ASDST
Aboriginal Sites Decision Support Tool

Statewide product outline and technical summary
ASDST product version 7
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<table>
<thead>
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<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACD</td>
<td>Aboriginal ceremony and dreaming</td>
</tr>
<tr>
<td>AFT</td>
<td>Stone artefacts</td>
</tr>
<tr>
<td>AHIMS</td>
<td>Aboriginal Heritage Information Management System – a database managed by DECCW to store NSW Aboriginal site information</td>
</tr>
<tr>
<td>APM</td>
<td>Archaeological predictive modelling</td>
</tr>
<tr>
<td>ARG</td>
<td>Aboriginal resource gathering</td>
</tr>
<tr>
<td>ART</td>
<td>Rock art</td>
</tr>
<tr>
<td>ASDST</td>
<td>Aboriginal Sites Decision Support Tool</td>
</tr>
<tr>
<td>BUR</td>
<td>Burials</td>
</tr>
<tr>
<td>Cell</td>
<td>A single object (ie pixel) within a raster dataset</td>
</tr>
<tr>
<td>CFT</td>
<td>Conflict site</td>
</tr>
<tr>
<td>CMA</td>
<td>Catchment Management Authority</td>
</tr>
<tr>
<td>CMR</td>
<td>Ceremonial ring</td>
</tr>
<tr>
<td>CSIRO</td>
<td>Commonwealth Science and Industry Research Organisation</td>
</tr>
<tr>
<td>DECCW</td>
<td>Department of Environment, Climate Change and Water (NSW) – includes its organisational predecessors, DEC and DECC.</td>
</tr>
<tr>
<td>DEM</td>
<td>Digital elevation model – a raster (grid) GIS layer depicting landscape terrain as elevation</td>
</tr>
<tr>
<td>DPI</td>
<td>NSW Department of Primary Industries</td>
</tr>
<tr>
<td>ETM</td>
<td>Western earth mounds and shell</td>
</tr>
<tr>
<td>FNCRS</td>
<td>Far North Coast Regional Strategy</td>
</tr>
<tr>
<td>FR</td>
<td>Forestry reserve</td>
</tr>
<tr>
<td>FSH</td>
<td>Fish trap</td>
</tr>
<tr>
<td>GAM</td>
<td>Generalised additive modelling – a form of non-parametric logistic regression</td>
</tr>
<tr>
<td>GDG</td>
<td>Grinding grooves</td>
</tr>
<tr>
<td>GIS</td>
<td>Geographic information system – a tool for visualising and analysing spatial data</td>
</tr>
<tr>
<td>GRASP</td>
<td>An implementation of generalised additive modelling in the statistical package S-Plus</td>
</tr>
<tr>
<td>Grid</td>
<td>Raster data format used by ESRI GIS applications for spatial analysis</td>
</tr>
<tr>
<td>HAB</td>
<td>Habitation site</td>
</tr>
<tr>
<td>HTH</td>
<td>Hearths</td>
</tr>
<tr>
<td>LALC</td>
<td>Local Aboriginal Land Council</td>
</tr>
<tr>
<td>LEP</td>
<td>Local Environmental Plan</td>
</tr>
<tr>
<td>MDBCC</td>
<td>Murray Darling Basin Commission</td>
</tr>
<tr>
<td>MDS</td>
<td>Multi-dimensional scaling is a statistical ordination method for assigning cases in ( N ) dimensional space where ( N ) is specified \textit{a priori}</td>
</tr>
<tr>
<td>NP</td>
<td>National park</td>
</tr>
<tr>
<td>OCG</td>
<td>Ochre quarry</td>
</tr>
<tr>
<td>PAD</td>
<td>Potential archaeological deposit</td>
</tr>
<tr>
<td>Raster</td>
<td>Type of GIS dataset used to describe phenomena that vary continuously across the landscape – the data are composed of a regular array of square grid cells (like pixels in a digital image) of fixed size</td>
</tr>
<tr>
<td>RERP</td>
<td>Riverine Environments Restoration Program</td>
</tr>
<tr>
<td>ROC</td>
<td>Receiver operating characteristic – a statistical method for evaluating models.</td>
</tr>
<tr>
<td>SALIS</td>
<td>Soil and land information system – a database of soil analysis sites, managed by DECCW</td>
</tr>
<tr>
<td>SHL</td>
<td>Coastal shell middens</td>
</tr>
<tr>
<td>SGA</td>
<td>Survey gap analysis – an approach to identifying gaps in survey data where more survey is required</td>
</tr>
<tr>
<td>SPOT</td>
<td>A form of satellite imagery used by DECCW covering the whole of NSW</td>
</tr>
</tbody>
</table>

ASDST: Statewide product outline and technical summary
SRTM  Shuttle Radar Topography Mission. A source of DEM data used for modelling.
STA  Stone arrangement
STQ  Stone quarries
TRE  Scarred trees
TSR  Travelling stock route
WTR  Waterhole
Executive summary

The Aboriginal Sites Decision Support Tool (ASDST) is a tool developed by the Department of Environment, Climate Change and Water (DECCW) to support the conservation of Aboriginal site heritage in NSW. The tool consists of a set of spatial GIS layers combined with analytical techniques that provide visual and quantitative information describing the distribution, accumulated impacts and conservation value of Aboriginal site features across the landscape. This report presents:

- a description of the ASDST products
- how they should be appropriately interpreted
- mapped examples of the products at the statewide and local scale
- examples of how the tool has been applied in a variety of projects across NSW
- illustrated examples of the analytical capability of the tool
- a technical description of how the products were derived using international best-practice in archaeological site modelling

As a tool that assists the assessment of Aboriginal site heritage, the ASDST supports several areas of DECCW’s business. The tool utilises data from the Aboriginal Heritage Information System (AHIMS), and is a projection to the landscape scale of the locality-based site feature information recorded in the database. The ASDST complements AHIMS by providing broad-scale datasets and analysis methods to place Aboriginal site heritage within the context of regional conservation planning. The ASDST data products can be used alongside other environmental data to undertake systematic assessment of conservation priorities in the landscape. This way the ASDST supports DECCW to meet its responsibility to regulate Aboriginal site issues at a regional level, and contributes to better incorporation of Aboriginal site heritage in natural resource management.

Getting Aboriginal site conservation issues incorporated into regional planning strategies is important to addressing them at the landscape scale. Such planning can have an important bearing on the investment strategies of agencies like catchment management authorities (CMAs). The flexibility of the ASDST system means that this can be achieved in a number of ways depending on the nature of the application. This report describes a variety of examples where the ASDST has been applied in this capacity.

Similarly, by generating estimates of total site distribution, a variety of regional planning approaches are possible. In each case, applying the ASDST has achieved its best outcomes when there has been a close collaboration with project partners through cross-DECCW collaboration, partnerships with other agencies and partnerships directly with Aboriginal communities. This way products can be best developed to meet the needs of each application. Such experience means the potential for better decision making is greater, and that future development of ASDST products can be improved to meet emerging regional planning needs.

A number of projects that have utilised the ASDST products have done so to develop a survey design for fieldwork. This has been an important application for the Parks and Wildlife Group (PWG) of DECCW where the objective was to locate new sites, primarily for on-park management. A survey design for these projects was developed interactively with maps and live GIS analysis in partnership with rangers for each park, Cultural Heritage staff coordinating the survey and representatives of the Aboriginal communities. This has produced better park management planning and more efficient allocation of resources in such projects.

The ASDST has demonstrated that is a flexible system capable of supporting critical areas of DECCW’s business. It also contributes to the department’s responsibility to apply best available practice to the regulation and care of Aboriginal site heritage in NSW. This publication provides the interpretive and technical background to deliver Aboriginal site management in a comprehensive and transparent manner.
1 ASDST background

The Aboriginal Sites Decision Support Tool (ASDST) has been developed to meet the critical need in Aboriginal Heritage planning: whole-of-landscape context setting for assessing regional Aboriginal site issues. It is well recognised that Aboriginal sites occur over the entire landscape\(^1\). However large parts of NSW have little or no information describing Aboriginal site heritage value due to:

- the focus on ‘sites’ in the Aboriginal Heritage and Information Management System (AHIMS)
- the legislative focus on ‘objects’, and
- the variability of recording density (see Section 8.3).

The core models of the ASDST provide an approach that allows these issues to be shown in a whole-of-landscape context. An additional application is as an analytical approach for incorporating Aboriginal site issues into regional planning. The ASDST meets this need through spatial products describing accumulated impacts, gap analysis, representativeness, and conservation priority. By combining datasets and analysis, the ASDST provides a basis for contextualising site assessment at the regional level.

The ASDST tool has been tested and applied in a number of projects at various scales across NSW (see ASDST projects in Section 7). These projects have included application of the tool in park management, regulation, and natural resource and cultural heritage management. Within projects, the ASDST has been tested during surveys and used to develop survey strategies. Product manipulation has also been adapted for application with local Aboriginal community organisations.

\(^1\) See (Guilfoyle 2006) and regional cultural heritage studies
2 Statewide ASDST products

The ASDST is composed of an integrated suite of spatial GIS layers that are organised around six key products:

1. Pre1750 (original) models
2. Current models
3. Feature landscape regionalisation
4. Combined accumulated impacts
5. Combined model reliability
6. Combined survey priority

The pre1750 (1) and current (2) models each comprise 10 raster (grid) GIS layers that represent different feature types. DECCW maintains the AHIMS database (DECCW 2009), which includes a register of Aboriginal site features recorded across the state. Each site is recorded, at a minimum, with the presence or absence of 19 feature types (see Table 6, p68). A single ‘site’ may have multiple feature types present (eg a rock art site may have features of art, stone artefacts, axe grinding grooves and potential archaeological deposit).

There is considerable geographic variation in the distribution of different features and the nature of threats they experience. For instance, coastal shell middens are associated with the exploitation of marine resources along the coast and tend to be impacted most by urban expansion. In contrast, open site hearths are primarily recorded in the western part of the state due to the preserving semi-arid conditions and tend to be affected most by soil erosion often associated with livestock grazing. Following Kvamme (2006, 24), splitting the ASDST products into separate feature types permits the distribution and impact characteristics to be modelled separately for each feature, leading to a more specific product. The last three products (4, 5 and 6) are single grid layers that are derivatives of the pre1750 and current products.

The following feature types form the pre1750 and current model suites:

- all feature types combined (ALL)
- stone artefacts (AFT)
- rock art (ART)
- burials (BUR)
- western mounds and shell (ETM)
- grinding grooves (GDG)
- hearths (HTH)
- coastal shell middens (SHL)
- stone quarries (STQ)
- scarred trees (TRE)

Each product (and individual feature products) is a raster GIS layer. These layers are composed of a regularly spaced arrangement of cells that cover the whole landscape and are used to describe continuously varying geographic phenomena over the landscape. Each cell in the ASDST product represents one hectare. Raster GIS layers are different to GIS vector data which represent features as points, lines or polygons. Each raster GIS cell has a number attribute indicating the relative value of what the layer is describing at that place. For the ASDST products, this may be the relative likelihood of a site feature, relative survey priority or the relative reliability of the model.

The ASDST statewide products have been developed to meet the needs of regional planning. They are designed to be used at scales of 1:100,000 and above. Application at finer scales, eg 1:50,000, is possible, but it should be borne in mind that the datasets used to derive the ASDST products were themselves mapped at a scale of 1:100,000 or above, and therefore the inaccuracies of those layers at finer scales will be carried through to the ASDST products.

As a constantly evolving tool, all ASDST products have developed and changed over time. They are under continuous review as new data becomes available, parameters are assessed, models are progressively better validated and modelling approaches are refined. For this
reason, all products have a version number attached, and for any analysis, mapping or reporting that is performed with the layers, the version that was used should be specified. The version of all products described in this document is version 7.

Whilst the initial focus has been on deriving statewide models to form a baseline for regional planning, the overall approach to model generation and product development can be applied at any scale providing there is sufficient and appropriately scaled data. Figure 1 outlines how the various components (data, GIS layers and tools/algorithms, discussed in more detail in following sections) have been combined to generate the current set of statewide ASDST products. Each of the components are described in more detail in Section 3 and discussed technically in Section 8. By substituting data from different scales, the same suite of products may be derived to meet the needs of different planning scales. In this way, the ASDST should be considered as an analytical toolkit with some static products. Fundamentally, it is designed to be a flexible system that can be adapted to meet the needs of individual projects and assessments.
Figure 1. ASDST product derivation diagram
3 Product descriptions

3.1 Pre1750 models

The pre1750 models are a set of raster GIS layers describing the relative likelihood of Aboriginal site features occurring across the landscape. (For statewide maps for each feature see Section 4). They have been derived using AHIMS data, and a set of spatial variables (see Figure 1 and Table 7) describing the landscape as it is estimated to have been prior to European settlement.

The pre1750 models do not take into account:

• the level of destruction of sites in the intervening period, eg from agriculture, mining or urbanisation
• the detectability of different site features, ie whether locating them would require excavation, or
• local conditions that may lead to the lack of a feature being preserved.

The models are therefore not meant to convey a likely profile of the present landscape or how easily sites could be located. When interpreting pre1750 models, the level of impact in the current landscape should be evaluated by comparing them to the corresponding current extent models (see Section 3.2).

The pre1750 models describe the relative likelihood of finding a particular type of Aboriginal site feature, eg a scarred tree or stone artefact, as it is assumed to have been in the pre1750 landscape. They are therefore a baseline for site potential in the landscape. The legend for each layer is scaled from white (low likelihood) to black (high likelihood) – see Section 4 for example maps of products. When looking at any pre1750 layer, the darker it is, the higher the likelihood that that feature could have been located there 250 years ago, according to the model’s predictions.

It is important to keep in mind when looking at how dark an area of the model is, that the darkness is a relative quality. Black does not guarantee that that feature would have been located there, or would still be there today. It represents an area where the model predicts a high likelihood of that feature at that location relative to all other areas of the landscape. Similarly, white areas do not indicate an absence of that feature, but the lowest relative likelihood resolved by the model.

The models are not calibrated to the absolute probability of presence or absence of site features, but instead describe relative likelihood as it changes over the landscape.

The relative nature of the likelihood values of each model also extends to the relative measurement of each cell value. When looking at any of the models, it should be kept in mind that relative likelihood is relative to the entire extent of the layer.

The likelihood at any given cell is relative to all over cells in the layer (ie the rest of NSW).

A further complication with the relative nature of the likelihood measure is that it is not directly comparable between site features. For instance, although one area might indicate high modelled likelihood of both stone quarries and artefacts, that does not mean they are both predicted to have an equal probability of occurrence. In this example, the absolute probability
of locating quarries is still less because they are generally less frequently observed than stone artefacts.

The relative likelihood between different site features is not directly comparable in terms of absolute probability.

3.2 Current models

The current models are modifications of the pre1750 models and reflect a more realistic likelihood of site features occurring in the present-day landscape. They do this by utilising tenure, extent of native vegetation, land-use mapping and mining history (eg sand-mining) to place parameters on the likely survival rates of different features under different types of land-use and land condition. A series of parameters estimating impacts were derived through consultation and series of expert workshops (Ecological 2006); and see also Section 8.6). The parameters were:

- tenure and tenure history – to provide an idea of how long parts of the landscape have been managed for conservation (eg as a national park)
- native vegetation extent – to identify those areas of the landscape subjected to clearing
- land-use mapping – to indicate how land is currently used (ie cropping, grazing, roads or urban), and
- mining – to reveal those parts of the landscape where site likelihood has been irretrievably degraded (even though it might now be in a national park and covered in native vegetation).

The current models take into account estimated historical impacts on Aboriginal features to describe their potential occurrence in the present-day landscape.

The caveats described in the previous section for interpreting likelihood for the pre1750 layers also apply to interpreting the current models (ie their scale is approximately 1:100,000).

However, current models take into account the relative likelihood of a landscape feature surviving under different land-use conditions. They do this by reducing the pre1750 likelihood values using the probable level of impact a land use had on a feature. For example, a cleared landscape would be expected to reduce the likelihood of scarred trees to almost zero, while the likelihood of stone artefacts surviving in the same landscape would be expected to be almost as high as before clearing.

Similarly, the regular cropping or laser-levelling for irrigation of a landscape has probably had a more detrimental impact on features like earth mounds and hearths than on grinding grooves on rocky outcrops in the same environment.

The current models are designed to be used in conjunction with the pre1750 models when interpreting the relative likelihood of a feature being present today. Similarly, the difference between the pre1750 model likelihood for a landscape feature and its current likelihood, gives an indication of the total impact on the feature. Comparing the current model to the pre1750 model (see sections 4 and 6) enables a visual assessment of the level of impact on that feature in that area of the landscape.

3.3 Aboriginal sites landscape regionalisation

The Aboriginal sites landscape regionalisation is a single GIS layer produced by classifying the set of pre1750 models (see Figure 49). The nine pre1750 models (excluding the all features model), were put together as a stack of layers, and put through a classification
algorithm classifying cells with similar levels of likelihood for the range of feature models. The result is a set of 25 regions that divides the landscape into areas where a similar suite of features are likely to occur. For instance, one region covers the Sydney sandstone basin, and is dominated by the occurrence of rock art sites and grinding grooves. In contrast, another region running along the coastal strip is dominated by the occurrence of shell middens. Still another, in riparian areas in the west of the state, is dominated by the occurrence of scarred trees with mounds and hearths. See Table 11 for a breakdown of AHIMS data for each region defined in this product.

The Aboriginal landscape regionalisation divides the landscape into regions where it is predicted that a similar suite of site features will occur at relatively consistent likelihoods.

In the landscape regionalisation layer, each colour (or region) represents a different site landscape. Table 11 summarises the major (high likelihood) and minor (medium likelihood) site features predicted to occur within each region, together with the frequency of recorded features from AHIMS.

3.4 Combined accumulated impacts

The accumulated impacts layer is derived from the difference between the pre1750 models and the current models for each feature type, and then summed together. As such, it reflects the combined impacts across all the nine features modelled. Areas with high values in the layer reflect areas where the majority of feature types have been heavily impacted. Areas where the combined impacts are low reflect areas where the land use has had only a minimum impact on the likely survival of features in that part of the landscape.

The combined accumulated impacts layer indicates the impacts of post-settlement land-use history on Aboriginal site features in the landscape.

Examples of areas with typically high impacts include mined areas, dense urban areas, or areas that have been cleared and regularly cropped.
Low impact areas tend to be those where land use has had minimal impact on the landscape, such as pristine environments within long-established national parks, or rangelands where the only agricultural activity has been livestock grazing.
Areas where the accumulated (ie summed) impact has been low, can be interpreted has having a comparatively high chance of preserving features close to the relative likelihood indicated in the pre1750 models. Correspondingly, areas where the accumulated impacts are high have little chance of preserving Aboriginal site features, or if they do, they are likely to be in a highly degraded state (ie mounds or middens within areas that are regularly cropped).

The accumulated impacts layer provides a landscape view of the level of impacts on Aboriginal site features, and can be useful in assessing the conservation significance of a site. For example, a site within an area with a high level of accumulated impacts could be considered as having higher conservation value because many similar sites in that area are likely to have either been destroyed or highly impacted. The idea of using such an index to measure conservation value is based on similar measures used to measure biodiversity value (Commonwealth of Australia 1997, 10), where it is the degree of loss that is identified as the key criteria for measuring conservation value.

In contrast, locations where accumulated impacts are low (especially if they occur within a region of high accumulated impact), may be used as areas for ground assessment for the

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location of unrecorded sites as these areas may preserve the last examples of some features (or features in the best condition) in that area.

### 3.5 Combined model reliability

The model reliability layer was derived by analysing the pre1750 model with a survey gap analysis (SGA) algorithm (Funk et al. 2005; Manion & Ridges 2009), that is based on the environmental diversity measure developed by Faith (Faith et al. 2004; Faith & Walker 1996). This algorithm looks at those areas where sites with a given feature type have been previously recorded in the landscape, combined with areas that have been surveyed. The algorithm assesses how much of the total landscape variability has been sampled through that recording and assessment history, taking into account the relatively likelihood of the feature occurring through the landscape.

The resulting layer is a guide to interpreting the overall reliability of the pre1750 models. Those areas which have been under-surveyed (high values in the reliability layer) are areas where the models are making predictions on the least amount of data, and therefore, are potentially the least reliable.

The combined reliability layer indicates those parts of the landscape that have been investigated the least. Areas with high values in this layer indicate where the predictions made by the model are based on the least amount of AHIMS data.

When assessing how well the landscape has been surveyed, the SGA algorithm compares the AHIMS sample against the same variables that were used to derive the model (eg terrain, proximity to water, soils, vegetation, as in Table 7). The result of the algorithm is a layer that produces high values in areas where the landscape has been under-surveyed, and low values where the survey coverage has been more comprehensive. The process is applied to all feature types, and then combined by summing them all together. See Section 8.9 for a technical discussion.

### 3.6 Combined survey priority

The survey priority layer is a derivation of the reliability layer, in that it combines the SGA result with the parameters used to derive current models to produce a layer that takes into account impacts on that feature and the relative likelihood of that feature occurring across the landscape. High survey priority areas are defined as those where there is an intersection of:

- medium to high pre1750 likelihood
- low accumulated impacts
- low site coverage and previous assessment.

The final step is to combine the survey priority layers of all features into a single combined survey priority layer.

The combined survey priority layer defines survey priority as the combination of low model reliability, high modelled likelihood and low accumulated impacts.

The approach to interpreting the priority layer is to use it as a guide to areas that would most benefit from on-ground assessment when the objective is to identify areas that haven’t been already adequately investigated. Since the combined survey priority layer takes into account
the relative likelihood of feature occurrence and its potential survival, areas flagged as high survey priority can potentially be areas of the landscape where assessment may be most productive in terms of identifying new sites, and improving overall coverage of the landscape.
4 Statewide pre1750 models

The following figures illustrate each model at the statewide scale in both their pre1750 and current forms.

Figure 2. Statewide model: all features combined
Figure 3. Statewide model: artefacts
Figure 4. Statewide model: rock art
Figure 5. Statewide model: burials
Figure 6. Statewide model: western earth mounds and shell
Figure 7. Statewide model: grinding grooves
Figure 8. Statewide model: hearths
Figure 9. Statewide model: coastal shell middens
Figure 10. Statewide model: stone quarries
Figure 11. Statewide model: scarred trees
5 Statewide derived products

The following figures illustrate those statewide products derived from the pre1750 models.
Figure 12. Statewide model reliability
Figure 13. Statewide survey priority
Figure 14. Statewide accumulated impacts
6 Local scale product examples.

The following maps provide examples of ASDST products. The products shown are statewide derived products, but displayed for the Upper Hunter and Merriwa areas.
Figure 15. Upper Hunter Valley and Merriwa area: LANDSAT with AHIMS sites (white dots)
Figure 16. Upper Hunter Valley and Merriwa area: pre1750 stone artefact model
Figure 17. Upper Hunter Valley and Merriwa area: current stone artefact model
Figure 18. Upper Hunter Valley and Merriwa area: model reliability
Figure 19. Upper Hunter Valley and Merriwa area: survey priority
Figure 20. Upper Hunter Valley and Merriwa area: regionalisation
Figure 21. Upper Hunter Valley and Merriwa area: accumulated impacts
7 Product application

The statewide ASDST product suite has been applied in a variety of projects across NSW (see Figure 22). The suite of products and analytical approaches comprising the ASDST has been combined in a variety of ways to meet the needs of each application (see Table 1). In all cases, the emphasis has been on identifying the information needs of each application and meeting these with custom product manipulation. The objective is to improve decision making through the use of appropriate and meaningful contextual information at the regional scale. To illustrate how the various products can be used in different projects, Table 2 summarises ASDST application types for those projects listed in Figure 22. As each project type required a different information profile, a unique set of products were also employed in each study.

Table 1. ASDST products used in different applications

<table>
<thead>
<tr>
<th>Application</th>
<th>Pre1750</th>
<th>Current</th>
<th>Accumulated Impact</th>
<th>Reliability</th>
<th>Survey priority</th>
<th>Regions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site potential mapping</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
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<tr>
<td>Regional context setting</td>
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<td>X</td>
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<tr>
<td>Model testing</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Survey design</td>
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<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conservation priority</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
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</table>

Figure 22. ASDST projects map
(see Table 2 for legend)
Table 2. ASDST project listing

<table>
<thead>
<tr>
<th>ID</th>
<th>Project name</th>
<th>Site potential mapping</th>
<th>Regional context setting</th>
<th>Model testing</th>
<th>Survey design</th>
<th>Conservation priority</th>
<th>Report</th>
<th>Published</th>
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<td>Alps to Atherton</td>
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<td>X</td>
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<td></td>
<td></td>
</tr>
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<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td>Ridges 2007</td>
</tr>
<tr>
<td>4</td>
<td>6 Foot track assessment</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Bongil Bongil NP</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Border Ranges Recovery Plan</td>
<td>X</td>
<td></td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>7</td>
<td>Darkwood Addition to New England NP</td>
<td>X</td>
<td></td>
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<td>Cathedral Rock NP</td>
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<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Hunter Central Rivers (HCH) CMA Investment Strategy</td>
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<td>14</td>
<td>Riverine Environments Restoration Program (RERP)</td>
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<td>15</td>
<td>Macquarie Marshes</td>
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<td>Molong TSRs</td>
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<tr>
<td>19</td>
<td>Peel Water Sharing Plan</td>
<td>X</td>
<td>X</td>
<td></td>
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<tr>
<td>20</td>
<td>Riverina Red Gum</td>
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<td></td>
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</tr>
<tr>
<td>21</td>
<td>Sydney Metro CMA</td>
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<td>X</td>
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<td>Yengo NP</td>
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<td>White Cypress Assessment</td>
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</tr>
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<td>28</td>
<td>Hay LEP</td>
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<td></td>
</tr>
</tbody>
</table>

ASDST: Statewide product outline and technical summary
To illustrate how ASDST products have been used in different applications, each application type is described in more detail below.

### 7.1 Site potential mapping

One common application of the ASDST products has been for site potential mapping. Often this has been in the form of maps of pre1750 or current models for a project area in order to gauge the relative likelihood pattern of different feature types across the landscape. Such maps have been supplied in digital form as jpeg images. They have been visualised interactively with a GIS enabled laptop and data projector and

- supplied as GIS layers clipped to a study area, or
- supplied in hard copy form for use in meetings or field work.

Despite the many layers, visualising the feature models offers several advantages:

- It allows users to understand the subtlety of how feature likelihood changes across a landscape.
- Pre1750 and current versions of each feature model can be compared side-by-side so that the spatial pattern of impacts can be visualised (see Figure 23).
- The pattern of likelihood can be tied in with users’ understanding of a landscape. This can be achieved by having accompanying maps of environmental context such as satellite imagery, terrain or infrastructure.
- Users can overlay AHIMS data on the pre1750 and current models to see how the model projects the information across the landscape. This also affords a visual assessment of model performance for the study area.

![Figure 23. Side-by-side comparison of pre1750 (left) and current (right) versions of the scarred trees model for the lower Hunter Valley](image)

In addition to displaying the models in their default display style (see Section 4) the products can be adjusted to meet particular display needs. For example, since the likelihood profile for each feature is a relative measure for the entire state, for a particular study area the likelihood values may not cover the full range of likelihood scores (0–1000). Hence there may be a predominance of low or high likelihood scores depending on whether the study area is in a part of the state where the model is predicting likelihood at either end of the likelihood range. In such cases it has been useful to stretch the likelihood scores within the study area so they give a better visualisation of how likelihood varies across the landscape (see Figure 24).
Another application along these lines has been to transform the continuous spectrum of likelihood values of a feature model into a simpler-to-interpret set of classes. For example, this has been applied by classifying likelihood values into low-medium-high categories (see Figure 25). To avoid an arbitrary or misleading classification, the cut-off points for each category in this example were determined using the proportion of AHIMS sites of each feature that fell within each class. This aided the interpretation of each category by having it associated with a meaningful description, such as: ‘High likelihood contains 63% of AHIMS sites’. For some applications, displaying site likelihood using such a classification enables decision making for each class to be applied against broad areas of a landscape.

Figure 25. Classification of likelihood values for the stone artefacts model
Model display can be simplified further to include just likely / unlikely categories using the all feature types combined model (see Figure 26). In this application, a series of cut-offs based on the percentage of AHIMS sites (all features) that would be included within the ‘likely’ category were generated and reviewed by the project team. For each of these a smoothing algorithm was applied, and included with a buffer of areas of cultural value nominated by the Aboriginal community. The final map depicted a cultural sensitivity zone that could be included as an overlay layer in a local environmental plan (LEP).

In summary, due to the relative nature of the likelihood measure, model display is an interactive and adaptable exercise. The examples above illustrate the flexible ways in which the ASDST products can be used to meet the interpretation and information needs of users in each application.

7.2 Regional context setting

The predictive models of the ASDST lend themselves to assessing the chance of locating site features in the landscape and this is the most commonly assumed application of a predictive model. However the prime reason for developing the tool as it is, was to apply it to regional context setting. Much archaeological assessment focuses on the site as the basis of investigation, and comparisons are often made between known sites and the expected location and content of yet to be discovered sites. However even in areas of high site-recording intensity, systematic regional-scale estimates of the level of accumulated impact using site data alone is difficult due to:

- the incomplete nature of the archaeological record and hence site database (see Section 8.3), and
- the continuous nature of feature distribution (Foley 1981).
Although ASDST products do not provide a direct measure of the number of sites, analysis using them permits a quantified assessment of impacts and conservation status because they attempt to describe site distribution in its totality. Such information can play an important role in establishing the significance of new finds. For example, is the discovery of a scarred tree significant when assessed in the context of the likely accumulated impact on scarred trees in a given landscape? Previously, it was not as possible to systematically address significance using traditional archaeological approaches as it now is through the application of the ASDST.

From Table 1 it can be seen that half the projects where the ASDST has been applied have involved regional context setting. Typically, analysis of regional context involves the calculation of the following indices for a study area:

\[
I_f = \left( \frac{\sum_x M_{f(\text{pre1750})} - \sum_x M_{f(\text{current})}}{\sum_x M_{f(\text{pre1750})}} \right) \times 100
\]

- Percentage impact

\[
C_f = \left( \frac{\sum_x M_{f(\text{pre1750})}}{\sum_x M_{f(\text{pre1750})}} \right) \times 100
\]

- Percentage conserved

\[
A_f = \left( \frac{\sum_x M_{f(\text{current})}}{\sum_x M_{f(\text{current})}} \right) \times 100
\]

- Percentage accessible to an Aboriginal community

Where:
- \(x\) = each grid cell
- \(f\) = each feature
- \(M\) = a model GIS layer
- \(SA\) = the study area
- \(C\) = all parts of the study area where Aboriginal features are conserved (eg national parks, flora reserves and Aboriginal owned lands)
- \(A\) = all parts of the study area where Aboriginal features are accessible to an Aboriginal community (eg national parks, state forests, travelling stock routes, Crown reserves and Aboriginal owned lands)

The percentage impact index measures the degree to which the cumulative effects of land use in the study area have impacted each feature. High values indicate a feature such as scarred trees in a cleared landscape that has been heavily impacted. A common application of the index is to give those features with higher percentage impact measures greater weight in the assessment of site significance.

The percentage conserved index measures the degree to which areas where site features are conserved are representative of the estimated total amount of each feature prior to any post-1750 impacts. The pre-colonisation version of each model is used for this index because the intention is to measure overall representativeness.

The conservation index has been used to identify which features are under-represented in conserved areas, and which might be targeted in the identification of new conservation areas. The index is used to measure the degree to which Aboriginal people in a study area can access and appreciate their heritage. This measure is similar to the percentage conserved index, but tends to be more inclusive in terms of land tenures. It is also a measure of the accessibility of extant features, which is why the current version of each model is used.

These indices are calculated by summing together the likelihood scores for each grid cell, and then performing the calculation of percentages on these totals.
The percentage accessible index has typically been used to identify the features which an Aboriginal community has least access to. For example, the index has been used to measure the benefit to an Aboriginal community of changes in public land tenure (eg with the Riverina Red Gum and White Cypress assessments of State Forests – project 20 and 27 respectively in Table 2).

Table 3 shows an example of regional context statistics calculated for the Muswellbrook 1:100,000 map sheet. This is an area with a high concentration of recorded sites (more than 3000), but despite five percent of the map sheet being conserved, no AHIMS sites have been recorded on conserved lands. In this case, the regional context analysis can still give an indication of the representativeness of what is potentially conserved, with rock art and scarred trees best represented, and stone artefacts and hearths least represented. Although the level of recording and subsequent mining impacts on stone artefacts is a real concern, the analysis also reveals the significant impacts on scarred trees, burials and hearths. These latter features are particularly vulnerable to agricultural clearing and cultivation which have occurred over a much greater proportion of the landscape. Such analysis can be used to situate the significance or conservation value of these features.

Table 3. Example of regional context statistics for Muswellbrook 1:100,000 map sheet

<table>
<thead>
<tr>
<th>Index</th>
<th>Total</th>
<th>AFT*</th>
<th>ART</th>
<th>BUR</th>
<th>GDG</th>
<th>HTH</th>
<th>STQ</th>
<th>TRE</th>
</tr>
</thead>
<tbody>
<tr>
<td>AHIMS ALL</td>
<td>3305</td>
<td>3232</td>
<td>2</td>
<td>5</td>
<td>6</td>
<td>0</td>
<td>4</td>
<td>51</td>
</tr>
<tr>
<td>AHIMS Conserved</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Percentage impact</td>
<td>21.4</td>
<td>23.4</td>
<td>14.1</td>
<td>64.5</td>
<td>19.8</td>
<td>73.9</td>
<td>14.7</td>
<td>68.2</td>
</tr>
<tr>
<td>Percentage conserved</td>
<td>6.5</td>
<td>4.6</td>
<td>11.1</td>
<td>7.7</td>
<td>8.3</td>
<td>2.7</td>
<td>7.5</td>
<td>12.3</td>
</tr>
</tbody>
</table>

(* see Glossary for codes)

Typically these indexes are calculated for the whole study area, and the results tabulated as in Table 3. However the indexes can also be calculated for each grid cell in a study region using the area around each cell. This approach produces a map of how the index changes across the landscape. An example is given in Figure 27, which shows the map produced when the percentage conserved index was calculated for a 10 km buffer around each cell in the scarred tree model. In this case, the amount of the scarred tree model that occurred in the pre1750 landscape around each cell is compared to how much is represented in conserved areas (mapped in green). The darker red areas indicate those parts of the landscape that have a higher proportion of the original scarred tree model occurring in conserved areas.

High values (darker red) can be produced in a number of ways:

- proximity to a conserved area
- the size of that conserved area, and
- the likelihood profile of the model within the conserved area.

A particular grid cell may be close to a conserved area, but unless there is a large patch of high likelihood for that feature within the conserved area then the score for this index would not be high. For this particular study, such a map was used to identify the parts of the landscape where investment in conserving areas with high scarred-tree potential for would best complement those areas where scarred trees are already conserved. In other words, those areas with low values for this index (ie white) would be good candidates for investment in scarred tree conservation. The layer was also used as input to more complex calculations of conservation priority (see Section 7.5).

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3 A distance decay model was also applied to the calculation of the index, as is applied in the combined accumulated impact algorithm, see section 8.9.
7.3 Model testing

In several projects where the ASDST has been applied (see Table 2), one of the specific objectives of the project was to test how well the models performed. These were projects where extensive surveying was planned in areas where previous surveys were limited.

In most cases the survey strategy was driven by management objectives, such as establishing visitor areas in a new national park or upgrading a hiking trail. However, use of ASDST products permitted an evaluation of how the models were performing. In some instances this involved looking at the likelihood values and seeing how they corresponded with the occurrence of finds (as with the Six Foot Track assessment in the Blue Mountains), in other cases it involved utilising the detailed land-use history of an area (such as in Bongil Bongil National Park) to evaluate whether appropriate parameters were being applied to the land-use classes used to derive the current likelihood models.

In other cases, the field work was an opportunity to consult Aboriginal people and archaeologists with a good knowledge of a particular area and explore where the models could be improved by deriving variables that better captured the drivers of site location in different parts of the landscape. This aspect was a key feature of the Yanga National Park assessment. Such consultation, for example, led to the development of the ‘proximity to wetland edge’ variable that proved an important factor for predicting the likelihood of finds in western NSW.

In the assessment of the Cathedral Rocks National Park, the objective was to explore issues with detectability and how this could be untangled from the overall predicted likelihood indicated in the models. This park is in a high altitude zone on the New England Tablelands with extensive woodlands and grasslands, resulting in limited archaeological visibility. In this example, the experience of applying the models produced a better understanding of how to explain appropriate interpretation of the models in the context of variable archaeological detectability.

For the Riverine Environments Restoration Program (RERP), the ASDST products were integrated into the survey design (see Section 7.4), ensuring a focus of survey effort in areas of largest data gap as indicated by the survey priority model. Figure 28 displays a map of survey priority for the RERP study region prior to fieldwork, and shows that large portions of the region had high survey priority due mainly to the lack of previous survey. The project generated some 1500 new sites – a tripling of the
number of recorded sites between Hay and Balranald. For stone artefacts, this represented a five-fold increase in data. Hence, together with the amount of new data that was generated through the project, and the targeted survey, it provided an ideal opportunity to test the models.

Figure 28. Survey priority for Riverine Environments Restoration Program (RERP) study region prior to fieldwork. White dots are sites

Figure 29 and Figure 30 present model comparison plots (see Section 8.8.2 for a discussion on these types of plots) for stone artefacts, western mounds and shell, hearths, and scarred trees. The plots were generated using the pre1750 models and site data from within the RERP project area. The likelihood scores are relative to the rest of the state for each feature.

Overall Figure 29 and Figure 30 show that, despite the significant increase in site data generated by the RERP project, the models were predicting likelihood scores comparable to those of the input data within the study region.

Results were best for the western mounds and shell, and hearths models, which show likelihood profiles very similar to the input data.

Results were not as good for stone artefacts and scarred trees. With artefacts this partly relates to the comparatively small amount of data available prior to the project, which is reflected in the bi-modal likelihood profile for the original input data. The high peak in low-likelihood scores is largely due to the comparatively low likelihood scores predicted for stone artefacts in the Riverina compared to those in other parts of the state. However, the predicted likelihood scores for the new data show an improvement in the modal likelihood scores, but an absence of sites predicted in the high-likelihood areas. The high-likelihood areas for artefacts within the study region generally occur along the Macquarie River, away from wetlands which were the focus of the study. These areas have also been highly impacted through agriculture and generally not sampled through the survey strategy adopted.

The result for scarred trees indicates that this model performed less successfully in predicting the location of new sites and suggests a deficiency which needs to be investigated. This will be a focus in the next version of the ASDST models when species data will be used to improve the scarred tree model.
7.4 Survey design

A number of projects that have utilised ASDST products have done so to develop a survey design for fieldwork. For the Cathedral Rock and Yanga national park assessments the objective was to locate new sites, primarily for on-park management. A survey design for these projects was developed interactively using maps and live GIS analysis during meetings with rangers for each national park, Cultural Heritage staff coordinating the survey and representatives of the Aboriginal communities.

In cases of both parks there had been minimal previous survey, so the objective was to develop a strategy for covering the survey area, and its potential archaeological variability, as best as possible given available time and resources. This was done by reviewing the pre1750 models in the context of other environmental data and on-ground staff knowledge. Issues explored were the types of sites that could be encountered, in which parts of the landscape and, in the case of Cathedral Rock, whether site potential could be used to ensure appropriate composition of survey crews, specifically gender.

Survey design in the two cases was focused on interactive discussion and review of maps and data.

For the Molong travelling stock routes (TSR) and Riverine Environments Restoration Program (RERP) projects, survey design involved a more technical analysis.
7.4.1 Example: Molong Travelling Stock Routes Project

The Molong assessment required a strategy to assess 172 stock routes located within 50 km of the township of Molong. The TSRs were to be assessed for potential sites and values of interest to the local Aboriginal community. Given the time and resources available, it was not possible to visit every TSR, so ASDST analysis was used to identify priority TSRs for field survey.

The first step in assessing the Molong TSRs involved calculating regional context statistics, using the indexes outlined in Section 7.2. The results are presented in Table 4. They highlighted the high degree of impacts on scarred trees, although these were also the feature with best overall conservation and level of accessibility. In contrast, stone artefacts and quarries were the least well conserved and accessible features in the region. On the basis of this analysis and frequency of occurrence, the survey strategy was weighted towards scarred trees, quarries and artefacts. AHIMS data and the ASDST models indicated that other features could occur in the region, but with low likelihood.

Table 4. Regional context statistics for the Molong Travelling Stock Route assessment

<table>
<thead>
<tr>
<th>Feature</th>
<th>Impacted (% lost)</th>
<th>Conserved (% national park estate)</th>
<th>Accessible (% on public land)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scarred trees</td>
<td>80.8</td>
<td>19.0</td>
<td>21.9</td>
</tr>
<tr>
<td>Stone quarries</td>
<td>24.4</td>
<td>4.9</td>
<td>6.1</td>
</tr>
<tr>
<td>Hearth</td>
<td>63.8</td>
<td>5.7</td>
<td>6.1</td>
</tr>
<tr>
<td>Grinding grooves</td>
<td>24.9</td>
<td>6.0</td>
<td>7.3</td>
</tr>
<tr>
<td>Burials</td>
<td>61.0</td>
<td>6.4</td>
<td>7.7</td>
</tr>
<tr>
<td>Rock art</td>
<td>24.1</td>
<td>6.9</td>
<td>8.0</td>
</tr>
<tr>
<td>Stone artefacts</td>
<td>25.4</td>
<td>5.5</td>
<td>6.9</td>
</tr>
</tbody>
</table>

The next step in the analysis considered the current likelihood of features on each TSR. The combination of land-use information and vegetation condition data indicated the likely condition of each TSR. This could then be confirmed by a visual check of the TSR location using SPOT satellite imagery. Some TSRs, for example, had been completely cleared of native vegetation, reducing the likelihood of scarred trees to zero, although they possibly still contained artefacts or quarries. The TSRs were intersected with each of the models (current), and the mean model value for the TSR was then compared to the mean value of the feature (current) for the study area.

TSRs with a mean current cell value more than one standard deviation above the mean for that feature were classed as being high likelihood, those within one standard deviation classed as medium, and those below one standard deviation classed as low likelihood. The 70 TSRs classed with a high likelihood for scarred trees, quarries or artefacts (out of the 172 TSRs within the study area) were then given a high priority for assessment.

Consultation with the local Aboriginal community identified a desire to assess TSRs associated with water. The set of 70 TSRs was thus further reduced to 27 by identifying those that were within 250 metres of a fourth order or higher stream (based on the stream ordering done for the ASDST – see Section 8.5.6). These TSRs are highlighted in Figure 31, overlain on the fourth order and higher drainage. The number of TSRs in the final priority set was based on what the project team thought was feasible to assess given the time and resources of the project. The approach was successful in the context of adopting a systematic strategy of reducing a large number of TSRs down into a manageable amount of fieldwork.
7.4.2 Example: Riverine Environments Restoration Program

The approach adopted for the Riverine Environments Restoration Program was somewhat different. The RERP focus was the cultural values associated with the wetlands of the lower Murrumbidgee River. The survey strategy therefore needed to identify those areas within or closely associated with the wetlands that would be ideal for fieldwork.

The choice of areas was complicated by:

- the limited amount of public land
- areas of significant impact associated with irrigated agriculture, and
- the lack of previous survey in the area (see Figure 28).

The survey design strategy was a two step process. First, a custom survey priority layer was derived incorporating two of the key objectives of the project:

- to address the survey gap in the region
• to focus on areas of high conservation value.

The derivation of these two priority layers involved some custom processing of the ASDST layers. The first objective, to address the survey gap in the region, was generated by combining three ASDST products:

• model reliability
• model impact, and
• the likelihood of the pre1750 model.

These products were combined to describe the data gaps, allowing for level of impact and underlying feature likelihood. The calculation was performed on just those features with medium to high likelihood in the study region (AFT, BUR, ETM, HTH and TRE), and the result was combined by summing them together (see Figure 32):

\[
SP = \sum_{M_f} R_f + \left( M_{f(1750)} - M_{f(\text{current})} \right) + M_{f(1750)}
\]

where:

- \(SP\) = survey priority
- \(M\) = all feature \(f\) models
- \(R_f\) = reliability GIS layer derived from SGA algorithm for each feature

One of the objectives of the study was to recommend areas where sites could be conserved through private property initiatives. The second priority layer therefore considered the degree to which each feature was already represented in conserved areas. This was achieved by applying the percentage conserved regional context index on a cellular basis as was illustrated in Figure 27. The application of the index in this case was performed on a 10 km radius around each cell, and calculated the proportion of each current feature model that occurred in conserved areas within that area. The
current version of each model was used as there were areas of impact within conserved areas and the objective was to map conservation status in the current landscape. Thus:

\[
CP = \sum_{M} f(x) \sum_{\text{SR}} M \sum_{x} f(\text{current})
\]

where:
- \(CP\) = conservation priority
- \(M\) = all feature (f) models
- \(X\) = focal cell
- \(SR\) = search radius (10 km of focal cell)
- \(C\) = all parts of the study area where Aboriginal features are conserved (eg National Parks, Flora Reserves, Aboriginal owned lands etc)

Figure 33. Conservation priority for RERP project

The second step in the generation of the RERP survey strategy was to consider access to properties. A workshop involving the project team developed the strategy interactively using:

- cadastral information on property boundaries
- the project team’s knowledge of property managers receptive to having surveys conducted on their properties, and
- survey and conservation priority layers.

The priority layers from step one were brought together into a combined priority layer, and each property considered in terms of the relationship with the property manager, the combined priority layer and the feasibility of the time and resources available. The exercise was carried out using a live GIS session running on a laptop and projected onto a screen. Through this approach it was also possible
to consider other contextual information including environmental data; AHIMS site data and satellite imagery. At the end of the workshop, the project team was able to schedule fieldwork and contact property managers accordingly (see Figure 34). Hardcopy maps of the priority layers and feature models were also taken into the field for reference.

The examples in this section highlight the flexible approach to survey strategy development in projects that have employed the ASDST. Developing a survey strategy is often a project specific exercise due to the particular context of the assessment and the required objectives. Thus, although the ASDST has some default products that can provide a standard context in which to evaluate survey priority, it has been a point emphasised to ASDST clients that the best results are obtained through a collaborative partnership where the products can be combined in various ways to meet the specific needs of each project. The examples in this section illustrate just some of the potential of a collaborative arrangement.

![Figure 34. Combined priority and final selected properties for RERP project](image)

7.5 Conservation priority

One application where the ASDST products can be a useful accompaniment to existing methods and data is in the development of regional conservation strategies. Applying the ASDST in these situations has required close collaboration to understand and identify the right kind of information for each strategy. The philosophy adopted has been that there is no ‘one-size-fits-all’ approach to conservation planning, and the examples below illustrate that in each case there has been a concerted effort to adapt the ASDST products to meet the objectives of each project.

7.5.1 Example: Far North Coast Regional Strategy

For the Far North Coast Regional Strategy (FNCRS), the ASDST was used in its regional context setting capacity to identify the conservation value and impact for conservation investment and development scenarios. An objective of the strategy was to identify:

- areas where the biodiversity impact of proposed development zones could be offset with public conservation areas, and
- areas where private investment could be made in biodiversity conservation.
An objective of the strategy was to also consider the impact of the development areas and proposed offsets in terms of their cultural value. The proposed areas, although extensive, had only a few AHIMS sites recorded, so site data was not a useful way to measure cultural value. Similarly, the project did not have the resources to undertake consultation with the Aboriginal community about the cultural values they may have identified for the proposed areas. Although only a partial solution, the ASDST provided a measure of the archaeological component of cultural value.

To develop measures of archaeological value, the ASDST regional context setting indexes were calculated using additional enhancements. Table 5 presents the statistics derived for the project. The percentage impact measure of status was calculated in the same way as that described in Section 7.2. However, the proportion of each current model within each of the proposed areas was also calculated and expressed as a percentage. Hence for each proposed area, the potential remaining distribution of each feature within the region could be estimated, providing a measure of the relative potential archaeological value in each case. These values could then be compared to the level of regional impact for each feature and used as a surrogate for the relative significance of potential sites discovered within each area.

Public conservation option 3, for example, would possibly make a significant contribution to two highly impacted features – shell middens and scarred trees – indicating that this might be a preferred conservation option on archaeological grounds. Similarly, the development areas had their largest potential impact on shell middens, perhaps flagging that given the level of impact regionally on this site type, it might require special consideration in the form of development consents. Having regional context information, processed as it was for this study, illustrates a way in which quantitative ASDST data can be used in the development of regional conservation strategies.

<table>
<thead>
<tr>
<th>Features:</th>
<th>AFT</th>
<th>ART</th>
<th>BUR</th>
<th>GDG</th>
<th>HTH</th>
<th>SHL</th>
<th>STQ</th>
<th>TRE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage impact in region (status)</td>
<td>30.2</td>
<td>32.3</td>
<td>57.3</td>
<td>38.6</td>
<td>86.7</td>
<td>60.1</td>
<td>34.2</td>
<td>81.7</td>
</tr>
<tr>
<td>Percentage remaining:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Private investment</td>
<td>8.4</td>
<td>15.7</td>
<td>6.9</td>
<td>13.0</td>
<td>4.3</td>
<td>9.7</td>
<td>10.4</td>
<td>12.8</td>
</tr>
<tr>
<td>Public conservation option 1</td>
<td>0.7</td>
<td>0.3</td>
<td>0.8</td>
<td>0.4</td>
<td>0.0</td>
<td>2.1</td>
<td>0.7</td>
<td>1.7</td>
</tr>
<tr>
<td>Public conservation option 2</td>
<td>0.2</td>
<td>0.1</td>
<td>0.2</td>
<td>0.1</td>
<td>0.0</td>
<td>0.8</td>
<td>0.1</td>
<td>0.5</td>
</tr>
<tr>
<td>Public conservation option 3</td>
<td>2.6</td>
<td>1.0</td>
<td>2.9</td>
<td>2.1</td>
<td>0.4</td>
<td>4.3</td>
<td>3.5</td>
<td>4.5</td>
</tr>
<tr>
<td>Public conservation option 4</td>
<td>0.9</td>
<td>0.4</td>
<td>1.0</td>
<td>0.7</td>
<td>0.1</td>
<td>3.0</td>
<td>0.9</td>
<td>3.0</td>
</tr>
<tr>
<td>Public conservation option 5</td>
<td>0.2</td>
<td>0.6</td>
<td>0.2</td>
<td>0.2</td>
<td>0.0</td>
<td>0.9</td>
<td>0.1</td>
<td>0.5</td>
</tr>
<tr>
<td>Public conservation option 6</td>
<td>0.1</td>
<td>0.0</td>
<td>0.1</td>
<td>0.0</td>
<td>0.0</td>
<td>0.6</td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>Public conservation option 7</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.2</td>
<td>0.0</td>
<td>0.1</td>
</tr>
<tr>
<td>Public conservation option 8</td>
<td>0.1</td>
<td>0.5</td>
<td>0.1</td>
<td>0.2</td>
<td>0.0</td>
<td>0.6</td>
<td>0.0</td>
<td>0.2</td>
</tr>
<tr>
<td>Public conservation option 9</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
<td>0.1</td>
<td>0.0</td>
<td>1.3</td>
<td>0.1</td>
<td>0.3</td>
</tr>
<tr>
<td>Public conservation option 10</td>
<td>0.1</td>
<td>0.0</td>
<td>0.1</td>
<td>0.0</td>
<td>0.0</td>
<td>0.5</td>
<td>0.1</td>
<td>0.3</td>
</tr>
<tr>
<td>Development areas</td>
<td>0.8</td>
<td>0.3</td>
<td>0.9</td>
<td>0.4</td>
<td>0.1</td>
<td>1.8</td>
<td>0.6</td>
<td>0.6</td>
</tr>
</tbody>
</table>

7.5.2 Example: Hunter Central Rivers CMA investment strategy

In other applications, the mapped form of ASDST products has been more useful in meeting planning needs. For the Hunter Central Rivers CMA investment strategy developed as part of TOOLS2 project (DECC 2009), the catchment management authority could use information to weight applications from private landholders for conservation projects on their properties. For each funding round the CMA would receive more applications than it could fund, so it developed a scoring system to identify high-priority projects. A project would attract additional weighting in the scoring system if it addressed a cultural outcome such as site protection. When there were multiple projects with site outcomes, it was desirable to weight the relative merit of the cultural project. An issue in defining how to apply a relative weighting to each cultural project was the lack of resources to assess the significance of the nominated site for every application. Instead, the CMA sought a rapid method for evaluating the

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4 Of the 560 AHIMS sites recorded in the study region at the time, only 44 occurred within the areas under consideration.
relative merits of site conservation programs proposed in each application. This was achieved using a combination of the accumulated impacts and percentage conserved regional context indices applied spatially (see example in Figure 27). Thus:

\[ P = \sum_{M} f(x) \sum_{x} I_x + C_x \]

where:
- \( P \) = priority for designating an additional weighting for a project application
- \( M \) = all feature \((f)\) models
- \( X \) = focal cell
- \( SR \) = search radius (10 km of focal cell)
- \( I_x \) = level of impact the model has experienced within the search radius
- \( C_x \) = proportion of the model that is conserved within in the search radius

The resulting layer (see Figure 35) was used by the CMA to compare project applications with cultural components. This was done by overlaying the project extent over the supplied GIS layer, and visually comparing the derived priority for each project. Those proposed site conservation projects in the blue and green zones were located in a part of the landscape where conservation of features was low and the impact levels had been high. In these cases, the project was given an additional weighting in the scoring system because it was being conducted in an area where it could be argued that site conservation value should be high.

**Figure 35. Priority layer developed for Hunter Central Rivers CMA**

### 7.5.3 Example: Lachlan and Murrumbidgee CMA

For other CMA applications (eg Lachlan and Murrumbidgee), approaches to visualising conservation priority have involved different calculations of conservation priority. In these cases, the objective was to derive a spatial layer that could be compared to conservation priority layers for other values (eg soil
or biodiversity conservation). To encapsulate priority for sites, the important factors were the level of impact experienced and the likelihood of survival in the current landscape, taking into account what was already represented in conserved areas. The calculations were therefore similar to those used for the Hunter Central Rivers CMA, but modified to include:

- the current likelihood of each feature, and
- a weighting for the combination of feature priority layers using the regional level of impact experienced by each one.

Thus:

\[
P = \sum_{M_j} \left( \left( \frac{f(x)}{\sum_{x} I_x + C_x} \right) + M_{f(current)} \right) \times I_{f(SA)}
\]

where:

- \( P \) = potential site conservation
- \( M \) = all feature \( f \) models
- \( x \) = focal cell
- \( SR \) = search radius (10 km of focal cell)
- \( I_x \) = level of impact the model has experienced within the search radius
- \( C_x \) = proportion of the model that is conserved within the search radius
- \( I_{f(SA)} \) = the regional level of impact experienced by each feature

The resulting map (Figure 36) is noticeably different to that derived for the Hunter Central Rivers CMA because in this case greater emphasis was given to the current likelihood of each feature. This effectively flags those parts of the landscape where feature likelihood is highest and combines with low representation in conserved areas. By including the regional level of impact in the calculation, a priority map was produced heavily influenced by the scarred tree model, since this was the most impacted feature in the region.

The Lachlan example shows that careful consideration of how the ASDST products are combined into a priority map can produce very different maps of priority. The issue for the development of a conservation strategy is therefore to think carefully about the objectives of the strategy and how these can be best conveyed through the use of the ASDST products.
One of the reasons it is worth exploring the development of a site conservation priority map is that it is similar in approach to the development of priority layers for other kinds of landscape values such as salinity or biodiversity. In the case of the Murrumbidgee and Hunter Central Rivers CMAs, the priority layers were developed to incorporate multi-criteria analysis tools like the Multi Criteria Analysis Shell (MCAS, see http://adl.brs.gov.au/mcass/ ). In such tools the objective is to incorporate priority layers for a variety of values, and the planning project team can then combine them with weightings derived by policy and consultation. In the case of the CMAs, the drivers have been objectives set out in their Catchment Action Plans. Through development of a comparable dataset that can be used alongside priority datasets derived for other values, at least one aspect of Aboriginal cultural value (site-based values) can be equitably included in such analysis.

7.5.4 Example: Darling Riverine Plain 2 Acquisition Strategy

Getting Aboriginal site conservation issues incorporated into regional planning strategies is important to addressing them at the landscape scale. Such planning can have an important bearing on the investment strategies of agencies like CMAs. However, it can be achieved in a number of ways with the ASDST products depending on the nature of the application. For the Darling Riverine Plain 2 Acquisition Strategy (DRP2) (see Table 2), the objectives were very different, and involved development of a strategy for the potential acquisition of properties for inclusion in the national park system. When properties will come on the market is hard to predict, and the development of a strategy that considers the benefits to the reserve system of purchasing individual properties enables a more rapid response to such opportunities when they arise. Because the reserve system has a mandate to represent and conserve cultural as well as natural values, it has been desirable to develop acquisition strategies that consider potential site-based values as well.

In the DRP2 project, site based values were incorporated into the strategy by using the site landscape regions dataset (see sections 3.3 and 8.11). This was because the other primary dataset that was being used to evaluate natural values was land systems, and the site landscape regionalisation provided a comparable dataset to analyse. The strategy was developed using a piece of conservation planning software called C-Plan (see http://www.uq.edu.au/ecology/index.html?page=101951 ) that considers the potential contribution each property in the landscape would make to the existing reserve system. It does this by calculating how much of each land system or site landscape type occurs on a property, combines it with what is represented in the current reserve system, and compares that to a set of regional-scale conservation targets for each land system or site landscape.

The degree to which each property contributes to achieving regional targets is represented as its **irreplaceability measure** (Ferrier et al. 2000). Those properties with high irreplaceability are crucial to achieving regional targets because there are few other replacement properties that can represent key land systems or site landscape sufficiently to meet those targets. The use of a tool like C-Plan is therefore invaluable for developing a strategy for achieving a given level of representation of land systems or site landscape in a region (Pressey et al. 1995; Pressey et al. 1993).

A key aspect to developing a strategy with C-Plan is the calculation of targets (Pressey et al. 2003). For the DRP2 project, targets for site landscapes were developed using the same criteria applied nationally for forest ecosystems (Commonwealth of Australia 1997), which states that the goal of achieving a comprehensive, adequate and representative reserve system should be to represent 15 percent of the pre-colonisation extent of each forest ecosystem.

For the DRP2 study, pre-colonisation extent was taken as the mapped area of each site landscape as based on the pre1750 models. In addition, it is usual practice to increase representation targets to take into account the level of impact or rarity of features. Using available spatial data for current vegetation extent in the region (used for the analysis of land systems), the potential current pristine extent of each site landscape was calculated by subtracting the cleared areas on each. Rarity of a site landscape was calculated as the proportion of the total study region each site landscape covered. Low values reflect small extent, or rare site-landscape types. Impact (percentage lost) and rarity values for each site landscape were then combined to calculate targets as shown in Figure 37. In this way, the minimum target for a site landscape was 15 percent, but increased proportionally with the rarity and degree of impact each had experienced.
For the C-Plan analysis, the potential current extent of each site landscape was calculated for each property, and this data, together with the derived targets, were used to calculate irreplaceability (see Figure 38). The project team, including a regionally affiliated Aboriginal staff member, was able to explore the best approach to developing an acquisition strategy that maximised both natural and cultural values. This was made possible by performing the C-Plan analysis using both sets of data simultaneously, and the displayed irreplaceability reflected both sets of values. The experience of working through this exercise with the project team highlighted the possibilities of incorporating site-based spatial information into current approaches for biodiversity regional planning.

The examples shown in this section illustrate what is possible when regional landscape information is available for Aboriginal sites. It highlights that by using estimates of total site distribution, a variety of regional planning approaches are possible. It also shows that in each case, applying the ASDST has achieved its best outcomes when there has been close collaboration with users so that products can be best developed to meet the needs of the project. Such experience means the potential for better decision making is greater, and that future development of ASDST products can be improved to meet emerging regional planning needs.

**TARGET CALCULATIONS**

For each site landscape:

\[ T = \left( 1 - \frac{A}{B} \right) \times 100 \]

If \( T < 15 \), then \( T = 15 \)

Where \( T \) = target %

Rarity = \( \frac{\text{feature area}}{\text{study area}} \times 100 \)

**Figure 37. Target calculations for Darling Riverine Plain 2 Acquisition Strategy C-Plan analysis**
Figure 38. Comparison of irreplaceability for Darling Riverine Plain 2 Acquisition Strategy
8 Technical summary

As with any modelled product, it is important to understand how it was developed and the assumptions made in order to understand its suitability in any given application. The use and appropriateness of archaeological predictive modelling has received considerable debate in academic literature, so the purpose of the following discussion is to demonstrate that the ASDST statewide pre1750 models have been developed using international best-practice, including innovative developments in this field. The method has an established scientific credibility being:

- based on well-established methods
- presented at academic conferences, and
- prepared for publication peer-reviewed journals (see Section 10).

While some archaeological scholars have argued that what is really required is a better understanding of archaeological meaning (Wheatley 2003), the approach adopted by the ASDST is to acknowledge that archaeological meaning is an on-going challenge for existing archaeological practices.

Instead, the emphasis in the ASDST is on:

- an estimate of whole-of-landscape archaeological potential
- condition, and
- threats and conservation status.

This kind of regional context setting is perhaps the area of greatest information gap in regional planning for Aboriginal site heritage in NSW. Regional context setting is also the basis for Aboriginal communities to appreciate their own heritage and from which archaeological meaning can be investigated. Understanding conservation status at a landscape scale is therefore a key application of the ASDST. The approach to developing the ASDST products has drawn heavily on the importance given to similar kinds of information used in systematic conservation planning for biodiversity (Ferrier & Wintle 2009).

Since the model building exercise was for such a large area (800,000 km²), and was based primarily on existing site data, it was logical to form a model using what has been called an ‘inductive’ or ‘correlative’ approach (Kohler & Parker 1986), or presence-only modelling in ecology (Zaniewski et al. 2002). However, this decision was largely determined by the scale and intended application rather than any pre-conceived idea about how archaeological predictive models should be formed (cf. Canning 2005), and acknowledges that the artificial dichotomy between inductive and deductive approaches is generally unhelpful (Kvamme 2006, 13; Ridges 2006, 124). Although primarily based on an inductive approach, the model building process involved elements of deductive approaches through the use of expert opinion (cf. Pearce et al. 2001). Nonetheless, the use of inductive approaches has generated considerable debate about methodology (Ebert 2000), which is addressed through the following technical discussion.

8.1 Statistical method

The statistical technique most commonly employed in inductive archaeological predictive modelling (APM) is logistic regression, with most discussion focusing on how to utilise it most appropriately (Warren & Asch 2000, 9; Woodman & Woodward 2002, 24). However, little of this discussion has incorporated advancements in technique developed in species modelling (Elith & Leathwick 2009; Scott et al. 2002), despite the statistical problem of modelling species being identical to modelling sites. There has been considerable effort in ecology given to developing better statistical methods to deal with most of the technical problems with presence-only modelling (eg Scott et al. 2002), with many of these issues being the same as those identified in the APM literature (Lehmann et al. 2002). The statistical approach adopted for the ASDST was a non-parametric form of logistic regression called generalised additive
modelling (GAM), as implemented in S-Plus with the GRASP tool (Ridges 2003, 104-108). The significant advancement with GAM models is the relaxation of the linear requirement of fitted models, enabling more realistic curves to describe the relationship between dependent and independent variables (Woodman & Woodward 2002, 24), an issue identified as hindering the use of logistical regression in APM (Elith et al. 2006; Elith & Leathwick 2009). The use of GAMs has been shown to perform strongly when compared to a variety of other statistical approaches used in species modelling (Insightful 2005, 298), substantiating its use in the ASDST.

Figure 39 displays the response curve for a fitted GAM model using the proximity to streamline weighted by stream order variable for the stone artefacts model. The response curve is the result of the algorithm used by the S-Plus GAM function to calculate the additive contribution of each variable using non-parametric smoothing methods, in this case a spline smoother that applies a cubic function over sections of the data like a kernel filter (for an archaeological example see Warren & Asch 2000, 18). In Figure 39, the horizontal axis is the variable values (bars are data values), and vertical axis is the scale of additive predictor prior to being combined with other variables in the model (positive values favour sites, negative values favour absences). The dashed line is the standard error about the fitted model. Such plots were evaluated for each variable during the model building process.

Figure 39. Example of a non-linear curve fitted for the proximity to stream line weighted by stream order variable (sth1k) by GRASP using a GAM model

GRASP version 3.3 was utilised for this project. One of the features of the current version that was missing from previous releases was the ability to force the inclusion of particular variables. Previously, GRASP would use a step-wise comparison of all variable combinations in order to select a combination that fitted the data best (Elith & Leathwick 2009, 85). However, for the first step of the model building process, models were formed using all variables so that during following workshops and model evaluation, particular variable combinations could be assessed systematically. This was an iterative procedure where a combination of statistical tests of model performance and validation tests looking at the pattern of mapped predictions of each model, was used to determine the final set of variables used in each model (see Table 7 for variables used in each model and Section 8.8 for further discussion).
Within GRASP, the following parameters were used for all models:

- Weights 0s = 1s: this was turned on so that models produced for rarer features would utilise the full predictive range of the input variables
- DF = 6: the degrees of freedom determines the complexity of the spline smoother fitted during the model building process, and is a compromise between model generality and over-fitting driven by the influence of outliers.

### 8.2 Generation of pseudo absences

The procedure of generating a model with logistic regression (and a GAM) is to use a binary dataset containing known sites (presences) and locations where sites are not present (absences). While the AHIMS database provided the source of the presences in this project; the database does not store information about site absences. Ideally site absences should be a set of locations that have been surveyed to confirm the absence of the features of interest. However, at the scale of this project, such a comparison set of data was not available or feasible to collect.

The literature on APM rarely discusses strategies of generating a comparison set of absences, with most applications using absences confirmed through survey (for smaller scale studies) or a set of random points. In the fauna modelling literature these are referred to as pseudo absences since any of these absences may contain an occurrence of the feature of interest. Several possible approaches to generating pseudo absences were investigated:

- DECCW’s GIS layer of archeologically surveyed areas. Although this provides some indication of site absences (areas where no sites were recorded), it was difficult to assume absences were real absences because of variation in survey design, sampling methodology, and the way detectability was addressed in different studies. Adding to this problem, the surveyed areas layer closely follows those areas of highest recording density, so while useful on a local scale, at the scale of the whole state, it suffers from the same biases in AHIMS data (see Section 4.3).

- An alternative approach was to use AHIMS data as the absences. In this approach, to generate a stone artefact model, all AHIMS sites with stone artefacts become the presences, and those without them become the absences. However this approach also has problems. For example, whether or not a particular feature occurs at a given AHIMS site depends on a variety of factors: whether that feature was once there but has since been destroyed or not preserved; whether the feature was detectable at the time of recording (i.e. whether the site was excavated or the level of detail in which was studied); and the pattern of absences would again reflect recording intensity, not necessarily the true pattern of absences in the landscape.

- A set of fully random points. This is the most common approach adopted in APM studies based on logistic regression. However, this approach was found to exaggerate the biases in the AHIMS database.
The problem of generating pseudo absences with method 2 and 3 are illustrated in Figure 40. Both maps are of the same area, modelled for stone artefacts. The bottom right hand corner of each map is the upper Hunter Valley where there is a very high density of site recording. The left map was produced using AHIMS data without artefacts as absences, and it has produced a model that emphasises areas away from the density of recording. The map on the right in Figure 40 was generated with a set of random points as absences, but has produced a model that over-emphasised predicted likelihood in the area of highest recording density. Consequently, it was decided that neither of these methods of generating absences was producing suitable results.

These are similar findings to those in other studies which have highlighted where the distribution of pseudo absences should be informed by the distribution of the feature of interest and biases in the input data (as of June 2010, see Department of Environment and Conservation NSW 2006). The approach adopted for this study was to use a combination of methods 2 and 3. A custom GIS script was developed that generated points randomly, but in varying density according to AHIMS records. This was achieved in the following way:

- For each occurrence of the feature of interest, generate a point at a random bearing and random distance (up to a maximum of 20 km) from the current site.
- Test to ensure that the point falls within the study region. If not generate another point.
- Check to see if the point occurs within 150 metres of an existing site. If so, generate another point.
- Check to see if the point occurs within 150 metres of a previously generated random point. If so generate another point.
- Continue until all input sites have had a random point generated for them.
- Combine these points with a set of fully random points of equal number to the number of input sites.
- Within GRASP, reduce the weight of each pseudo absence to 0.5 so the sum of weights of absences equals the number of input sites.

This approach of generating absences was found to produce results that best balanced the recording intensity bias in AHIMS, and sampled the entire landscape.

8.3 Data quality

The AHIMS database holds information about approximately 60,000 records (cf. Martin 2006). However the distribution of these sites is far from uniform due primarily to spatial bias in recording intensity (see Figure 41). Recording density has been highest in the Sydney basin, upper Hunter Valley and parts of the south coast. Regionally, there are densities of recordings around towns and roads and other infrastructure (ie pipe lines). Significantly, there are also
large gaps in AHIMS recording which highlights why AHIMS data are not a good indicator of total archaeological potential across the landscape in many parts of the state.

The information in the AHIMS database may be up to 50 years old, leading to variety of potential errors such as positional and attribute accuracy. At the time of initial model development (October 2007) AHIMS contained 52,160 records (see Table 6 for a breakdown by feature type). Some of these records were eliminated because they either contained no spatial reference, or the spatial reference was plotted outside NSW. Some of these were plotted in the ocean, others in adjoining states. The total records plotting within NSW was 51,100. Of these, 49,472 contained features that were modelled. Data were also screened for attribute errors, such as sites incorrectly labelled as ART instead of AFT (due to data entry errors). Similar issues with the way shell and mounds have been recorded in the database (many coastal middens are recorded as mounds, and many western mounds contain shell), were also addressed. In this case, mounds and shell from coastal drainage basins were modelled as one feature, and mounds and shell from western NSW drainage basins were modelled as a separate feature. Further work, involving review of site cards, is required on the models of these features to ascertain an appropriate approach to distinguishing the occurrence of mounds as a unique archaeological feature (Ridges 2006).

Figure 41. Distribution pattern of AHIMS data as of June 2010 (n = 63,833)

Given the size of the database it was not possible to adopt an approach to data screening that was exhaustive. However, data quality in AHIMS is an ongoing commitment by DECCW and is regularly reviewed as inaccuracies in the data become apparent.
Table 6. Breakdown of feature frequencies modelled for the ASDST (at October 2007)

<table>
<thead>
<tr>
<th>Feature</th>
<th>Records</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stone artefacts (AFT)</td>
<td>32,339</td>
</tr>
<tr>
<td>Rock art (ART)</td>
<td>6,942</td>
</tr>
<tr>
<td>Burials (BUR)</td>
<td>1,208</td>
</tr>
<tr>
<td>Western mounds and shell (ETM)</td>
<td>1,354</td>
</tr>
<tr>
<td>Grinding grooves (GDG)</td>
<td>3,169</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Feature</th>
<th>Records</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hearths (HTH)</td>
<td>2,369</td>
</tr>
<tr>
<td>Coastal shell (SHL)</td>
<td>3,785</td>
</tr>
<tr>
<td>Stone quarries (STQ)</td>
<td>395</td>
</tr>
<tr>
<td>Scarred trees (TRE)</td>
<td>6,147</td>
</tr>
</tbody>
</table>

8.4 Appropriate variables

The variables used to form the pre1750 models are listed in Table 7 (see Section 8.5 for a description of variable derivation). One of the critical areas of forming predictive models is the choice of variables (Gaffney & van Leusen 1995; Wheatley 2003). There has been sustained criticism of APM based on inductive models because of its reliance on environmental variables at the expense of variables describing social and cultural behaviour (following Llobera 2001). While the need to define appropriate cultural variables was recognised, the difficulty of doing so at the scale of this project also had to be acknowledged. The models incorporate variables describing the inter-visibility of key parts of the landscape such as ridgelines and prominent peaks, as these are a form of cultural variable that is regularly explored in analysis of cultural landscapes (Keith 2004) and could be derived from available statewide datasets. Inter-visibility was found to be a key factor influencing the occurrence of rock art sites.
Table 7. Variables used to derive each pre1750 model

<table>
<thead>
<tr>
<th>Variable*</th>
<th>AFT**</th>
<th>ART</th>
<th>BUR</th>
<th>ETM</th>
<th>GDG</th>
<th>HTH</th>
<th>SHL</th>
<th>STQ</th>
<th>TRE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aspect</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coast proximity</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Terrain curvature</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Easting/northing</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elevation</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Geology</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Landscape inter-visibility</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Pre1750 vegetation</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proximity to lakes</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proximity to quarry geology</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Proximity to rivers</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Proximity to streamline weighted by stream order</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proximity to streamlines</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<td>X</td>
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<tr>
<td>Proximity to wetland edge</td>
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<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rainfall</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ruggedness</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slope</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soils</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Temperature</td>
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<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Wetlands</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* For a discussion of how these variables were derived, see Section 8.5
** These codes are listed in the Glossary.

A related point about the choice of variables is the method developed in this study for the inclusion of categorical variables for particular feature types. For feature types like rock art and grinding grooves, categorical variables such as geology were critical for describing their potential distribution across the landscape. In these cases some geology types (e.g., sandstone) could be identified as playing a key role. However, for other categorical variables like soils and vegetation, the spatial bias in AHIMS data (see Section 8.3) meant that a large number of classes had little or no AHIMS site data, hindering their effective use in model building. The solution to this problem was to transform statewide soil and vegetation data into continuous data. For vegetation (see Section 8.5.4 and Figure 42) this was achieved using compositional data (Mitchell 2002) intersected with ecosystems (McKenzie et al. 2000). For soils (see 8.5.5 and Figure 43) it was achieved by utilising continuous data describing the physical properties of soil types (Chapman & Geary 2000; Wheatley & Gillings 2000).

The transformation of these categorical variables into continuous ones resulted in models that could deal with the spatial bias in input data much more effectively than in previous APM studies. What the models could describe for well-sampled vegetation types and soils it could project onto to similar vegetation and soils that were less well-sampled.
8.5 Variable derivation

8.5.1 Elevation

The elevation layer (digital elevation model or DEM) was derived from data produced by NASA's Shuttle Radar Topography Mission (SRTM, see: http://www.jpl.nasa.gov/srtm/). The data was downloaded from their FTP site (ftp://e0mss21u.ecs.nasa.gov/srtm/), as 1 degree x 1 degree tiles and combined into a single GIS layer for the state. The product downloaded was the Shuttle Radar Topography Mission (SRTM) version 2, which had been subjected to more rigorous data cleaning prior to public release. The grid cell resolution of the data was 90 metres, which was re-sampled to 100 metres for use in this project.

The SRTM data was used in preference to other DEM data held by DECCW because it provided a single consistently collected set of elevation data across the whole state at reasonably high spatial resolution. However, the SRTM data contained numerous data gaps that had to be cleaned prior to use in model building. These gaps were filled by performing a focal median with a radius of three cells on the DEM and these values substituted for gaps in the original layer. For larger gaps, values obtained from Geoscience Australia's 9 sec DEM of Australia were used to replace null cells.

8.5.2 Terrain indices

The SRTM DEM was used to derive a variety of terrain indices to form variables for use in the pre1750 models. These included slope, aspect, ruggedness, topographic position and inter-visibility.

Slope was derived using the standard GIS slope function in ESRI’s ArcGIS, and calculated as degrees of slope. Aspect was also derived using the standard GIS function in ArcGIS, and expressed as bearing in degrees. Ruggedness was derived using a focal cell function that performs a calculation using the surrounding cell values of each cell in a raster grid layer. The ruggedness index calculates the standard deviation of cell values in the window cells around each cell in the SRTM dataset. The calculation was performed using windows of two sizes, a 3x3 cell window, and a 9x9 cell window, generating two ruggedness variables of different scales that could be used for modelling. Topographic position was derived by using the curvature GIS function on the DEM layer. The function examines the degree to which the 3x3 cell window around each cell describes a surface that is upwardly convex or concave. Positive values in the resulting layer identify terrain that is on a ridgeline or top of a hill, whereas negative values describe valleys. Zero values reflect flat terrain. The topographic position variable is useful for describing the terrain position at each cell in the DEM.

Inter-visibility is a variable that has been used extensively in the investigation of cultural landscapes (Mitchell 2002). The approach involves taking a location and identifying which parts of the landscape are visible from that place. For this project, the process was modified whereby a grid of points regularly spaced at 1 km intervals was placed across the state, and for each grid cell, the number of these points that were visible within a 20 km radius, and which were higher in elevation than the given grid cell, was calculated with the visibility function in ArcGIS. The process is a computationally intensive exercise, and it took a GIS workstation three weeks to derive. However, the result is a GIS layer that shows those visually prominent places in the landscape such as peaks and ridge lines. In terms of behavioural theory, it is assumed that visually prominent places might be those preferred for particular activities, such as producing rock art.

8.5.3 Geology

The geology layer used for this project was bedrock geology compiled by the Department of Primary Industries, NSW (DPI), and supplied to DECCW. This layer is a vector polygon GIS layer combining the best-available geology mapping merged into a single layer with consistent attributing for rock unit and rock type.

The layer used for modelling was derived from this product. Geology was used for modelling three feature types: rock art, grinding groves and stone quarries. AHIMS records for these
features intersect with a large number of mapped geology units (too many to incorporate as classes in a categorical variable), so rather than use all unit types or rock types (which still resulted in too many category levels), a two-step method was used to identify those polygons suitable for including in a geology variable for each feature.

**Step 1. Identifying rock units**

AHIMS data for grinding grooves, rock art and quarries was intersected with the geology layer to identify the rock units associated with these features. This was done as follows:

- Query AHIMS data for feature type (ie rock art, grinding groves or stone quarries)
- Perform a spatial query to select those polygons in the geology layer that contain any of the selected AHIMS records.
- Identify the key geological units that define the distribution of the feature of interest\(^5\).
- Perform a query on the geology layer to select all areas where these geological units occur.

**Step 2. Simplified geology attributes**

The number of units for each of the site features to be modelled with geology was too large to be used as a variable in its own right (see Table 8). Incorporating categorical variables into the model exponentially increases the computational demands of deriving a model. Ideally, categorical variables for the model should be limited to one or two with fewer than 20 categories each (Lehmann pers. comm.). To overcome this problem, each geological unit was assigned a simplified rock type according to the scheme set out below:

- Sedimentary – fine grain size (eg mudstone)
- Sedimentary – medium grain size (eg sandstone)
- Sedimentary – coarse grain size (eg conglomerate)
- Metamorphic – fine grain size (eg slate)
- Metamorphic – medium grain size (eg quartzite)
- Metamorphic – coarse grain size (eg gneiss)
- Intrusive (eg granite)
- Volcanic (eg basalt)
- Unconsolidated (e.g. Quaternary alluvium)
- Other

Assigning the simplified rock type to each unit was achieved using the rock description for each polygon (a single geological unit could have different rock types described if it had sub-units assigned). These polygons were then converted to a grid layer using the simplified rock types to assign cell values, and formed the basis of the variable used within the respective models.

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\(^5\) This step involved a considerable amount of manual intervention using the geological descriptions of each rock unit as a guide, in order to eliminate those units that were identified by the query, but were the result of inaccuracies in the spatial location of the AHIMS records. However, by conducting the process with geological units rather than rock types, a more specific set of geological units were identified. For example, rather than just identifying ‘granite’ as a predictor for rock art sites, it was only those granite rock units which had art sites recorded within them that were incorporated into the geology variable.
Table 8. Number of geological units each feature occurred within

<table>
<thead>
<tr>
<th>Feature type</th>
<th>Number of geological units occurring within feature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Art sites</td>
<td>220</td>
</tr>
<tr>
<td>Grinding grooves</td>
<td>77</td>
</tr>
<tr>
<td>Stone quarries</td>
<td>90</td>
</tr>
</tbody>
</table>

8.5.4 Pre1750 vegetation surrogate

An important variable for describing the distribution of Aboriginal features is vegetation or some measure of landscape variation such as land system. However, at the scale of this project, there were no suitable layers for the whole state that captured landscape variation at a comparable scale to the spatial resolution of survey bias in the AHIMS database (see Section 8.3). The most consistent and appropriately scaled mapping across the state is the Mitchell Landscapes layer (Mitchell 2002). However, of the 571 mapped landscapes, 56 didn’t contain any AHIMS records, and further 95 had five or fewer sites. It was therefore clear that the level of splitting of the landscapes was at a resolution that was higher than the spatial consistency of AHIMS recording density for significant portions of the state.

The vegetation (pre1750) layer developed by Keith (2004) was also considered an important surrogate for biodiversity features across the state. However, a limitation of the layer (for the purposes of this project) was the method used to spatially represent the distribution of the vegetation communities it describes. The layer represents vegetation communities as squares of variable size depending on the accuracy of the underlying vegetation mapping. The strength of the dataset (for the purposes of this project), was the consistency of the classification of vegetation communities for the whole state.

To make the most of the strengths of both these datasets, the two were used in conjunction to derive a similarity matrix for the Mitchell Landscapes. The procedure for undertaking this is described below:

- Each vegetation formation in Keith’s dataset was converted to grid layers using the density class assigned to each mapped polygon (n = 119).
- The area of each density class of each formation occurring within each landscape was tabulated. This produced an area matrix of landscapes by density class for each vegetation formation. For each of these matrices, a pseudo-summed area was derived by summing the areas for each density class with a weighting. The classes used in the vegetation layer were 1 = 0–1% density; 2 = 1–10%, 3 = 10–50%; and 4 = 50–100%. The weightings were applied as follows: (area of density class 1 * 0.01) + (area of density class 2 * 0.05) + (area of density class 3 * 0.25) + (area of density class 4 * 0.75).
- The combined pseudo-summed area for each formation within each landscape was then divided by the area of each landscape to give a pseudo percentage of each landscape containing that community. These values were then combined into a single landscape by community matrix, where the cell values were pseudo percentages.
- The matrix was then converted into dissimilarity scores and analysed with multi-dimensional scaling (MDS). This approach is similar to performing an ordination with principle components analysis except that the technique attempts to describe all variability into a specified number of dimensions, in this case three dimensions. The resulting dimension scores were assigned to each Mitchell Landscape, and used to derive a grid layer for each of the three dimensions. The values along each dimension indicate the similarity of landscapes based on the vegetation communities they contain. Figure 42 shows the result of portraying the three dimensions for each Mitchell Landscape combined as a red-green-blue composite image. The resulting map portrays the degree of similarity in the vegetation of each Mitchell Landscape as similarity in its mapped colour. In this way the map describes spatial turnover in vegetation similarity.
The three grid layers derived using the scores along each dimension then formed three separate variables that were used for modelling.

![Figure 42. Mitchell Landscape similarity obtained from analysing Keith vegetation classes. Similarity in colour represents similarity in pre1750 vegetation](image)

### 8.5.5 Soils surrogate

Soils are a regularly identified variable for influencing the occurrence of Aboriginal sites. This is because soil properties are an important factor affecting the location and preservation of some Aboriginal features (eg burials), and they can be a factor determining landscape variation (particular vegetation resources used by Aboriginal people). Soil properties can also influence the detectability of some Aboriginal features (eg aggrading soils may cover stone artefacts, which then require excavation to determine their presence). However, soils are a problematic variable to use in APM because they are a categorical variable where every class is usually considered independent, and many of these may contain no recorded Aboriginal sites. A further problem is that there is no systematic soils dataset of usable scale (eg 1:500,000 or better) for the whole state.

The following method, effectively transforming the soil categorical data into ratio-scale data, was developed to compile best-available soil mapping for NSW, and utilise data to model spatial turnover in similarity of soil physical properties across the state:

- An updated soil physical properties matrix was obtained for Northcote et al’s (1975) Principle Profile Forms (PPF) as originally published in McKenzie et al. (2000, 5). The data matrix was supplied by Neil McKenzie from the CSIRO.
- The matrix contained 51 fields describing the estimated physical properties of each PPF (Bui et al. 1998). These were evaluated for suitability for quantitative analysis. Seven variables were subsequently excluded because they were categorical variables. The remaining variables were all ordinal-scale data or better.
- The data matrix was transposed and converted to correlations using a Brae-Curtis measure of dissimilarity.
The correlation matrix was analysed with multi-dimensional scaling (MDS) with the following parameters: solve for three dimensions, 50 iterations, Kruskal loss function with non-metric scaling.

Best available soil mapping was compiled from available 1:100,000 and 1:250,000 soil datasets, Murray Darling Basin Commission (MDBC) Mapping (Northcote et al. 1960-1968), and remaining gaps were filled using Mitchell Landscape data and 1:1,000,000 CSIRO soils mapping (e.g. Pickering 1994).

For each dataset, the three MDS dimension scores for each Northcote class were linked to each map unit. This was done in different ways depending on the dataset:

- For the 1:100,000 and 1:250,000 scale soil datasets, the soil classes were generalised into their super-groups (i.e., a map unit of Cd, was generalised to Cd). This significantly reduced coding differences between map sheets and facilitated a better match with soil analysis data in the Soil and Land Information System (SALIS) database. SALIS point data that contained PPF attributes was intersected with the mapping units. For instance, a soil landscape might intersect with 50 SALIS records, each with a PPF linked to the dissimilarity matrix. These were combined into a single dissimilarity score by using frequency that each PPF in the SALIS points intersected with each mapping unit.

- A similar approach of linking the MDS data using SALIS records was performed for the Mitchell Landscape data. Due to spatial bias in the density of SALIS data (there was a strong bias towards the soils landscape mapping areas), only those Mitchell Landscapes that contained a minimum of 10 SALIS points were linked to the MDS data.

- For the MDBC data, a weighted combination of PPFs was used as this information was included in the dataset. Each MDBC soil mapping unit has three PPFs assigned for each mapping unit with a relative percentage for each.

- For the CSIRO 1:1 million scale data, the predominant PPF unit was used to link the MDS data to the mapping units.

The final task was to merge the datasets together. This was achieved by taking the average between MDBC and soil landscapes where they overlapped, and their derived values where they didn’t. For remaining areas outside these two datasets, gaps were firstly filled with available data from the Mitchell Landscapes dataset where there were sufficient SALIS data, and the remaining gaps filled with the CSIRO data.

The final result is a three-axis (i.e., three GIS layers) dataset where each axis is a colour band in a red-green-blue image. Figure 43 depicts the result as a map, where similarity in colour represents similarity in soil physical properties.
8.5.6 Stream orders

Another important variable known to have an influence on the distribution of Aboriginal site features is stream order (Tobler 1993). However, there were no available drainage datasets for NSW that contained information about stream order. While stream orders can be derived from an elevation layer (DEM), the approach is hampered by how accurately the drainage network modelled from the DEM reflects real drainage. Alternatively, stream orders can be assigned manually to a line coverage of drainage, but since the drainage coverage at 1:100,000 scale for NSW contained 175,000 line segments, it was not considered a feasible approach. The process can be automated, but its operation depends on the degree of prior data cleaning performed (ie all line segments need to have node order progressing downstream), a process which again was prohibitive for such a large number of line segments.

Instead, a combination of the two approaches was used:

- The SRTM DEM for Australia was clipped to those catchments that lead into NSW. This included the entire Murray-Darling basin for example, since correct automated ordering of streams requires it be performed on entire catchments. It was another reason for using the SRTM data source since it covers all of Australia.

- The SRTM DEM layer was ‘burned in’ using the real drainage layer. This is a process whereby the DEM layer is artificially altered to create a surface that conforms to real drainage patterns. This was done with a GIS script obtained from www.ce.utexas.edu.au/prof/maidment/gis hydro/ferdi/research/agree/agree.html

- The result from the previous step is then cleaned by performing a ‘fill’ on the surface, ensuring all pits in the layer are removed. Cell values in the layer must first be converted from integer to floating point to perform this function.

- A drainage network was then derived from the cleaned layer. Parameters for this were set to generate a network with approximately the same level of complexity as that seen in the 1:100,000 drainage layer.
• The drainage network was then ordered using the Strahler method and standard hydrology GIS functions.
• The median value of the modelled stream order that intersected with each line segment of the real drainage layer was calculated, giving an initial ordering.
• The resulting orders were then manually edited to ensure consistency and accuracy – especially in the areas of higher stream order where the modelled orders didn't perform very well, and the derived stream network diverged most from the real network of drainage. Manual intervention was also required in floodplain areas like the Riverina because of the complexity of flow direction in these areas.

8.5.7 Proximity measures to water and other resources

Proximity to water and other key resources is an important variable for understanding site distribution in a dry landscape like Australia. However, water is a complex variable since it occurs in a variety of forms (surface/ground, stream/wetland). For this reason, several water proximity measures were derived for input into the models. A key to all of these measures is the use of cost-distance rather than linear distance as a measure of proximity. Unlike linear distance, cost distance takes into account the difficulty (or cost) of traversing a given distance. Thus, for two pairs of locations separated by an equal distance, with one set having a mountain range between locations, then the cost distance of traversing this pair would be higher. The calculation of cost-distance requires a friction surface that reflects the cost of traversing across each grid cell. The cost surface used for deriving the proximity variables was based on Tobler’s (see Ridges 2006, 128) equation of hiking velocity, which models hiking speeds of 5 km/h on level terrain then decreasing exponentially as slope increases. Thus:

\[ W = 6 \left( \exp^{-3.5 \times \left( \frac{dh}{dx} + 0.05 \right)} \right) \]

where:

\[ W = \text{walking speed in km/h} \]
\[ \frac{dh}{dx} = \text{slope expressed as rise over run} \]

Tobler’s equation was applied to the SRTM DEM to produce a layer that modelled the potential walking speed for all areas of the landscape based on slope. This layer was used as the cost surface for the following proximity measures:

• Cost-distance from all drainage lines. This variable captures proximity to drainage of any kind.
• Cost-distance from rivers. Rivers were identified by line segments that had ‘Rivers’ included in the name attribute. This variable captures proximity to major rivers.
• A proximity to drainage weighted by stream order. This was derived by taking a cost-distance from all segments of each stream order. The resulting layers were combined using a weighting for each order, i.e. cost-distance from first order streams + (2 X cost-distance from second order streams) + (3 X cost-distance from third order streams). A custom GIS script was developed that calculated the cost-distance from each stream to a nominated maximum total cost. The larger the maximum cost, the more generalised the result. Two distances were used – an estimated walking time of one hour, and of two hours. The resulting variable describes water proximity adjusted for stream order, along with confluences where larger drainage lines meet (DECC 2008).
• Proximity to wetland edge. This captures those areas that are close to wetlands.
• Proximity to the coast. This measure captures a surrogate of proximity to marine resources.
• Proximity to lakes. This captures proximity to inland lake systems.
• Proximity to stone quarry geology. For the identified geology classes to be associated with stone quarries (see Section 8.5.3), the proximity to them was derived with the Tobler cost surface. This was used as a variable for the stone artefact model.

8.6 Land-use parameters for estimating impacts

In order to describe the predicted likelihood of features in the current landscape, each pre1750 model was modified to take into account estimated impacts since European settlement. The basis of this approach is that land use and land-use history act to reduce the likelihood of site feature survival to different amounts depending on the feature and the nature of land use. The process followed was to prepare parameters for a set of land-use classes against each feature type estimating potential survival rates of features under each land use. This involved two datasets, a land-use layer, and a parameter lookup table.

The pre1750 models were modified to reflect current likelihood with the following methodology:

• A copy was obtained of the land-use layer prepared for the NSW Interim Native Vegetation Extent project (see DECC 2008). This layer represents best-available land-use data for NSW.
• Land-use classes in this layer were simplified into 33 categories.
• National park tenure was modified to reflect the original tenure before the gazettal of each park. ‘NP, new class’ was added to give parameters to those parks that had previously been state forests or other production-based land uses.
• The resulting land-use classes were intersected with a simplified classification of the NSW Interim Native Vegetation Extent layer. This layer was originally classified based on the confidence in each grid cell being native vegetation or not (DECC 2008 Appendix 1).
• The NSW Interim Native Vegetation Extent layer was simplified into the following three categories: highly modified (some native vegetation including native grasslands but in poor condition), cleared non-native (plantations, orchards etc), and native.
• The land-use layer was intersected with the vegetation extent layer, and parameters were entered for each resulting class (134 in total) against each feature on the likely survival of that feature under that land-use / land condition scenario. The parameters were derived from consultation with DECCW staff, personal experience, application in various projects (see Section 7), and the Nativeness Lookup table in the Interim Vegetation Extent Report (eg Fielding 2002). The parameters entered ranged from 0 (assumed the feature would be completely destroyed under the land-use scenario) to 100 (assumed the feature would be preserved at a similar likelihood under a no impact land-use history). The parameters used in deriving the version 7 current models are listed in Table 9.
• The current likelihood version of each model was derived by assigning the relevant parameter values to the grid cells in the derived land-use / condition layer, dividing the values by 100, and multiplying this layer with the relevant pre1750 model. If the parameter was 100, then the likelihood value in the current layer would be the same as that in the pre1750 layer. Lower parameters reduce the likelihood scores, thus 50 reduces the likelihood by a half, 0 reduces the likelihood to zero. Thus:

\[ M_{f_{\text{current}}} = M_{f_{\text{pre1750}}} \times \left( \frac{I_x}{100} \right) \]

where:

\( I_x \) = is the impact parameter for the given feature, based on land-use lookup parameter at grid cell x (see Section 8.6)
8.7 Derivation of the ALL model

Along with models for each of the feature types that were modelled for the ASDST, it considered desirable to combine these into a single model simplifying some of the visualisation and analysis. Two approaches were investigated to do this:

- Deriving a new model incorporating all the variables used to form the feature models
- Combining the models arithmetically.

The first method was complicated by uncertainty about how to appropriately incorporate all the variables when each had been modelled with different curves for each feature. One concern was that the way particular features respond to each variable would be lost or remodelled in this approach. A further complication was how to develop a current version of the ALL model if this approach was used. This would require a separate list of land-use parameters which wasn’t desirable as it would possibly mask how individual features had been impacted.

The preferred option was to combine the models arithmetically by taking the maximum likelihood for each model, for each grid cell. This was replicated for both the pre1750 and current versions of each model. The resulting ALL models are therefore true to the underlying feature models, and represent the maximum likelihood for any feature.

The ALL model represents the maximum likelihood of all feature models. This is true for the pre1750 and current version of the ALL models. In this way interpretation of the ALL models follows that for the feature models in terms of the relative nature of predicted likelihood.
Table 9. Parameters used for calculating impacts

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8.8 Model validation

A critical aspect of any model building exercise is validation. However, a little explored aspect of APM are the analytical complexities of model validation (Altschul 1988, 62). Factors influencing the ability to validate a model appropriately include:

- spatial variability in original site probability
- taphonomic factors influencing site preservation
- land-use history affecting accumulated impacts, and
- feature detectability (eg whether surface inspection or excavation is required to locate stone artefacts).

All these factors affect how and whether models can be effectively validated. Thus effective model validation is a complex task and requires a number of approaches, the untangling of several interacting factors, and ongoing investigation.

Errors in the modelling process can be of two kinds (Ebert & Kohler 1988, 105):

- the model predicts features to be present, when in fact there are none (a Type I error), and
- the model predicts that no features are present when in fact some are (a Type II error).

Ideally, a model aims to minimise both types of errors. However, from a heritage management perspective, Type II errors are potentially worse since decisions made on the assumed absence of sites can lead to their inadvertent destruction.

Errors in the predictions of models are inevitable and can come from a variety of sources including:

- insufficient sample size
- measurement error in the site data (location or attribute errors)
- inadequate spatial resolution or measurement error in the GIS layers used as variables
- insufficient knowledge about the motivations of Aboriginal behaviour in particular places or contexts, leading to non-incorporation of key variables

For this project, the intention of forming a model was to map the spatial pattern by likelihood of features occurring. However, this does not take into account detectability of the features. For example, in considering the current distribution of stone tools, factors such as geomorphology and vegetation can have a great influence on whether or not they are detectable (through surface inspection) at any given location – regardless of whether or not they are actually there. Thus it is important to be clear about what a model is describing. Is it all possible distributions of features or a distribution taking into account the difficulty of locating them (Elith & Leathwick 2009, 82)? Consequently, whether or not feature detectability is built into a model greatly influences the approach adopted to validate it.

As the focus in ASDST is on management of Aboriginal site heritage in its totality, all the models described in this report do not take into account the detectability of the features they describe.

8.8.1 Model evaluation tools

In one sense, if a model is derived using correlative or statistical based methods, and it cannot be shown that the model adequately reflects the data fed into it, then the model would have to be seriously questioned. However, as a general rule, the larger the sample of data fed into a model, the greater the likelihood that a statistically significant result will be obtained even if the predictions may not be particularly useful. For this project, with over 60,000 sites to work with, the probability of being able to achieve a statistically significant model was quite high. However, this does not equally mean that a useful model has been formed. A more considered approach to evaluating a model is to not only ensure that it passes a statistical
significance test, but to ensure as best as possible that the predictions made from it are sensible.

Presence-only models, because they are based on a comparison with pseudo absences rather than real absences (see Section 8.2), cannot be evaluated with normal model evaluation statistics because they are not a measure of real cases, but a measure against a sample of landscape variability. This makes appropriate validation statistics difficult, with the most useful (Fielding & Bell 1997) being the receiver operating characteristic (ROC) (Lehmann et al. 2004, 41) implemented in GRASP (Dalla Bona 2000).

This procedure involves a cross-validation made with subsets of the entire dataset, where each subset contains an equal number of randomly selected data points. Each subset is then dropped from the model, and the model is recalculated and predictions made for the omitted data points. This is similar in principle to the method commonly used in the APM literature for finding a cut point to calculate the proportion of observed presences correctly predicted by the model (Phillips et al. 2006, 244), but applies it for all possible cut points and combines the results. The ROC statistic is then calculated as the area under the curve which measures the degree to which the model, on average, can distinguish between presences and absences (Ebert 2000, 133). Figure 44 shows an example ROC for the stone artefact model with a ROC result of 0.748. The ROC statistic was calculated for all models evaluated. Results generally ranged between 0.70 and 0.85, confirming all models were statistically valid – an improvement on the observations of common site predictive model performance observed by Ebert (Lehmann et al. 2004, 42).

![Figure 44. Example of ROC curve and statistic for the stone artefact model produced by GRASP](image)

Although the ROC was calculated for all models evaluated, it was found to vary only little between model permutations even though there could be radical differences in the spatial pattern of predictions. In other words, a variety of models could be defined for a single feature type that were equally good at statistically distinguishing between presences and absences, although not all were equal in terms of generating sensible and usable predictions. Hence it was found that the real issue with evaluating a model was to understand the inherent variation in the variables used and the sensibility of the predictions made from the model. For this reason, the most useful tools in GRASP for evaluating each model were found to be the lookup tables used for rapid calculation of predictions in the GIS, and variable contribution plots.

GRASP utilises a method of calculating prediction summaries in lookup tables that can be exported to the GIS and converted into spatial maps of predictions using the highly efficient...
raster calculations in the GIS. By adopting this approach, the spatial predictions of a model for the whole state could be viewed within a few minutes, even though this involved predictions for over 80 million grid cells. This permitted many permutations of each model to be visualised against landscape context and AHIMS data in the GIS and enabled the ‘sensibility’ of predictions to be evaluated against landscape context.

The other approach used for model evaluation was the derivation of variable contribution plots using GRASP (Faith & Walker 1996). Figure 45 presents an example of a variable contribution plot illustrating the relative contribution of each variable to the model presented in three ways. Each histogram bar represents a variable, and the same bar on each row across all three histograms represents the same variable.

The left histogram, selection contribution (drop), measures the drop in deviance explained if the variable is removed from the model. The central histogram, model contribution (inside) shows the relative contribution of each variable within the model. The right histogram, potential contribution (alone), quantifies variable performance measured if they were the only variable used to form the model.

The variable contribution plots allowed a sophisticated comparison of many permutations of variable combinations and permitted an informed decision (incorporating review by archaeologists familiar with particular regions) about choice of variables and parameters. For example, variables that consistently measured low in the drop measure were left out of the model, and variables that performed well against the alone measure (such as proximity to water), were found to be less important when the combination of variables, inside, was considered. The final combination of variables used in each model (see Table 7), was largely a result of considering many combinations of variables with the variable contribution tool and the spatial pattern of the predictions they produced.

8.8.2 Validation using independent data

Generally it is accepted that the best approach to validating a model is to measure how well it performs against independent data. The approach taken here was to accept that at the statewide scale, validation will have to be an ongoing exercise. There are no datasets outside AHIMS that could test the models in their entirety. However, the approach adopted for the project was to use the independent data added to the AHIMS database since model building began in 2007. The majority of this data has been collected without knowledge of, or guidance from, ASDST products.

Since 2007, approximately 10,000 sites have been added to the AHIMS database. However, much of the new recording has been influenced by the same type of biases identified in the original model input data (see Section 8.3). Little of the new data has been targeted to test critical areas of the model. This is illustrated by the fact that 82 percent of the sites recorded since 2007 are located within five kilometres of previously recorded sites. Nonetheless, the data can be used to give some indication of model performance.
Table 10. Validation results using post2007 AHIMS data\(^6\)

<table>
<thead>
<tr>
<th>Code</th>
<th>Model</th>
<th>Input sites</th>
<th>New sites (since 2007)</th>
<th>% new</th>
<th>Mean (pre2007)</th>
<th>Mean (post2007)</th>
<th>% diff of means</th>
<th>% new sites predicted &gt; 250</th>
</tr>
</thead>
<tbody>
<tr>
<td>AFT</td>
<td>Stone artefacts</td>
<td>32339</td>
<td>6495</td>
<td>20.1</td>
<td>590</td>
<td>555</td>
<td>3.5</td>
<td>95.6</td>
</tr>
<tr>
<td>ART</td>
<td>Rock art</td>
<td>6942</td>
<td>317</td>
<td>4.6</td>
<td>656</td>
<td>605</td>
<td>5.1</td>
<td>92.4</td>
</tr>
<tr>
<td>BUR</td>
<td>Burials</td>
<td>1208</td>
<td>162</td>
<td>13.4</td>
<td>611</td>
<td>634</td>
<td>2.3</td>
<td>95.7</td>
</tr>
<tr>
<td>ETM</td>
<td>Western mounds / shell</td>
<td>1354</td>
<td>714</td>
<td>52.7</td>
<td>696</td>
<td>662</td>
<td>3.4</td>
<td>96.9</td>
</tr>
<tr>
<td>GDG</td>
<td>Grinding grooves</td>
<td>3169</td>
<td>234</td>
<td>7.4</td>
<td>633</td>
<td>542</td>
<td>9.1</td>
<td>88.0</td>
</tr>
<tr>
<td>HTH</td>
<td>Hearths</td>
<td>2369</td>
<td>783</td>
<td>33.1</td>
<td>671</td>
<td>583</td>
<td>8.8</td>
<td>94.8</td>
</tr>
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<td>SHL</td>
<td>Coastal shell</td>
<td>3785</td>
<td>201</td>
<td>5.3</td>
<td>799</td>
<td>727</td>
<td>7.2</td>
<td>96.0</td>
</tr>
<tr>
<td>STQ</td>
<td>Stone quarries</td>
<td>395</td>
<td>67</td>
<td>17.0</td>
<td>668</td>
<td>613</td>
<td>5.5</td>
<td>73.1</td>
</tr>
<tr>
<td>TRE</td>
<td>Scarred trees</td>
<td>6147</td>
<td>1126</td>
<td>18.3</td>
<td>570</td>
<td>566</td>
<td>0.4</td>
<td>98.8</td>
</tr>
</tbody>
</table>

\(^6\) Means for pre- and post-2007 AHIMS data are based on the likelihood score the model predicts for each site. Likelihood scores in the GIS layer range between 0 and 1000. The percentage of new sites predicted at more than 250 is the proportion of sites recorded post 2007 that were predicted by the model to have a likelihood score more than 250.
Figure 45. An example of a variable contribution plot generated by GRASP for the stone artefact model\textsuperscript{7}

\textsuperscript{7} Variable codes: s(wetland): wetland proximity; s(soilav1-3): soil surrogate; s(temp): mean annual temperature; s(stqcost): proximity to stone quarry geology sources; s(sthlk1k and 5k) = proximity stream lines weighted by stream order; s(slope): slope from DEM; s(rugg1 and 3): ruggedness measures; s(rain): mean annual rainfall; s(lakes): proximity to lakes; s(elev): elevation as derived from DEM; s(drncst): proximity to drainage lines; s(curv): curvature.
The proportion of post 2007 sites occurring in areas with medium to high likelihood scores (i.e. greater than 250) for the majority of site features was found to be greater than 90 percent (see). The result highlights that for all models, the majority of new sites are being predicted with medium to high likelihood.

However, also shows that for all models except burials, the mean likelihood scores for the post-2007 data are lower than those used to generate the model. Figure 46 presents the likelihood profile of pre- and post-2007 site data for stone tools. Although the two profiles are very similar, there is a clear shift to the left for the independent data, as is reflected in the lower mean for likelihood scores. Thus, while the models are doing a reasonably good job of predicting the site data recorded since 2007, it is clear that the performance is not as good as the original input data. The largest shifts in mean likelihood scores are seen for grinding grooves and hearths (see Table 10).

For grinding grooves, this is associated with the recording of 20 new sites (10 percent of the new sites recorded since 2007) in the Riverina bioregion, when there had previously only been two. This produced a spike in low likelihood values (see Figure 47). The next version of the model will address this issue by reviewing the geology associated with grinding grooves in this bioregion.

In the case of hearths, the drop in performance is associated with a significant increase in the recording rate of this feature type (up 33 percent). A significant proportion of the new hearth recordings have been on the eastern side of the Great Dividing Range, where previously very few had been recorded. This is presumably associated with how infrequently they are observed along the coastal margin during surface surveys. It is suspected that the increase in frequency of coastal hearths may be connected with them being identified in excavations, but this will require further investigation during the next phase of model review.

In terms of the proportion of sites predicted with medium to high likelihood, the poorest result was for stone quarries. In part, this is associated with this feature having the fewest number of pre-2007 occurrences used to form a model, in which case it takes fewer instances to produce a poor validation result. However, it is also connected with the number of quarries that were recorded in association with geological units where no previous quarries have been recorded. This may indicate that a more inclusive definition of rock types needs to be considered in the next model version (compare with the discussion in Section 8.5.3), and that understanding about the geological sources of stone for making artefacts across all of NSW is a knowledge gap requiring further research.

The best performing model was scarred trees, having one of the lowest drops in mean predicted likelihood for the post-2007 data and the highest rate of new sites with predicted medium to high likelihood. Although this suggests that there would be little to benefit from modifying the model, as with all the feature types, further improvements have been identified for the next version modelling. For scarred trees this will include a review of the tree species that have been scarred, and the creation of spatial variables describing the occurrence of these species specifically.
Figure 46. Stone artefact model predicted likelihood profile for input data and AHIMS data post-2007

Figure 47. Grinding grooves model predicted likelihood profile for input data and AHIMS data post-2007
8.9 Accumulated impacts algorithm

The accumulated impacts product models the level of historical loss of site likelihood as the result of land use since European settlement. For mapped examples see sections 4 and 6.

The degree of loss at any location in the landscape (ie GIS grid cell) has been estimated using the parameters assigned to the probability of survival of each feature type under different land-use classes (see Section 8.6). Such analysis provides an estimate of the level of accumulated impact at that location. However, another aspect of accumulated impact is to consider the level of impact surrounding each point in the landscape. For instance, although the level of impact at any point on the landscape may be low, it is desirable to place that in the context of the degree of loss surrounding it.

The calculation performed adds the amount of loss in the area around each grid cell in each model, applying a distance decay function to the sum, and then combining the results for each feature into a single layer. The steps involved in this calculation are:

- For each feature model, derive the level of impact by subtracting the current model from the pre1750 model.
- For each grid cell in the resulting layer, sum the impact values in a 1 km radius around the cell, applying a weighting as the radius increases to each surrounding cell (to equalise for the larger number of cells at increasing radii), and then a further weighting so that as the 1 km radius is approached the contribution each cell makes to the summed total approaches zero. See Figure 48.
- The final step was to add together the result for each feature into a single layer.

Figure 48 illustrates how the calculation makes use of a focal function to calculate the index. The left map shows an area around a grid cell with surrounding cells coloured by the impact values. To sum the amount of impact in the area around the grid cell, the function adds together impact values applying the distance decay function as shown on the right. The algorithm then repeats the calculation for all cells in each feature model. Mathematically, the calculation for the combined accumulated impact can be given as:

\[ I_{\text{Accumulated}} = \sum_{M_f} f(x) \sum_{I_{SR}} \left( \frac{I_{f(c)}}{2\pi r_{x(c)}^2 \times \frac{R_{SR} - r_{x(c)}}{R_{SR}}} \right) \]

where:
- \( I_{\text{Accumulated}} \) = accumulated impacts summed across all feature models
- \( M \) = all feature \((f)\) models
\( f(x) \) = the expression describing the calculation performed for each grid cell  
\( I_{GR} \) = accumulated impact within search radius of focal cell for current feature model  
\( x \) = focal cell  
\( I_{c} \) = Impact for the feature calculated as: \( M_{1750} - M_{\text{current}} \)  
\( x(c) \) = cell within the search radius of the focus cell  
\( r_{c} \) = radius (in cells) from focal cell \( x \) to surrounding comparison cell \( x(c) \)  
\( R_{GR} \) = search radius (in cells)

### 8.10 SGA and survey priority

As well as model validation in terms of the overall predictive performance, it was deemed desirable to also have an understanding of the spatial expression of that performance. For the ASDST version 7, this was achieved using an implementation of a survey gap analysis (SGA) technique used in ecology based on the environmental distance (ED) measure developed by Faith and Walker (1996). The approach measures the extent to which a selected subset of locations (ie a set of previously recorded sites) represents the overall environmental variability of a landscape, and the degree to which that sample would be more representative if a given grid cell were added to the set. Where the potential contribution of a given cell to improving the overall representativeness of the set of sites is comparatively large, it reflects a large data gap by the set of sites in the set. If the given set of sites is the one used to form the model, then large data gap values indicate where predictions from the model area based on a site sample that poorly represents those areas. Such areas can then be assumed to be less reliably predicted given they are in an area where the set of sites doesn’t sample environmental variability very well. Calculating the potential contribution to improving representativeness of the site sample for all grid cells produces a spatial layer describing the reliability of predictions for that model.

The analytical approach of Faith and Walker (Tansel et al. 1983) utilises the \( p \)-median problem, which models the efficient location of public or industrial facilities in operations research (Manion & Ridges 2009). The objective of the \( p \)-median problem is to locate \( p \) facilities in a space or network so as to minimise total transportation costs to each facility. In the context of SGA, the problem can be adapted to model how to locate \( p \) locations (as new places to survey) such as to maximise the improvement in the representation of landscape variability.

The algorithm developed to apply the \( p \)-median problem involves using the multivariate (ordination) space given by the set of raster GIS layers describing the landscape, and that are used as variables to input into each model. The SGA algorithm (Funk et al. 2005) works with two sets derived from this environmental ordination space, a set of unbiased regularly spaced points that are a sample of the environmental space, referred to as the demand points \( I = \{1, \ldots, n\} \), and the set of sites used to form the model, \( J = \{1, \ldots, m\} \). For each demand point, the algorithm finds the distance (in ordination space) between it and the nearest site location in the site set. The sum of all distances is then used as a measure of the representativeness of existing survey coverage, where smaller totals indicate better representation. All distances are Manhattan distances calculated in ordination space (not geographic space) using range standardised copies\(^8\) of each model input variable:

\[
D_{ij} = \sum_{g=1}^{g=n} |g_i - g_j|
\]

where:

- \( i \) and \( j \) are locations of demand points \( (I) \) and sites \( (J) \), and \( g \) refers to a stack of \( n \) raster grid layers used as input to the model.

---

\(^8\) For categorical variables, grid cell values were derived from the factor loadings calculated by GRASP for each class in the model lookup tables. These give a relative score for the degree to which each class influences predicted likelihood.
For each grid cell, the algorithm then recalculates all distances to compare existing survey coverage to what it would be if the cell was added to the survey set. The difference between these two values measures the improvement in landscape coverage that would be gained if that cell was recorded as a site. In ecological applications, this approach has been used to map the spatial pattern in variation of survey coverage across a region (Manion & Ridges 2009).

For the ASDST, two additional terms were added to the approach. The first of these were weights given to each input grid dataset. Weights were derived from the variable contribution scores for the ‘within model’ variable contribution plots calculated within GRASP for each model (see Section 8.8.1). These scores were range standardised and included as a term in the addition of distances in ordination space. By adopting this procedure, the relative contribution of each variable to the model is replicated in the calculation of survey gap.

The second term added to the SGA algorithm was a weighting for each demand point based on the likelihood predicted from the model. Since the occurrence of site features is not uniform across the landscape, and each feature follows a particular gradient against each input variable (i.e., see Figure 39), applying the predicted likelihood at each demand point as a weight to the calculation of distances permits the distribution pattern of each feature to influence the calculation of survey gap. For example, if a particular feature, like coastal shell middens, is closely associated with the coast, and all previously recorded midden sites are near the coast, then without this type of weighting applied, the SGA algorithm would calculate very large survey gaps for all inland parts of NSW even though there is little chance of this feature occurring there, and therefore it does not represent a real gap in survey data.

The calculation of the SGA algorithm is a computationally intensive process, requiring each of the 80 million grid cells of the analysis mask to be revisited multiple times to calculate ordination distances for 50,000 demand points, against as many as 17 environmental layers. For a GIS workstation this would typically take around 120 hours for each feature, but it was made possible because of an optimisation incorporated into the algorithm (2004).

The resulting raster GIS layer of the SGA algorithm calculated for each feature is summed together into a single layer to produce the model reliability product (see sections 4 and 6). High values in this product identify those parts of the landscape where there is a survey gap against one or more feature types. However, to derive survey priority, it was calculated as the product of three interacting factors:

- the pre1750 likelihood of the feature being present in the landscape
- the level of impact to that feature, and
- the reliability of the model expressed spatially by the SGA algorithm.

The combined survey priority was calculated as the product of these three factors, for each feature and summed together into a single model, thus:

\[
SP_{\text{combined}} = \sum_{f}^{M} M_{f(\text{pre1750})} \times I_{f} \times R_{f}
\]

where:
- \(SP_{\text{combined}}\) = combined survey priority
- \(M\) = all feature \((f)\) models
- \(R_{f}\) = reliability GIS layer derived from SGA algorithm for feature
- \(I_{f}\) = is the impact parameter for the given feature, based on land use at the focal cell (see Section 8.6)
- \(M_{f(1750)}\) = is the pre1750 model for that feature
8.11 Site landscape regionalisation

The site landscape regionalisation product was developed as a method to divide the landscape into areas with a similar archaeological profile in terms of the likelihood of the feature types modelled. The approach is similar in concept to the regionalisation of NSW devised by Witter (2004), however the intention of the ASDST product was to apply the concept at a finer resolution. Such a product can be used for measuring conservation status and representativeness in a similar way to a vegetation or land system map (see Section 7.5). Depending on the application it is also a simpler product to interpret than a stack of 10 predictive models.

The site landscape regions were derived by performing a classification of pre1750 models. The models were combined into a grid stack (like a multi-band satellite image) and analysed in Erdas Imagine using the Maximum Likelihood classifier. The tool performs an unsupervised classification, which involves the algorithm looking at the likelihood scores across all feature models and compares cells to identify a specified number of groups. It is called unsupervised because the algorithm defines the groups on its own. Group assignment is based on the largest differences in likelihood scores between each group, but maximised for intra-group similarity. Once the groups are defined, each cell is assigned a group based on which group it is most alike.

The classification was initially run by specifying three outputs of 50, 20 and 10 groups. Additionally, a comparison dataset was created by performing a Principle Components Analysis on the feature model grid stack, and combining the components into a new grid stack that could be viewed as a colour composite image. This layer showed variation in the similarity of likelihood scores on a cell by-cell-basis as variation in colour. The first three components were those mostly used for this purpose. The 50-class layer was then manually modified by combining groups based on:

- comparisons with the 20 and 10 group classifications
- patterns in the Principle Components Analysis result
- other contextual environmental data (ie terrain and land systems), and
- the distribution of AHIMS feature types.

The final classification into 24 groups (plus a water class) was an arbitrary number based on how well each group was representing AHIMS feature type distributions. The final task was to clean the dataset using a majority filter, which is a GIS function that replaces the class of each cell by the majority class of its neighbours in a 3 x 3 cell window. Table 11 summarises the AHIMS profile for each region.
Figure 49. Site landscape regionalisation
Table 11. Percentage of AHIMS feature types within each site landscape region

<table>
<thead>
<tr>
<th>Label</th>
<th>Major</th>
<th>Minor</th>
<th>Total</th>
<th>ACD</th>
<th>ARG</th>
<th>AFT</th>
<th>ART</th>
<th>BUR</th>
<th>CFT</th>
<th>ETM</th>
<th>FSH</th>
<th>GDG</th>
<th>HAB</th>
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<th>OCQ</th>
<th>PAD</th>
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<th>STA</th>
<th>STQ</th>
<th>TRE</th>
<th>WTR</th>
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<td>AFT, STQ</td>
<td>GDG, TRE</td>
<td>111</td>
<td>1</td>
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acd = ceremony and dreaming, arg = resource gathering, aft = artefacts, art = rock art, bur = burials, cft = conflict, cmr = ceremonial rings, etm = earth mounds, fsh = fish traps, gdg = grinding grooves, hab = habitation sites, hth= hearths, ocq = ochre quarries, pad = potential archaeological deposits, shl = shell middens, sta = stone arrangements, stq = stone quarries, tre = scarred trees, wtr = water features

NOTE: Water class has numerous AHIMS sites recorded for it due to the overlap between mapped lake edges and the locations recorded for sites.
9 References


Ferrier, S., R.L. Pressey & T.W. Barrett. 2000. A new predictor of the irreplaceability of areas for achieving a conservation goal, its application to real-world planning, and a research agenda for further refinement. Biological Conservation 93, 303-325.


Manion, G. & M. Ridges. 2009. An optimisation of the survey gap analysis technique to minimise computational complexity and memory resources in order to accommodate fine grain environmental and site data. In 18th World IMACS / MODSIM Congress. Cairns, Australia.


10 ASDST references


Manion, G. and M. Ridges. 2009. An optimisation of the survey gap analysis technique to minimise computational complexity and memory resources in order to accommodate fine grain environmental and site data. Presented at the 18th World IMACS / MODSIM Congress. Cairns, Australia. 13–17 July 2009.

Forthcoming: