NZ soil data

Manaaki Whenua - Landcare Research
• National Soils Database
• Land Resource Information
• Fundamental Soil Layers
• S-map
• Additional soil property maps
NZ NSD Distribution

NSD site distribution and data content is influenced by former soil surveys and requirements of projects.
NZ National Soils Database

- Point – multiple attributes (<500)
- 2500 samples
- Analyses for 800 of our 2000 soil series
- Patchy distribution

- Moisture retention (e.g. water %)
- Horizon data (e.g. colour)
- Sample Index (e.g. sample No.)
- Site Description (e.g. locality)
- Chemistry (e.g. carbon %)
- Mineralogy (e.g. mica %)
- Particle Size (e.g. fine clay %)
- Analytical Notes (e.g. taxonomy)
- Analytical Method (e.g. Ph-H₂O)
- XRF Analyses (e.g. lead ppm)
NZ Land Resource Inventory

1st Ed 1973-79
1:63,360 scale
90,000 polygons
MMU 40ha
Digital / 320 maps

2nd Ed 1982-98 (20%)
1:50,000 scale
100,000 polygons
MMU 10ha
Digital

Physiographic units
Single polygon set – multiple attributes

Rock - Soil - Slope Erosion - Vegetation

Rock type
Surface rock
Underlying rock
Soil code
Soil survey

LUC
LUC Unit
Potential erosion
P radiata site index
Stock Carrying Capacity
NZ Land Resource Inventory and Land Use Capability
NZ Fundamental Soil Layers
Hybrid between NZLRI and NSD

NZLRI Soil boundaries
Single polygon set – multiple attributes

NSD database of soil profiles, chemistry, mineralogy, etc

NZLRI polygon
Soil code

Soil polygon
14 Soil Attributes

Data plus Knowledge
NZ Fundamental Soil Layers

- Physiographic units
- Soil survey & code
- Soil series, type, phase
- Soil set & genetic group
- NZ Soil Classification
- Fixed classes
- No depth info
- Class uncertainty info

- 1st Ed 1999
- 1:63,360 /1:50,000 scale
- 100,000 NZLRI polygons
- MMU 10ha
- Digital

- pH
- Salinity
- CEC
- Carbon
- P retention
- Gravel content
- Rock & boulders
- Depth
- Drainage
- Available water
- Macroporosity
Status of soil information in NZ

Old information inadequate to support new sustainable management tools

• Old soil data is
  ➢ Patchy
  ➢ Qualitative,
  ➢ Imprecise & Inaccurate

• Reflects needs of the 1950-70s

• Only 700 of our 2000 soils have adequate data

New tools require quantitative data, better detail new types of information
S-map

The newest (but incomplete) soil layer

- One soil map for NZ – unified correlation
- Best available data (digital not cartographic)
- Soil only (not climate or topography)
- Combination of soil survey techniques and DSM approaches where appropriate
- Not just data but an inference system
- Many soil and land attributes (whether measured, estimated or derived)
- Explicit uncertainty for all data, and source
Mapping procedure

• Mixture of conventional soil survey and modelling
  – to new S-map standard
  – Correlating to NZ legend

• New mapping to fill in the gaps
  – Lowlands: conventional soil survey techniques
  – Uplands: model the landscape using a DEM
S-map

**Lowlands** by conventional survey

**Uplands** by soil-landscape modelling
Modelling in hilly & mountainous land

- Within land systems - use a DEM to divide a landscape into ‘land elements’

- Use field work and expert knowledge to develop soil-landscape models to predict soils within the land elements

- Models mainly in the form of rules that relate land elements to soil classes and attributes.
Topographic form elements

A landscape model based on local form: form elements

<table>
<thead>
<tr>
<th>horizontal/tangential curvature</th>
<th>maximum curvature</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>convex</strong></td>
<td><strong>convex</strong></td>
</tr>
<tr>
<td>nose</td>
<td>X/X</td>
</tr>
<tr>
<td>shoulder</td>
<td>X/S</td>
</tr>
<tr>
<td>hollow shoulder</td>
<td>X/V</td>
</tr>
<tr>
<td><strong>straight</strong></td>
<td>peak</td>
</tr>
<tr>
<td>spur</td>
<td>X/X</td>
</tr>
<tr>
<td>planar slope</td>
<td>X/S</td>
</tr>
<tr>
<td>hollow</td>
<td>X/V</td>
</tr>
<tr>
<td><strong>concave</strong></td>
<td></td>
</tr>
<tr>
<td>spur foot</td>
<td>S/S</td>
</tr>
<tr>
<td>footslope</td>
<td>S/V</td>
</tr>
<tr>
<td>hollow foot</td>
<td>S/V</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

This diagram illustrates the classification of topographic form elements based on horizontal/tangential curvature and maximum curvature.
Land elements
Dry greywacke terrain – Ben More Range
Land Elements
## Associating land elements with soils

<table>
<thead>
<tr>
<th>Landform component</th>
<th>Soil series</th>
</tr>
</thead>
<tbody>
<tr>
<td>ridges</td>
<td></td>
</tr>
<tr>
<td>All elevations and aspects</td>
<td>ORx2z (85%) + TM1z (15%)</td>
</tr>
<tr>
<td>Rolling plateau summit</td>
<td>BMa1z (100%)</td>
</tr>
<tr>
<td>backslopes</td>
<td></td>
</tr>
<tr>
<td>&gt;1100m N aspect</td>
<td>BRa2z (50%) + ORx2z (25%) + BMa1z (25%)</td>
</tr>
<tr>
<td>W and E aspects</td>
<td>BMa1z (60%) + BRa2z (25%) + ORx2z (15%)</td>
</tr>
<tr>
<td>S aspect</td>
<td>BMa1z (45%) + TM1z (45%) + BRa2z (10%)</td>
</tr>
<tr>
<td>&gt;750&lt;1100m N aspect</td>
<td>TM1z (70%) + ORx2z (30%)</td>
</tr>
<tr>
<td>E aspect</td>
<td>TM1z (60%) + BMa1z (40%)</td>
</tr>
<tr>
<td>S aspect</td>
<td>BMa1z (90%) + TM1z (10%)</td>
</tr>
<tr>
<td>W aspect</td>
<td>BMa1z (70%) + ORx2z (30%)</td>
</tr>
<tr>
<td>&lt;750m N, W, and E aspects</td>
<td>ORx2z (65%) + TM1z (35%)</td>
</tr>
<tr>
<td>S aspect</td>
<td>TM1z (80%) + ORx2z (20%)</td>
</tr>
</tbody>
</table>
High Resolution DTM

Old 25m DTM
Limited accuracy model soil in detail

Develop high resolution ~ 5m TDM

1\textsuperscript{st} Using ALOS optical imagery
2\textsuperscript{nd} Using Radar imagery

Two trial areas
• Port Hills
• Manawatu soft rock hill country

Good farm scale analysis possible
Soil Digital Mapping

Represent soils as rasters rather than polygons
Predicting the most probable soil type & attribute value for every pixel

Methods in two trial areas
- Port Hills
- NI soft rock hill country

NZ Strategy by defining NZ soilscapes
- to set up spatial predictor data sets
- To plan a national strategy for matching methods to land type and data resources
Functional horizons
Building blocks for NZ soils

Horizons based on soil physical functions

- tLw
- Lw
- LCs
- Ac
Soil classes and attributes in the S-map database

<table>
<thead>
<tr>
<th>Core Dataset (Class data)</th>
<th>Core Dataset (as Prob. dist. functions)</th>
<th>Derived data (modelled mean and variance)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil Order</td>
<td>Depth</td>
<td>PAW</td>
</tr>
<tr>
<td>Soil Group</td>
<td>- Rooting</td>
<td>Field capacity</td>
</tr>
<tr>
<td>Soil Subgroup</td>
<td>- Diggability</td>
<td>Wilting point</td>
</tr>
<tr>
<td>Soil family</td>
<td>- to slow permeable layer</td>
<td>Aeration</td>
</tr>
<tr>
<td>Parent material</td>
<td>Rooting barrier</td>
<td>Macroporosity</td>
</tr>
<tr>
<td>Rock Class</td>
<td>For each Functional horizon:</td>
<td>Bulk density</td>
</tr>
<tr>
<td>Texture Group</td>
<td>Thickness</td>
<td>Total carbon</td>
</tr>
<tr>
<td>Permeability</td>
<td>Stoniness</td>
<td>Total nitrogen</td>
</tr>
<tr>
<td>Depth class</td>
<td>Clay content</td>
<td>P (H2SO4)</td>
</tr>
<tr>
<td>Stoniness class</td>
<td>Sand content</td>
<td>Ca</td>
</tr>
<tr>
<td>Texture</td>
<td></td>
<td>CEC</td>
</tr>
<tr>
<td>Drainage</td>
<td></td>
<td>pH</td>
</tr>
<tr>
<td>Functional horizons</td>
<td></td>
<td>P retention</td>
</tr>
</tbody>
</table>
Te0z (50%) + Rg3l (30%) + Wk0z/s (20%)

Legend
Te = Templeton family
Rg = Rangitata family
Wk = Wakanui family
0 = deep
3 = shallow
z = silt
l = loam
z/s = silt over sand

Confidence code + qualitative uncertainty code for all classes
Representation of uncertainty (in S-map)

- Correlation attributes
  - Confidence code
  - Alternate codes with probability

- Models
  - Interpreted and Derived attributes
  - Propagated error estimates
  - Model error / goodness of fit

- Polygons
  - Variability described via 5 siblings
  - Sibling proportion confidence code

- Base property attributes
  - Confidence code (source)
  - Variability via Pdfs
<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Confident that classification/correlation is correct (based on an acceptable level of auger and pit observations or other data).</td>
</tr>
<tr>
<td>2</td>
<td>Reasonably confident that classification/correlation is correct or that it is one of the listed alternatives (based on an acceptable level of auger and pit observations or other data)</td>
</tr>
<tr>
<td>3</td>
<td>Classification/correlation is probably correct (based on limited or historical data, or strong inference)</td>
</tr>
<tr>
<td>4</td>
<td>Classification/correlation is possibly correct (usually based on reasonable model or poor data)</td>
</tr>
<tr>
<td>5</td>
<td>Classification/correlation is unreliable (there is no data or good model, or variability is very high)</td>
</tr>
</tbody>
</table>
Representation of uncertainty (in S-map)

- Correlation attributes
  - Confidence code
  - Alternate codes with probability

- Interpreted and Derived attributes
  - Propagated error estimates
  - Model error / goodness of fit

- Models
  - Confidence code (source)
  - Variability via Pdfs

- Polygons
  - Variability described via 5 siblings
  - Sibling proportion confidence code

- Base property attributes
Probability distribution functions
for soil attributes within functional horizons

1st Functional horizon
Thickness (cm)

12 20 25

1st Functional horizon
Stones (%)

25 40

Probability distribution functions (pdf) to express variability and uncertainty
<table>
<thead>
<tr>
<th>Code</th>
<th>Observation type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1</td>
<td>Measured(^a)</td>
<td>Unbiased sampling at the individual mapunit level</td>
</tr>
<tr>
<td>M2</td>
<td>Measured(^a) or Observed</td>
<td>Has at least 15 good quality measurements, widely distributed within the sibling in the survey area, or extrapolated from many highly consistent measurements from a landscape of similar soil material and origin</td>
</tr>
<tr>
<td>M3</td>
<td>Observed(^b) or measured</td>
<td>Limited sampling, (biased, localised or incomplete)</td>
</tr>
<tr>
<td>E</td>
<td>Estimated</td>
<td>Values are estimated by comparison with related soils</td>
</tr>
<tr>
<td>G</td>
<td>Unreliable estimate</td>
<td></td>
</tr>
</tbody>
</table>

\(^a\) Indicates the measurement was collected using a standardized protocol. 
\(^b\) Indicates the observation was collected using a non-standardized protocol.
All siblings in map unit

Deep (70%) + Shallow (30%)

by the range of all the siblings

by the weighted average of all the siblings

Te0z (50%) + Rg3l (30%) + Wk0z/s (20%)

by the class proportions

82 cm

40-100 cm
Primary ancillary layers

- DEM (15m)
- Geology (1:250,000)
- Landcover (25m)
- Landuse (~1:50,000)
- Climate (20 or 25m)
New Zealand Climate Layers

Derived from 100m and 25m DEMs coupled with a thin-plate spline surface fitted to meteorological station data from 1950-1980

Mean average daily air temperature
Mean max daily air temperature
Mean min daily air temperature
Earth temp normals (10cm depth)
Mean daily rainfall
Mean daily rainfall variability
Mean 9am VPD
Mean 9am humidity
Mean daily solar radiation
Mean av.daily wind speed

..... and released with LENZ....

Mean annual temperature
Mean minimum temperature of the coldest month (July)
Mean annual solar radiation
Winter (June) solar radiation
October vapour pressure deficit
Annual soil water deficit
Average monthly ratio of rainfall to potential evaporation
## Developing NZ’s GSM layers

<table>
<thead>
<tr>
<th>Property</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>total profile depth (cm),</td>
<td>S-map data + ? Geostats?</td>
</tr>
<tr>
<td>Root depth (cm)</td>
<td>S-map pdf data + FSL</td>
</tr>
<tr>
<td>Organic Carbon (g/kg)</td>
<td>GLM model</td>
</tr>
<tr>
<td>pH</td>
<td>Splines + geostats?</td>
</tr>
<tr>
<td>Sand/silt/clay (g/kg)</td>
<td>S-map pdf data + geostats?</td>
</tr>
<tr>
<td>Gravel</td>
<td>S-map pdf data + FSL</td>
</tr>
<tr>
<td>ECEC (cmol$_c$/kg),</td>
<td>None (FSL for base cations)</td>
</tr>
<tr>
<td>Bulk density (fines)</td>
<td>S-map PTF (linear regression model) + ??</td>
</tr>
<tr>
<td>Bulk density (whole soil)</td>
<td></td>
</tr>
<tr>
<td>Available water (mm)</td>
<td>S-map PTF (Generalised linear model; Gamma distribution with a log link) + FSL</td>
</tr>
</tbody>
</table>
Rooting depth & Gravel

• FSL data is in depth classes – with uncertainty of class
  15-25; 25-45; 45-60; 60-90; 90-120; 120-150 cm
• Gravel is topsoil only
• S-map info is pdfs
Bulk density – S-map PTF

![Graph showing the relationship between estimated and measured bulk density with theoretical and sample quantiles of residuals.](image)
Available water

- GSM PTF (error propagation?)

Or

- FSL (classes and whole profile) + S-map PTFs for functional horizons
Clay/silt/sand

- FSL info = silty/sandy/loamy etc (no depth info)
- S-map info is pdfs for functional horizons
- Tried a random forest model for clay at GSM depth intervals using NSD data + 4 covariates
Organic Carbon

- A generalised least squares model predicting log-transformed soil carbon stock (0-30cm)
- ~ a dozen explanatory variables and one interaction, along with a correction for spatial autocorrelation
- 3200+ training samples
- Predicts μ and 95% CI
Some points on uncertainty

• Collecting new statistically sampled evaluation data is not an option
• Which will make uncertainty quantification very difficult
• Will need make use of the splines to match the GSM intervals \(\rightarrow\) uncertainty propagation?
• But we do have some expert knowledge on the reliability of the information
• All our info is only down to 1 m
• S-map supports Monte Carlo approach to providing quantitative estimates of uncertainty but ..... 
• based on expert info