

# SOILS INFORMATION BY GIS FOR IN-GROUND ASSET ANALYSIS

I Allan, R van de Graaff

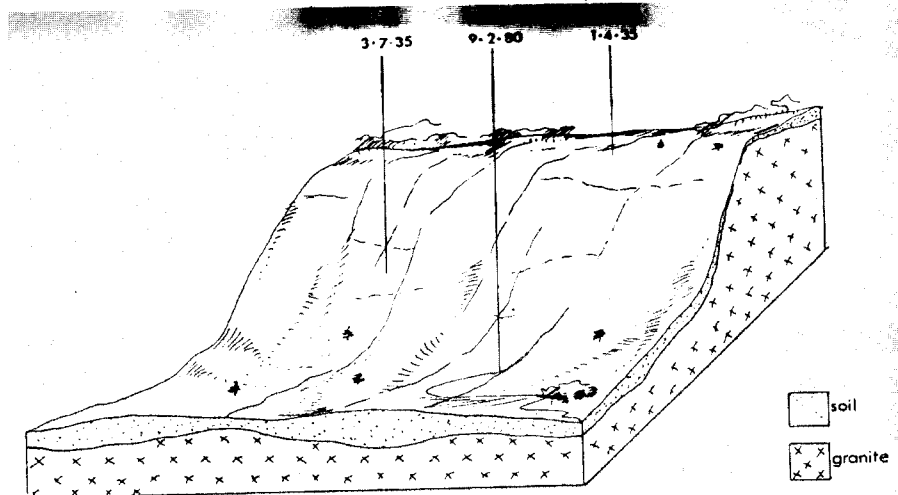
## Abstract

In the water industry, in-ground asset performance is assessed according to factors such as failure frequency, asset condition and material life expectancy. It is known that soil mechanical, chemical, acidity and moisture properties impact on asset life expectancy, but such information is not generally factored into asset life estimates because it is rarely available. In this sense, urban areas tend to be asset rich but information poor. In this paper we show that soils information often exists as archives that can be restored. However, to be most useful, this information requires manipulation by software to ensure a consistent spatial database.

Soil science expertise can be encapsulated in the software and database, and any number of user-defined maps (ie shrink/swell, pH, etc. at user defined depths) can be produced. Using the spatial query functionality in a GIS, attributes of individual assets can be applied at the point in the soil profile in which they lie.

## Introduction

Society has a great need for protecting and managing existing infra-structure such as roads, pipelines, sewer and storm water drainage systems, and for making best use of any terrain knowledge upon which new infra-structure will be built. Geological and topographic maps are already widely used, often in combination with aerial photographs and other remote-sensed data. However, soil maps are often overlooked and the geological maps may be inadequately utilized. Soil maps often portray the distribution of soil types in terms which are not easily understood by the engineer, as most of these maps are produced not by geotechnical or civil engineers, but by agricultural scientists using their own terminology. Geological maps too are made by geologists for their



**Figure 1.** A block diagram of a Terrain Pattern on Melbourne's Mornington Peninsula (Grant 1973). Note the application of the catena concept. The 34.001-44/2 terrain pattern has three soil descriptions that relate to hill crests, slopes and drainage lines.

own purposes and usually ignore the geomorphological processes - erosion, deposition, weathering and hence the soil mantle - that have affected the landscape and the soils formed from the geological parent materials.

When all these databases are combined and produced in an accurate spatial database, new and valuable inferences can be made with regard to society's infra-structure assets that are located in or on the soil. Moreover, the boundaries of the mapping units can become more reliable as these are related to topography for which much more precise information is now available.

Using the CSIRO's numerical system for identifiers of properties of geological and soil properties and for landforms (Grant, 1975(a), 1975(b)), we describe a method of mapping and value adding of the terrain patterns around Melbourne that has great potential for society.

## Understanding Soil Surveys

Traditional soil mapping is slow going because it involves much fieldwork, soil augering and hand texturing. In the

1960s-1970s techniques known as Terrain Pattern Mapping evolved (Aitchison and Grant, 1967) and Land Systems Mapping (Christian and Stewart, 1968) that allowed large areas of terrain to be mapped very quickly at low cartographic detail but relatively high descriptive content. The former took an engineering focus, whilst the latter had an ecological, multidisciplinary approach as it aimed at sound land development and management in rural and undeveloped regions. At the time Australians were amongst the world leaders in its use.

The land systems technique applied a soil scientist's knowledge of soil processes to existing geological maps and known geomorphological history to produce models of soils in the landscape. For example, the concept of catena allowed a soil scientist to predict with a degree of certainty that soils at the top of hills would be less moist, better drained (more oxidized) and have bedrock at shallower depth, compared with soils at the base of hills that would tend to be deeper, more moist and subject to frequent periods of anaerobic reducing conditions, heavier in

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texture, with bedrock at greater depth (Figure 1). Similarly, older, more highly weathered soils show chemical, mineralogical and morphological features that younger soils do not have. These weathering processes - soil formation - have been thoroughly studied by soil scientists for most of last century. For example, the old plateau remnants along Whitehorse Road in Nunawading, Victoria, have much deeper soils than the young dissection slopes towards the Yarra and its tributaries in Templestowe. These processes even influence the movement and immobilization of heavy metals in the environment and are useful in assessing contaminated sites.

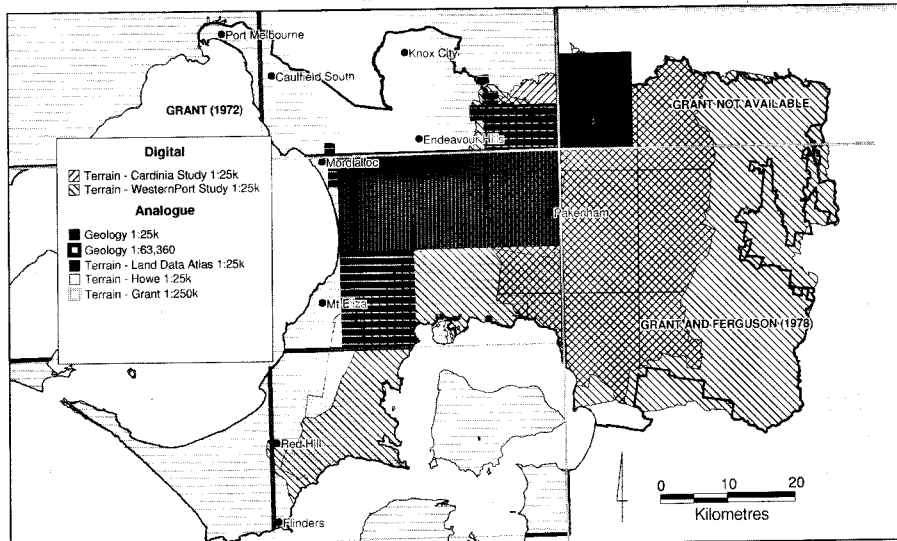
We have found that using GIS in combination with soil science knowledge allows for much value adding to be undertaken. Other relationships such as soil pH and salinity can also be explored. Where parent geological formations are constant over wide areas, associations can be made between soil types and rainfall. In high rainfall areas soils become leached and develop low pH and negligible salinity and the pH will tend to be lower with increasing soil age; however, a pH of 4.5 is usually the minimum value found. An example of this is the soils in the Heidelberg/Rosanna area (mean annual rainfall 860mm) and those in the Wandin area (mean annual rainfall 1000mm).

Other areas might be affected by acid sulfate soils, in which case the pH can be much lower. Such areas are generally old swamps, the soils from which contain sulfides, which combine with air when disturbed to form dilute sulfuric acid. This knowledge has implications for construction management because the longer these soils are exposed to air, the more acidic they become. In Melbourne, areas of the old Carrum Carrum Swamp come to mind, but the Coode Island Silts have become more notorious.

Soil surveys tend to exist as paper archives that can be restored and made digital. In the next section we describe some issues that should be considered before restoration begins.

#### Digital maps versus spatial databases

Many people think that a digitized paper map in a GIS is a spatial database, but this is rarely the case. The conceptual difference between a digital map and a spatial database can be difficult to grasp. A paper map that has been digitized is most often just a digital map. Digital soil maps are very useful in a GIS because they can be visually related to in-ground assets,



**Map 1.** The key map from the SEWL scoping study. There were 14 separate datasets in the study area, most of which were of different scales and descriptive systems. These were interpreted to be a single standard.

but they are rarely organized in a manner that makes it easy for any comparisons other than visual ones to be reliably undertaken. Conversely, a spatial database is one that is especially designed to allow valid queries to be made across a map. A digital map is often the starting point for a spatial database, but it must be developed further. Two important aspects of a spatial database relate to spatial integrity and attribute consistency.

#### Spatial integrity

Spatial integrity relates to the accuracy of the boundaries used to create a digital map. The accuracy should be appropriate for the use to which the boundaries are to be put. For example, it may be inappropriate to relate a very generalized soil map to a very accurate cadastral map. If many different soil maps from many different sources are to be joined, then the resulting map is unlikely to be valid if the mapping scales and boundary accuracies of the constituent maps differ.

#### Attribute consistency

Adjoining soil maps are often produced in ways that describe identical soils differently, because over time different authors used different soil classification systems and mapped at different scales, so that mapping units are generalized variously. These need to be reinterpreted to a single standard. Even those maps that have been configured in such a way are rarely (never?) configured to be searchable within a relational database.

Most often, in our work, soil attributes are provided as text descriptions (e.g. in an Excel spreadsheet) that are attached to the mapped data in the GIS. This means

that a description can be displayed with the mouse cursor. This functionality is useful to help explain problems in individual areas. However, the interpretation of the description requires much skill, is labour intensive, and difficult to apply to a whole study area in a computer modelling sense.

#### The importance of software

A software component is required to exploit a spatial database. This ensures that all mapping that a user undertakes can be repeated. Because software is not forgiving of poorly formatted data, it also ensures rigor in the way that data are represented. Software can also help overcome mapping issues where, as is often the case, a soil polygon is described in greater detail than it can be mapped.

#### What sort of information can be produced

Descriptive soil information (such as clay content, gravel, presence of 'buckshot', colours and mottling, soil structure and consistency, field pH, penetration by plant roots, biological channels, etc.), provides important clues that a soil scientist can use to derive those soil "attributes" that are relevant to the water industry's quest to explain asset failure, model asset failure risk, and schedule and budget asset maintenance.

For example, soil texture refers to the proportion of sand, silt and clay particles in the soil and therefore plays a role in soil structure formation which refers to the system and stability of inter-particle, inter-aggregate and biological voids, which in turn affects permeability and natural drainage. Soil texture is also of

great importance in governing water-holding capacity. Depending on the mineralogy of the clay as well as the percentage of clay in the soil, the soil will be more or less subject to volume change stresses, which are related to stresses experienced by pipes and footings.

Soil colour is an important, rough, indicator of the state of aeration of the soil. Whole coloured soils, especially if the colours are reds and browns, are indicative of soil water regimes dominated by oxidising conditions, i.e. very good drainage. Grey and yellow mottles, or uniform grey and bluish colours indicate respectively periods of reducing conditions, hence periodic waterlogging, or constant saturation. Rusty mottling along root channels in the topsoil indicates frequent and long-lasting waterlogging.

Few plant species can extend their roots into permanently saturated soil. Therefore the occurrence of root channels and living or dead roots at depth indicate that at least for much of the time there is a supply of oxygen there. Buckshot concentrations in the subsurface soil on top of a clay subsoil indicates the occurrence of frequent perched water tables on the subsoil. From the mineral transformations in these processes, mainly exhibited by the ubiquitous iron and manganese compounds, one can deduce the chemical boundary conditions of pH and redox potential that govern in the soil.

Following are some examples of soil attributes that we believe are especially relevant to the water industry.

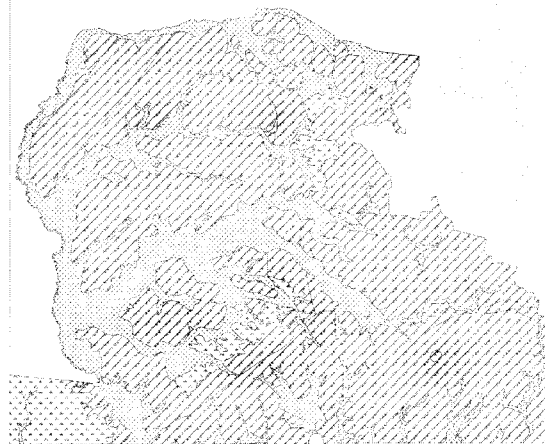
- **Mechanical attributes:** Shrink/swell maps should indicate areas where the differing wetness regimes of driveways and nature strips will lead to mechanical pressure on assets. Also relevant is the interface between very heavy and very light soils.

- **Profile water-holding capacity:** Soils with high water-holding capacity remain moist much longer, potentially increasing the time of exposure of the asset to corrosive agents in the soil moisture, as well as potentially affecting the ease of excavation, but will dampen the intensity of soil volume change.

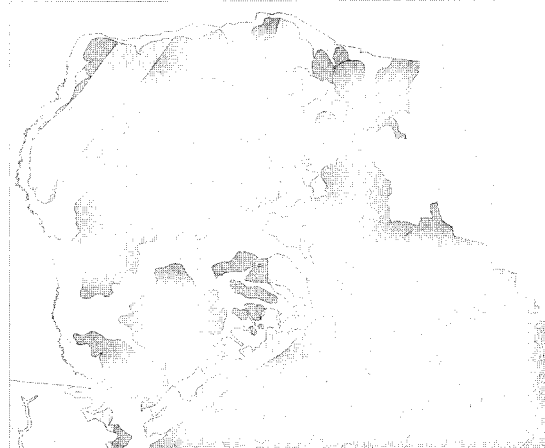
- **Soil wetness:** This attribute has a bearing on the length and frequency of periods during which low redox potentials exist. If combined with salinity it affects the degree of dilution of salts in the aqueous phase in contact with the asset. It also affects the depth to which roots will penetrate, as most terrestrial plants require oxygen around their roots.



Map 2: Composite soil profile



Map 3: Soil texture at depth



Map 4: One soil attribute (shrink/swell) at depth

Maps 2,3 and 4.

- **Biology:** Input from plant biologists with regard to the soil environment is likely to lead to greater predictive power about where the roots of certain tree species are more likely to invade drains.

- **Corrosivity:** Acid-sulfate soils are especially destructive on steel and concrete pipes, and, if brought to the surface in excavations may produce highly acid leachate, which could kill vegetation and mobilize heavy metals already in the soil.

- **Resistivity:** This is especially relevant in predicting the deterioration of cast iron pipes. The opposite of resistivity is electrical conductivity, a test that is routinely carried out on soil samples in the laboratory for testing soil salinity.

- **pH:** Some general interpretations can be made using geological descriptions, terrain pattern descriptions and rainfall records. pH is important because increased

Continued on page 56

