

RESULTS

of

SITE INVESTIGATION

for

BARIUM CONTAMINATION

at a

PROPOSED RESIDENTIAL DEVELOPMENT

at

ROBINSONS ROAD, DEER PARK

by

Robert van de Graaff, PhD
and
Simone Lang, BSc (Env. Sci.)
van de Graaff & Associates Pty Ltd

and

R.J. Wrigley
Wrigley-Dillon

TABLE OF CONTENTS

1. Introduction	3
2. Process of Site Investigation	3
3. Geology and Geomorphology	3
4. Field Results of Site Investigation by Wrigley & van de Graaff	4
4.1 Observations	4
4.2 Expected behaviour of barium in the soil.....	5
4.3 Soil Profile Information.....	6
5. Discussion of the barium results obtained by the Chadwick Group.....	7
6. Depth Function Test Results and Final Risk Assessment	10
7. Gypsum application to improve soil conditions at the surface.....	11
8. Conclusions	12
9. References	14

1. Introduction

Following extensive surface and subsurface investigations as part of a contaminated site audit, some elevated barium concentrations were measured at two borehole locations in a 14.7 ha allotment at 170 Robinsons Road Deer Park (refer to Appendix A for a locality plan). Based on the adopted criteria, exceedances occurred at depths of 0.5 m and 1.0 m at Test pit 76 and at 1.0 m at Test pit 104 in a site investigation array that contained 114 holes which were gridded across the site (refer to Appendix B for the array of site investigation boreholes and pits). In all cases the order of magnitude was the same as the adopted criteria, with similar concentrations at Test pit 76 (varying by up to 90 units) at the two test depths of 0.5 and 1.0 m with a threefold increment at Test pit 104, but only at 1.0 m.

The exceedances were measured at these two locations that had been part of a sampling regime for 114 site boreholes (and limited number of test pits) and it was therefore resolved to conduct a further site investigation to ascertain:

- why the levels were high,
- if they are likely to be restricted to these two locations,
- whether an anthropogenic input was likely.
- if there was evidence of site disturbance or encapsulation of wastes.

Additionally, potential issues with barium mobility and risks to human health or the environment as well as potential soil or site amendment were to be evaluated.

2. Process of Site Investigation

Dr Roger Wrigley and Dr Robert van de Graaff, the independent soil scientists, met at the site on Tuesday 7 March, having previously agreed to employ a backhoe to excavate inspection pits at selected locations. The sites selected for inspection were numbered 76 and 104 on the base plan provided, whilst a third was installed at Site 36 which had not been subject to Barium assay. This sampling regime enabled the investigators to focus on two potential problem sites on the western boundary, whilst the third site in the north-eastern corner was primarily selected to gauge the uniformity of soil profiles and the depth to rock.

The backhoe excavated the three pits to a depth in excess of one metre, all being founded on a hard layer of vesicular basalt overlain by an extensive calcareous soil layer that ranged in thickness from 100 mm to 200 mm.

Following excavation, soil samples were extracted from the walls of pits at locations 76 and 104 to represent materials at 100 mm intervals from the natural surface to the rock.

3. Geology and Geomorphology

Parent material for the Robinsons Road site is vesicular Quaternary Basalt. This flat and gently sloping surface is classified as “Lava Plains” by the Geological Survey of Victoria

(1967) and also “Newer Volcanics”; this mafic parent material contains high levels of iron, magnesium and calcium with plagioclase the dominant feldspar.

Jeffrey (1981) conducted a land-use study north of the site and based upon this investigation the site is likely to be similar in landform to the Cottrell Land System. Assuming that the site evinces similar characteristics, soil profiles are potentially calcareous sodic and potentially duplex with a coarse structure founded on Pleistocene basalt. Whilst free iron levels are not documented in soil profile chemical data for this type of soil profile, sodicity was found to increase in depth from an ESP of 2 in the A-horizon to an ESP of 22 at the base of the B-horizon, with pH increasing correspondingly from 5.7 to 8.8. As the site possesses some rocky rises and minor depressions the soil profile is likely to change, with Vertosols dominating the lower land and red duplex the slopes and rises, so the land is not wholly consistent with the Cottrell Land System. However, heavy alkaline clay subsoils will be present everywhere.

The terrain pattern for the site is accorded the Province No. 52.009 and Pattern 02 (Grant, 1972). The lithology is basalt with the flow possibly derived from Mt. Atkinson, a volcanic cone located approximately 6.5 km to the north-west. Under the CSIRO PUCE classification system the site is close to the boundary between two Provinces and based upon the mapping the soil profile is more likely to be vertosol than duplex. Site drainage features and soil types were found to be consistent with the CSIRO classification.

4. Field Results of Site Investigation by Wrigley & van de Graaff

The soil profile at location 76 was between 1 m and 1.2 m deep, the excavation limited by weathered rock floaters that were of vesicular basalt. Layering in the profile was obvious, with 600 mm of red-brown clay-loam A-horizon overlying a calcareous grey B-horizon – horizons which were well aggregated and contained slickensides providing abundant evidence of shrinkage and swelling with fluctuations in soil moisture content. The B-horizon was flecked with lime and underlain by an extensive calcareous layer about 100 mm thick.

The profile at location 104 was subject to better drainage, with more pronounced layering and of a more duplex character; additionally, when compared with location 76, the rock was closer to the natural surface and the B-horizon thinner. Extensive floaters were located nearby, possibly indicating that a rocky rise had once been situated nearby.

A random soil profile was subjected to pit inspection; this was located in the north-eastern corner of the property near bore hole site 36. At this location, which was adjacent to a rocky rise, there was evidence of a profile that was similar to the aforementioned profiles – a profile with a 1.0 m depth to rock, brown clayey-loam A-horizon, grey clay calcareous B-horizon and an extensive lime layer above the rock. This calcareous layer was 200 mm thick.

4.1 Observations

An inspection of the property on foot and by motor car confirmed that the site was dominated by a gilgai landform and, whilst introduced pasture and weeds dominated the

western side of the property adjoining Robinsons Road, Wallaby grass (*Danthonia purpurascens*) – a native species - dominated the eastern part, providing evidence of minimal cultivation or land disturbance.

A heap of rocks in the south-western corner indicated previous extraction activity, with this portion of the property markedly disturbed by excavations and spoil heaps. Lesser disturbance was evident in the north-eastern corner, probably associated with a rocky rise despite its use as a temporary horse paddock.

On the basis of reconnaissance there was no evidence at either location 76 or 104 of anthropogenic disturbance or the surface deposition of material containing barium. Encapsulation can be ruled out because the soil profiles exposed were formed by natural processes and did not show a layer of overburden or destruction of soil structure patterns. Accordingly, it must be assumed that the barium levels measured were derived from the parent rocks and may have been translocated by natural geomorphic processes dominated by leaching in this terrain.

4.2 Expected behaviour of barium in the soil

Barium is likely to concentrate in intermediate and acid magmatic rocks, although in this case the barium is derived from mafic (or “basic”) rocks; commonly, the concentration range is 400 ppm to 1200 ppm (A.K. & H. Kabata Pendias, 2001). World average natural abundance of barium in basaltic rocks is 250 mg/kg, but some basalts have much higher barium levels, for example, tholeiite basalt in North East Ireland contains 1,350 mg/kg of barium (Krauskopf, K.B., 1967). As far as we know, there is no systematic survey of Victorian basalts that provide data on barium levels in these rocks and hence it is unknown what barium levels may be expected in the rocks from which these soils have developed.

Barium released from weathering is not very mobile and readily precipitated as sulphates and carbonates as long as sulphates and carbonates are available in a profile, as they are, or can be applied as amendments. It also must be remembered that, as other rock constituents are lost by leaching in the soil formation process, those constituents that are less likely to be lost become proportionally more abundant in the residue.

The magnitudes derived from soil laboratory tests, although exceeding the threshold, are within the typical range measured from soils in their natural state around the world. Fortunately the elevated magnitudes are associated with depths of between 0.5 m and 1 m in well-defined soil profiles that have a rock pavement with little colonization of roots beyond 450mm due to the presence of a calcareous clay dominant B-horizon. They also occur in a zone in the profile where free lime is omnipresent and the pH high, thereby limiting plant availability.

Barium precipitates in the presence of sulphate (SO_4^{2-}) to form barite (BaSO_4) which is extremely insoluble; thus sulphate can be employed to assess the actual level of risk to health and control mobility (Lehr, Hyman, Gass & SeEVERS, 2002). Further barium, like carbon, hydrogen, phosphorus and sulphur, is a common constituent of plants and soils around the world. It is present in the form of a radioactive isotope from past atomic weapons testing in the open air, but there is no likelihood that the material found is derived from such fall-out due to the observed barium concentration gradient (Pierzynski, Sims & Vance, 2000).

Plant toxicity is possible at the levels indicated, if the barium were more soluble, but the roots would need to penetrate to 0.5 m to exploit the soil profile to the depth where elevated barium levels were recorded in soil samples. To reduce the prospect of plant toxicity or uptake the application of gypsum is proposed, thereby providing both calcium and sulphate to limit plant uptake by rendering the barium even more insoluble. In addition, the substantial lime layers in the B-horizon and particularly at the top of the C-horizon will pose a major impediment to root penetration for all but the most lime-tolerant deep-rooted vegetation so it is unlikely plant roots could reach the depth where barium could be a problem.

4.3 Soil Profile Information

The description of the soil profile was limited to noting the Munsell colours for each of the 10-cm intervals sampled. The information is tabulated below.

Table 1 Soil colours throughout the profiles sampled by Wrigley & van de Graaff

Backhoe pit at # 76 bore hole			Backhoe pit at # 104 bore hole		
Depth (cm)	Munsell Colour		Depth (cm)	Munsell Colour	
0-10	10YR 3/1	Very dark grey	0-10	7.5YR 3/4	Dark brown
10-20	10YR 3/3	Dark brown	10-20	7.5 YR 3/4	Dark brown
20-30	10YR 3/2	Very dark grey brown	20-30	7.5YR 3/2	Dark brown
30-40	10YR 3/2	Very dark grey brown	30-40	7.5YR 4/2	Brown
40-50	10YR 3/2	Very dark grey brown	40-50	7.5YR 4/4	Brown
50-60	10YR 3/3	Dark brown	50-60	7.5YR 4/4	Brown
60-70	10YR 4/3	Brown	60-70	2.5Y 3/2	Very dark greyish brown
70-80	10YR 4/2	Dark greyish brown	70-80	2.5Y 4/2	Dark greyish brown
80-90	10YR 4/2	Dark greyish brown	80-90	2.5Y 5/2	Greyish brown; much lime accumulation
90-100	10YR 5/3	Brown			

The Munsell colour scheme divides the colour spectrum up in “hues” which transgress the full primary colour range from reds (R) to yellows (Y), with 7.5YR a mix of these, in this case being the most reddish hue observed, 10YR being in the middle and more brownish and Y being the most yellow hue noted. The first numeral following the hue indicates the amount of black mixed in with the primary colour, and the lower the number, the blacker or darker the soil (i.e. the less colour reflection and the more light absorption, whereas the higher the number, the more white is mixed with the primary colour, diluting, as it were the primary colour. The second numeral is a measure of the dominance of the primary colour; thus 2.5Y 6/8 is a brighter yellow shade than 2.5 Y 6/1, which is predominantly a mix of black and white, in other words a grey shade, with a little yellow.

Soil colours are useful for deriving information on natural drainage of the soil profile as well as the likely abundance of metal oxides-hydroxides, as it is the latter that produce the colours and as it is the oxidation state of the oxides that governs the redness, brownness or yellowness of the soil material. Soil colour, therefore is also used in distinguishing the natural horizationation in the soil profile, which in turn provides information on the vertical translocation of soil constituents as a result of percolating rainwater over thousands of years.

On the basis of profile colour, the profile at backhoe pit 104 has better natural drainage and is better oxidised than the profile at backhoe pit 76, however none of them indicates significant waterlogging during the year. Therefore the evidence is that reducing conditions do occur and sulphates should remain in sulphate form.

5. Discussion of the barium results obtained by the Chadwick Group

Testing by The Chadwick Group, in their report of 20 November 2005, omitted the determination of barium levels from nearly every sample taken, except at borehole sites 104, 106, 108, 109, 110, 112, and 114, but their Figure 2 “Sampling Locations at 170 Robinsons Road”, only shows site 104 and this is located within the Deer Park site. Borehole sites 106 to 114 are not shown on the Figure. Off-site boreholes are numbered OA, OB, OC, OD, OE, and OF are shown close to the periphery of the subject land and for each of these barium levels were determined for the surface soil and for the soil at 0.5 m depth. It was only borehole 104 that had 1300 mg/kg of barium at 0.5 m depth.

A subsequent round of sampling was reported in a fax by MGT Environmental Consulting, the laboratory, to the Chadwick Group on February 23, 2006. This set of sampling consisted of four boreholes situated in very close proximity to borehole 76 and are labelled BH76/1, BH76/2, BH76/3 and Bh76/4 and a similar set was sampled around borehole 104, which had the one high value of 1300 mg/kg. At each of these samples were retrieved from the surface soil, at 0.5 m depth and at 1 m depth. We do not know why this particular borehole was selected for this detailed sampling. The results are tabulated below.

Table 2 Validation sampling by the Chadwick Group around two bore holes

Depth (m)	Sample #	Ba mg/kg	Sample #	Ba mg/kg	Sample #	Ba mg/kg	Sample #	Ba mg/kg
Surface	76/1-1	51	76/2-1	33	76/3-1	37	76/4-1	45
0.5	76/1-2	210	76/2-2	300	76/3-2	320	76/4-2	150
1.0	76/1-3	390	76/2-3	160	76/3-3	360	76/4-3	350
Surface	104/1-1	28	104/1-1	29	104/3-1	22	104/4-1	36
0.5	104/1-2	70	104/2-2	190	104/3-2	84	104/4-2	240
1.0	104/1-3	220	104/2-3	270	104/3-3	250 & 190 (dupl.)	104/4-3	910

These results show, with one exception, that the barium levels increase with depth, and therefore resemble other well-known depth functions of salts in soils. The heavy clay soils on basalt universally show a zone of calcium carbonate concentration lower down in the soil profile, which indicates the maximum depth at which there was enough percolating rainwater to keep calcium carbonate in solution. As during the process of water percolation the vegetation removed water from the soil, so that the remaining solution became more concentrated, at the point where the solubility of the calcium carbonate was exceeded, it would precipitate out from the solution and form solid calcium carbonate.

It is known that, when the soil profiles are deep enough and gypsum is present, there will also be a gypsum layer in the profile. That layer will be found below the calcium carbonate layer, because gypsum is more soluble in water and hence the soil needs to dry out more before gypsum precipitates.

As the likely forms of barium in the soil are barium sulphate and/or barium carbonate, the barium profile illustrated in the laboratory data is suggestive of a similar down-profile enrichment of the soil with barium. Unfortunately, these samples were not analysed for either sulphate or carbonate as generally the focus of environmental testing is on the potential toxicant and ignores any other compounds that can render it harmless. Thus environmental testing often disables itself when a risk assessment has to be the final outcome.

Groundwater samples were analysed both for barium and sulphate, as shown in Table 3.

Table 3 Relevant groundwater analytes with regard to barium behaviour

	MW1	MW2	MW3	MW4	MW5	MW6	MW7
Barium (mg/L)	0.061	0.048	0.044	0.031	0.02	0.042	0.046
Barium (mmole/L)	0.000,45	0.000,35	0.000,32	0.000,23	0.000,15	0.000,31	0.000,34
Sulphate (SO ₄ ⁻²) (mg/L)	230	54	170	92	270	130	120
Sulphate (SO ₄ ⁻²) (mmole/L)	2.396	0.563	1.771	0.958	2.813	1.354	1.250
Bicarbonate alkalinity (CaCO ₃) (mg/L)	500	560	550	600	820	360	320

Table 3 Continued

pH	7.7	8.2	8.5	8.1	8.0	7.6	7.6
Total Dissolved Solids (mg/L)	10,000	2,600	6,300	4,200	9,311,000	5,400	5,300

By expressing the concentrations of barium and sulphate in the groundwater as molar quantities (mmole/L = millimole/L) it can be seen that the sulphate ion concentration is many times greater than the barium concentration. The geometric mean barium concentration in these seven monitoring wells is 0.0397 mg/L or 0.000,29 mmole/L. The geometric mean sulphate concentration is 135 mg/L or 1.406 mmole/L. In other words, the sulphate anions outnumber the barium cations by about a factor of 5,000. Therefore, any solid phase barium sulphate in the earth/rock materials below the groundwater table at equilibrium with the dissolved species will be a system in which the dissolved barium concentration is minimised by the great excess of dissolved sulphate. This is illustrated in the Figure 1 below.

Figure 1 Relationship between dissolved barium concentration to dissolved sulphate concentration in pure water

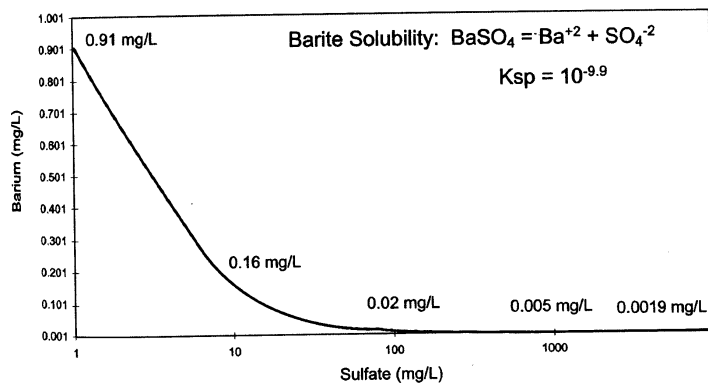


FIGURE 7.5 Barium solubility as a function of sulfate concentration in pure water.

In the groundwater, the barium concentration is on average (geometric mean) about one half of the adopted NHMRC (2004) value of 0.7 mg/L, and therefore of no concern under those guidelines. Apart from the barium issue, the groundwater is also extremely saline. Any water with more than 1,500 mg/L of Total Dissolved Solids is classed as “Very High Salinity Water” which is unsuitable for irrigation. These ground waters, excluding the sample from MW5 (apparently 260 times more salty than seawater!) have a geometric mean salinity of more than 5,000 mg/L TDS. The NHMRC adopted threshold value appears to be for fresh water ecosystems, so would not be relevant in any case.

However, if there is so much sulphate in the groundwater, there must be sulphate in the soil above the groundwater table. However, the Chadwick Group’s sampling has not determined it.

The testing regime adopted by Wrigley and van de Graaff is to sample two soil profiles at 10 cm intervals and determine a range of parameters that may show there is a similar process at work for barium. In addition, by testing for free sulphate, it will be possible to

obtain evidence of the likely form in which the barium exists, and from that to assess the risk of barium human health and the wider environment.

6. Depth Function Test Results and Final Risk Assessment

The results of analyses of samples collected at 10 cm intervals are presented in Table 4. With regard to the Electrical Conductivity (EC) the table shows that salinity increases with depth until it reaches a more or less constant maximum level at 50 to 60 cm depth. This depth function (Figure 1, Appendix 1) indicates that in the main rainwater does not percolate much below this level. It also is indicative of the reverse process whereby dissolved salts can move up in the profile when the subsoil still contains water but the topsoil is being depleted of water by transpiring vegetation. The net equilibrium with regard to transport of salt in the soil profile at Deer Park is that below 60 cm the levels remain constant.

The pH shows a much more regular depth function (Figure 2, Appendix 1). The pH of the soil is influenced by the proportion of the exchangeable cations on the clay taken up by sodium, compared to calcium and magnesium, as well as by the possible occurrence of sodium bicarbonate, which is very soluble and hence more easily transported to lower portions of the soil.

Barium released by extraction with 1 molar hydrochloric acid has a depth function showing depletion of the surface layers and a addition causing a bulge between 40-60 cm depth and continuing elevated levels deeper down. This barium is the fraction that will largely consist of barium carbonate.

Total barium levels were obtained by a method that is relatively insensitive but can detect concentrations above 500 mg/kg. In profile # 76 only one sample had just over 500 mg/kg at 510 mg/kg. Profile 104 had four samples exceeding 500 mg/kg, with values respectively, 610, 540, 570 and at 80-90 cm depth even 2000 mg/kg.

Water soluble sulphate, expressed as sulphur (S), is abundant throughout both profiles and increases sharply below approximately 40 cm depth. As this represents free SO_4^{-2} anions, it means that water soluble barium concentrations must be severely depressed as is shown in Figure 1. Even acknowledging that the water in the soil is not pure water, but a rather saline aqueous system, the relationship is still of general validity in predicting that soluble, mobile barium levels must be low also.

Leachable barium levels are uniformly extremely low. The leachable barium may be reasonably equated with the water-soluble barium as the extractant is a buffered solution of acetic acid and sodium acetate with a pH that does not depart in an extreme fashion from normal soil pH values. These concentrations can be compared to the concentrations of water-soluble sulphate, with both expressed on a molar basis. If this is done we note that the sulphate concentrations exceed the barium concentrations by between 5 and 6 orders of magnitude (Table 4).

Table 4 Comparison of concentrations of water soluble sulphate with leachable barium

	Depth (cm)	Sulphate as S (mg/kg)	Sulphate as SO ₄ (mole/kg)	Ba Leach. (mg/kg)	Ba Leach. (mole/kg)	Molar Ratio Sulphate to Barium
Soil Profile # 76	0-10	630	0.210	0.43	3.1 x 10 ⁻⁶	6.7 x 10 ⁴
	10-20	<100		0.17	1.2 x 10 ⁻⁶	
	20-30	<100		0.08	5.8 x 10 ⁻⁷	
	30-40	410	0.137	0.19	1.4 x 10 ⁻⁶	9.9 x 10 ⁴
	40-50	1400	0.467	0.34	2.5 x 10 ⁻⁶	1.9 x 10 ⁵
	50-60	780	0.260	0.31	2.3 x 10 ⁻⁶	1.2 x 10 ⁵
	60-70	550	0.183	0.29	2.1 x 10 ⁻⁶	8.7 x 10 ⁴
	70-80	680	0.227	0.23	1.7 x 10 ⁻⁶	1.4 x 10 ⁵
	80-90	1100	0.367	0.29	2.1 x 10 ⁻⁶	1.7 x 10 ⁵
	90-100	1700	0.567	0.29	2.1 x 10 ⁻⁶	2.7 x 10 ⁵
Soil Profile # 104	0-10	240	0.080	0.08	5.8 x 10 ⁻⁷	1.4 x 10 ⁵
	10-20	980	0.327	0.07	5.1 x 10 ⁻⁷	6.4 x 10 ⁵
	20-30	670	0.223	0.06	4.4 x 10 ⁻⁷	5.1 x 10 ⁵
	30-40	1400	0.467	0.28	2.0 x 10 ⁻⁶	2.3 x 10 ⁵
	40-50	1600	0.533	0.72	5.2 x 10 ⁻⁶	1.0 x 10 ⁵
	50-60	1800	0.600	0.4	2.9 x 10 ⁻⁶	2.1 x 10 ⁵
	60-70	1900	0.633	0.33	2.4 x 10 ⁻⁶	2.6 x 10 ⁵
	70-80	3100	1.033	0.38	2.8 x 10 ⁻⁶	3.7 x 10 ⁵
	80-90	2400	0.800	0.4	2.9 x 10 ⁻⁶	2.7 x 10 ⁵
	90-100	n.s.	n.s.	n.s.	n.s.	n.s.

As the sulphate concentration far outstrips that of the leachable barium, the bulk of the solid phase barium in the soil will be in the barium sulphate form and will be inert.

7. Gypsum application to improve soil conditions at the surface

Gypsum applications to the soil are recommended, not in the first place as a means of further reducing any soluble barium remaining in the topsoil, but chiefly to improve the soil structure in upper soil layers to enable better growth of street and garden plantings and thereby improve prospects for revegetating the new residential developments.

Phosphogypsum amendment is recommended and in the past this type of gypsum has been accessed from Pivot in Geelong. Unfortunately supplies of this product are now very limited and natural gypsum is likely to be more accessible from deposits in North Western Victoria where calcium sulphate concentrations are lower.

Soil tests conducted on samples collected from the two locations have confirmed that the profiles are both sodic (Exchangeable Sodium Percentage (ESP)>6) with the profile at Site 76 yielding higher ESP values than those found at Site 104. Assuming that correction is aimed for the top 100-200mm of soil profiles where the ESP variation is between 6 and 19 an amendment rate of 3 to 6 t/ha is flagged. This should be incorporated by ripping and rotary hoeing to a depth of at least 100mm prior to planting.

8. Conclusions

All the results of this investigation concur to indicate that the hypothesis underlying our investigative method is correct:

- 1) The barium in the soil is native barium;
- 2) The barium has become concentrated in the subsoil through losses in the topsoil by normal geochemical processes over many thousands of year;
- 3) The barium in the soil is present largely as barium sulphate, i.e. as an inert solid compound;
- 4) The barium is of nil environmental and public health risk.
- 5) Environmental assessments and audits should be based on more than routine soil sampling and analyses of contaminants in the soil or groundwater only. Analyses should include those other chemical factors that are well known to control the solubility, mobility and toxicity of each contaminant. A sound understanding of geochemistry and soil chemistry is essential.
- 6) Gypsum applications to the soil are recommended, not in the first place as a means of further reducing any soluble barium remaining in the topsoil, but chiefly to improve the upper soil layers to enable better growth of street and garden plantings and thereby improve the new residential developments.

Table 4 Results of van de Graaff – Wrigley samples testing

Sample Site # 76							Sample Site # 104					
Depth (cm)	EC (μ S/cm)	Water Soluble Sulphate (as S) (mg/kg)	pH (H ₂ O)	Ba Total (mg/kg)	Ba 1 M HCl extract. (mg/kg)	Ba Leachable (mg/kg)	EC (μ S/cm)	Water Soluble Sulphate (as S) (mg/kg)	pH (H ₂ O)	Ba Total (mg/kg)	Ba 1 M HCl extract. (mg/kg)	Ba Leachable (mg/kg)
0-10	76	630	6.9	<500	100	0.43	130	240	6.8	<500	27	0.08
10-20	260	<100	7.0	<500	89	0.17	220	980	7.5	<500	31	0.07
20-30	300	<100	7.1	<500	42	0.08	520	670	8.0	<500	29	0.06
30-40	650	410	7.3	<500	110	0.19	830	1400	8.4	<500	110	0.28
40-50	940	1400	7.6	<500	130	0.34	950	1600	8.5	610	180	0.72
50-60	1200	780	8.0	510	140	0.31	1100	1800	8.9	540	160	0.40
60-70	1300	550	8.2	<500	120	0.29	1100	1900	9.2	<500	130	0.33
70-80	1300	680	8.3	<500	110	0.23	1100	3100	9.5	570	110	0.38
80-90	1300	1100	8.5	<500	110	0.29	1100	2400	9.6	2000	84	0.40
90-100	1400	1700	9.0	<500	97	0.29	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

n.s. = No sample taken as bedrock occurred at this depth.

9. References

Geology Survey of Victoria (1967). "Geology of the Melbourne District, Victoria", Bulletin No. 59, Mines Department, Victoria

Grant.K. (1972)

"Terrain Classification for Engineering Purposes of the Melbourne Area, Victoria"
Division of Applied Geomechanics Technical Paper No.11, CSIRO

Jeffrey. P.J. (1981). "A Study of the Land in the Catchments to the North of Melbourne".
Soil Conservation Authority Victoria

Kabata Pendias. A.. (2001). "Trace Elements in Soils and Plants". 3rd Edition, CRC
Press, Boca Raton, Florida.

Krauskopf, K.B., (1967). "Introduction to Geochemistry". McGraw-Hill Book Company,
New York

Lehr.J., Hyman.M., Gass.T.E. & Seevers.W.J. (2002). "Handbook of Complex
Environmental Remediation Problems". McGraw Hill, New York

Pierzynski.G.M., Sims.J.T. & Vance.G.F.(2000). "Soils and Environmental Quality". 2nd
Edition. CRC Press, Boca Raton, Florida

Appendix 1

Diagrams of depth functions

Figure 1: Electrical conductivity ($\Phi\text{S/cm}$) and pH as a function of depth

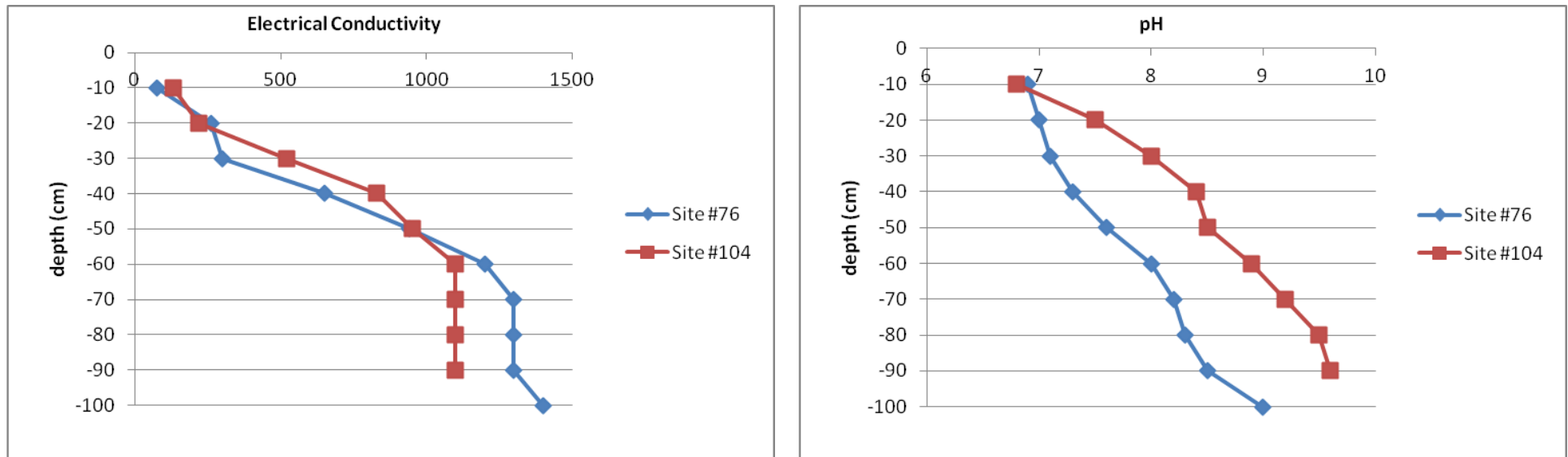


Figure 2: Ba and water soluble SO_4^{-2} as a function of depth

