Restructuring the New Zealand Land Resource Inventory to meet the Changing Needs for Spatial Information in Environmental Research and Management.

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Presented at the 10th Colloquium of the Spatial Information Research Centre, University of Otago, New Zealand, 16-19 November 1998

Abstract

This paper describes a new structure designed for the Land Resource Information System(LRIS) suite of databases. This structure incorporates both the existing classified data layers like the New Zealand Land Resource Inventory (NZLRI) and fundamental data layers (FDLs) which provide data for mechanistic modelling of environmental systems.

Over the last three years LRIS researchers have concentrated on developing our suite of soil FDLs. A first approximation for soil FDLs has been derived by a direct classificatory link between the soil polygons recorded in the NZLRI or more detailed soil surveys, with measured soil attributes stored in the National Soils Database (NSD). Soil attributes being generated as FDLs comprise: cation exchange capacity, pH, phosphorus retention, total carbon, depth to slowly permeable layer, saturated conductivity, soil temperature (at 30 cm), potential rooting depth, total available water capacity, readily available water capacity, macro-pores, flood interval, topsoil gravel (%), dry bulk density, salinity, soil moisture/water balance, and slope, rock outcrops, surface boulders, and internal drainage.

Keywords and phrases: land resource data, database structure, GIS, fundamental soil attributes.

1 Introduction

The Land Resource Information System programme is the curator of two major physical resource databases recognised by the Foundation for Research, Science and Technology (FRST, 1993) as having national significance: the New Zealand Land Resource Inventory (NZLRI) and the National Soils Database (NSD). In addition the LRIS also maintains a number of regional databases, which provide a discontinuous coverage of New Zealand soils at a range of detailed scales (Newsome, 1994). These databases underpin a broad range of Public Good Science Fund (PGSF) research on land and freshwater ecosystems and global change, while also providing biophysical information for resource management decision-making at local, regional, and national scale. The goal of the LRIS programme is to provide timely and relevant biophysical information to researchers, policy makers, managers, and private users from easily accessible databases.

In 1996 the LRIS programme, recognising the rapid pace of technological development in GIS and the recently changed environment for both researchers (FRST/PGSF) and land managers (e.g., Resource Management Act, 1991), began a series of meetings with stakeholders. From these meetings the LRIS programme wanted to gauge the degree to which the LRIS was meeting stakeholders needs, and how well those databases are expected to be able to meet future user needs for environmental data. From user feedback (Newsome and Barringer, 1996) a strategy for strengthening the LRIS suite of databases to meet the future needs of users was developed.

The stakeholder meetings indicated clearly that while many users are satisfied with the existing database structure, an increasing number of existing and potential database users have needs that the existing databases and database structure cannot easily satisfy. The more “traditional” LRIS stakeholders of policy-makers, land managers and planners in government agencies remain largely satisfied with GIS map overlay analysis techniques based on classified data layers like the NZLRI or soil maps. These analyses provide interpreted data layers (e.g., high class land) which have the advantage of synthesising the knowledge of expert data providers into easily understandable maps. These maps can be readily applied to the planning process. Demand for this type of database product is likely to continue.

However, as GIS has steadily penetrated the full spectrum of government institutions (Anderson and Benwell, 1992; Fraser and Todd, 1994), and their use of GIS has matured (Marr and Benwell, 1996), some stakeholders have sought more objective approaches to land management and planning. In addition, an increasing number of commercial users and research institutes funded by the PGSF are seeking spatial data in a form suited to numerical and mechanistic modelling of natural systems. This demand is focussed primarily on utilising data of a more fundamental nature as input to models (e.g., Muller *et al.*, 1997).

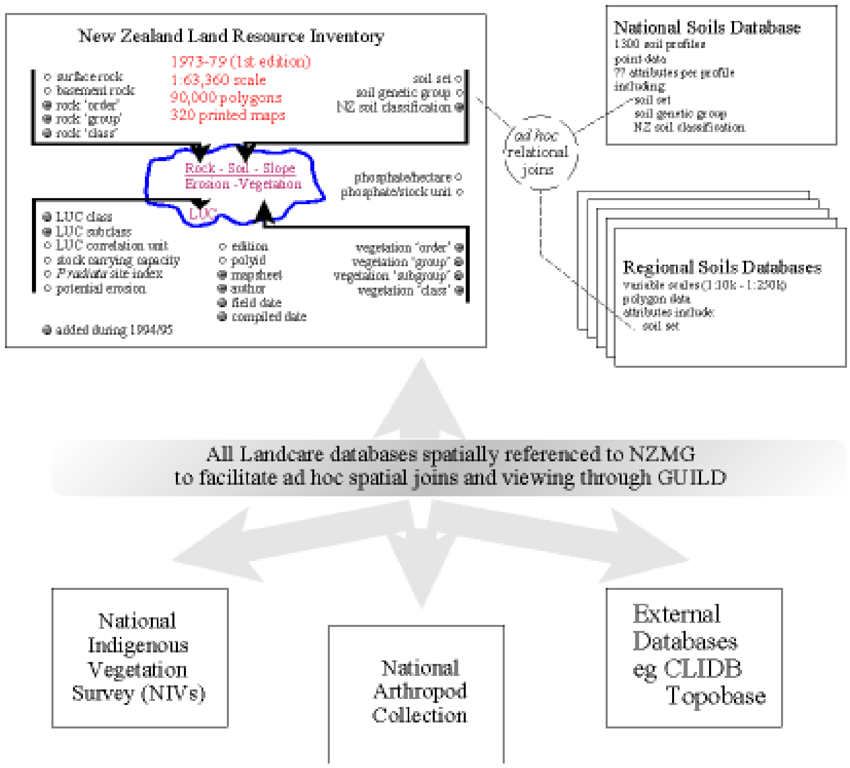

Figure 1:. The existing database structure within the LRIS is an ad hoc *structure based around the NZLRI, NSD and regional soils databases. Some external links to other Landcare databases have also been developed. Data is largely stored in spatial layers as classified information derived either directly from field work, although fundamental data may be recorded in supporting documents like soil survey bulletins.*

This paper describes the changes being implemented within the LRIS suite of databases to meet the changing needs of our stakeholders, with particular emphasis on the development of fundamental data associated with soils.

2.0 From Old to New

The existing database structure within the LRIS programme is an ad hoc structure based around several spatial databases that have been brought together as a result of Government science restructuring in the late 1980s and early 1990s (Figure 1). The main database is the NZLRI, which contains approximately 90 000 polygons covering all of New Zealand, excluding Stewart Island, at a nominal scale of 1:50 000. Nominal minimum polygon resolution is 25 hectares, and average polygon size is approximately 300 hectares. Lithology, slope, soil type, vegetation, and erosion attributes are recorded for each polygon, and these attributes, along with climate and response to past land use, are then assessed for land use capability (LUC) class. In addition a number of derived attributes are linked to each polygon using the LUC (e.g., *Pinus radiata* index, stock carrying capacity, and fertiliser recommendations). All of the attribute data stored in this database is in the form of classes.

The LRIS programme also maintains a large number of regional soil databases derived from soil surveys at a range of scales. For both the NZLRI soil attribute and the regional soil databases the primary thematic expression is a soil classification. However, underpinning each soil survey are numerous soil samples and laboratory analyses, so identified soils will have soil attributes derived from these analyses. While these analyses yield measured data, the variability of these data across mapped soil units is significant, and attributes are commonly recorded as ranges or classes, as well as the analysed result.

Finally, approximately 30% (1450) of New Zealand soil series have been "fully characterised", and a complete set of soil attributes recorded in the NSD (Wilde *et al.* - in prep. 1). The NSD is a relational database storing attribute data only, but this does include an attribute referencing the location of the soil pit from which soil samples were taken.

Each of these databases have common soil identification codes that enable the NZLRI, regional databases, and the NSD to be linked to generate maps combining information from several different databases. Alternatively, interpretations are made using the attributes recorded in the databases and expert knowledge or logical models (e.g., Webb *et al.*, 1995). In addition, all Landcare Research databases that record location are being standardised to use the New Zealand Map Grid projection and coordinate system, which means that data from these or other Landcare Research databases, as well as many external (non-Landcare Research) databases can be geographically overlaid to determine spatial relationships between data from disparate sources. (e.g., see the Geographic User Interface to Landcare Research Data (GUILD) -

The new structure designed for the LRIS (Figure 2), incorporates both the existing classified data layers (CDLs) like the NZLRI and regional soil databases, and more fundamental data layers (FDLs) like the NSD. FDLs are defined as spatial data layers containing data that are both measurable and recorded in appropriate units of measure. For the LRIS programme and other databases within Landcare Research, FDLs will be in point or raster format. The CDLs are spatial layers of classified data recorded in an appropriate naming schema. Interpreted data layers (IDLs) are spatial data layers containing information derived from FDLs and/or CDLs using some form of model (classificatory or physical).

Thus FDLs will represent basic data (e.g., soil depth, slope angle, etc.) and may include point databases recording actual field measurements (e.g., soil depth) through to modelled surfaces derived by geostatistical or mathematical modelling from other FDLs (e.g., a slope layer derived from a digital elevation model). While intended to contain numeric data, there may occasionally be categorical data recorded in FDLs (e.g., plant names). These will be cases where the categories used are effectively immutable and where the categories represent a true discretisation. Because

FDLs will have differing origins, they will be structured to include intensive meta data describing the origin of the data, any inherent variability, and sources and estimates of uncertainty. The meta data itself may be represented as a spatial layer showing spatial variations in data quality for each FDL. This data representation will be useful in providing a picture of data quality to end-users, as well as in identifying areas in more urgent need of data upgrade.

The CDLs will represent a range of simple or complex classified views of FDLs, or combinations of more than one FDL (e.g., slope class, soil class, etc.), and IDLs will represent information that has been interpreted from FDLs, and/or CDLs, to provide answers to questions posed by end-users and decision-makers (e.g., erosion hazard, land suitability, etc.). The CDLs and IDLs will fall along a continuum where there is an increasing level of information content and customisation for the end-user.

It is also intended that the models used to combine or classify FDLs into CDLs or FDLs, and CDLs into IDLs, will also be stored explicitly as part of the database structure. This “model-base” would include instructions on how to implement models (meta task information) as well as information about the accuracy and precision of the models. In addition, each data layer will include attributes which define data quality, and these meta data along with the meta task information in the model-base will guide appropriate use of the data held in the database structure.

This new structure has the advantage that it preserves the existing CDLs like those in the NZLRI, while also providing access to a range of new layers at both the fundamental and interpreted ends of the data spectrum. Similarly, traditional classification models and spatial overlay analyses can be accommodated along with spatial models involving numerical and mechanistic models of environmental rocesses.

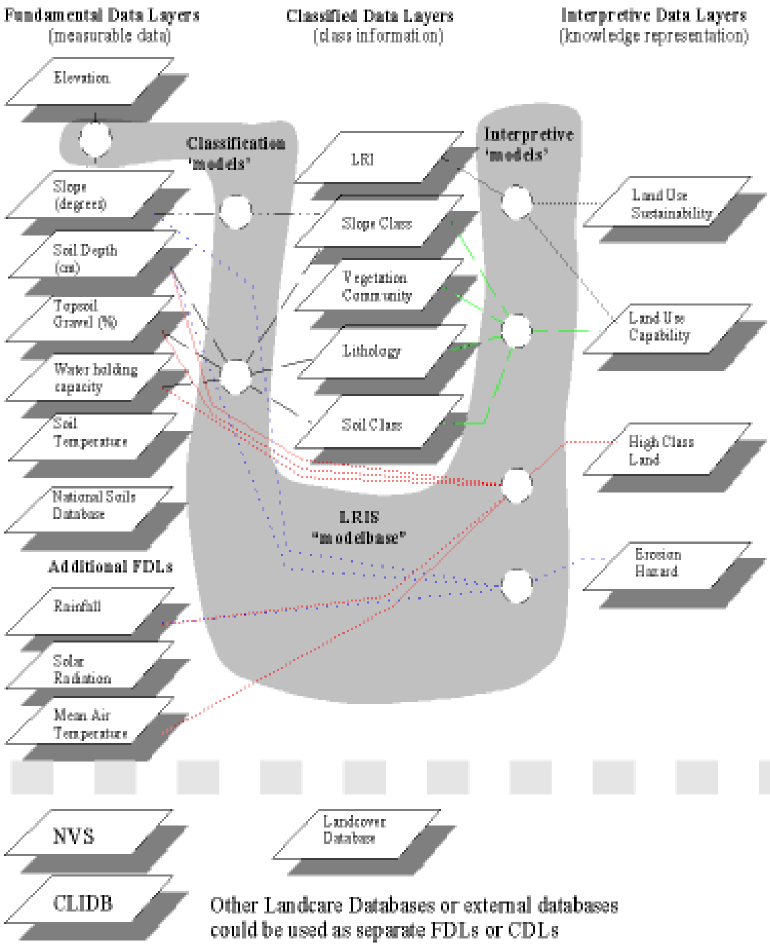

Figure 2. The new LRIS database structure incorporates the rock type, soil, slope ,erosion, vegetation and LUC layers of the “NZLRI” and any regional soils layers or interpretations based on them as CDLs or IDLs. It can also incorporate the NSD as a point based FDL, as well as any new FDLs required by stakeholders. Each layer will incorporate meta data defining data origin/quality which may also be displayed as a spatial layer. The models that link various layers will also be explicitly recorded within the broader database structure.

Soil Form	Order Group Subgroup Parent material Particle size grouping Permeability class		
	Attribute	**Measure**	**Type**
	Slope	degrees	T
	Potential Rooting Depth	cm	P
	Topsoil Gravel Content (A horizon)	% by volume	P
	Rock Outcrop/Surface Boulders	% by area	P
	pH (20 - 60 cm)	pH	F
	Salinity	millimho/cm	F
	Cation Exchange Capacity (0 - 60 cm)	meq/100 g	F
	Total Carbon (0 - 20 cm)	% (g/100 g)	F
	Phosphorus Retention (0 - 20 cm)	%	F
	Flood Return Interval	Years	T
	Soil Temperature (@ 30 cm)	C	T
	Total Profile Available Water (0.9/PRD)	mm	P
	Profile readily Available Water (0.9 or PRD)	mm	P
	Drainage Class	% mottling by area	P
	Macro-pores (shallow = 0-60 cm)	% by volume	P
	Macro-pores (deep = 60-90 cm)	% by volume	P
	Dry Bulk Density (A horizon)	kg/m^3	P

Table 1: Seventeen soil attributes derived primarily from the existing classified layer which records the spatial distribution of soil forms and the National Soils Database which records detailed soil attributes for New Zealand soils.

3 A First Approximation of Fundamental Data Layers

While some FDLs may be realistically modelled or estimated using relatively straightforward methods, the task of generating other FDLs from scratch to replace the existing CDLs stored in the LRIS would be an unrealistic short-term goal. For example, given access to suitable digital contour data (e.g., 20-metre contour data), generating a national digital elevation model at 25-metre resolution, and from it creating an FDL of slope in degrees to specified accuracy involves an established operational procedure. Barringer (1997) showed that the accuracy of such a layer could be expected to be at least as accurate, and in many areas substantially better than the existing slope CDL within the NZLRI database. By contrast, generating an FDL such as soil depth or carbon content is a challenging research exercise (e.g., Moore *et al.*, 1993; Tate *et al.*, 1997; Lilburne *et al.*, in prep; Webb *et al.*, in prep). While some tools for this type of mapping are being developed (Cook *et al.*, 1996), there are no established operational procedures for carrying out such an exercise.

Clearly, a problem exists with respect to some FDLs. The stakeholder meetings have identified a need among users for these data, and while research into techniques for generating FDLs is advancing, operational methods for carrying out this process are not yet available. The LRIS programme's strategy to resolve this impasse has been to develop a database structure that will accommodate both fundamental data and classified data. This will ensure there are no structural constraints to progress. Meanwhile, first approximations of key FDLs are being generated by "reverse engineering" existing CDLs into FDLs. In most cases this has involved reassociating classified data with its underlying analytical data and expressing the result in appropriate units of measure, with a suitable description of data origin/accuracy/quality.

3.1 Soil Fundamental Data Layers

Initial focus has been on soil-related FDLs as these are an area of core expertise for Landcare Research. Through the consultation process with stakeholders, 18 key soil attributes were selected that met most requirements described by database users. These attributes are listed in Table 1. The attributes generally fall into three groups: soil fertility/toxicity (F); soil physical properties (P), particularly those related to soil moisture; and topography or climate (T).

Regional soil databases were the key to generating the soil FDLs. New Zealand was subdivided into several geographic regions and soil scientists were allocated a region for which they developed a "regional legend" (regional database) (Wilde *et al.* in prep.2).

The task of building the FDLs was done in three steps: correlating soil units within regions using the New Zealand Soil Classification (NZSC) (Hewitt, 1998) and assigning all soils identified in the NZLRI to soilforms; relating site, physical, and chemical attributes to each soilform by referencing the NSD (Wilde and Ross, 1996) and other relevant data sources; linking the soilforms and their attached attributes to the soil polygons in the NZLRI.

3.2 Assigning Mapped Soils to Soilforms

Correlating soils and assigning them to soilforms was done when compiling the regional databases (Wilde *et al.*, in prep 2). All published and unpublished soil surveys, including those incorporated into NZLRI, were used. Soil units in each of the surveys were classified to soilform (the fourth level of the NZSC) using the best available data for each survey. Where possible, published soil survey bulletins, papers, and reports were used. Where published work was not available, soil profile descriptions and other information collected during soil survey operations and preserved within soil survey records were used. Map units encountered included (1) soil types and phases, including hill and steepland soils, from surveys with map scales larger than 1:63 360; (2) soil series from surveys of scales of 1:63 360 or smaller; and, (3) soil sets from 1:253 440 scale General surveys of the North and South Islands. The soils contained in these map units were all assigned to soilforms, with reliability directly related to the scale of the original soil surveys. Definition and naming of soilforms was carried out following Clayden and Webb (1994).

Where hill-soil units were mapped, these were separated from similar soils on rolling land, and each given a separate entry in the database. Double-symbolled map units were handled by giving each discrete soil its own entry in the database.

3.3 Attaching Attributes to Soilforms

The term "attribute" is used here in the sense of a "quality assessment" of the various soil properties attributed to each soilform. It consists of five components: the *property class* (e.g. P-retention Class 2), *class description* (e.g. high P-retention), the *numerical range* (e.g. P-retention range 60–80%), and a two-part *reliability estimate* that conveys information about the accuracy and precision of the reported measurement or estimate. The soil properties and their rating classes and class descriptions were selected from Webb and Wilson (1995).

The regional collections of soilforms were sorted according to their NZSC subgroup, lithology, permeability, and topography, and topographic, physical, and chemical attributes were attached to each soilform using the best available data. This included complete chemical, mineralogical, and physical analytical data from the NSD, and from other published and unpublished work. However, for a substantial proportion of almost 4000 soilforms identified, analytical data were not available, so the properties of similar soils were used to guide selection of attributes.The resulting database of soilforms and attached attributes is intended to grow to meet specific needs. In time we expect to increase the proportion of soilforms with analyses and add more attributes.

3.4 Linking the Soilforms with NZLRI Polygons

Soils information in the NZLRI contains a soil survey code and a soil unit code for each polygon. These two codes correlate directly to the soilforms, which are in turn linked to the 17 soil attributes; thus, a relational link between the NZLRI and the NSD provides the mechanism for spatially projecting the soil attributes as a series of single factor polygon layers (e.g., Figure 3). These single factor polygon layers are converted to raster representations to form the initial FDL.

4 Progress and Future Plans

The initial task of compiling 17 of the 18 attributes for almost 4000 soilforms is largely completed and soil FDLs will shortly be available. Generating a bulk density FDL has proven more problematic and will be addressed in the near future. The initial soil FDLs derived from NZLRI polygons will also be progressively refined, by folding in, firstly, data of higher spatial resolution from local soil surveys and, secondly, data from soil pit information in the NSD. For each measure there will then be a number of layers of source information with varying coverage and precision from national through local scale, to widely spaced points, with the highest precision data coming from individual soil pits. An algorithm will then be constructed and applied to the whole collection of layers to derive a single layer that contains the "currently best available" information for that parameter. All the source layers and the algorithm for combining them will be retained in the LRIS so that as new information comes to hand, typically from additional field work, it can be added to the system, the algorithm updated if necessary, and a new "currently best available" layer constructed. It is possible that for some analyses, variations of the combining algorithm may be needed. In such cases both variants would be retained in the LRIS, with suitable annotation (or meta data) to describe their purposes.

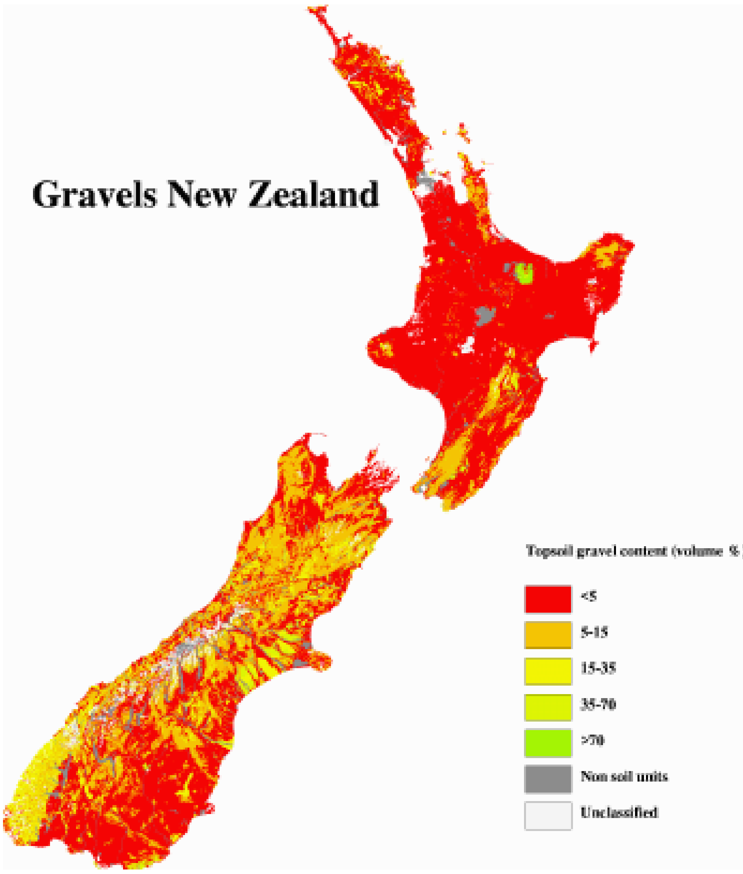

Figure 3 FDL for topsoil gravel content by percent volume for New Zealand.

The new LRIS structure demands that both data quality and models of data behaviour are stored explicitly in the LRIS for the first time. While a great deal of work has been done in NZ and overseas on both data quality and developing and using models, the idea of formalising the work in explicit database structures is quite new outside experimental systems, and brings together the realms of geostatistics (as in spatial quality), object orientation (as in the relationship between models as methods and their data) and traditional GIS. Two streams of work have been started to explore the issues and provide practical solutions.

The first, started in early 1998, is to extract a formal model of LUC from existing descriptions of best practice and test and refine it against NZLRI data. The LUC model will use data from current FDLs such as the soil FDLs described here rather than the classifications in the NZLRI.

The second stream of work commenced in mid-1998 and aims to develop and test a set of meta data layers for characterising data quality. The NZLRI layers will be used as the source data layers and these will be combined with new field work to determine the variability within the "homogeneous unit areas" that are the basic unit of NZLRI mapping. The outcome of this work will be a specification (or model) for making probability estimates of the presence of a mapped factor (such as "P1" vegetation) at a particular location within a polygon, given the presence or absence of that factor in the surrounding polygon's attributes.

As this work progresses we will start to make a catalogue of models in use within the LRIS, that will evolve into a true model base as we gain an understanding of the operational requirements of the new LRIS structure.

Acknowledgements

We would like to thank Ian Lynn, Grant Hunter, Trevor Webb for helpful comments on drafts of this paper, and Caroline Bezar for editorial assistance. The development of the new database structure for the LRIS programme and the development of soil FDLs has been funded by the Foundation for Science, Research and Technology under research contract C09626.

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