Title: GIS-based spatial analysis for archaeological site prediction and evaluation

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Abstract

Application of GIS-based spatial analysis for archaeological site prediction and evaluation

Predictive modelling of Aboriginal archaeological sites has been a common thread in Victorian archaeological practice for many decades. With the advance of GIS-based mapping methods, it is now possible to employ more sophisticated and automated techniques to characterise the available archaeological data, and to develop analytical methods to assist in the identification, investigation and evaluation of the archaeological record.

The use of spatial data is now embedded in the Aboriginal heritage legislation, with specific geographic criteria to determine "Aboriginal cultural heritage sensitivity" as one trigger for a Cultural Heritage Management Plan. By describing the landscape features of recorded cultural heritage sites, criteria for mapping cultural heritage sensitivity have been derived, such as distance from waterways, coastlines, and existing archaeological places, and the presence of sand ridges, swamp margins, and ancestral streams.

However, it is often the finer resolution geographic features that are crucial to predicting and understanding Aboriginal archaeology. The influence of micro-topography - fine resolution landscape, topographic and environmental factors - in campsite selection can be helpful in narrowing down the potential locations of archaeological sites and improving the effectiveness of field survey programs. By testing and characterising the site types, we can better understand the human behavior behind the choices made in selecting campsites, and the way the landscape was used and inhabited by people.

For example, along the Maribyrnong Valley, a number of silcrete outcrops have been identified as ancient sources of stone for tool making. The various sites appear to occur consistently at about the 37m contour on slopes greater than 25 degrees. At the same time, nearby occupation sites appear to be restricted to the few areas of flat land less than 15 degrees slope, near the river, or on the more distant high ground on the change of slope at the edge of the valley escarpment.

Investigation and refinement of the patterns of Aboriginal site distribution using GIS-based analysis and remotely acquired datasets such as LiDAR can therefore help us better predict where new sites will be found, and understand how Aboriginal people used the landscape. While the current use is broad scale and coarse in its predictive capacity, there is potential for far more targeted use of the techniques if more accurate and specific data on environmental conditions, landform and ethnographic behaviour can be compiled and built into the models.

While an intuitive approach to understanding the landscape from a human perspective might still be superior to most algorithms so far developed for predictive modelling of Aboriginal sites, there will be greater roles of GIS in managing cultural heritage in the future.

Key words: archaeology, predictive modelling, landscape evaluation

Author biographies

G Vines; Archaeologist

Gary has worked as a consultant in heritage and archaeology for over 25 years. He has worked for the Museum of Victoria, conservation departments and community museums, in archival research, oral history, historic site assessment and interpretation, industrial and historical archaeology, and conservation management. His heritage work has included managing the City of Hume and City of Brimbank Heritage Studies, contributing the industrial and archaeological components to Heritage Studies of Dandenong, Flinders, Hobson's Bay, and Maribyrnong and undertaking a variety of historic site assessments including the Pipemakers Park Conservation Plan. Gary has undertaken a large number of Cultural Heritage Management Plans for a range of developments in Victoria, such as the Places Victoria's Aurora and Officer developments His work on industrial heritage includes comprehensive inventories of industrial heritage places in Melbourne and Victoria, and extensive research on historic industries including bridges, tanneries, meatworks, manufacturing, dry stone walls and chaffmills. His involvement in defence heritage

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includes the original cultural heritage assessment of the Albion Explosives Factory, research and exhibition development on the munitions industry, and archaeological surveys at a number of defence properties including the Broadmeadows and Puckapunyal Army Camps and Maribyrnong Explosives Factory.

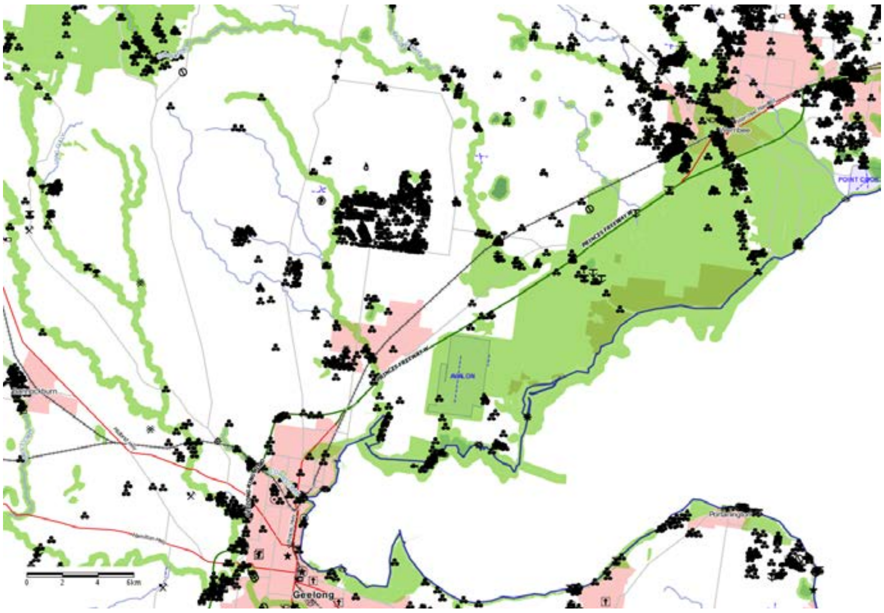
Stephen Page; GIS Officer
Stephen is a GIS Officer with Biosis Research. Previously he was employed as a GIS Officer at RMIT University Centre for Remote Sensing. He has experience in Geographical Information Systems, Remote Sensing and Cartography. Stephen has a background in natural resource management and expertise in publishing and communicating complex natural resource information to a variety of audiences. He is able to manage spatial data from a variety of sources through collection, conversion and analysis, producing electronic and hard copy maps and spatial layers.

Introduction

Predictive modelling for characterising the location and distribution of Aboriginal archaeological sites and assisting in their discovery has been a common thread in Victorian archaeological practice for over 25 years. These models have been for the most part broad scale and generic– proximity to water and vantage points are the main predictors – but do little to enable more tightly focused field investigations. Nor have they been rigorously tested.

The use of spatial data is embedded in Aboriginal heritage legislation, with specific geographic criteria to determine "Aboriginal cultural heritage sensitivity" as one trigger for a Cultural Heritage Management Plan. Criteria for mapping cultural heritage sensitivity have been derived from landscape features of recorded cultural heritage sites. Criteria include distance from waterways, coastlines, and existing archaeological places, and the presence of sand ridges, swamp margins, and ancestral streams (Figure 1).

Figure 1: Areas of Aboriginal archaeological sensitivity and recorded archaeological sites (AAV ACHRIS interactive mapping system)



However, this approach relies on existing datasets mapped at broad scale resolutions. Additionally, criteria may be tied to legislative definitions such as "Named Waterways" (defined by the Geographic Places Names Register), or management and administrative functions such as Parks, and RAMSAR Wetlands. As a consequence, laser leveled artificial sewage ponds situated at a considerable distance from natural water are included simply because these ponds are part of the larger RAMSAR area. By contrast, the You Yangs, which do not meet the definition for parks and contain numerous waterways with unregistered names, are excluded. These anomalies are evident in figure 2.

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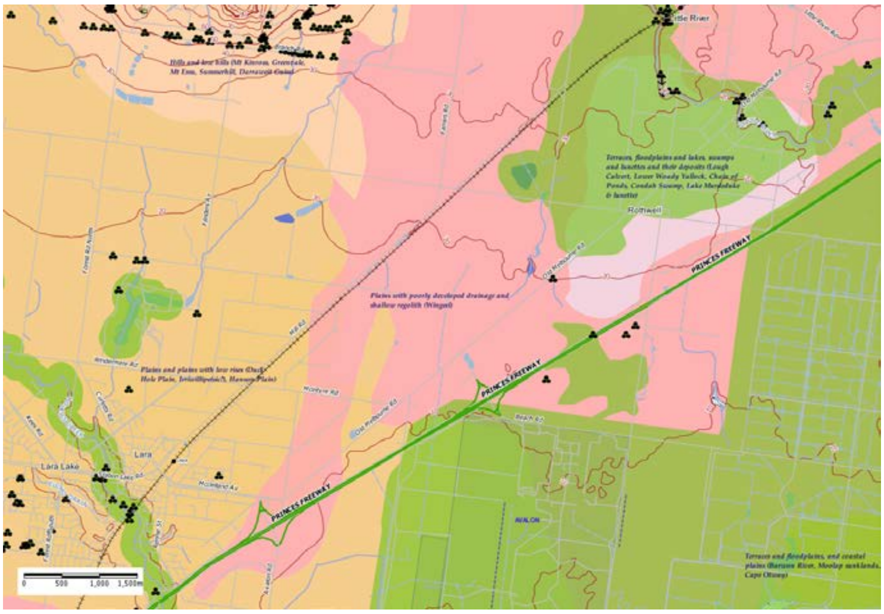
Figure 2: Areas of Aboriginal archaeological sensitivity and geomorphological areas, Avalon (AAV ACHRIS interactive mapping system)



A number of regional or subregional studies on the western urban fringe of Melbourne have involved more advanced predictive modelling. These have generally followed an inferential or inductive approach, examining existing site records from the Victorian Aboriginal Heritage Register (VAHR) and previous archaeological survey and excavation reports. Predictive patterns are identified from the relationships between recorded sites and environmental factors such as proximity to water, elevation, and slope.

These broad studies generally consider Aboriginal sites as a single type with little distinction regarding the type, quality or significance with the exception of scarred trees, where the rarity of old growth trees is the primary constraint. The results are sometimes compromised by the inclusion of the background archaeology (isolated artefacts) with the larger camp sites.

The resulting models, while useful in characterising broad patterning, are limited in their ability to improve site discovery during surveys. This inferential or inductive approach to predictive modelling has been criticized for its inability to cope with the low quality of many archaeological datasets (Brandt et al.1992). Thus, more intuitive models have been developed which combine quantitative data with more deductive mapping; i.e. based on specific investigations of ground characteristics, deducing from the immediate circumstances, such as the suitability of flat ground, relative ease of access to water, or quality of the immediate vantage.

The multivariate approach is replaced by a reduced number of variables intended to give a more stringent predictive power for a particular region or archaeological period. Such models have been characterized as ‘hybrids’, or descriptions of existing knowledge, rather than extrapolations. However, this approach has been critiscised for not specifying error margins and uncertainties, and a consequent lack of “…a clear formalized methodology for including both ‘hard’ and ‘soft’ knowledge” (Verhagen 2006).

It is often the finer resolution geographic features that are crucial to predicting and understanding Aboriginal archaeology. The influence of micro-topography - fine resolution landscape, topographic and environmental factors - in campsite selection can be helpful in narrowing down the potential locations of archaeological sites and improving the effectiveness of field survey programs. By testing and characterising the site types, we can better understand the human behavior behind the choices made in selecting campsites, and the way the landscape was used and inhabited by people.

Improvements in modern spatial data mapping tools provide more sophisticated and automated techniques to characterise the available archaeological data and to develop analytical methods to identify, investigate and evaluate the archaeological record. Furthermore, spatial analysis tools allow us to more effectively manipulate and analyse the data used in predictive modelling and present the results visually.

This paper proposes a model that attempts to refine these existing models to improve accuracy and precision, and to more thoroughly characterise the nature of the archaeology being predicted. To some extent, the model outlined is based on the same inductive process as its predecessors. But it also applies an intuitive approach based on common sense human behaviour (e.g. minimising effort, maximising returns, improving comfort or convenience), and observations from ethnographic literature and personal experience in Melbourne's western and northern basalt plains over the last 25 years.

This paper firstly reviews the recent development of approaches to investigations and predictive modelling applied to archaeological studies in the Melbourne outer fringe regions. The paper then describes two case studies where the proposed model has been applied to investigations.

Previous investigations and predictive models

Among the earliest of the broad area studies which formulated predictive models for the Melbourne outer fringe regions were the VAS-conducted studies involving regional and development corridors, including the Melbourne metropolitan region (Presland 1983), Melbourne's western region (du Cros 1989a), the Sydenham corridor (du Cros 1989b), the Plenty Valley corridor (Ellender 1989) and the Werribee corridor (du Cros 1996).

The models derived from these studies were more accurately descriptions of observed patterns of site locations in relation to environmental variables. These models were inductive - created after the field work and site recording had been finished - with the main objective being to inform future land use planning and archaeological investigations. There was little testing of the validity of their 'predictive' capacity. These models identify zones based on geographic or topographic features as having an elevated probability of having various Aboriginal site types. A typical model would be:

- *Most large or dense artefact scatters will be within 100m of reliable waterways;*
- *Shell middens and artefact scatters will be found within 100m of the coastal foreshore.*
- *Some hills and stony rises will have isolated artefacts;*
- *Scarred trees are found where suitable old growth native species survive;*
- *Burials occur only where there are soft sediments, such as sand dunes or river alluvium. (du Cros 1996).*

More specific site location models have been prepared for smaller areas, such as the linear study area at Sunbury (Clarke 1993). This model states that:

- *Larger sites and numbers of sites are likely to occur:*
  - *On well drained ground which is level or slightly sloping,*
  - *Near food or raw material resource zones such as swamps, river flats and the junctions of larger streams,*
  - *On the flood plains of major steams such as Jackson's Creek and Emu Creek,*
  - *On spurs overlooking river meanders;*
- *Quarries will occur where suitable stone is available;*
- *Grinding grooves will occur where sandstone beds outcrop;*
- *Scarred trees will occur where suitable stands of large thick parked trees such as red gum or box remain close to waterways;*
- *Greater numbers of sites (and larger sites) are generally found on undulating or flatter land;*
- *On hills and uplands, sites are generally smaller and more scattered. They tend to be found on ridges and spurs (which were used as access routes). Aboriginal archaeological sites in these areas were formed by small groups moving through the upland areas, in contrast to the more permanent campsites that occur, for instance, on flood plains (Clark 1993:13).*

These studies did not map the locations of the predicted site potential and are therefore open to interpretation. It is rare in such studies that predictive maps are presented.

Studies have developed and tested regional predictive models for the Otway Range (Richards 1998) and Barwon River Basin (Richards & Jordan 1999). For the latter study, sampling included survey and excavated test pits, but was hampered by visibility and access limitations. While none of the 466 test pits yielded artefacts, the survey identified 57 previously unrecorded sites and proposed a model of 'Zones of archaeological sensitivity'. The highest sensitivity Zone 1 was determined to be 300m from permanent fresh water (Richards & Jordan 1999:124). The authors offered a tentative model of seasonal occupation involving dispersed occupation in wet/dry months and dry/warm months spent near permanent water. However, the model was not tested against the survey results.

Canning proposed a predictive model based on analysis of site data on the 1:25,000 Keilor Map sheet, covering Melbourne's north western fringe. This area includes a section of the Maribyrnong River containing a high density of recorded Aboriginal archaeological sties and includes the significant Dry Creek and Green Gully excavation sites (Canning 2003). Canning correlated existing archaeological site records with a range of environmental variables. Table 1 discusses the possible implications of these variables and possible refinements.

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Table 1: Canning predictive model variables

Canning predictive variable	**Implications**
Geology –	Focuses on the location of potential tool-making stone and specifically silcrete. Such locations are poorly known and rarely shown in any geological mapping. Known sites are generally already recorded as Aboriginal archaeological sites. However, the level of analysis is not sufficient to demonstrate a relationship between types of site densities and density of the local stone within sites to proximity to the stone source. The effect of other variables means that site density and locations do not correlate particularly strongly with known stone sources.
Topography –	Focuses on elevation and notes a paucity of sites at higher altitudes. However, the general south-westerly fall of the basalt plains towards Melbourne, and the concentration of recent urban development (and therefore archaeological assessments) at the lower altitudes on the edge of the urban area bias the archaeological record. It is claimed that "…elevation is not a particularly strong predictive variable, particularly in areas that display relatively little topographic variation…" However, <u>relative elevation</u> is not assessed. Comparing local site elevation with the elevations of immediately adjacent areas, or the surrounding catchment, may give an indication of the potential for the site to provide a vantage point or stand proud of surrounding land. In flat swampy areas, even minor relative elevation of less than a metre may be significant. Unfortunately most available topographic data is insufficient to recognise these variations.
Distance to water –	The water source is not defined, though the mapping (figure 1) suggests only perennial water bodies are included. A fixed zone is given as the predictive variable (67% of sites within 100m, 80% within 200m). However, differences in ease of access to water (e.g. dense vegetation, steep slopes, etc.) or the quality of the water (flowing versus still, large waterholes suitable for swimming compared with drinking only supplies) are not considered.
Slope –	With 90% correlation for sites on slopes between 0º and 10º, it is suggested that "…slope is a variable with little real predictive power". Again, the <u>relative slope</u> in comparison with surrounding land has not been considered, (for example small level areas at the base of steep valleys) or identifying the flattest part of a rise or sand hill.
Aspect –	Canning reports "…no clear pattern in the site data to suggest that one 'aspect' was preferred over any other." However, aspect appears to only refer to the absolute compass direction the site faces, rather than its relative outlook over the surrounding landscape, or towards or away from other features. In practice, a site with a broad vantage point over surrounding plains might be favoured over one enclosed and hidden, or visa versa.

While this approach gives some indication of the probability of sites occurring within the specified zones, it does not provide sufficiently fine resolution for improving the capacity of surveys to discover sites. For example, the 100 to 200m zone along the 8 major permanent waterways of the volcanic plains[1] would include more than 192 square kilometres of high potential landscape within a region of a total area of about 4800 square kilometres.

[1] From east to west – Hovells Creek, Little River, Werribee River, Kororoit Creek, Maribyrnong River, Moonee Ponds Creek, Merri Creek, Darebin Creek.

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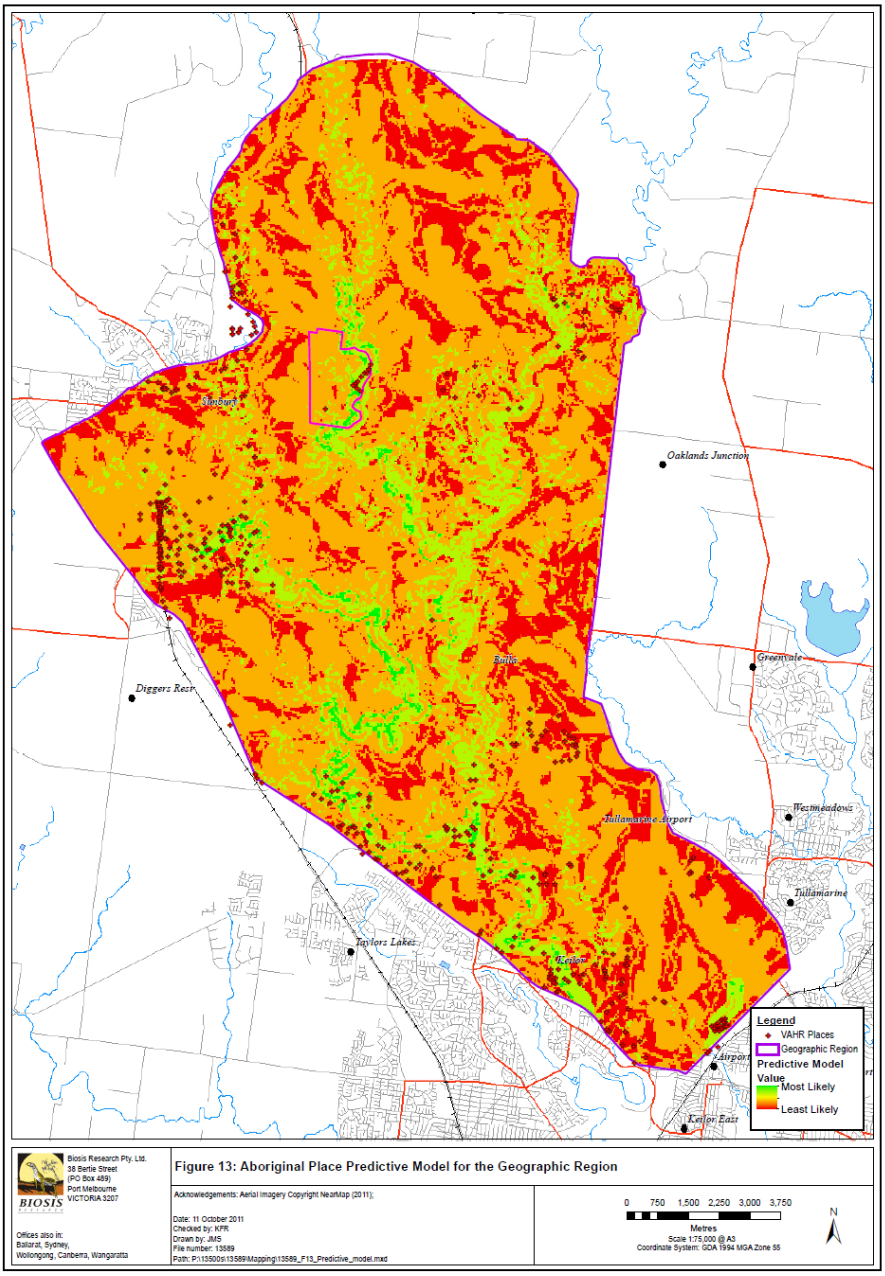
Site density in the region can be assessed in some instances where intensive archaeological surveys and investigations have been carried out. For example in the 20km long stretch of the Maribyrnong River between Steels Creek and the Organ Pipes, which takes in Brimbank Park and various recent developments around Keilor, a total of 218 sites have been recorded within 200m of the river. Similarly, a stretch of about 9km of Kororoit Creek between Ardeer and Caroline Springs, also intensively assessed, contains 167 sites. These two examples provide a very rough estimate of 10-15 sites per kilometre along waterways. Most of these sites comprise surface scatters of more than 10 artefacts. A similar area along the Calder Highway beyond Keilor has about 20 sites in 10 km, but most of these are isolated artefacts or very low density artefact scatters (less than 1 artefact per 100 sq. m.) (Vines 2011).

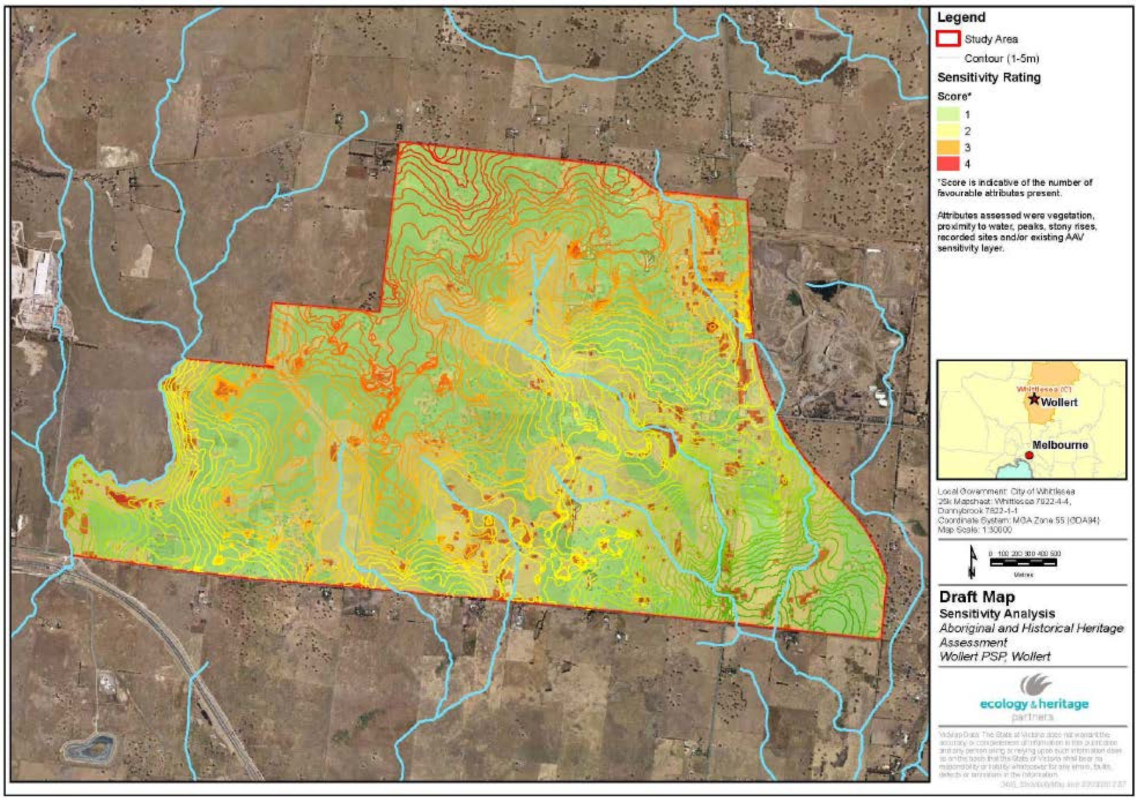
A number of recent GIS-based predictive modelling projects have used the primary site determinants of proximity to water and elevation to model site locations. Other measures, such as degree of slope or the presence of remnant indigenous vegetation or stony rises may also be considered. These studies have tended to be cumulative and unweighted; degrees of likelihood are determined by the number of attributes present at each point on the landscape. Recent examples include Biosis' mapping of the Sunbury area, aimed at refining survey strategies in a large landholding adjacent to Emu Creek (figure 3). In this figure, green areas are most likely to have Aboriginal sites and red least likely.

Figure 3: Sunbury Emu Creek area predictive mapping



Another similar map has been produced for the Wollert precinct structure plan also north of Melbourne. Again, a small range of attributes have been applied to determine levels of archaeological potential, although the colours are reversed in this case – red denotes the most sensitive, and green the least sensitive for Aboriginal sites.

Figure 4: Wollert PSP archaeological predictive map (Ecology & Heritage Partners 2012, with permission)



These predictive models have not generally assessed the relative density of artefacts, or the extent of sites of specified densities, although the earlier models of du Cros, Ellender and others sometimes distinguished between the likelihood of the occurrence of artefact scatters or larger sites, compared with isolated artefacts. Critical in this respect is the potential for discovery of sites at different densities, and the way that archaeologists define site and 'background' archaeology (Gallant 1986).

Site differentiation, in the above models, appears to encompass any and all occurrences of Aboriginal cultural materials whether a single isolated artefact or complex stratified occupation site with thousands of artefacts and many other features such as hearths or middens. Given 40,000 years of occupation and utilisation of all of the landscape in some form, there is potential for Aboriginal artefacts from accidental discard or sue during foraging or traversing between campsites or other resources, almost anywhere.

A better distinction of site might be gained from understanding how a place might have been occupied; that a place was intensively or regularly inhabited with a range of activates liable to produce archaeological evidence to distinguish it from the background. Such a threshold has not yet been established, but for the sake of this paper we might put it at more than 10 artefacts per 10 square metres.

Applying a micro-topological model

The previously mentioned modelling projects do not allow for the micro-topography, micro-climates and localised resource distributions that might determine much more precise occupation locations within the broader area. Careful appraisal of the sites along waterways such as the Maribyrnong river and Kororoit Creek shows that they are not evenly, nor randomly distributed along the waterways. In many cases, sites are associated with specific local topographic features. Some sites occur on the top of the escarpment edge at locations providing a vantage point both down into the valley and back across the surrounding plains. Sites also occur regularly on spurs between the main valleys and tributaries, where the side gully provides easier access to the valley bottom. Another favoured location appears to be the elevated, flat terraces on inside bends of the river, particularly where surrounding valley sides are steep and enclosing.

Other factors generally not considered in existing predictive models include: soil conditions; shelter from prevailing winds, sun or other climatic extremes; aesthetic values of a location; and immediate ecological characteristics, such as proximity to tree lines

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and ecotones. While proximity to natural resources is often included as a predictive variable, the nature of the resources are not specifically described with respect to their individual local characteristics.

Vegetation is probably a critical factor. Important elements of vegetation patterns might include the former boundaries of tree lines; presence of open plains; differentiation between dryer grasses, signifying dry ground conditions, and sedges indicating waterlogging; and the presence of ecotones and rich resource zones that may have provided more abundant food, fibres and useful plant and animal products. Importantly, individual trees or plants may have provided a focus for activities, such as large sheltering trees in otherwise exposed landscapes, or specific plants which provided cultural markers. However, reconstruction of the vegetation character in the immediate pre-white settlement period is problematic and even more difficult for earlier climatic periods.

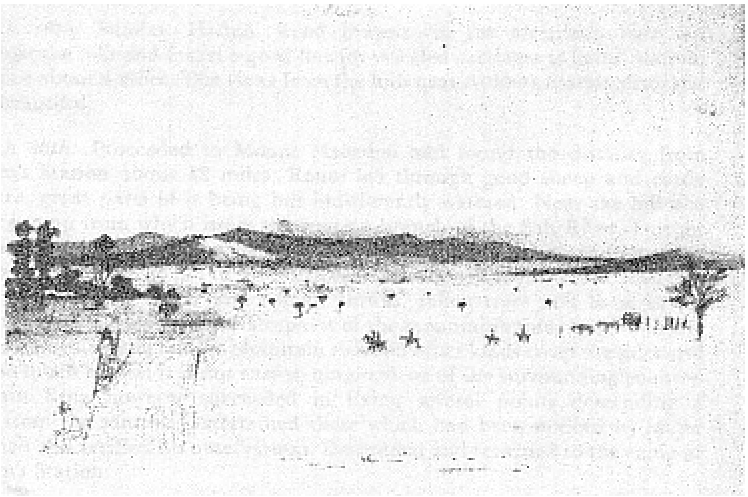
Temporal change in landscape can to some extent be incorporated into predictive models. In the case of the basalt plains, this is in most parts a very stable and constant geomorphology, with the exception of alluvial terraces in confined sections of the Maribyrnong and Werribee Rivers, and to a lesser extent Kororoit Creek and Merri Creek. The shifting sands, changing sea levels and fluctuating swamps of the south east of Melbourne are more difficult.

Soil may also be a critical factor, as there is likely to have been a preference for soft and dry ground surfaces. Even slight sand ridges on the Carrum Swamp margins (Vines 2008; Lawler et Al. 2012) have been shown to contain sites, while artefacts are almost never found on drained swamp bottoms, clay pans and the like. In parts of the Plenty River valley, the occasional exposure of Brighton Sands between Silurian clay and basalt clay layers has been shown to consistently produce preferred site locations (Vines 2012b).

The exposed nature of the Keilor – Werribee Plains, with cold winter south-westerly winds and hot dry summer northerlies, may have been an important factor in site selection. The presence of shelter could be derived from relative aspect and elevation, as well as other local topographic factors. Sites may have been chosen on the leeward site or on rises dependent on season, or depressed sites subject to cold air drainage, dew and mist may have been avoided in winter in preference to elevated locations.

Landscape change, including swamp drainage, vegetation clearance and scrub regrowth from changed fire regimes, can be reconstructed and plotted from historical descriptions and existing landscape evidence (such as artificial drains, remnant and roadside vegetation, ring-barked trees and grubbing holes).

Figure 5: Captain PP King's sketch of the ford at Werribee, looking north towards Melton (1837) (Historical Records of Victoria, Vol.1, p.104)



To overcome some of the limitations outlined, a model is proposed whereby local field assessment data is incorporated into the existing inductive modelling approaches. This additional data may include finer resolution topographic information. Critically however, the approach also applies an intuitive approach based on common sense human behaviour (e.g. minimising effort, maximising returns, improving comfort or convenience), and observations from ethnographic literature. Isaac Batey offers several examples of specific locations and activities of Aboriginal people in the Sunbury district – for example that *"…the aboriginals who used to live about Glencoe and Red Stone Hill stations. Mr. Richard Brodie, a pioneer of 1836, informed me that their*

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favourite camping ground was known as "Native Point," and was at the junction of the Emu and Deep Creeks, a few miles above the present village of Bulla. Their last visit to our locality was about 185 1, when four lubras, with an infant, came to wait for the brother of one of them to escort them to another part of the country." (Batey 1907).

Another example records a site at Greensborough on *"…the hill above the flat, and on which Frederick Flintoff built his house, was called by him "Point Look Out." For many years there has existed a local tradition that this hill was the regular meeting-place of the aborigines."* (Prescott 1942).

William Thomas provided a number of specific account of how aborigines' preferences for encampments, such as the shelter provided by narrow valleys, and for the larger camps the tendency to place themselves in the direction of their own country, one group separated from another, suggesting the need for several separate flat areas (Thomas in Bridge 1898).

Personal experience of archaeological site surveys in Melbourne's western and northern basalt plains over the last 25 years can also contribute to a more detailed understanding of site location. Forms of subjective or expert knowledge have been recognised as valid datasets for archaeological site prediction, although they are difficult to quantify (Verhagen et al 2011).

By applying the proposed model to a little-surveyed area in a similar landform, opportunities arise for more rigorous and objective testing. Although statistical analysis has not been used in any sophisticated manner for this paper, the resultant model might readily be held up to testing using statistical sampling methods.

The proposed model is applied to two case studies. The first case study is a large area west of Melbourne, with little development and only limited previous archaeological investigation. Mapping and analysis suggest a possible hierarchical occupation/settlement pattern and highly specific topographic and environmental determinants of site selection. The second case study is a smaller locality with complex landforms and distinctive Aboriginal site patterning. Here spatial data analysis can assist in understanding and refining patterns of Aboriginal resource use and economic behavior at a day to day level.

Case Study 1: Avalon Refined Site Prediction Model

More refined predictive modelling for Aboriginal sites requires more detailed and reliable data sets. These datasets were developed through a more detailed analysis of previous studies and existing archaeological site records, interpretation of landform, historical mapping, environmental factors, ethnographic research on available resources and Aboriginal occupation patterns and movement.

Mapping method

A wide range of landscape attributes were used to determine potential Aboriginal site locations, including pre-settlement wetlands and vegetation patterns, soil types, field identification of vantage points, former swamps and drainage lines (cleared and drained in the historic period for farming) and interpretation of slope angle, shelter from prevailing winds, suitable creek crossing points and other topographic and geological features.

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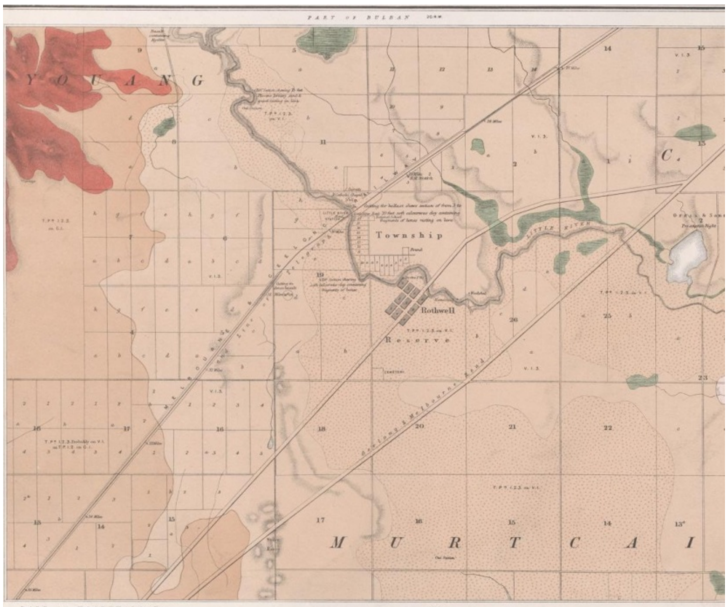
Figure 6: Elevated bank near deep section of Little River- the track follows the change of slope, which is the limit of flat ground, dense artefacts extend back only about 10m from this point.

Wetland areas and stony rises were considered the most critical geographic features for site determination. These were initially mapped from 1:25,000 topographic maps, with additional data added from early Parish Plan feature surveys, the 1860s Geological Survey and the DSE 1788 EVC and wetland mapping. Ephemeral water bodies are often mapped in early feature surveys, and can be recognised in 19th century mapping, for example the 1860 geological survey shown in figure 7. These wetlands can then be correlated with field observations of tell tale signs such as black clay soils or where water lies after heavy rain.

Figure 7: Geological Survey of Victoria, Sheet 20 SW **1863 (State Library of Victoria MAP RM 2335/20)**



The assumptions made from these data sources were then field checked. An unusual rain event in mid-December 2011, when over 80mm of rain fell on the Avalon area, clearly demonstrated the natural (pre-drained) water level on some swamps and the abundance of birdlife attracted to the water within hours of the storms.

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Figure 8: Flooded depression (Cherry Swamp) following 80mm rail in December 2011 – normally drained and cropped

Rather than use a standard buffer around water bodies (both current and historic), variables such as elevation, slope angle, shelter and ground condition were taken into account. Where there were several suitable sites within close proximity – for example a number of rises within 50-100m with relatively level tops and at least some stone-free areas - then a choice was made on the balance of these criteria as to which would have been preferred.

Figure 9: Slight ridge (on right) near ephemeral waterhole – moderate to high potential for sites

In predicting site preference decisions, the various criteria were given weightings. Weightings were applied manually, as it was determined that numerical weighting required further testing and confirmation before this would be viable.

The major consideration in preparing the mapping was the concept of preferential location. Where a number of potential sites met the basic requirements, such as level areas with vantage over the surrounding country and access to water and/or other resources, then the locations that provide a relative advantage would be preferred. Given a choice, one or more locations would be preferred over others.

Refined predictive modelling criteria

The criteria for predicting areas of archaeological potential include:

- Within 20 m of Little River and Hovells Creek (high)
- Within 30m of fresh water (moderate)
- Within 100m of fresh water (low)
- Adjusted for reliability of water supply
    - occasionally inundated (low)
    - perennial or regularly inundated (moderate)
    - deep and reliable, suitable for swimming (high)
- Less than 15 degree slope (moderate)
- 15-20 degrees slope (low)

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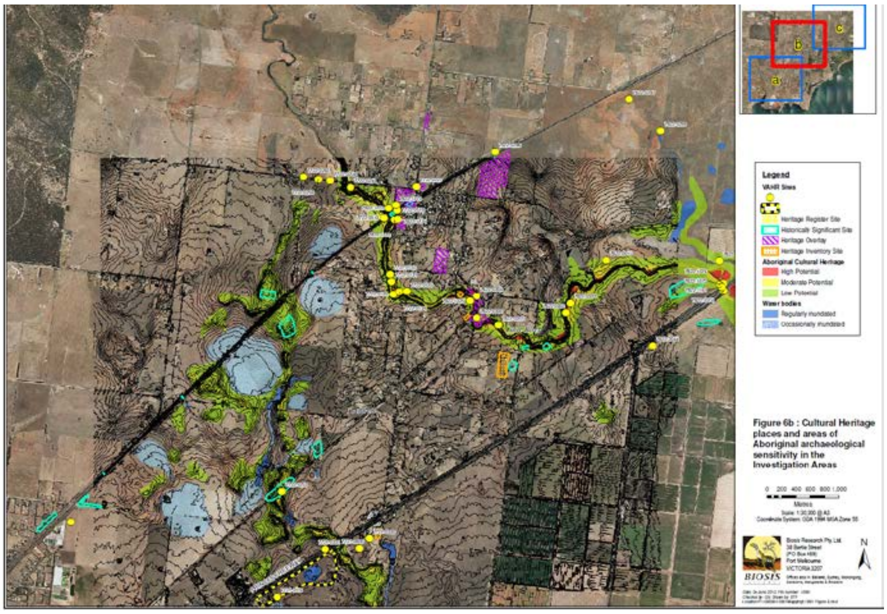
- In areas of remnant indigenous vegetation (low) ,
- Proximity to boundaries of vegetation, tree lines, ecotones and rich resource zones (low)
- Elevated vantage more than 5m above water body (moderate)
- Aspect elevation of position provides shelter (moderate)
- Highest local elevation within 50m of water body (moderate)
- Highest elevation in area for long vantage (low)
- Elevated more than 2m above high water of waterway or water body (low)
- Within 50m of localised resource including artefact stone source, creek ford, etc. (this criteria has yet to be mapped or tested as it is dependent of detailed field survey)
- Sandy or soft, sandy/loam preferred over clay, hardpan or rocky surfaces (moderate)

The various layers were mapped manually on air photos, against historic mapping and field survey observations, and then transferred to a digital mapping base. In some instances existing mapping layers were also overlaid – for example the Vicmap hydrology layers or 1788 wetlands, to cross check against the air photo and field data.

In applying this predictive modelling, the study area was categorised into areas based on four levels of potential:

- high potential - on prominent escarpment edges and flats, and in horseshoe bends on Little River and to a lesser extent Hovells Creek – where sites will comprise greater than 1 artefact per 1 sq. m., over areas of 100m or more;
- moderate potential - considered to have a likelihood of extensive low density stone artefact scatters of around 1 artefact per 10 sq. m., to occur with extents of 100 square metres or more, and occasional high density stone artefact scatters;
- low potential - considered to have a likelihood of occasional small low density artefact scatters and isolated artefacts at densities of 1 artefact per 100 sq. m.;
- background potential - considered to have a very low density of isolated artefacts at less than 1 artefact per 1000 sq. m. This area covers the balance of the landscape not within the high, moderate or low areas, or areas where disturbance has destroyed or disrupted any potential sites.

Figure 10: Avalon predictive map



The effectiveness of this categorisation still needs testing through field checking, but in comparison to the earlier predictive models, it identifies less than 1% of the study area as having low, moderate or high sensitivity. This does not preclude Aboriginal sites in the remainder of the study area, but the evaluation proposes that the vast majority of sites will be within this 1% of the landscape.

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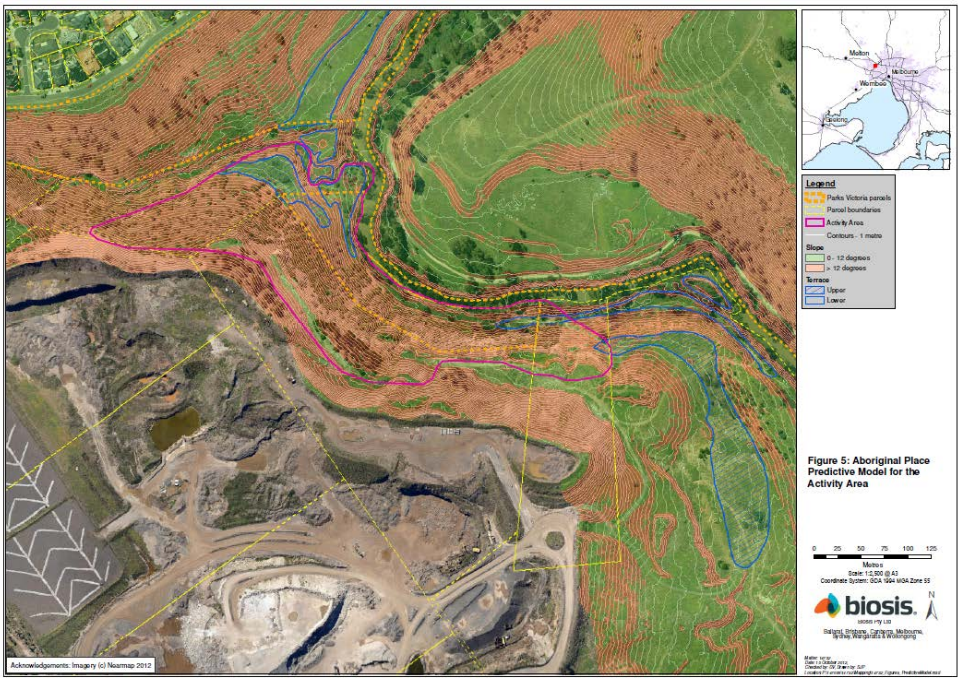
Case Study 2: Maribyrnong Terrace and silcrete

At Sunshine North and Keilor, near Brimbank Park, the Maribyrnong River has cut a deep valley through the basalt plain, exposing underlying Pliocene 'Brighton Sands' and Silurian mudstone. At the interface between the underlying sediments and the base of the basalt, a thin layer of silcrete has formed. This is the primary stone tool making material of Aboriginal people. The various Aboriginal silcrete quarry sites in the valley appear to occur consistently at about the 37m contour on slopes greater than 25 degrees.

Elsewhere in the valley, alluvial terraces from at least three phases dating to about 1-5,000 years, 5-18,000 years and 18-30,000 years have developed. These are highly significant for preservation of Pleistocene Aboriginal occupation. These complex sequences of alluvial terraces are difficult to distinguish from each other, requiring geomorphological analysis. However, their presence can be determined from the changes of slope and the expanses of relatively level ground at different heights above the river and current flood plain. The geomorphological and temporal analysis of changes in these Pleistocene sediments is for another project the current case study has been confined to addressing only the stable late Holocene environment.

For this study area, the availability of LiDAR datasets provided a new opportunity for obtaining landscape information. Individual alluvial terraces may not be completely flat, and often cover relatively small areas. Such areas are not particularly apparent from current topographic mapping with contour intervals of 5-10 metres. An existing LIDAR dataset was used to produce 1m contours. Combined with field assessment, a breakpoint of 12 degrees of slope was determined, enabling alluvial terraces to be clearly visualized.

Figure 11: Maribyrnong terraces and silcrete predictive map



The evaluation here is more straightforward, in that it takes well tested determinants of highly significant archaeological sites, namely stone quarries and alluvial terraces, and provides a reliable method for mapping them. The model's effectiveness is in mapping landforms with high archaeological values to a high resolution, and so affording confidence that significant cultural heritage is both identified and managed during future activities.

Conclusion

GIS mapping and predictive modelling for archaeological sites have been proven to be useful tools in identifying and managing Aboriginal archaeological sites. While the current use is broad scale and coarse in its predictive capacity, there is potential for far more targeted use of the techniques if more accurate and specific data on environmental conditions, landform and ethnographic behavior can be compiled and built into the models.

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An intuitive approach to understanding the landscape form a human perspective might still be superior to most algorithms so far developed for predictive modelling of Aboriginal sites. As the field progresses and both the practitioners and the market for consultants' reports becomes more sophisticated, there will be greater roles for GIS in managing cultural heritage.

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