Land-Parcel Land-Use History as a Key to Site Selection for Documenting Soil Contamination Risk: a Case Study from Australian Suburbia

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ABSTRACT In that orcharding in early-to-mid twentieth century southeastern Australia involved use of certain heavy metal and As compounds in regular pest-control spray procedures, some interest attaches to the possibility that these landparcels are underlain by soils with above-background Cu, Pb and As levels. Interpretation of Land-cover changes allowed land parcels previously occupied by orchards to be identified in the 1950s through time-series air-photos. A comparison of soil analysis results referring to soil samples from control sites, and from land parcels formerly occupied by orchardists, shows that contamination (above-background) levels of cations in the pesticides can be found in the top 6 cm of former orchard soils. It is clear that digital spatial data handling and culturally-informed air photo interpretation has a place in soil contamination studies, land-use planning (with particular reference to re-development) and in administration of public health.

KEYWORDS aerial photography; digital orthophoto image; soil contamination; soil analysis; land-use planning; public health

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Introduction

Agri-chemical insecticides based on lead, copper, and arsenic compounds were commonly applied in commercial Australian orchards and vineyards until, after a century or so, they were largely (and completely, in the case of arsenic and lead) replaced by organic pesticides [1]. However, insecticide residues can be particularly persistent in soils [2-4] and so elevated concentrations can be found long after there has been a change of land use. Such changes include suburbanisation. Until recently, and despite the efforts of city planners to address the environmental consequences of sustained low density suburbanisation has characterised Australian urban expansion, each new house occupying less than half of its “quarter acre block”/land parcel (0.1 Ha). Accordingly, gardens (including hobby gardens devoted to growing vegetables) in some suburban areas will have been made on contaminated soils. This kind of urban soil contamination has been of concern for a decade or so[5] in Australia, and is widely recognised as worthy of documentation in both urban [6] and agricultural areas[6,7].

It is clear that in many cities, amendments to land-use planning schemes that allowed conversion of orchard land to suburban occupation via land sub-division and re-development took place without reference to the possibility that land-parcel attribute documentation in terms of soil contamination might be useful. Even if contamination by heavy metals and arsenic might be comparatively harmless/ bio-unavailable at the time of land-parcel sub-division, continuing suburbanisation will change run-off ratios and water...
Retention and release reactions in soils are controlled by environmental factors such as soil physical and chemical properties (e.g., texture, pH, CEC), climatic conditions (e.g., rainfall, temperature, sunlight), type of chemicals applied, and biological population. Thus, to the natural diversity (topographic and hydrological) among land parcels is added, as a legacy of "post-orchard" land use referring to multitude of recreational horticultural practice, a range of possibilities, some of which might enhance the reactivity of the pollutant ions. The implications directly refer not only to the welfare of plants and animals feeding from suburban gardens, but, in areas with perennial streams, to urban water quality also.

It is in preparation for serving a future recognition by governors of any city that the land-parcel attribute database should be improved, that this study has been undertaken. As a case study it refers to Monash City, Australia (Fig. 1) a region of water surplus (i.e., perennial drainage) that supported early-to-mid twentieth century orcharding; a land-use readily mapped from the archival air photos. The work amounts to a test of scope for data integration in land-parcel attribute assembly with special reference to alerting planners to the need for environmental investigation, and, in that context, to matters of soil sample site selection.

The project task-list included items under two main categories: (1) spatial database building (a typical pre-requisite for site selection projects); (2) field sampling, chemical analysis, and information integration (Fig. 2).

1 Materials and methods

1.1 Database building

The spatial database was assembled in ArcGIS. The image data (archival air photos) was assembled by scanning (in Photoshop) and georeferencing with image-handling tools in ERDAS (Fig. 2).

1.2 Soil sampling/Sampling procedure

Apart from the valley bottoms, the study area soils have evolved in comparatively undisturbed regolith. The soil samples were collected so that areas never used for commercial orcharding as well as areas that were formerly orchard sites (all but 2 from soils with the same parent material/regolith) were represented. The distribution of the sample sites is depicted in Fig. 3. The sampling strategy was, perforce, pragmatic. Public land within orchard polygons was identified, and samples collected if site disturbance since redevelopment that followed orcharding
was apparently minimal. For instance, samples taken from beneath overhead high tension power cables and from public parks that were larger than a hectare or so and without land-forming earthworks were preferred. Each soil sample (400-500 grams) was stored in a sealed plastic bag until being prepared for chemical analysis.

Collected soil samples were air-dried at approximately 30 °C, gently ground and sieved at a 2 mm sieve. All chemical analysis were performed in duplicate on the size fraction smaller than 2 mm. Soil pH was measured in deionised water in soil/solution ratio 1 : 5 as described in the Laboratory Handbook of Soil and Water Chemical Methods. Concentrated nitric acid digests\(^{17}\) were used to measure total concentration of copper, lead and
arsenic. An inductively-coupled plasma atomic emission spectrometer (ICP-AES) was used to determine the concentration of copper and lead in the digests. The arsenic concentration was measured by inductively-coupled plasma optical emission spectroscopy (ICP-OES). Based on reproducibility of analyses, the precision of ICP-AES and ICP-OES measurements is estimated to be astray by less than 1%.

2 Results

Inclusion of time-series land-cover snap-shots in the project spatial database has enabled land-use changes relevant to soil contamination studies to be documented. The mid twentieth-century historical geography of the study area, in terms of orchard distribution, allows registration of the “orchards map” with any other city map that has been compatibly georeferenced. Sample display from such spatial modelling is offered in Fig. 4. The 1951 extract is overlain with contemporary orchard boundaries in Fig. 4(a), and with the modern cadastral in Fig. 4(b), progressive suburbanisation is depicted by the other two images; 1989 (Fig. 4(c)) and 2001 (Fig. 4(d)).

![Fig. 4 Orthophoto mosaics in time series show land-use change](image)

The three control sites, which was not occupied by orchards (5, 6 and 10 of Table 1) showed such low concentrations of Cu, Pb and As, that “orchard mapping” projects designed to identify contaminated ground in suburbia can surely be justified. Although we cannot exclude the possibility inputs of copper, lead and arsenic other than those associated with pesticide use has occurred on these sites, the history of land-use information as interpreted from the time-series snapshots, together with the low concentration of these elements outside the former orchards indicate that we are justified in regarding the results from the “non-orchard” sites of Monash City as representative of local values for the background levels of the elements measured. The average background concentrations (+/− standard deviation) of Cu, Pb and As in surface soil in Monash City are as follows: copper −7.1 mg/kg (+/− 4.3), lead −19.4 mg/kg (+/−2.9) and arsenic −4.7 mg/kg (+/−1.2) see Table 1.

All mid twentieth century “orchard sites”, which was occupied by orchards, showed elevated concentration of one or all three elements; Cu, Pb, As (Table 1).

Copper concentration is up to 9 times higher than the background concentration and for one case (site 4) exceeds 60 mg/kg value, which is the Australian and New Zealand environmental investigation level for copper [16]. The results confirm that copper based fungicides; most likely Bordeaux mixture and copper oxychloride [1], were commonly used in the Melbourne area in the last century.

Because lead and arsenic were applied together in the form of lead arsenate (PbHAsO₄), sites with elevated lead content have raised As level as well. Although the concentration of lead does not exceed the environmental investigation level of 300 mg/kg[19], it is up to 9 times higher than the background concentration in Monash City.

Arsenic concentration is up to 18 times higher than the background values, and in three cases (site 1, 4 and 8) exceeds the environmental investigation level of 20 mg/kg[16].

The total content of copper, lead or arsenic in soils is an indication of potential contamination problems but it does not provide enough infor-
mation about the environmental impact and possible implications. In this study, we did not carry out sequential extraction analysis nor did we deploy any other techniques that would allow us to measure the forms of the elements that influence their activity. However, the previous studies found that, for example, anthropogenic copper exists in soils mainly in active form and persists for a long period of time. It is worth noting, in this context, that the City soils are generally acidic (Table 1) and that such soils are more likely to promote higher rather than lower ionic activity.

### Table 1 Selected chemical properties of sampled soils

| Site | Depth/cm | pH   | Cu (mg kg⁻¹) | Pb (mg kg⁻¹) | As (mg kg⁻¹) |
|------|----------|------|--------------|--------------|--------------|
| 1    | 2.0      | 5.6  | 43.2         | 108.5        | 43.4         |
|      | 4.0      | 5.6  | 47.2         | 137.8        | 66.2         |
| 2    | 2.0      | 5.7  | 31.2         | 18.3         | 3.6          |
|      | 4.0      | 5.6  | 31.1         | 21.3         | 6.8          |
| 3    | 2.0      | 4.6  | 43.7         | 33.2         | 13.1         |
|      | 4.0      | 4.6  | 47.3         | 36.5         | 15.2         |
| 4    | 2.0      | 5.4  | 55.5         | 132.7        | 65.7         |
|      | 4.0      | 5.4  | 65.3         | 167.7        | 84.3         |
| 5    | 2.0      | 5.8  | 12.7         | 23.2         | 3.8          |
|      | 4.0      | 5.8  | 12.1         | 22.4         | 5.3          |
| 6    | 2.0      | 6.3  | 6.8          | 16.8         | 3.2          |
|      | 4.0      | 6.3  | 4.7          | 15.9         | 3.8          |
| 7    | 2.0      | 5.7  | 17.2         | 38.3         | 5.0          |
|      | 4.0      | 5.7  | 16.8         | 38.2         | 4.2          |
| 8    | 2.0      | 5.3  | 29.8         | 46.2         | 19.5         |
|      | 4.0      | 5.2  | 35.1         | 60.4         | 28.2         |
| 9    | 2.0      | 5.3  | 34.0         | 36.1         | 17.9         |
|      | 4.0      | 5.3  | 38.6         | 49.6         | 17.0         |
| 10   | 2.0      | 5.6  | 3.7          | 19.4         | 5.8          |
|      | 4.0      | 5.6  | 2.8          | 18.9         | 6.2          |

Note: sites 5-10 are "control sites"; site 1 is "edge sites"; site 1, 2, 3, 4, 8, 9 are "orchard sites".

### 3 Discussion

This study exemplifies the application of time-series land-use information in soil contamination studies. For instance, it is relevant to sampling site selection for establishing background levels of elements of interest, and for refining the identification of contaminated soils, land parcel by land parcel. Extrapolation of our results to all of the city land parcels suggests that 3.71% of the city terrain is underlain by soils that have raised Cu, Pb and As levels.

Time series land-use information is not so commonly referred to during urban planning because it is not always readily accessible, but recently-published research results are such as to suggest that the adoption of digital spatial data handling methods in accordance with public policy can be worth while during urban re-development. It is therefore important that the value of the air photo archive in this context (let alone others) be widely acknowledged.

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