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The role of soils in water authority asset risk analysis

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Abstract

In the water industry, in-ground asset performance is assessed according to failure frequency, asset condition, material life expectancy, soil water chemistry and site based soil resistivity. 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 mapping (hence re-interpretation on the basis of known field relationships), database and software components.

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 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 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 on an accurate spatial database, new and valuable inferences can be made with regard to society's infrastructure assets that are located in or on the soil. Moreover, the boundaries of the mapping units can

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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 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 (Aitchison and Grant, 1967) and Land Systems Mapping (Christian and Stewart, 1968) evolved 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[3] allowed a soil scientist to predict with a degree of certainty that soils at the top of hills would be less moist and better drained (more oxidized), and have bedrock at shallower depth, than 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 texture, with bedrock deeper (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 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. With parent geological formations being constant over wide areas, for example between Heidelberg-Rosanna with about 860 mm per year and Wandin with some 1000 mm per year, associations can be made with soil types in relation to 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, but pH = 4.5 is usually the minimum value found. Other areas might be affected by acid sulphate soils, in which case the pH can be much lower. Such areas are generally old swamps, the soils from which contain sulphides, which combine with air when disturbed to form dilute sulphuric acid. This knowledge has implications for construction management because the longer these soils are exposed to air, the more

[3] From the Latin word for 'chain', a recurring suite of soils occurring on slopes on the same parent materials, resulting from systematic changes of soil drainage and the balance between oxidation and reduction of Fe and Mn compounds in the soil profile.

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 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, 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 modeling 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. And 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

Soil texture information (texture such as clay content, gravel, presence of ‘buckshot’, colours and mottling, soil structure and consistence, field pH, penetration by plant roots, biological channels, etc.) is useful to a soil scientist. We believe that soil “attributes” are most relevant to the water industry, especially in their 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 greatest 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 indicate frequent and long-lasting waterlogging.

Few plant species can extend their roots into permanently saturated soil. Therefore the occurrence of root channels, 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 just over 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.

- **Bio-geology:** Input from plant biologists is likely to lead to greater predictive power about of where the roots of certain tree species is more likely to invade drains.

- **Corrosivity:** Acid-sulphate soils are especially destructive on steel pipes, concrete and cement, 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:** The opposite of resistivity is electrical conductivity, a test that is routinely carried out on soil samples in the laboratory for testing soil salinity, whereas resistivity is measured on the whole soil body in situ.

- **pH:** Some general interpretations can be made using geological descriptions, terrain pattern descriptions and rainfall records. pH is important because increased acidity also increases the corrosivity of the soil. If the soil's buffering capacity is taken into account, the pH can be a measure of the difficulty of amending the soil with lime.

- **Redox potential:** The variation of soil pH and redox potential in natural soils has been delineated by several researches in order to predict the possible reactions that may take place that can affect speciation and solubility of metals in the soil (see figure 2; Dragun, 1988). It may well be predictive of corrosivity too.

Archival mapping is the biggest obstacle

One of the biggest obstacles to gaining soils information is that a single soil archive rarely covers an authority's area, and where multiple archives exist, they are rarely compatible. When restoring soil archives, the bigger the area, the more difficult the task becomes. The example in Map 1 relates to soil mapping we undertook for South East Water. There were fourteen different studies, of different scales, with different spatial extents, using different methodologies, and with different descriptive detail.

In the study, we applied the very detailed attributes from a small-scale CSIRO series of terrain pattern studies to much larger scale (and poorly described) geological boundaries. The result was a 1:250,000 scale terrain pattern map reinterpreted to be 1:63,360. We are currently undertaking a similar sized project for Yarra Valley Water. In the Melbourne metropolitan area it is not uncommon to find geological boundaries ranging from being perfectly positioned, to being as much as 200m displaced. Last year we discovered a soil boundary in a rural area that was misaligned by more than two kilometers. Reasons for such map error relate to scale of interpretation, a cartographic requirement to accentuate areas of geological importance, and the technology used to produce the maps. These discoveries have allowed us to improve our methodology. In the current study, we're using a variety of datasets to improve accuracy and are presently interpreting this data and a scale of 1:25,000.

Clearly, if you know what you're looking for, many archival maps can be salvaged, and indeed, value added. The biggest challenge is knowing what is important and what is not. In the following section, we'll look at the benefit that can be gained when a spatial database is combined with software.

Example

Clearly, there is much value adding that can be undertaken by using the spatial database / software approach to soil mapping. Map 2 shows the sort of mapping that was undertaken in the 1970s when GIS functionality was but a dream. In those days, the production of each additional theme required enormous consideration due to the implications for additional time and expense. Hence maps such as this one showing dominant soils only. More significantly, Map 2 is a composite map of an entire soil profile based on the understanding of an experienced soil scientist.

Map 3 shows the same area as in Map 2, this time mapped for soil texture at a depth of 0.5 metres. The soil descriptions are simplified in this map, and the six classes in Map 2 have become three. Because the software was instructed to ignore rocks, areas of rock outcrop have been redefined to be heavy clay.

Finally, Map 4 is in a form that is probably of the greatest use to decision makers. The legend documents the map in nominal/relative terms. It is interesting to note that the three types of clay shown in Map 3, each have different shrink/swell characteristics.

Because the soil scientist's expertise has been encapsulated in the software and database, any number of user-defined maps (ie shrink/swell, resistivity, etc. at user defined depths) can be produced, and using the spatial query functionality in a GIS, be applied to individual assets at the point in the soil profile in which they lie.

Conclusion

The information that is available in geological maps, soil maps and terrain maps of varying dates and scales can be 'mined', updated and presented in an accurate spatial data base for a range of practical interpretations. The systematic method of using identifiers developed by Keith Grant of CSIRO also allows subsequent subdivision of spatial and categorical information as new information is obtained. To do this requires a re-interpretation of the older data bases, in which geomorphology and soil science are particularly useful elements.

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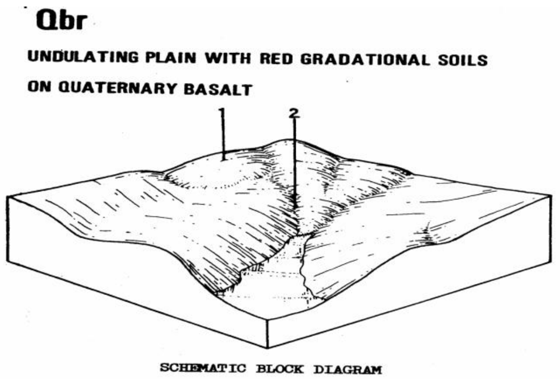
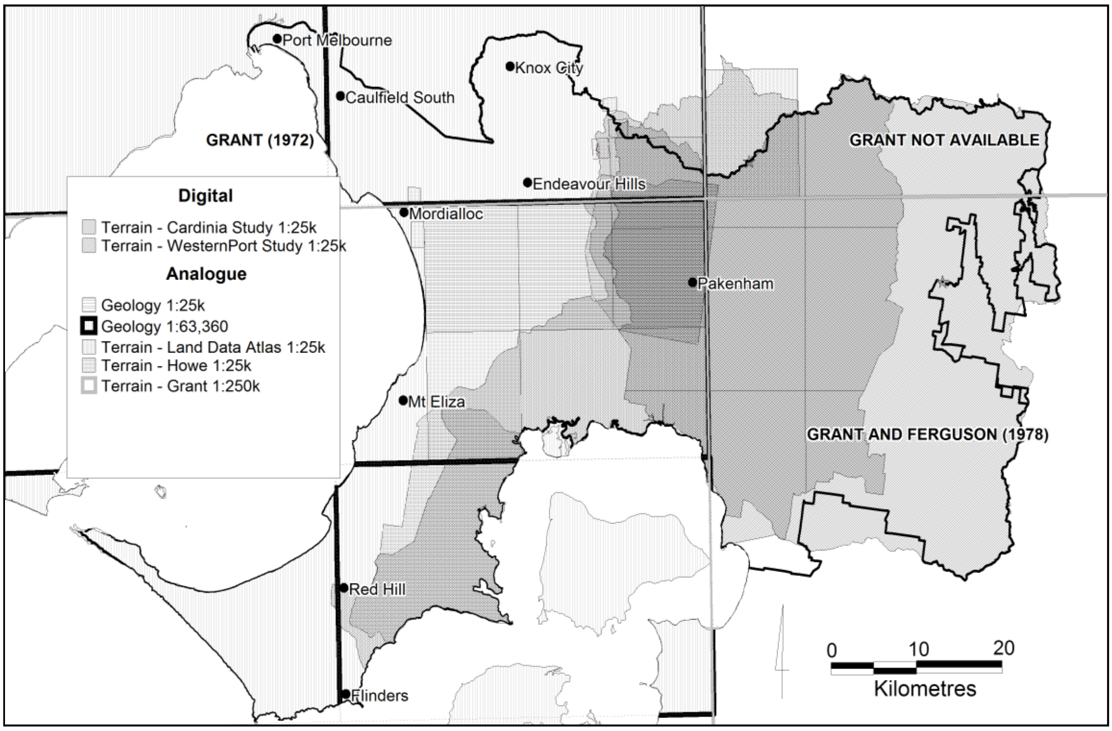


Figure 1: A block diagram of a Land System from a study in Ballarat. Note the application of the catena concept. The Qbr terrain pattern has two soil descriptions. The first relates to hill slopes and the second to drainage lines.



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.

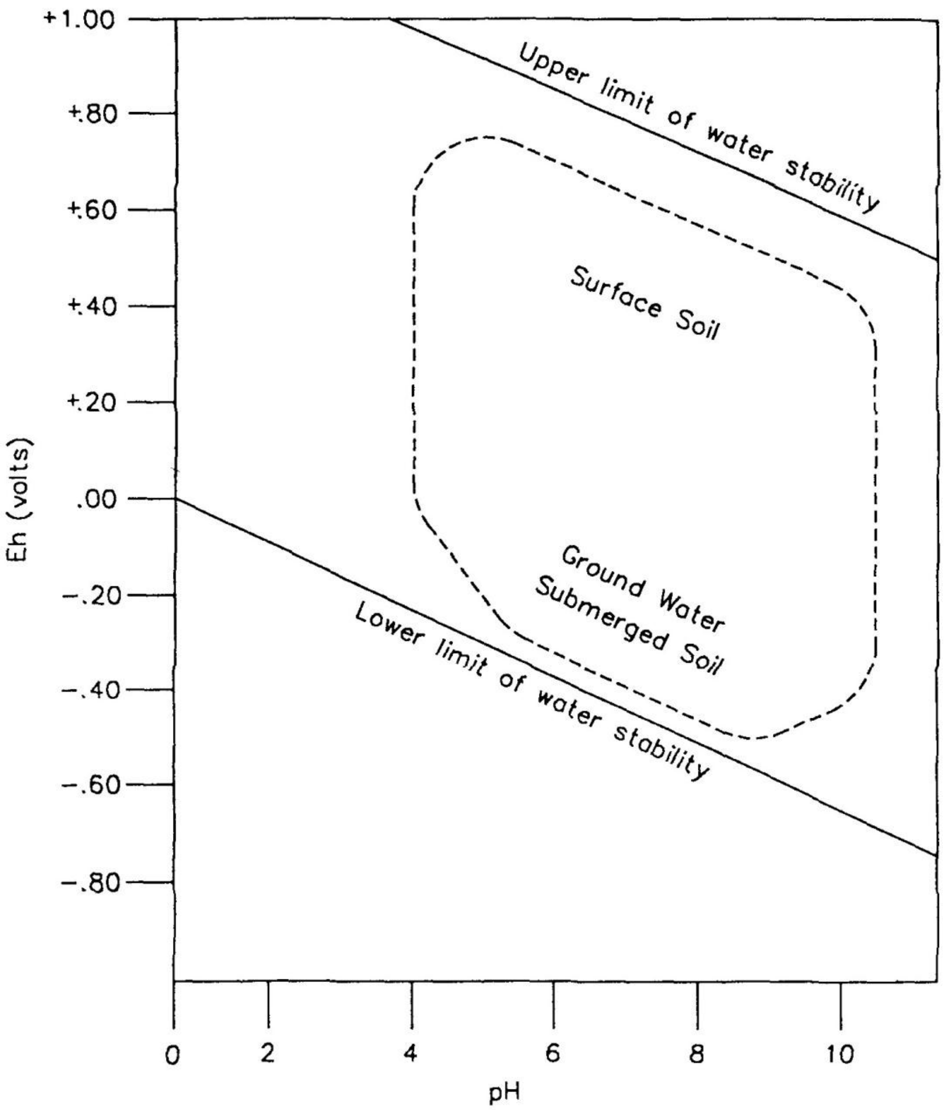


Figure 2: Approximate Eh-pH limits observed for naturally-occurring soil from James Dragun – The soil chemistry of hazardous materials. 2nd Edition 1998. Amherst Scientific Publishers, Amherst, Massachusetts, USA.