rainfall and low temperatures) and within particular soil orders (R.A. Andrew, pers. comm.).

Purposive sampling for the NSD

Historically, sampling for the NSD was carried out as one of the functions of soil surveys undertaken by Soil Bureau DSIR. Profiles were selected to characterise what were considered to be typical soil profiles representing soil units mapped during the course of the survey. Sampling began during the early 1930's. This method of selecting sample sites is called purposive sampling (Webster and Oliver (1990) cited in McKenzie et al. 2000) and relies heavily on personal judgement.

Soil characterisation sites were carefully selected to ensure that the soil exhibited properties considered by the pedologist to be diagnostic of the soil class they represented, and to demonstrate particular features of the soil unit in question. These soils were regarded as the 'central concept' of that soil class. If the central concept of a particular soil class showed a silt loam texture, for example, but the allowable range of textures for that entire soil class ranged from silty clay loam through silt loam to very fine sandy loam, then the pedologist would search for a profile with silt loam textures to demonstrate the properties of the 'central concept' for that soil unit.

During soil survey operations there were a number of issues that are now recognised as creating bias within the profiles contained in the NSD.

- There was an obvious bias in the fact that sampling was undertaken wherever soil surveys were undertaken, and this accounts for the lumpy nature of the national distribution of sites, and the fact that most samples are taken from agricultural land.
- During soil survey operations pedologists were careful to select stable sites with minimum disturbance. If a site showed recent signs of development from either scrub or forest into pasture, then it would be likely to be rejected as a characterisation site.
- Likewise, where land use had changed from pasture to market gardening or arable use, it would be rejected because the resultant disturbance and mixing of upper horizons would compromise the characterisation process. Other forms of disturbance such as erosion (either scars or detritus) would also be avoided for selecting characterisation sites, unless the aim of the project was to characterise eroded soils.
- The choice of what profile to sample was subject to each pedologist's judgement as to whether a soil series was sufficiently important to warrant sampling and to the pedologist's understanding of the 'central concept' of the soil being sampled. These decisions were mainly made in the context of districts or regions, with little regard being taken of representativeness on a national scale.

Thus purposive sampling introduced biases into the database, depending on why the profile was sampled. As stable sites were sought for soil characterisation, then it is safe to assume that the "representative" sample is probably uneroded, or at most has only undergone very slight erosion, whereas for the mapped unit as a whole, there would be a range of erosion severity. Consequently, the organic matter contents of topsoils could range from high at sites where there was no erosion, to moderate or low where erosion had occurred.

To avoid bias, sample sites must be randomly selected using a large number of sites. This is termed probabilistic sampling and is both time-consuming and expensive. Probabilistic sampling has not been used to select sample sites in New Zealand for soil characterisation, although it has been used in some early soil variability studies. Probabilistic sampling is currently used for the Carbon Monitoring System (CMS). Here, randomly-selected vegetation plots are sampled for organic

carbon and bulk density, to determine the extent to which carbon is sequestered in New Zealand soils within 1 m depth.

1.2.2 Future sampling methods for gap filling

To minimise biases from purposive sampling during NSD gap filling, stratified random sampling could be an acceptable compromise. For this method, all known areas of the particular soil class to be sampled are identified and plotted onto a map, and sample sites randomly selected from those areas. Should a selected site be unsuitable for sampling (for example, through disturbance or erosion), a set of explicit rules must be used to choose an alternative site to minimise bias in the site selection. One problem with this approach is that continued rejection of unsuitable sites can lead to biases in the database that are similar to biases resulting from purposive sampling.

Rather than continuing to ‘ignore’ this problem, Trevor Webb of Landcare Research has tentatively suggested that we develop a procedure to sample ‘disturbed’ profiles when they are typical of a significant proportion of map units. Where ‘disturbed’ profiles are estimated to represent, say, 20% or more of a particular map unit, we recommend that limited sampling of these ‘variants’ be carried out and a few key parameters used to characterise the differences between the disturbed and undisturbed profiles. We would need only bulk density, organic carbon, pH, and possibly phosphate retention in some places, for the upper one or two horizons. We would also need to develop a method of presenting this difference data in the database.

1.2.3 Representativeness of the site

Each attribute of a soil class (e.g. a soil series) will show a range of properties. For example, texture may range from silty clay loams to very fine sandy loams, and internal drainage may range from well drained to moderately well drained. The ‘central concept’ of the series by definition should lie close to the middle of the range. Efforts need to be made to locate a modal pedon for sampling.

It is difficult to gauge whether a particular pedon represents the central concept of a soil class unless the entire range of pedons is examined. This requires extensive fieldwork—at the very least a significant examination of prospective sample sites. Where the distribution of the soil class is reasonably well known, one method is to select a number of profiles at random throughout the entire known area of the soil class, record their essential profile characteristics, and sample for several diagnostic properties. The representative pedon is then selected on the basis of the profile characteristics and the modal values of the diagnostic properties. Where the distribution of the soil class is unknown, sufficient profiles need to be examined so that the class range can be reasonably well defined and a profile identified that represents the central concept of that class.

1.2.4 Using CMS samples to fill data gaps

The number of soil samples available for NSD data gap filling can be increased by using samples collected for other Landcare Research programmes, for example the Carbon Monitoring System (CMS) programme (Scott et al. 2002), and carrying out the soil analyses conforming to the NSD Minimum Data Set (see Chapter 1), in addition to any other analyses carried out. Although CMS samples are collected from fixed depths (0–10 cm, 10–20 cm, 20–30 cm and 30–100 cm), the soil profiles at the CMS sites have been described and the horizon designations and depths are known. We can therefore provide reasonable estimates of soil chemistry on a horizon basis using a combination of weighted averages and interpolation.

Using previously analysed soils to fill data gaps

Much soil analytical data resides in university theses and some of this work is eminently suitable to fill data gaps. However the minimum data set outlined in Chapter 1 must be adhered to, and minimum standards for analytical methods need to be agreed and documented. Good metadata including methods of analysis are essential if site and profile descriptions, and analyses from

outside Landcare Research are to be included in the NSD.

2. Field sampling procedure

2.1 Introduction

Soil characterisation sites need to be sampled using a fresh excavation. Several methods are available whose advantages and disadvantages (after McKenzie et al. 2000) are listed below.

2.2 Methods of exposing the soil profile for description and sampling for analysis

2.2.1 Freshly dug profile pit

Digging a pit (by hand or machine) is the preferred method for collecting soil characterisation samples. As data-gap filling will tend to concentrate on more remote areas, often in hilly and steep land, there will be access problems for mechanical diggers, making hand digging the only option.

Benefits of using a freshly dug pit are:

- vertical and lateral changes in the soil are shown
- samples are not compacted
- sampling of horizons is relatively easy and straight-forward
- the profile can be easily photographed, and
- undisturbed samples for physical analyses can be readily collected.

2.2.2 Mobile 200 mm diameter truck-mounted corer

Cores with a diameter of 200 mm can be sampled with Landcare Research's mobile corer. This uses a system of rotating flights to cut the corer into the soil, and is especially suitable for deep coring of loess or tephra layers below the modern soil. There are significant costs, however, associated with using this equipment, because two drill operators are required and there is the expense of moving the drilling rig about. Other disadvantages include:

- lateral variability cannot be observed in the cores
- cores cannot be subsampled for many soil physical analyses, because the core diameter is too small
- some minor compaction of samples may occur
- the vehicle can access only flat and easy rolling land
- gravelly soils cannot be sampled.

2.2.3 Giddings light truck-mounted corer and Giddings hand-operated percussion corer

The Giddings light truck-mounted corer (diameter 75 mm) uses a rotary action without flights to push the core barrel into the soil. The hand-operated Giddings corer (diameter 48 mm) uses a sliding hammer arrangement to hit the corer into the soil. Both methods are quick, enabling large numbers of samples to be collected and examined. The main disadvantage of the light truck-mounted corer only, is that access is restricted to flat and easy rolling sites. Other disadvantages are:

- there is significant compression of the core
- lateral variability cannot be observed
- samples are too small to adequately examine soil structure
- gravelly soils cannot be sampled
- undisturbed samples for physical analyses cannot be collected.

The 75 mm diameter corer is not suitable for collecting soil characterisation samples, particularly those for physical analyses. It is suitable, however, for sample collection for skeletal data sets.

2.2.4 Road and railway cuttings and stream banks

These exposures are not suitable for sampling chemical and physical analyses unless a significant amount of the dried soil materials are removed from the face, i.e. the face must be dug back, and sampling is only carried out from fresh materials. Horizons can also be disturbed, especially at roadsides, so care must be taken to avoid disturbed areas. Furthermore, as roads and railways tend to be sited on more stable parts of the landscape, the sampling of road and railway cuttings may introduce bias.

2.3 Preferred sampling method

The preferred method of soil profile exposure for soil characterisation studies is the freshly dug pit that is situated at least several metres from any cuttings or scarps. Once the pit is dug, it is described following the methods of site and soil profile description given by Milne et al. (1995). A photograph of the soil profile should be taken before sampling disturbs the soil.

2.3.1 Sample increments and sampling procedure

Entire horizons should be sampled for chemical analysis and the whole profile sampled to at least one metre depth, even if not all samples are to be analysed immediately. Samples should be taken from channels cut down at least two faces of the sampling pit, thoroughly mixed and quartered down to provide at least 400 g of fine earth per sample, to ensure that a complete sequence of soil samples is available from each horizon for analysis, and for archiving in case future analytical work is required. In addition, each horizon in the profile should be separately sampled for particle-size and particle-density determinations. Collectively, these three samples will provide enough sample for the range of analyses that may be required.

Soil physical sampling for undisturbed samples for bulk density and moisture release should sample as much of the horizon as possible, with samples sited one above the other unless the horizon is very thin. Two types of soil sampling rings for undisturbed sampling are in general use in Landcare Research, a 98 mm inside diameter by 75 mm deep ring, and a 48 mm inside diameter by 30 mm deep ring. These sample rings should be carefully cut into the soil and not hammered in, because hammering can cause wobbling and produce gaps between the core and ring, as well as causing compaction of the core. The cores should not be trimmed flush but left slightly proud of the ring to prevent smearing of the upper and lower surfaces during transit. The cores should be treated with 4% formalin dissolved in water and applied with a squeeze bottle to fumigate the sample to prevent damage by burrowing fauna, and to reduce microbial activity. They should then be wrapped in clingfilm (e.g. Gladwrap) and placed in a plastic bag (one sample to a bag) to prevent drying out. Undisturbed soil cores should be carried to the laboratory in a padded wooden box to prevent damage, and stored in a cool room until analysed to further slow any biological activity.

2.3.2 Sample handling

Ideally, the plastic sample bags containing either bulk or undisturbed samples should be marked with a sticky, waterproof bar code label, in addition to a handwritten label, with the date, profile identifier and sample depth placed inside the sample bag. The bar code can be followed through to the laboratory analyses, and beyond, to the transfer of results to the database, to minimise the possibility of either samples or analyses being mis-identified. If duplicate bar coded labels are used, the duplicate label can be stuck in a notebook and details of the sample written alongside.

Until a bar-code system becomes available, double labelling of sample bags is important, particularly when working in wet environments, where even 'indelible' marker pen lettering may have rubbed off the outside of plastic sample bags by the time the samples arrive at the laboratory. Two waterproof 'nursery' labels should be used, and marked with the date, profile identifier and sample depth using a 'Vivid' brand marker pen in preference to a ballpoint pen. (Labels marked with an indelible marker pen and placed inside sample bags remain legible for longer than do labels

marked with a ballpoint pen). One marked label should be placed in the sample bag and the other tied securely to the outside of the bag.

3. Acknowledgements

Trevor. Webb, Landcare Research, Lincoln, provided valuable advice and comments on this chapter. Funds for this research were provided by the Foundation for Research Science and Technology.

4. References

McKenzie, N.J.; McDonald, W.S.; Murtha, G.G. 2000: Network of Australian soil and land reference sites: Design and Specification. ACLEP Technical Report No. 1. 42 p.

Milne, J.D.G.; Clayden, B.; Singleton, P.L.; Wilson, A.D. 1995: Soil Description Handbook Revised Edition. Published by Manaaki Whenua Press, Landcare Research, P.O. Box 40 Lincoln 8152, New Zealand. 156 p.

New Zealand Soil Bureau 1968: Soils of New Zealand. Part 3. New Zealand Soil Bureau Bulletin 26 (3). 127 p.

Scott, N.A.; Tate, K.R.; Giltrap, D.J.; Smith, C.T.; Wilde, R.H.; Newsome, P.F., Davis, M.R. 2002: Monitoring land-use change effects on soil carbon in New Zealand: quantifying baseline soil carbon stocks. *Environmental Pollution* 116. S167–S186.

Willoughby, E.J.; Wilde, R.H.; McLeod, M.; Hewitt, A.E. and Webb, T.H. 2001: National Soils Database Audit: A document describing Landcare Research soils data. Landcare Research Unpublished Report.