Integrating GIS and remote sensing technologies for indigenous resource management in the Northern Territory of Australia

By Janice McGibbon Crerar

Thesis submitted by Janice Crerar as partial fulfillment of the requirements for the degree of Bachelor of Science with Honours in the School of Biological and Environmental Sciences, Faculty of Science, Northern Territory University. Submitted January 1998.
Statement of authorship:

"I declare that this thesis is my own work and has not been submitted in any form for another degree or diploma at any university or other institute of tertiary education. Information derived from the published and unpublished work of others has been acknowledged in the text and a list of references given"

[Signature]

19th January 1998
Acknowledgements

There are many people who have assisted me throughout the past year and to whom I would like to express my gratitude.

I would like to thank Professor G. Hill, Mr. C. Devonport and Dr W. Ahmad for continued support and time. It was greatly appreciated.

Thanks also to Mr. J. Dillon for technical support when needed, especially during printing of this thesis.

I would like to extend thanks to those who provided me with information regarding both Aboriginal culture and saltwater crocodile biology. Peter Cooke and Michael Storrs of the Northern Land Council for advice and financial assistance for trips to Maningrida. Staff at Wildlife Management International, namely Brett Ottley and Michael Vardin.

Members of BAC, in particular Ian Munro, for advice, encouragement and accommodation during my visits to Maningrida. Thanks also to the Maningrida community, as a whole, for making me welcome during the visits.
ABSTRACT

The use of Geographic Information systems (GIS) by indigenous communities is a growing research field in Australia and overseas. The potential use of GIS by an indigenous community in central Arnhem Land was investigated during this research project. Focus of use for the GIS was resource management of saltwater crocodile eggs. Involvement of the Maningrida community, during development of the GIS, ensured that cultural needs of the community were considered. Hardcopy map output is designed to represent 'country' in a way that is appropriate to the end users of the GIS. Hypothetical clan boundaries were mapped in relation to saltwater crocodile nesting sites using GIS methods to demonstrate the advantages of integrating indigenous knowledge in a GIS. A saltwater crocodile habitat map was derived from Landsat TM imagery by integrating GIS and digital image processing techniques. The resultant map has an estimated accuracy of 93% and identifies potential saltwater crocodile habitat in the study area. In conclusion, results indicate that a GIS can be designed to meet the cultural needs of an indigenous community in central Arnhem Land. There is potential for the GIS to be used successfully at community level for resource management of saltwater crocodile eggs. The GIS is designed so that incorporation of other environmental and cultural information for future management of resources is possible. Furthermore, guidelines have been suggested for the development of GIS for other Aboriginal communities in the Northern Territory of Australia.
Table of contents:

Chapter 1 Introduction ......................................................................................................... 1
  1.1 The relationship between resource management, indigenous peoples and.............. 1
    GIS ........................................................................................................................................ 1
  1.2 Background history to project ..................................................................................... 2
  1.3 Aims and research questions ......................................................................................... 3
    1.3.1 Specific aims of the project are as follows: ......................................................... 3
    1.3.2 Research questions ................................................................................................. 4
  1.4 Significance of Study .................................................................................................... 4
  1.5 Thesis Outline ................................................................................................................ 5

Chapter 2 The Study Area: Central Arnhem Land ......................................................... 6
  2.1 The Bawinanga Aboriginal Corporation ......................................................................... 6
    2.1.1 The research office of the Bawinanga Aboriginal Corporation............................. 7
    2.1.2 Languages of the Maningrida area ......................................................................... 8
    2.1.3 Infrastructure at Maningrida and the Outstations ................................................ 8
  2.2 Environmental characteristics of Central Arnhem Land .............................................. 8
    2.2.1 Climate ....................................................................................................................... 9
    2.2.2 Description of the study area .................................................................................... 10
  2.3 Saltwater crocodile habitat and nesting sites ............................................................... 12
    2.3.1 Habitat of saltwater crocodiles in the Northern Territory of Australia. ................. 13
    2.3.2 Factors affecting nesting and survivorship of saltwater crocodiles ...................... 14
    2.3.3 Resource management of saltwater crocodile eggs .............................................. 16

Chapter 3 Literature review .............................................................................................. 18
  3.1 Indigenous GIS .............................................................................................................. 18
    3.1.1 Indigenous people and GIS: A global perspective .................................................. 18
    3.1.2 Research in indigenous GIS .................................................................................. 19
  3.2 Remote sensing and GIS technologies for resource management .............................. 22
  3.3 Research needs in indigenous GIS .............................................................................. 23

Chapter 4 Indigenous cultural issues in GIS ................................................................. 25
  4.1 GIS, indigenous knowledge and privacy ....................................................................... 25
  4.2 Cultural differences in GIS .......................................................................................... 26
  4.3 Australian Aboriginal relationships with country ........................................................ 28
    4.3.1 The nature of Aboriginal boundaries ................................................................... 29
  4.4 Summary ....................................................................................................................... 32

Chapter 5 Technical issues in GIS, remote sensing and integration ............................ 33
  5.1 Defining remote sensing, GIS and integration .............................................................. 33
  5.2 Data representation within the GIS environment ....................................................... 34
Chapter 6 Methodology ......................................................... 48

6.1 Source Data ................................................................. 48
   6.1.1 Landsat Thematic Mapper image data .......................... 48
   6.1.2 GEODATA AUSLIG TOPO-250K data ......................... 49
   6.1.3 GEODATA 9 second digital elevation model ................. 50
   6.1.4 Crocodile nesting data ............................................... 50

6.2 Creating basemaps of the study area ............................... 51
   6.2.1 Creating a landcover basemap of the study area from
classified remotely sensed imagery .................................. 51
   6.2.2 Creating a topographic basemap for the study area from AUSLIG TOPO-250K data ......... 58

6.3 Mapping saltwater crocodile habitat ................................ 60
   6.3.1 Methodology for applying decision rules to GIS data .... 63
   6.3.2 Applying the mask to Landsat TM image ..................... 65

6.4 Mapping saltwater crocodile nesting sites ........................ 68

6.5 Mapping Clan Boundaries .............................................. 68
   6.5.1 Mapping ‘working’ clan boundaries ............................ 69

6.6 Field Work ................................................................. 70
   6.6.1 Methodology to collect GPS readings in the field .......... 70

6.7 Designing a culturally appropriate GIS ............................ 71

Chapter 7 Results and Discussion ......................................... 74

7.1 Results ........................................................................... 74
   7.1.1 Topographic basemap of study area derived from AUSLIG data ........................................ 74
   7.1.2 Landcover basemap of study area derived from Landsat TM imagery ............................ 74
   7.1.3 Mapping saltwater crocodile habitat ........................................ 88
   7.1.4 Mapping saltwater crocodile nesting sites ............................ 88
   7.1.5 Mapping clan boundaries ............................................. 88
   7.1.6 Designing a culturally appropriate GIS for use by the Maningrida community ............... 88

7.2 Discussion of results in relation to aims and research questions ......................................................... 92
   7.2.1 Investigating the potential of integrating GIS and digital image processing techniques to map the potential habitat of saltwater crocodiles ........................................ 92
   7.2.2 Investigating the potential for using GIS methodologies to map Aboriginal clan boundaries ........................................ 95
   7.2.3 Creating a GIS that will assist in resource management of saltwater crocodile eggs for the study area ........................................ 97
   7.2.4 Creating a GIS that can be expanded to incorporate a range of cultural and environmental information ........................................ 101
   7.2.5 Developing a design concept for a culturally appropriate GIS database for use by Aboriginal people in the Northern Territory ........................................ 102
   7.2.6 General discussion of the overall project ........................................ 103

7.3 Conclusion ....................................................................... 104
List of Figures:

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Location of the study area in relation to the Northern Territory of Australia</td>
<td>7</td>
</tr>
<tr>
<td>2.2</td>
<td>Aboriginal seasonal calendar for Arnhem Land</td>
<td>9</td>
</tr>
<tr>
<td>2.3</td>
<td>Global distribution of saltwater crocodiles</td>
<td>12</td>
</tr>
<tr>
<td>2.4</td>
<td>Floating mats of vegetation form on billabongs</td>
<td>15</td>
</tr>
<tr>
<td>2.5</td>
<td>Mound structure of saltwater crocodile nests</td>
<td>16</td>
</tr>
<tr>
<td>4.1</td>
<td>Clan estates in Central Arnhem Land as described by Hiatt</td>
<td>31</td>
</tr>
<tr>
<td>4.2</td>
<td>McConvell's model of clan estates in the Victoria River Region</td>
<td>32</td>
</tr>
<tr>
<td>5.1</td>
<td>Usery's model for fuzzy boundaries</td>
<td>39</td>
</tr>
<tr>
<td>5.2a</td>
<td>Vector representation</td>
<td>46</td>
</tr>
<tr>
<td>5.2b</td>
<td>Raster representation following conversion from vector</td>
<td>46</td>
</tr>
<tr>
<td>6.1</td>
<td>Unclassified Landsat TM image</td>
<td>53</td>
</tr>
<tr>
<td>6.2</td>
<td>Buffer around tidal sections of rivers</td>
<td>64</td>
</tr>
<tr>
<td>6.3</td>
<td>Final mask that is representative of saltwater crocodile habitat</td>
<td>66</td>
</tr>
<tr>
<td>6.4</td>
<td>Laptop computer experiences in the field</td>
<td>71</td>
</tr>
<tr>
<td>7.1</td>
<td>Topographic basemap derived from AUSLIG TOPO-250K data</td>
<td>75</td>
</tr>
<tr>
<td>7.2</td>
<td>Landcover basemap derived from Landsat TM imagery</td>
<td>76</td>
</tr>
<tr>
<td>7.3</td>
<td>Paperbark stand observed in the field</td>
<td>78</td>
</tr>
<tr>
<td>7.4</td>
<td>Saltwater crocodile habitat map</td>
<td>80</td>
</tr>
<tr>
<td>7.5a</td>
<td>Geographic position of saltwater crocodile nesting sites</td>
<td>82</td>
</tr>
<tr>
<td>7.5b</td>
<td>Saltwater crocodile spatial data linked to attribute tables</td>
<td>83</td>
</tr>
<tr>
<td>7.6</td>
<td>Saltwater crocodile nesting sites flooded during the 1996-97 season</td>
<td>84</td>
</tr>
<tr>
<td>7.7</td>
<td>Saltwater crocodile nesting sites in relation to elevation</td>
<td>85</td>
</tr>
<tr>
<td>7.8</td>
<td>Saltwater crocodile nesting sites mapped in relation to hypothetical clan boundaries</td>
<td>89</td>
</tr>
<tr>
<td>7.9</td>
<td>Final map after consultation with BAC</td>
<td>91</td>
</tr>
</tbody>
</table>
List of Tables:

Table | Page Number
--- | ---
2.1 Rivers included in this study and distance upstream under tidal influence | 13
6.1 Landsat TM detail | 48
6.2 Spectral Bands of Landsat TM | 49
6.3 AUSLIG themes and corresponding layers | 50
6.4 Training areas collected for hybrid classification of Landsat TM images | 54
6.5 Results of applying Minimum-Distance-to-Mean algorithm for hybrid classification | 54
6.6 Six-parameter affine transformation | 57
6.7 Shapefiles derived from AUSLIG data | 60
6.8 Results of applying Minimum-Distance-to-Mean algorithm | 67
7.1 Error matrix for landcover basemap | 77
7.2 Error matrix for saltwater crocodile habitat map | 81

List of Flowcharts:

Flowchart | Page Number
--- | ---
6.1a Creating a landcover basemap from Landsat imagery | 52
6.1b Registration and rectification of the classified basemap | 56
6.2 Deriving a topographic basemap for the study area from AUSLIG TOPO-250K data | 59
6.3a Applying decision rules to GIS data | 61
6.3b Applying the crocodile habitat mask to Landsat TM image | 62

List of Charts:

Chart | Page Number
--- | ---
7.1 Saltwater crocodile eggs harvested from nests on the Blyth River system | 86
7.2 Saltwater crocodile eggs harvested from nests on the Cadell River system | 86
7.3 Saltwater crocodile eggs harvested from nests on the Liverpool River system | 87
7.4 Saltwater crocodile nests harvested from Nests on the Tomkinson river system | 87
List of Appendices:

<table>
<thead>
<tr>
<th>Appendix</th>
<th>Page Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appendix 1: Raw data provided by Wildlife Management International</td>
<td>106</td>
</tr>
<tr>
<td>Appendix 2: Dendrogram used to aggregate classes of landcover basemap</td>
<td>110</td>
</tr>
<tr>
<td>Appendix 3: Dendrogram used to aggregate classes of saltwater</td>
<td>113</td>
</tr>
<tr>
<td>crocodile habitat map</td>
<td></td>
</tr>
<tr>
<td>Appendix 4: Data obtained during field survey of the study area</td>
<td>115</td>
</tr>
<tr>
<td>Appendix 5: Specht MKII</td>
<td>119</td>
</tr>
</tbody>
</table>

List of Acronyms:

- AUSLIG: Australian Surveying and Land Information Group
- ANGD: Australian National Gravity Database
- AFN: Assembly of First Nations (Canada)
- BAC: Bawinanga Aboriginal Corporation
- CLC: Central Land Council
- DEM: Digital Elevation Model
- FATSIS: Faculty of Aboriginal and Torres Strait Islander Studies
- GIS: Geographic Information Systems
- GPS: Global Positioning System
- IGC: Intertribal GIS council (USA)
- KBS: Knowledge Based System
- MDM: Minimum-Distance-to-Means
- MLC: Maximum-Likelihood-Classifier
- NLC: Northern Land Council
- WMI: Wildlife Management International
Chapter 1 Introduction

This study examines the potential use of Geographic Information Systems (GIS) by Aboriginal people, in the Northern Territory of Australia, for resource management of saltwater crocodile eggs. Contents of this Chapter set the scene by briefly describing the relationships between resource management, indigenous people and GIS. Relevant background history and significance of the project are described. In the following Section the aims and research questions addressed are presented. The Chapter concludes with a general overview of thesis structure.

1.1 The relationship between resource management, indigenous peoples and GIS

In the latter part of the twentieth century, there is a growing awareness of environmental problems and an increased understanding of the dynamic nature of the earth’s natural systems. Resource management provides a means to contain environmental problems, especially where the unpredictable aspect of natural systems is accounted for in management plans. There is a growing recognition of the advantage of incorporating indigenous knowledge and traditional practices into natural resource management (e.g. Marchand and Winchell, 1994; Harmsworth, 1997a). Western science and indigenous perceptions of the natural world are often quite different (Knudston and Suzuki, 1992). As stated by David Suzuki, “profoundly different notions of our relationship with nature do exist” (Suzuki, 1992, pp XXIV). Integration of indigenous knowledge with western science can provide a view of the world that is more holistic than either one of these alone.

Efficient resource management relies on effective management of data. Resource management problems are inherently spatial in nature and management strategies should ideally incorporate this spatial dimension. GIS provide a means to include the spatial dimensions of natural resources and are consequently the tool of choice for resource management. GIS also provides a tool that can accommodate holistic perspectives in resource management by integrating indigenous knowledge with western scientific information. GIS can represent the dynamic nature of natural systems by providing analytical and modeling capabilities. Issues of security that arise when sharing and using traditional knowledge can be accounted for during the design phase of the GIS.

The integration of GIS and remote sensing technologies for resource management is well documented (e.g. Trotter, 1991; Ahmad, 1992; Hinton, 1996). However, to date there are no
studies which report on the use of remotely sensed images as a data source for resource management by indigenous people. One of the most expensive parts of a project is the acquisition of spatial data for incorporation within a GIS. Remotely sensed images are a valuable and cost-effective information source for a GIS. Remotely sensed images in a GIS environment can form an up-to-date basemap from which other data layers can be derived. Integration of GIS and digital image processing techniques can provide resource managers with maps specifically for the resource being managed. The full potential of integrating western technologies, such as GIS and digital image processing, with indigenous knowledge has yet to be realised.

Despite the fact that GIS has potential as an invaluable tool for resource management, there is limited research on the use of this technology by Australian Aboriginal people. In Australia, Aboriginal people manage many natural resources. In the Northern Territory over 80% of the coastline is Aboriginal land (Langton, 1997). Hunting and gathering rights for Aboriginal people on land are also extensive in this part of Australia (Altman, 1993). Many natural resources on Aboriginal land have cultural significance. Sustainable management of resources is essential, especially where the resource is exploited as a business venture and not purely for local use. The use of GIS by indigenous people in the Northern Territory can provide a cost effective and timely method of monitoring and managing resources, environmental and cultural.

1.2 Background history to project

Until recently the harvesting of saltwater crocodile eggs in the Maningrida area of Arnhem Land was conducted by Wildlife Management International (WMI). There is now a management plan for the harvesting of saltwater crocodiles and their eggs in place at Maningrida. Collected crocodile eggs are incubated at Maningrida until hatchling stage at which point the hatchlings are sold to WMI.

The Bawinanga Aboriginal Corporation (BAC) initiated this project as they are interested in exploring the potential use of GIS for the management of saltwater crocodile egg harvesting. At the time of writing, Aboriginal clan territories for the area are not mapped. BAC would like to include the geographic boundaries of clan territories in the GIS as an aid to managing natural and cultural resources. This study is a pilot project and there are plans to expand the GIS to incorporate all environmental and cultural information relevant to the region. An important aim of the pilot project is therefore to develop a design concept for a culturally appropriate GIS database.

Defining what constitutes a culturally appropriate GIS is not a simple matter. Aboriginal people at
Maningrida are the only people who are in the position to truly define what is 'culturally appropriate' to their needs. For this reason it is essential to work closely with the community during the development of the GIS. As indicated by Harmsworth (1997a) if local people are involved during the design stages, then the resultant GIS will have a cultural imprint unique to that group of people. Several members of BAC and Peter Cooke of the Northern Land Council were also involved in this project and offered advice when needed.

1.3 Aims and research questions

The overall aim of this project is to create a GIS that will assist in resource management of saltwater crocodile eggs in the area serviced by BAC. Geographic data relevant to the project includes topographic data, known crocodile nesting sites, crocodile habitat and the position of clan boundaries. An important aim of the project is to ensure that the resultant GIS is culturally relevant for Aboriginal people.

1.3.1 Specific aims of the project are as follows:

- To investigate the potential of integrating a GIS and digital image processing techniques to map the potential habitat of saltwater crocodiles (*Crocodylus porosus*).

- To investigate the potential for using GIS methodologies to map Aboriginal clan boundaries.

- To create a GIS which will assist in resource management of saltwater crocodile eggs for the study area.

- To create a GIS which can be expanded to incorporate a range of cultural and environmental information.

- To develop a design concept for a culturally appropriate GIS database for use by Aboriginal people of the Northern Territory.

From the aims, as outlined above, several research questions have been formulated.
1.3.2 Research questions

- Can a GIS be created to assist BAC with resource management of saltwater crocodile eggs?

- Is it possible to map crocodile habitat by integrating GIS and digital image processing techniques?

- Can dynamic clan boundaries be effectively mapped using GIS methodologies?

- Can a GIS database be developed that integrates cultural information appropriate to the needs and interests of indigenous people?

1.4 Significance of Study

GIS are increasingly used as a tool for resource management by government departments and private industry. In Australia the Aboriginal use of GIS as a tool to manage cultural and natural resources remains limited. Studies that investigate the potential for integrating Australian indigenous knowledge within a GIS for resource management are not recorded in the literature. There is a need for research in this area if the full potential is to be realised. Studies that address issues regarding security of culturally sensitive information within a GIS are also lacking.

Central Arnhem Land is largely unmapped, especially with regard to the position of clan territorial lands. Studies from New Zealand and the USA indicate that GIS technology provides a feasible way to map traditional land. Crocodile habitat within the study area has not been mapped previously using integrated digital image processing and GIS techniques. Many crocodile surveys have been conducted on the waterways of the region over the years and saltwater crocodile habitat in the area has been well studied. This project, therefore, is significant in that it will investigate the potential for using remote sensing and GIS technologies to map saltwater crocodile habitat and Aboriginal boundaries.

The inclusion of the clan boundaries within a GIS can assist in resource management of environmentally and culturally important areas. The sensitive nature of indigenous information is such that accessing of data must be restricted. Guidelines must be established during the planning stages of a project to accommodate the privacy requirements for the information. The use of GIS and remote sensing technologies provides an economic and effective method to map clan boundaries.
and potential crocodile nesting habitat.

At the time of writing there is limited research on the use of GIS by Aboriginal people in Australia. Overseas studies indicate that GIS has provided an efficient tool for decision support in resource and cultural management for other indigenous cultures. To date there is also limited research on the role of remote sensing to map crocodile habitat and potential nesting sites. This project is therefore expected to form the basis from which further studies will emerge.

1.5 Thesis Outline

The following Chapters are designed to describe the many aspects that are relevant to this study as well as providing a complete description of the project itself. Chapter 2 describes the study area and provides insight into the most suitable habitat for saltwater crocodiles. Further information on BAC is included in this Chapter. Chapter 3 reviews relevant studies and discusses research needs that presently exist in the field of indigenous GIS. Special issues pertaining to the use of GIS by indigenous people are discussed in Chapter 4 and technical considerations are reviewed in Chapter 5. Chapter 6 describes methodology used in this project and results are presented and discussed fully in Chapter 7.
Chapter 2  The Study Area: Central Arnhem Land

The main aim of this project is to create a GIS that will assist Aboriginal people in Central Arnhem Land with resource management of saltwater crocodile eggs. To meet this aim it is useful to determine cultural and environmental factors that will influence the GIS design. Section 2.1 describes the Bawinanga Aboriginal Corporation and provides a brief overview of the infrastructure of the area serviced by them. The multilingual nature of the Maningrida community is also described. The effect of language on the end user of a GIS is further discussed in Chapter 4.

Section 2.2 summarises climatic and environmental information about the study area. During this study remotely sensed imagery is used as a data source to form a basis from which other information can be derived. It is helpful to have some knowledge of the environmental characteristics of the study area during processing of remotely sensed data.

Another aspect of this project is the integration of GIS and digital image processing techniques to map the potential habitat of saltwater crocodiles. The Chapter concludes with an insight into the habitat and nesting patterns of saltwater crocodiles. This information is essential for mapping the habitat of saltwater crocodiles in the region serviced by BAC.

2.1 The Bawinanga Aboriginal Corporation

Figure 2.1 depicts that area of Central Arnhem Land serviced by BAC. The Bawinanga Aboriginal Corporation was established in the early 1970s and is committed to the maintenance and improvement of life for Aboriginal people in the Central Arnhem Land region. Originally BAC acted as a support agency for Aboriginal people who chose to stay on their traditional clan estates rather than in a central community. In 1979 BAC were incorporated under the Federal Associations Act to function as a resource centre for the outstations. Approximately 800 people reside on the 25 outstations at this point in time. The corporation is responsible for supporting Community Development and Employment programs (CDEP), a community Ranger program and an arts centre that has an associated research office. BAC achieves its aims by providing essential services, enhancing self-determination, improving educational and training opportunities and by developing sustainable enterprises. The chief executive officers (CEO) and chairperson of BAC recently expressed a desire to investigate GIS as a tool that can assist in cultural and environmental resource management.
Chapter 2 The Study Area: Central Arnhem Land

for the area (Carew, 1997).

2.1.1 The research office of the Bawinanga Aboriginal Corporation

An Aboriginal cultural officer (Peter Danaja) and a linguist (Murray Garde) staff the research office. This office is responsible for maintenance of information relevant to the needs of BAC. The information includes a Maningrida dictionary of languages database, clan register, sites register, outstation register and an art and craft database. Staff of the research office are also involved in internet publishing and desktop publishing. Ongoing management of the GIS that results from this study will become a responsibility of this office. An important part of this project is to involve the staff of the research office during the development phase.

---

Figure 2.1: Location of study area in relation to the Northern Territory of Australia
2.1.2 Languages of the Maningrida area

As demonstrated in Figure 2.1, the area of land serviced by BAC is extensive. Maningrida is one of the most multilingual communities in the world (Carew, 1997). Most people in the community have the ability to converse in three or four languages, including English. The predominant languages spoken include Eastern Kunwinjku, Kune, Rembarrnga, Dangbon/Dalabon and Burarra. The Central Arnhem Land area has a great variety of languages each with an associated knowledge and culture. Traditionally these languages are in oral format, rather than written, although European linguists have in recent times worked out systems for writing these languages. Spelling and structure of the languages are based on the Roman alphabet; despite this some languages use different symbols for the same sounds. Aboriginal people in the area generally dislike seeing their language written wrongly (Carew, 1997). Furthermore, several of the council members at Maningrida indicate that most of the community responds better to English as a written language, rather than traditional languages. To meet the aims of this project it is useful to consider languages common to the study area so that the most suitable one can be used in the resulting GIS. More detailed discussion of the issue of language in a GIS is included in Chapter 4.

2.1.3 Infrastructure at Maningrida and the Outstations

Within the area serviced by the Bawinanga Aboriginal Corporation there are approximately 25 outstations. During the months October to April some of these outstations become inaccessible except by plane. Maningrida is the central community for the outstations and as a result many people visit relatives in Maningrida frequently. Health care on the outstations is looked after by a mobile clinic and an environmental health program is in place. Education is also provided and is supported by a “Homelands Schools” program that is funded by the Northern Territory Government. Matters of policy are decided upon during meetings where a consensus must be reached for decisions to be made. Residents of the outstations attend such meetings, although during the wet season many of these people would be unable to get to Maningrida. Eventually the GIS developed during this project will be expanded to incorporate information on the infrastructure of the area to assist with ongoing management.

2.2 Environmental characteristics of Central Arnhem Land

The character of this part of Australia is largely determined by the extremes of the wet-dry tropical climate experienced here. Climate also has a strong influence on crocodile habitat and nesting patterns of the saltwater crocodile (Crocodylus porosus).
2.2.1 Climate

From a European perspective Central Arnhem Land experiences a tropical climate with two predominant seasons, the wet and dry. Officially, the wet season extends from October 1 to April 30 and the dry season for the rest of the year. During the dry season light to moderate southeasterly winds predominate and rainfall is low (Harrison, 1996). Bushfires are very common in the Northern Territory at this time of year. During the wet season, monsoon weather is common but the pattern of this weather varies yearly. Tropical cyclones can form off the coast of northern Australia at any time from November to April (Bureau of Meteorology, 1997). Temperatures are highest early in the wet season and coolest at the height of the dry. There is generally very little variation in temperature throughout the year. Rainfall, temperature and relative humidity are important factors in determining the state of the vegetation or land cover of an area, and greatly influence the time and effort of crocodile nesting. Aborigines in Central Arnhem Land recognise six main seasons through the year. The seasons are illustrated in Figure 2.2. When compared to the European seasonal calendar, the months from October to April are separated into three seasons. The Dhuludur (pre-wet season), the Barramirri (growth season) and the Mayaltha (flowering season). The dry season as described above is separated into the Midawarr (fruiting season), Dharrathamirri (early dry season) and the Rarrandharr (main dry season) (Davis, 1984).

Figure 2.2: Aboriginal seasonal calendar for Arnhem Land (Source: Davis, 1984)
2.2.2 Description of the study area

Central Arnhem Land is bound to the north by coastal habitats that merge into floodplains and swamps. Further inland there are open forest and woodland communities that stretch to the escarpment country to the south. Many major rivers in the Central Arnhem Land region originate from springs and creeks in the escarpment country. The river systems connect vegetation communities as they flow from the escarpment through the forest communities and across the floodplains to reach the sea. Changes in one ecosystem have an effect on the whole environment as one system interacts with another. Suitable habitat for the saltwater crocodile extends from the sea to inland floodplains as is described in Section 2.3. The environment of the region as a whole is briefly described in the following Section. An aim of this project is to develop a GIS that can be expanded to include information for other natural resources. As described in Chapter 6, a basemap for the study area was derived from remotely sensed imagery. Understanding of the environmental characteristics of the region assisted during processing of the imagery.

Coastal habitats

The Top End of Australia has the richest mangrove communities in Australia (Harrison, 1996). The mangrove communities form belts along coastal zones and banks of tidal creeks or rivers, which are subjected to periodic tidal inundation. These communities can form narrow bands or dense closed forests in sheltered bays. The typical formation of mangrove communities is to grow in zones of different species which form bands parallel to the coast or river (Brock, 1993). Much of the importance of mangrove communities is their provision of nursery beds for many fish species.

Lowland Habitats

Floodplains of Arnhem Land have a flat, treeless aspect, broken occasionally with river channels, billabongs and paperbark swamp. A great diversity of fauna is supported on the floodplains. Saltwater crocodiles, turtles, file snakes and many bird species depend on wetland areas for habitat and breeding sites.

Large rivers meander across the flood plains, cutting a path as they move back and forth. The flow of the river causes erosion on one bank of the river and consolidation of sediment on the other. Mangroves are typically found on the consolidated bank but are lost on the other due to erosion. On the eroded bank, flood plain grasses and sedges are commonly found (Webb and Manolis, 1989). In the dry season the flood plains dry out and isolated billabongs are found on
sections of the river. Floating rafts of vegetation form on the billabongs and often completely cover the surface. The billabongs and the floating mats of vegetation are important nesting areas for saltwater crocodiles. This is described in Section 2.3.

Permanent freshwater swamps are found on the floodplains usually on the edge of the plain near more solid land. The swamps are generally spring fed and usually support dense stands of paperbark trees (*Melaleuca spp.*) (Brock, 1993). Paperbark swamps are important nesting areas for saltwater crocodiles.

**Eucalypt Communities**

*Eucalyptus tetradonta* and *Eucalyptus miniata* dominate in the open forest and open woodland communities found in this part of Australia. Open forests of these species occur in deep well-drained soils and are found with a patchy understorey. In savanna communities light penetration is such that the understorey consists of shrubs with a lower layer of both annual and perennial grasses. Fire is a factor that greatly influences the structure of Eucalyptus communities. The ability of Eucalypts and Acacia to cope with fire is one reason they are so abundant in the northern part of Australia (Brock, 1993).

**Feral animals of the Top End**

Feral animals are a problem in the Top End of Australia due to the habitat destruction they cause. Habitat destruction contributes to natural resource management problems. Feral pigs (*Sus scrofa*) are well established in northern Australia and tame ones can be seen wandering freely around Maningrida. Pigs are a major cause of habitat destruction in monsoon and paperbark forests, as they tend to dig for roots, killing trees and shrubs in the process. The water buffalo (*Bubalus bubalis*) is also a major culprit of habitat destruction, especially on floodplain areas (Goodfellow, 1993). Destruction of floodplain and paperbark forests by feral animals has implications for resource management of saltwater crocodile eggs, as these areas provide major nesting sites for this animal.
2.3 Saltwater crocodile habitat and nesting sites

The aim of this Section is to identify the habitat and nesting patterns of saltwater crocodiles as outlined in literature. This is done so that spatial and temporal patterns identified in this Chapter can be considered during the design stage of the GIS. The following is not intended to be a comprehensive exploration of saltwater crocodile biology.

Through the years there have been a few names that are prevalent in crocodile work. Most recently Graham Webb and Charlie Manolis are leaders in this field within Australia. In the past Harry Messel contributed greatly to crocodile biology and surveyed the waters of Arnhem Land area extensively. Information pertaining to saltwater crocodiles found within this Section has predominantly been obtained from papers and books written by these experts in crocodile biology and management. The world distribution of saltwater crocodiles extends from India through the southern parts of Asia and into the "Top End" of Australia (Figure 2.3). In the context of this research, however, it is their natural habitat in northern Australia that is of interest.

Figure 2.3: Global distribution of saltwater crocodiles (Source: Grenard, 1991)
2.3.1 Habitat of saltwater crocodiles in the Northern Territory of Australia.

The northern parts of Australia provide suitable habitats for two species of crocodiles, *Crocodylus porosus* and *Crocodylus johnstoni*. In northern Australia, saltwater crocodiles (*Crocodylus porosus*) are found in coastal areas, including tidal and non-tidal rivers, saline swamps, freshwater swamps and coastal billabongs (Webb and Manolis, 1991). Coastal wetlands of the Northern Territory are important habitats for this species. Crocodile surveys by Webb *et al.* (1977) covered much of Arnhem Land and examined crocodile nesting in the Liverpool, Tomkinson, Goomadeer, Blyth and Cadell Rivers and Numbulgari Creek. The surveys indicate that the greatest density of saltwater crocodiles is found in the meandering sections of the rivers that remain under tidal influence. Table 2.1 shows areas under tidal influence for rivers in the study area. The information provided by this table is used during the development of a saltwater crocodile habitat map as described in Chapters 6 and 7.

<table>
<thead>
<tr>
<th>River system</th>
<th>Section of river under tidal influence (Km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liverpool</td>
<td>70</td>
</tr>
<tr>
<td>Tomkinson</td>
<td>100</td>
</tr>
<tr>
<td>Goomadeer</td>
<td>50</td>
</tr>
<tr>
<td>Blyth</td>
<td>55</td>
</tr>
<tr>
<td>Cadell</td>
<td>37</td>
</tr>
<tr>
<td>Numbulgari Creek</td>
<td>16</td>
</tr>
</tbody>
</table>

Table 2.1: Rivers included in this study and distance upstream under tidal influence
(Source: Webb *et al.*, 1977)

Climatic changes have dramatic effects on crocodile habitats in northern Australia. The rainfall pattern in particular has a major effect on crocodile habitat. During the dry season, many of the floodplains and swamps dry out, rivers become narrow and shallow, often with only a few stagnant pools of water remaining. During this season crocodile populations are found concentrated in the permanent water bodies. The onset of the wet season brings a different picture of northern Australia and the landscape changes as rivers flow fuller, spilling over into the floodplains and billabongs which link into creek systems. The coastal floodplains provide possibly the most important habitat
of the Saltwater Crocodile. It is in the floodplains that the favoured nesting site of *C. porosus* is found (Webb and Manolis, 1989).

Floodplains are extremely important crocodile habitat, as are the tidal rivers that spread across them. More specific areas are, however, of interest if favourite nesting habitats are considered. The following Section discusses favoured nesting sites for saltwater crocodiles, and describes factors that affect patterns of nesting and survivorship of crocodile eggs.

### 2.3.2 Factors affecting nesting and survivorship of saltwater crocodiles

Saltwater crocodiles nest at the height of the wet season in the Northern Territory with the peak of hatching occurring during March and April (Webb and Manolis, 1991). Hatching occurs in the Aboriginal seasonal calendar during the Midawarr (Figure 2.2). Rivers are full and the floodplains become inundated with water. It is in the dry season however that the scene is set for suitable nesting sites. In the dry season there is generally a build up of salinity in the floodplain rivers and many of the rivers stop before reaching the coast. Deep billabongs form along the length of the river section and are not connected during the dry season. The billabongs generally contain permanent freshwater and have floating mats of vegetation, which cover the surface of the billabong (Figure 2.4). The floating mats of vegetation are regarded as excellent nesting sites for the saltwater crocodile.

Another important saltwater crocodile nesting site on the floodplain is the spring fed freshwater paperback swamps. Where these swamps occur close to tidal rivers is probably the best areas for nesting (Webb and Manolis, 1989).

Saltwater crocodiles build nests as mounds as demonstrated in Figure 2.5. This structure plays a part in keeping the eggs in a dry environment. Timing and effort of nesting during the wet season is associated closely with climatic conditions in the latter half of the dry season. In years where the late dry is very dry, water levels are low and high temperatures predominate, there is generally a reduced effort in nesting during the wet season. Variables such as water levels, rain and temperature are interconnected in influencing nesting time and effort (Webb and Manolis, 1989). Courtship and mating are stimulated by rain, either in the late dry season or in periodic bouts during the wet. The nest is built by the female crocodile, in a secluded area close to permanent water. The mounds are typically built from vegetation with mud and/or soil, depending on what material is available (Webb *et al.*, 1983). The variation in amounts of mud, soil and vegetation is usually reflective of the habitat that the nest is being
Saltwater crocodile eggs laid in the wild of the Northern Territory have a 25 per cent chance of surviving to hatchling stage. Flooding of nests is a common reason for the low survivorship of saltwater crocodile eggs. Very ‘wet’ wet seasons cause extensive flooding and in some years 90 per cent of the nests become submerged (Webb and Manolis, 1989). Crocodile eggshells are porous to allow embryos in the eggs to respire hence, the submerged embryos will drown. Topography of an area is a major factor that influences flooding of nests (Webb et al., 1983). This fact indicates that the use of a digital elevation model in a GIS could assist in resource management of saltwater crocodile eggs.

Figure 2.4: Floating mats of vegetation form on billabongs (Source: Webb and Manolis, 1989)
2.3.3. Resource management of saltwater crocodile eggs

Resource management of saltwater crocodile eggs has until recently been conducted by experts in the field of crocodile biology. As discussed earlier, management of this resource in Central Arnhem Land is now conducted by rangers from BAC. To ensure effective management, knowledge of the potential habitat of saltwater crocodiles is useful, as is a map of potential nesting sites. Many of the nests in this region have been traditionally harvested by the local people of the area. Other potential nest sites can, however, be identified by the use of GIS and remote sensing technologies as tools for resource management.

Saltwater crocodile habitat mapping in a GIS should indicate areas where the species are found in greatest density and areas that provide preferred nesting sites. Overall such areas include coastal floodplains, meandering sections of floodplain rivers under tidal influence, paperback swamps and billabongs with floating vegetation mats. The favored nesting sites of saltwater crocodiles are paperback swamps that are found on the edges of floodplains and vegetation mats on billabongs.

The major threat to survival for saltwater crocodile eggs is flooding of nests. Flooding of nests is related to climatic conditions and topography of the area. By integrating climatic models and digital elevation models in a GIS, it may be possible to determine areas that are most prone to flooding. Resource management plans could use this knowledge to design egg collection strategies to ensure best results for least effort.
There is a potential for GIS and remote sensing technologies to play an important part in resource management of saltwater crocodiles and their eggs. While there are no studies that demonstrate the use of GIS and remote sensing technologies for saltwater crocodile wildlife management, other studies do demonstrate the capabilities of this technology. The next Chapter reviews past research and identifies methods used that are relevant to this project. The use of GIS for resource management by indigenous people is also reviewed.
Chapter 3 Literature review

During the planning stage of any project it is important to review relevant research studies. The aim of this process is to analyse rationales adopted in previous studies and identify research needs that exist. The following Chapter describes research, as published in the literature, relevant to the field of indigenous GIS. The first Section (3.1) discusses past research experiences and describes the existing use of GIS by indigenous people in various countries.

Section 3.1 briefly describes integration of GIS and remote sensing technologies. While research on the integration of GIS and digital image processing technologies is extensive, to date there are no studies available that demonstrate integration of the technologies for resource management by indigenous people. The Chapter concludes by identifying research needs in this relatively new field of study.

3.1 Indigenous GIS

Published research into the use of GIS by indigenous people is limited. However, the advantages of integrating indigenous knowledge with western science are generally becoming more recognised (e.g. Tabor and Hutchinson, 1994; Mathias, 1995; Harmsworth, 1997a). Reviews of the literature indicate that integration of indigenous knowledge with GIS, global positioning systems (GPS) and remote sensing technologies is an expanding field of research.

3.1.1 Indigenous people and GIS: A global perspective

An aim of this project is to develop a culturally appropriate GIS for use by Aboriginal people in the Northern Territory. To meet this aim it is useful to investigate present use of GIS by other indigenous groups. In Canada, USA and New Zealand, indigenous communities are using GIS as a tool for effective cultural and natural resource management (Neto and Neto, 1997a; Harmsworth, 1997a). In the USA and Canada indigenous use of GIS is regarded as an important research issue and many Native Americans have established GIS at community level. Information regarding some community experiences is available on the Internet, mostly from one URL (www.cycor.ca/neto/natgis.htm). Linked to the native GIS page are articles that indicate the widespread use of GIS across the USA and Canada. The Shuswap Nation Tribal Council in British Columbia, the Assembly of First Nations (AFN) in Ontario and additional groups in Canada use GIS. In the USA, native North American tribes have established the Intertribal GIS Council (IGC). The IGC recognises the importance of GIS in assisting with natural resource management on native American lands. A key goal of the council is to educate
native Americans about GIS and the potential of this technology to map traditional lands (Neto and Neto, 1997a).

In New Zealand, Manaaki Whenua-Landcare Research and representatives from five iwi (tribes) are presently carrying out research. The aim of the research is to develop a framework and methods for recording, organising, analysing and displaying Maori values in a GIS. Ultimately the GIS will be used to assist with policy development and will contain biophysical, economic and social information, as well as Maori traditional information (Harmsworth, 1997b).

In Australia, use of GIS by indigenous groups is not widespread and research surrounding its implementation is limited. There is, however, a growing trend towards the use of GIS for indigenous natural and cultural resource management. Recently an Aboriginal community at Tennant Creek, Northern Territory, purchased a GIS from a local vendor (pers. comm. P. Cooke, 1997). The Jawoyn Association in Katherine is also establishing a GIS with the assistance of Chris Devonport and Leo Farrell at the Northern Territory University. The Jawoyn Association is utilising the GIS to assist in the development of mining policies for their area (pers. comm. C. Devonport. 1997). The Central Land Council (CLC) in Central Australia has utilised a GIS for many years. The CLC utilises the GIS to record cultural heritage information and preparation of material for native title claims (Turk, 1996). FATSIS (Faculty of Aboriginal and Torres Strait Islanders Studies) have recently been organising mapping courses that include discussion on the use of GIS for Aboriginal communities (pers. comm. S. Heffernan, 1997). Research into the use of GIS by Australian Indigenous people remains limited and yet Aboriginal people in the Northern Territory manage many of the natural resources (Altman, 1993).

Experiences of other indigenous groups can provide insight into possible methodologies that can be used to meet the aims of this research. The following Section outlines methods used by other researchers and indigenous groups and problems that have been encountered.

3.1.2 Research in the world of indigenous GIS

Despite the fact that many indigenous communities in the USA and Canada are using GIS at community level, published research is scarce. Some studies discuss issues involved with indigenous GIS or describe a possible framework for integrating indigenous knowledge within a GIS (e.g. Tabor and Hutchinson, 1994). Published studies describing real life experiences of indigenous people establishing or using GIS continue to be limited.

One aim of this project is to map Aboriginal clan boundaries. Previous studies indicate that
Integration of GIS and GPS technologies can be used successfully to map traditional lands (e.g. GPS World, 1996; Sirait et al., 1994). GPS surveying of traditional land by the landowners can provide data for input into a GIS (GPS World, 1996). In situations where the traditional landowners do not participate in the GPS survey, some method must be found to clarify the position of traditional boundaries. One method that was used by Sirait et al. (1994) was to take oral histories from the traditional landowners. This process combined with sketch maps of the area provided a means to map boundaries using a GPS. This technology can also be used to map sites of cultural or environmental interest and thus provide a tool for management of such areas (e.g. GPS World, 1996; Harmsworth, 1997a).

A further aim of this project is to create a GIS that can be expanded to incorporate Aboriginal cultural knowledge. The advantages of integrating indigenous knowledge within a GIS are demonstrated in several studies (e.g. Gonzales, 1995; Harmsworth, 1997a). Maori people in New Zealand view GIS as a useful tool for resource management and environmental planning. In addition they view GIS as a tool that can assist with tribal history archiving, tribal and economic development, property management, education and social planning (Harmsworth, 1997a). In New Zealand the full potential of integrating indigenous knowledge within a GIS is being realised.

Integration of traditional knowledge can give an added dimension to management policies as is demonstrated in a study by Gonzales (1995). In that study, traditional knowledge was used in a GIS to assist with agricultural planning. The study integrated indigenous knowledge in a GIS as the basis of a Knowledge Based System (KBS). While the use of a KBS is not directly pertinent to this project, it is useful to consider the advantages of integrating such a system in future research. Management policies resulting from research by Gonzales (1995) were better suited to the needs of the local people. By integrating local knowledge in a GIS for decision making, traditional views of the land were considered during the decision making process. Map output from the GIS was also more useful to the local people as it described the land in a way that they related to, as opposed to traditional mapping terminology.

While integration of traditional knowledge within a GIS is advantageous, it is important to recognise that problems do arise during the process. Security was identified by most authors as a major issue in studies reviewed (e.g. Neto and Neto, 1997b; Harmsworth, 1997a). Neto and Neto (1997b) state that the issue of ownership and sensitivity of traditional information is a major obstacle in the development of an indigenous GIS. Another problem identified is that culture has an influence on how people view their landscape and the spatial dimensions of that landscape (Sirait et al., 1994; Campari and Frank, 1995; Gonzales, 1995). Since an aim of this
project is to map Aboriginal clan boundaries, it is important to keep in mind that culture does influence spatial perception. Further discussion on the issues briefly mentioned here is included in Chapter 4 (Cultural issues in GIS).

Tabor and Hutchinson (1994) identified as a problem the use of western classification systems to map traditional lands. The authors question the effectiveness of using these classification systems and suggest they do not accommodate local resource values or management practices. This comment is relevant to survey work in Aboriginal areas of Australia, where western classification systems are frequently used. It could be more useful for resource management practices if local classification systems were used in the GIS.

Apart from issues that arise from integrating indigenous knowledge, there are other factors that influence success of a GIS in an indigenous community. Neto and Neto (1997b) outline several common problems encountered during implementation and maintenance of indigenous GIS at community level in Canada and the USA. Cost and training of staff are problems experienced by most organisations and are not peculiar to indigenous groups. Indigenous tribes in the USA and Canada, which have successfully implemented GIS at community level, are those that have natural resources to manage and the funds to implement and maintain a system. Most success has been achieved by those tribes who spend money for training needs of their own people rather than hiring ‘outsiders’ to do the job. Tribes that have had least success are those who bought expensive systems. Maintenance of these systems requires hired staff and this proves expensive in the long term (Neto and Neto, 1997b). With this point in mind, it would be interesting to assess the success of the GIS bought by the Tennant Creek community. These points indicate the need for indigenous people to have full input into the design and implementation of the GIS. Harmsworth (1997a) suggests that only by being involved in the development and maintenance of a GIS, can indigenous people add their own cultural imprint. This cultural imprint adds further potential to GIS applications.

There have been several studies on the use of GIS by indigenous people. Most of these studies, however, do not involve integration of remotely sensed images within the GIS. There are no studies that describe the interaction of indigenous people with remotely sensed images as a map form. Tabor and Hutchinson (1994) discuss the relevance of using remotely sensed images as an input to a GIS, for resource management by indigenous people. The paper does not discuss responses of indigenous people to satellite imagery.

To meet the overall aims of this research, a basemap has to be input into the GIS. Inaccuracy of basemaps has been cited by several authors as a problem during their research (e.g. Sirait et al.,
Neither of these research projects derived a basemap from remotely sensed data. Sirait et al. (1994) derived basemaps for a GIS from old Forest Department maps of their study area in Indonesia. However, the basemaps were found to be less accurate than data obtained from GPS surveys. Maier (1996) mapped traditional lands in Ontario, Canada, as part of an environmental health study. During that research, the time taken to edit basemaps acquired for the GIS was one of the largest barriers of the project. The basemaps that were acquired in digital format had to be edited to account for inaccuracies. As discussed above, culture has an effect on how people view their environment. It may be inappropriate to use basemaps in a GIS that have been derived from traditional European maps. The use of remotely sensed imagery as a basemap in an indigenous GIS is worth further investigation, and the potential of this practice is assessed in this project.

3.2 Remote sensing and GIS technologies for resource management

One aim of this research is to investigate the potential of integrating GIS and digital image processing techniques to map saltwater crocodile habitat as an aid to resource management of saltwater crocodile eggs by indigenous people in the Northern Territory. This Section discusses previous research relevant to this aim in order to identify possible methodologies. No studies are available that discuss integration of the technologies to map saltwater crocodile habitat.

The benefits of integrating GIS and digital image processing techniques is detailed in many studies (e.g. Klock et al., 1985; Kushwaha et al., 1996; Blackburn and Milton, 1997). GIS can provide the means to integrate other spatial dimensions with remotely sensed imagery (Carver et al., 1996). Digital elevation models and topographic data in a GIS environment can be used to delineate potential habitat for species where environmental factors such as elevation, distance from permanent water or other environmental factors determine their distribution. Digital Elevation Models can be integrated with remotely sensed data to classify species with habitats differentiated by elevation (e.g. Klock et al., 1985; Palacio-Prieto and Luna-Gonzales, 1996). In the study by Palacio-Prieto and Luna-Gonzales (1996) classification accuracy was improved from 55% to 83% by integrating a DEM and terrain-mapping units to remotely sensed data in a GIS.

Saltwater crocodile habitat is influenced by elevation, and integration of a DEM with remotely sense data to improve classification accuracy is a feasible methodology for this project. As indicated above, other data stored in a GIS can also be applied to remotely sensed data to improve classification accuracy. This is demonstrated in a study by Sader et al. (1995) who applied topographic data to a remotely sensed image during the pre-classification
stages of digital image processing. The accuracy of the resultant map was compared with that of maps produced using a variety of digital image processing techniques. Results of that study indicate that similar map accuracies were achieved by hybrid classification techniques as those attained by integrating GIS data. As suggested by the authors, these findings indicate that increased classification accuracy could be achieved by integrating GIS data with remotely sensed imagery and applying a hybrid classification in a digital image processing system (Sader et al., 1995).

Deriving a habitat map from remotely sensed data requires an understanding of the electromagnetic (EM) reflectance of objects in the natural environment and the ability to determine which bands best suit the project. Saltwater crocodile habitat encompasses coastal wetland areas, as described in Chapter 2. Several studies demonstrate that wetland areas can be successfully mapped using remotely sensed imagery (e.g. Everitt et al., 1996; Cowardin et al., 1995; Johnston and Barson, 1993). In the study by Johnston and Barson (1993) Landsat TM bands 1,3,4 and 5 were found to be most suited to mapping wetland areas in New South Wales. Results of that study, however, do indicate that the spatial resolution of Landsat TM is too coarse for detailed mapping of these areas.

The studies reviewed indicate that application of a DEM and topographic data to a remotely sensed image during pre-processing stages may provide a feasible methodology to map saltwater crocodile habitat. Technical issues that can arise during the integration process are further discussed in Chapter 5.

3.3 Research needs in indigenous GIS
In this Chapter, research in the field of indigenous GIS is discussed. From this several research needs can be identified. In Australia research into the use of GIS by Aboriginal people is extremely limited despite the fact that Aboriginal people in the Northern Territory manage a significant part of the natural resources (Altman, 1993). This, coupled with the growing need to manage cultural resources, indicates that GIS could play a vital role in the future of Aboriginal people.

An area where there is need for research is integration of remote sensing technology with GIS for indigenous resource management. No studies that discuss integration of remote sensing and GIS in the indigenous context were found, despite the fact that integration of these technologies for resource management has several advantages (Trotter, 1991; Tabor and Hutchinson, 1994). To date, no research is available that describes the interaction of indigenous people with remotely sensed images as a map form.
As indicated in this Chapter, there are several issues that arise when indigenous knowledge is integrated in a GIS. Chapter 4 discusses these issues in detail.
Chapter 4 Indigenous cultural issues in GIS

To address the research questions outlined in Chapter 1, it is important to consider the issues that can arise during the development of a GIS that will be used by indigenous people. The aim of this Chapter is to identify these issues as they are recorded in the literature. Section 4.1 discusses issues that arise when indigenous knowledge is integrated in a GIS. Privacy of information must be ensured and should be considered during the planning stages of a project. Section 4.2 discusses the influence of culture on how people view their environment and its processes. One of the aims of this project is to develop a design concept for a culturally appropriate GIS for use by Aboriginal people in the Northern Territory. To meet this aim it is useful to realise that cultural differences do exist so that this can be considered during development of the GIS. The final Section of this Chapter describes Aboriginal relationships with country. Aboriginal clan boundaries are complex and understanding of the complexities will lead to a more appropriate representation of them in a GIS.

4.1 GIS, indigenous knowledge and privacy

A number of authors have addressed the issues that arise when indigenous knowledge is integrated in a GIS (e.g. Harmsworth, 1997a; Turk, 1996; Tabor and Hutchinson, 1994; Marchand and Winchell, 1994). Indigenous knowledge usually has levels of sensitivity or security (Harmsworth, 1997a). Some indigenous knowledge can be shared with the general public, however, ownership of this information remains with the source group (Harmsworth, 1997a). Other indigenous information is not for public access and may only be available to certain members of the indigenous group (Turk, 1996). In New Zealand, Maori people have information that can be shared between tribal groups and information that can only be shared by certain members of a group (Harmsworth, 1997c). The situation is similar in Australia where some indigenous knowledge is available to all Australians, for example bush tucker, but more sensitive information remains only with certain members of the group (Turk, 1996). Harmsworth (1997c) outlines the methods used in New Zealand to secure sensitive knowledge that is integrated in a GIS. The GIS is split into levels. At the top level, access to the GIS is national. There are several lower levels, however, which have varying access rights. Information is secured so that only those people who are allowed the information have access to specific levels of the GIS. Highly sensitive information is not recorded in a GIS but can be linked to the GIS by the use of silent or concealed files. In New Zealand less than 10% of total indigenous knowledge is stored in the GIS that is utilised for land resource management (Harmsworth, 1997a). In the USA, the Colville Confederated Tribes in Colorado also chose not
to include very sensitive information within their GIS. Some less sensitive information included in the GIS is maintained at community level only and thus not available to other tribes or the general public (Marchand and Winchell, 1994). Tribal control of sensitive data is essential and provides a valid argument for the development and maintenance of a GIS at community level (Marchand and Winchell, 1994).

Turk (1996) discusses the fact that inclusion of sensitive knowledge in a GIS should only be attempted if extensive protection measures have been implemented. Sensitive information should not be produced in hard copy form, unless it is the specific wish of the indigenous group who own the knowledge (Turk, 1996). It may be more difficult to maintain privacy of information once it is available in hardcopy form.

Decisions need to be made early in the project planning stages about what information should or should not be included in the GIS. The maintenance of clear guidelines helps to ensure that the knowledge is available only to those who have authorisation. Furthermore, it is important that use of indigenous knowledge does not compromise the Aboriginal groups and their beliefs (Turk, 1996).

One aim of this project is to use GIS methodologies to map Aboriginal clan boundaries in Central Arnhem Land. The sensitive nature of this information has led to some debate on whether or not such boundaries should be included in a GIS. For this reason, hypothetical clan boundaries are mapped for this project. This will provide an example of how GIS can represent this information and demonstrate the advantages of doing so. The nature of Aboriginal boundaries is quite different to the European perspective. As can be seen in the next Section, how people view geographic space, territories and boundaries is influenced by their culture.

4.2 Cultural differences in GIS

The way humans view their environment and its processes is influenced by their culture (Campari and Frank, 1993). Since GIS represents the environment and to some extent its processes, culture will influence how people view GIS. Culture is defined by Bjorklund (1991, pp 65) as "the ongoing outcome of organised experience". Humans learn culture by cognitive and sensory experiences. Differences in how people view their environment are important considerations during implementation of a GIS project that involves people of different cultures.
Sirait et al (1994) concluded that a major problem experienced during the course of their research was the cultural differences in understanding spatial organisation. Cultural differences in how people understand and relate to spatial concepts are becoming increasingly recognised as important research topics (Mark, 1995). However, previous research on this topic has been in the European context and not relevant to the use of GIS by indigenous communities. Studies published describing the use of GIS by indigenous people often fail to discuss cultural differences in using a GIS.

In the GIS environment geographic space is represented as thematic layers, or maps. The use of maps as a method to graphically portray country, and spatial relationships within the country, is a European tradition (Stanner, 1965). Maps in the traditional sense are not part of Australian Aboriginal culture, however, after a ‘walkabout’ Aboriginal people can draw their route on the sand and depict sources of water and food along the journey (Balodis and Pupedis, 1996). Aboriginal people in Arnhem Land do traditionally use “pictures of country” (Berndt, 1970, pp 11) to represent their land. Berndt (1970) observed that in Arnhem Land, Aboriginal people often drew pictures that were not unlike European maps. The pictures were line drawings and usually depicted areas of land and their forms. The traditional medium for drawing these maps was apparently the ground and a stick and some have been found as bark paintings (Berndt, 1970). Therefore, how people historically depict their country would ideally be reflected in views composed of thematic layers and hardcopy output from a GIS.

Other issues arise due to cultural differences between GIS software designers and GIS users. Most GIS software is designed in English speaking countries, but many GIS users do not have English as their first language (Campari and Frank, 1995). Language differences may cause problems when a GIS is implemented and used in an indigenous community where the first language is not English. Incorporation of a native language in the GIS may be appropriate at some point during the development of a GIS for a non-English speaking community. Campari and Frank (1995) and Gould (1995) have researched the effect of language on GIS users. However, the studies concentrated on European languages, which have certain similarities, thus the research is not a real indication of problems that may be encountered by Australian Aboriginal GIS users.

Cultural differences between the end users of a GIS and GIS ‘experts’ highlight the need for involvement of the users during implementation and maintenance of the system. As noted by Harmsworth (1997b), involvement of community members is the only way to ensure that the resultant GIS is unique to that group of people. Representation of country in a way that is appropriate to the people of that community can only be done when members of the
community are involved in the GIS process. Furthermore, a GIS can become more relevant to the needs of a culture by including information that can show relationships between country and cultural beliefs. An example of this is discussed by Turk and Mackaness (1995) who demonstrate that by combining conventional maps with cultural images, relationships between beliefs and the land can be represented. Sacredness of an area of land can be conveyed within a GIS by displaying the link between artwork at a site and the terrain (Turk and Mackaness, 1995).

Other issues, such as differences in spatial cognition and the use of computer technology by indigenous people, deserve consideration (Mark, 1995). However, full discussion of these issues is not within the scope of this project.

4.3 Australian Aboriginal relationships with country

As discussed in Section 4.2, different cultures have different perceptions of geographic space and as a result how people view their country is influenced by their cultural background. Before mapping boundaries of Australian Aboriginal land it is essential to understand Aboriginal relationships with country and the nature of clan boundaries. This Section is simplistic from an anthropological viewpoint and does not claim to be a definitive work on Aboriginal boundaries. It is an attempt to describe the nature of Aboriginal clan boundaries so that GIS methodologies for mapping these boundaries can be identified.

Aboriginal relationships with land are complex and cannot be fully described within the context of this Chapter. The following is a brief summary of observations by Berndt (1970) on the relationship of Aboriginal people with their country.

Australian Aboriginal people have an intimate and meaningful association with their country and specific sites within the country. Aboriginal connection to the land is not only a social one, it is socio-religious in nature (Berndt, 1970). Berndt (1970) suggests that in an Aboriginal context, if no sacred sites exist, then there is no religion. Aboriginal bonds with particular land are ancestral and spiritual, the land is personified by the mythic beings that passed through the land during the time of the Dreaming. At certain sites the beings left their own "sacred essence" (Berndt, 1970, pp 6); this essence remains at certain sites today. Aboriginal religion is deeply rooted in the land, particularly sacred sites. For traditional people in Arnhem Land the land is "a sacred inviolable possession" (Berndt, 1970, pp54). It is this relationship with land that is reflected in the nature of boundaries and territories in Aboriginal land.
4.3.1 The nature of Aboriginal boundaries

The use of the term 'boundary' in relation to Aboriginal land is found by some anthropologists to be quite inappropriate (e.g. Williams, 1982; Young in Sutton, 1995). A boundary is something that indicates closure around a piece of land and it suggests limits to the extent of land (Davis and Prescott, 1992). Aboriginal land does not have limits or boundaries in the conventional European sense, however, it must be recognised that certain groups have affiliation with certain land even if boundaries are not physically drawn (Sutton, 1995).

The aim of this research is to investigate a methodology to map Aboriginal clan boundaries, although it must be remembered that larger groups than clans do exist. Larger groups than clan groups are formed by the language group, that is people of the same dialect (Berndt, 1970). Dialect units as described by Berndt (1970) may also be referred to as tribes (Tindale, 1976). A tribe usually consists of contiguously placed hordes. A horde is a clan group minus those members who have left to marry into another clan but adds those people who have married into the group from another clan (Tindale, 1976). The relationships are generally complex, however, they are well understood by people who live in this social system and by anthropologists who have studied particular areas in depth.

Sutton (1995) uses four main concepts to describe 'territoriality' in the Aboriginal Australian context. The concepts are divided into “the band (land-using group), the clan or estate group (land-holding group), the estate (area held by a clan or estate group) and the range (area used by a band)” (Sutton, 1995, pp 40). The clan estate is that area of land held by the clan who are groups of people descended from common ancestry and who have ownership to a definite area of country.

Aboriginal clan territories are made up of composites of sites with significant sites having a strategic role in determining the rights and responsibilities of the people for that land (Davis and Prescott, 1992). Clan boundaries in Australia tend to follow ecological and geographical boundaries (Tindale, 1974). Mountain ranges, rivers, ecological zones, and other environmental changes often form natural boundaries between clan areas. This is certainly true for the Yolgnu in north-eastern Arnhem Land (Williams, 1982). Ian Keen, an anthropologist at Millingimbi during the 1970s, produced an analytical model of clan estate boundaries (Sutton, 1995). Keen suggested three degrees of boundedness in that region. Clearly defined natural features such as rivers form clear-cut boundaries. However, boundaries may also consist of invisible lines between natural objects such as trees. There are
other boundaries that are not clear cut and are dictated by a change in the ecological characteristic of an area, a gradient between one ecological zone and another (Sutton, 1995). Such a boundary could be the gradient between forest and grassland or changes in elevation. Keen concluded that the clearest boundaries are found more in ecologically rich areas than in desert regions.

In reality Aboriginal land does not stop and start at a single line or boundary and there are areas of overlapping interest between aboriginal groups (Davis and Prescott, 1992). There are areas where the clan boundary zones are loosely defined and responsibility for areas of land is shared between aboriginal groups. Marriage between such groups is apparently common (Young in Sutton, 1992) and marriages such as these probably strengthen land alliances.

In the northern coastal area of Arnhem Land there are no exact boundaries unless a river or other body of water defines the boundary (Sutton, 1995). During the years 1958-1960 L.R. Hiatt surveyed land in the Maningrida area and described clan estates in this area as clusters of sites and surrounding country (Sutton, 1995). This concept is depicted in Figure 4.1. Hiatt observed that the local people had intimate knowledge of sites of importance and of the country surrounding the sites. Hiatt also pointed out that as distance from the site increased, interest in the land weakened.

In some areas of Australia, including northern Arnhem Land, a clan may hold proprietary right over land which is not contiguous (Sutton, 1995). An area belonging to one clan may lie within the lands of another clan. Land shared by two or more groups is a common phenomenon in central and coastal Aboriginal Australia; usually the land is centered at a site important to more than one clan.

Land ownership is also closely associated with dreaming tracks. However, when these tracks are considered for mapping boundaries the concept becomes very complex. Patrick McConvell suggests a way to mark a clan estate by marking points along a dreaming track (Figure 4.2) (Sutton, 1995). Points where songlines enter or leave an area form the 'boundary' of the estate. Sites within the estate also form the basis for setting the boundary. This design for mapping clan estates indicates the difficulties of such mapping. Knowledge of songlines, dreaming tracks and sacred sites is needed. In essence, a solid knowledge of anthropology for the area is essential.
In conclusion, the complexities of Aboriginal land relationships cannot be overstressed. This Section allows some insight into the relationship and extracts some guidance for mapping Aboriginal clan boundaries in a GIS environment. Several points on the nature of clan boundaries are worth summarising.

1. Clan boundaries tend to follow ecological or geographic natural boundaries, and as such tend to be determined by changes in natural features.

2. Overlaps in land ownership do occur as more than one clan may have responsibility for a piece of land that is associated with a special site.

3. Clan estates in general are determined more by a composite of sites than by boundaries. Away from the site proprietal interest over land is less important.

4. Land may not always be contiguous and may be separated by other clan estates.

This list is not exhaustive in describing the features of Aboriginal boundaries, however, it is a starting point for working out methodologies to incorporate these features in a GIS. If a methodology can be developed to incorporate these features, future research can expand on the rationale to develop a means to accommodate the complexities of Aboriginal boundaries.

Figure 4.1: Clan estates in Central Arnhem land as described by Hiatt (Source: Sutton, 1995)
4.4 Summary

The use of GIS by indigenous people gives rise to issues that should be considered during planning and implementation of a GIS in an indigenous community. When indigenous knowledge is integrated within the system then security of that information must be maintained at a predetermined level. Other issues that arise when developing a GIS for use by indigenous people include the different perceptions of country and boundaries within the country.

Australian Aboriginal relationships with their country are unique to that group of people. The relationship with country directs the nature of boundaries that exist. Clan estates have no clear boundaries in the European sense, however, boundaries do exist. Depicting the complexities of these boundaries in a GIS requires an understanding of the complexities involved. Further issues arise when mapping boundaries that have the characteristics of Aboriginal clan boundaries. These considerations are mainly technical in nature and are discussed in the next Chapter with other technical considerations for this project.
Chapter 5 Technical issues in GIS, remote sensing and integration

To meet the aims of this project it is useful to identify potential technical issues that can arise when data from a variety of sources are integrated in a GIS. Decisions on how the information is best represented in a GIS should be made during the planning stage of any project. Fundamental differences in data structure and representation can cause problems when remotely sensed data are integrated with GIS ancillary data. Furthermore, the remotely sensed data generally requires processing before useful information for analysis in the GIS can be obtained. The aim of this chapter is to provide insight into some of these issues.

5.1 Defining remote sensing, GIS and integration

To understand the technical issues involved it is useful to define the terms remote sensing, GIS and integration. Remote sensing is broadly defined as “the technology of measuring the characteristics of an object or surface from a distance” (Bird, 1991, pp1). The term is more often used to describe data acquisition by satellite or airborne systems. The data acquired by using these technologies are quantitative and contain much information about the surface of the earth. Efficient data analysis and interpretation is required to derive useful information from quantitative data. GIS can be seen as a toolbox of commands for the input, analysis, storage, retrieval and display of spatially related data (Skidmore et al., 1996). GIS provide tools that can be used to manage the information acquired by using remote sensing technologies. Furthermore, GIS provides a means to integrate remotely sensed data with information from a variety of sources.

To date there is no clear cut and well-used definition of an integrated GIS. Ehlers et al. (1989) defined an integrated GIS and the concept continues to be cited by other authors (e.g. Hinton, 1996). This definition outlines three possible levels of integration and is interesting from a historical perspective. The final level of integration defined in the Ehlers et al. (1989) paper depicts a fully integrated GIS such as is available now e.g. ArcView (with Imagine extension) and IDRISI. Software used in this project is described in Chapter 6. As demonstrated there, the software used was not fully integrated and the following definition by Trotter (1991) is relevant to this project. Trotter (1991) describes integration as the interchange of data between a GIS and a digital image processing system.
5.2 Data representation within the GIS environment

Data representation in a GIS environment is an issue that needs serious consideration during the planning stage of any project. The aim of this section is to review methods of data representation so that the most suitable models can be identified for the geographic features mapped during the course of this project. Representation of spatial information within a GIS requires some abstraction and generalisation of the source data into a form that people can understand (Burrough, 1996). Generally, what is good for one type of spatial data is not suitable for another. There are two common data models available to represent spatial data within a GIS, the vector model and the raster model. The vector model is feature orientated whereas the raster model is more suited to continuous data. The type of model used to represent data in a GIS depends on the nature of the spatial information and how it is acquired.

The vector data format represents geographic entities as points, lines and polygons. A point has no length or volume. A line consists of a series of points and has length but no volume. A polygon consists of a series of lines, a central point and has volume (van der Knapp, 1992). In a vector GIS the points, lines and polygons are defined by their spatial location and by their attributes (Wang and Hall, 1996). A polygon is representative of a homogenous area relative to an attribute. Vector representation is best suited to data that has well defined boundaries. This type of data representation therefore tends to suit data that has human determined boundaries or features such as roads. In a vector GIS the spatial data are linked to attribute data in tables using a unique identifier or key.

To ensure successful storage and display in a GIS the vector data are stored with attached information. Properties of the GIS that require measurement between distances and coordinates rely on geometric information (Laurini and Thompson, 1992). However, other properties do not require measurement but have important spatial qualities. These include connectivity, orientation, adjacency and containment. Connectivity is usually indicated by a link-node list that shows from- and to- nodes. Orientation is necessary to indicate the flow of rivers or one way roads in the GIS. Adjacency properties are important to indicate neighbouring polygons and this is addressed by including details of right and left polygons in the attribute table. The containment property is relevant to whether one spatial entity is included within the bounds of another. Examples of this are seen with point-in-polygon or line-in-polygon searches (Laurini and Thompson, 1992). Topological properties must be maintained for successful storage and display within the GIS. Any process that changes the structure of vector data in a GIS usually 'destroys' the topology of the data. For this reason some measure has to be taken to ensure that the topology of vector data is 'rebuilt' after
every restructuring process. Information for this project was derived from AUSLIG data, as described in Chapter 6 this data is in vector format.

Raster data structure is fundamentally different from vector in that raster represents spatial data in a series of rectangular grid cells with a matrix of grid cells making up a thematic map (van der Knapp, 1992). Each grid cell is coded with a number that indicates attribute information for the thematic map. Some raster systems have the ability to link the raster attribute values to a database through which other information can be added or retrieved (e.g. IDRISI). Spatial data that is best represented by the raster structure is continuous data. Natural phenomena that have no human-made boundaries are best represented in the raster model. Raster representation is also useful for rainfall and elevation data. Raster data used to meet the aims of this project include a digital elevation model and data derived from remotely sensed imagery.

Because of the fundamental differences in data representation in the GIS environment it is essential to decide which model will best represent spatial data relevant to a particular project (Burrough, 1996). This decision is largely dependent on the type of GIS that is already in place within an organisation. Ideally, an existing GIS will either be able to support both data types or will have the ability to extend to include both data types. For this project a ‘dual’ system was available in the form of ArcView (version 3.0, ESRI 1997) with a spatial extension. In situations like this when a ‘dual’ system is available, decisions have to made regarding the best storage format for the spatial data before implementation (Burrough, 1996). Before deciding on the best representation it is essential to know the nature of the data that will be incorporated within the GIS. The research questions of this project address mapping of saltwater crocodile habitat and nesting sites and Aboriginal clan boundaries. The nature of these has been described in Chapter 2 and 4 respectively. It is important to remember that even in a GIS that can support both data structures, there can be no analysis between vector and raster data. For analytical purposes data must be represented in the same format and at some point data conversion must occur to make analysis possible. Problems that occur during the data conversion process are discussed in section 5.4.

Representation of data in a GIS is scale dependent, and how certain geographic features are represented depends on the scale of the map. Scale is defined by Laurini and Thompson (1992, pp300) as a factor that denotes the “order of magnitude or level of generalisation at which phenomenon exist or are perceived or observed”. Scale affects representation of data in both raster and vector GIS. For example, a city represented as a point at a scale of 1:250000 would be represented as a polygon at a scale of 1:50000. The polygon
representation is obviously a less generalised view of the city. The relevance of scale to data used in this project is further discussed in Chapter 7.

Storage space and processing time are two factors that influence whether data are stored in raster or vector format. Representation of thematic data, especially linear and point features, in a raster format is more expensive in storage and processing time as well as in cost (Carver et al., 1994). Vector representation of spatial data is less expensive and is generally used for data that are represented by points, lines or polygons with determinate boundaries. The GIS that results from this project will be installed at community level in Maningrida. Consideration of cost during the development of the GIS will be influenced by cost of storage and by hardcopy maps output from the GIS.

The output from the GIS, the hardcopy map, is generally more satisfactory from a vector system. Maps produced by vector GIS tend to be more akin to conventional maps. Traditional maps use lines and homogenous polygons to represent spatial information as does vector representation of spatial information. However, as discussed in Chapter 4, culture has an effect on how people view their environment and ultimately influences what map form people respond best to. Mapping of Aboriginal clan boundaries as homogenous polygons may be inappropriate. The ultimate decision on which structure best suits the data is dependent on several factors. Availability of software, cost of data, scale and objectives of the project influence the end decision. The maps output from this project are described and discussed in Chapter 7, as are the factors that influenced data representation in the GIS.

5.3 Fuzzy boundaries and GIS

This section briefly describes the nature of indeterminate boundaries and outlines a basic method for representing these boundaries. As described in Chapter 4, Aboriginal clan boundaries are not exact and it is useful to consider the fuzzy boundary concept as a possible method to represent these boundaries. It is essential to understand the fundamentals of fuzzy boundaries before proceeding to the more complex. It is the aim of this section to describe the fundamental principles involved with fuzzy boundaries and their representation in a GIS.

Most naturally occurring geographic entities do not have definite boundaries. This fact is well demonstrated when looking at soil or vegetation types. Traditional soil and vegetation maps are of the choropleth type, where the soil or vegetation types are distinguished as homogenous areas (Trotter, 1991). In this type of map, each soil or vegetation type is enclosed by definite boundaries. In reality, soil or vegetation classes are rarely enclosed by such stringent boundaries. The data have been abstracted and generalised to provide
information that is more readily understood. However, there are circumstances when it is quite inappropriate to abstract data to a level that insinuates the existence of exact boundaries. In most situations there is some discrepancy between what is mapped and what exists in the real world (Burrough, 1996). The use of the fuzzy boundary concept is an attempt to reduce discrepancies in certain circumstances. As previously discussed, vector GIS are suited to the representation of feature orientated data and are well suited to mapping cadastral boundaries, census tracts and other human-made boundaries. There are times when it would be useful to show the gradient that exists between natural phenomena. For example, studies indicate that interpolation of soil properties is improved when discontinuities in soil boundaries are accounted for (Lagacherie et al., 1996).

Before proceeding with discussion on fuzzy boundary concepts, it is important to distinguish between the concepts of 'fuzziness' and 'uncertainty'. The concept of fuzziness applies to information that cannot be precisely defined (Lagacherie et al., 1996). For example, geographic space that can neither be defined as eucalyptus woodland or savanna because the area is one of transition falls into the fuzzy category. In other words, the geographic space belongs to both sets, the eucalyptus set and the savanna set. In this situation a grade of membership to each class exists. Alternatively, uncertainty applies to a situation where there is lack of knowledge about the geographic space. In this example there may be uncertainty as to whether the actual vegetation community that occupies this geographic space is eucalyptus or savanna. The focus of this discussion is on fuzziness rather than the concept of uncertainty.

Fuzzy set theory was introduced by Zadeh in 1965 to deal with inexact concepts in a definable way (Burrough, 1996). Burrough (1996, pp18) defines fuzziness as "a type of imprecision characterising classes that cannot, or do not have sharply defined boundaries". Fuzzy sets are inexacty defined classes that do not have 'true' boundaries. Fuzzy set theory can be applied to geographic data in an attempt to map inexact objects more appropriately (Wang and Hall, 1996). In recent years there have been a few studies on the fuzzy boundary issue (e.g. Wang and Hall, 1996; Kollias and Voliotis, 1991; Openshaw, 1989; Walsh, 1989), however, it is a field that still requires much research.

Burrough (1996) differentiates between fuzzy sets and crisp sets and described how attributes can be defined as belonging to either set. Crisp sets only allow a binary membership function where membership can be either true or false. Crisp set representation is ideal for feature orientated geographic phenomena like cadastral boundaries. A piece of land either belongs within the cadastral boundary or not. Fuzzy set representation allows for
“continuous partial membership” (Burrough, 1996, pp18) and accounts for phenomena which have no clearly defined boundary. Fuzzy sets can define membership function as a grade between 0 and 1. Geographic space with a membership value of 1 is closer to the core zone. Values lessening towards zero have a declining membership.

Fuzzy set theory works well in the field of mathematics, however, the application of this mathematic model to spatial data is presently under review by researchers (e.g. Burrough, 1996; Wang and Hall, 1996; Lagacherie et al., 1996). Conceptual models for defining fuzzy boundaries have been suggested by a few researchers. Leung (1987) proposed a model that represents boundaries as zones, each with a varying membership value. In this model the geographic space has a region core. The space surrounding the core has a membership value that determines closeness to the core. The possibility of applying this model to map Aboriginal clan boundaries is discussed in Chapter 7.

Walsh (1989) also proposed that boundaries could be represented as transition zones rather than as definite boundaries. An important property of models based on fuzzy set theory is the fact that an element may have partial and multiple membership. For example vegetation polygons could have membership grades attached which would indicate the extent to which that polygon was associated with different vegetation types. Partial memberships and multiple memberships to attribute values are possible using this model.

Using the model outlined above requires rationale upon which to apply membership. Burrough (1996) suggests two possible ways to choose membership function. Either expert knowledge can be incorporated in the system or a numerical taxonomy approach can be used. Assigning membership using numerical taxonomy is a complex process and does not fall within the scope of this research project. However, the techniques used to define membership using mathematical techniques are well demonstrated in several papers including Burrough (1996) and Wang and Hall (1996).

Using expert knowledge to define membership values is usually simpler than the mathematical approach. The use of expert knowledge to map Aboriginal clan boundaries could be considered for this and future projects. Expert knowledge incorporated in the system requires only two parameters, the upper and lower boundaries (Burrough, 1996). The following example by Usery (1996) demonstrates the use of expert knowledge to assign membership values. The example involves mapping air pollution around a city centre when the upper and lower boundaries are known. Air within 30 km of the city is definitely polluted, while air 60 km from the city is not polluted. Pollution properties of that geographic
space which lies in the region 30 km - 60 km from the city is a variation from 'polluted' to not 'polluted' and degrees of membership exist. As distance from the city increases then the less polluted the air is and pollution is therefore a function of distance (Figure 5.1). As Usery (1996) suggests, this example is a simple one compared to the complexities that can exist. However, this does illustrate the concept well.

Figure 5.1: The core represents areas that are definitely polluted with a gradual lessening of the levels of pollution away from the core. At a distance of 60 Km there is no pollution (Source: Usery, 1996).

Applications where fuzzy boundary representation is appropriate are well documented in the literature (e.g. Kollias and Voliotis; 1991; Ballantyne and Sutherland, 1994; Lagacherie et al., 1996; Wang and Hall, 1996). Fuzzy set theory is commonly used to reduce errors that result from a generalisation process. An example of generalisation is the classification and aggregation of data obtained from satellite remote sensing. The process of generalisation in this context is further discussed in section 5.4. Polygon generalisation is also common in vector GIS as the spatial data are represented as points, lines or polygons. Application of fuzzy set theory to this data can reduce introduced error (Wang and Hall, 1996).

In many circumstances, there are implications when boundaries are mapped in an inappropriate way. In any circumstance where the mapping of boundaries has political or cultural significance, serious thought has to be given to the process of generalisation and abstraction of boundaries in the GIS environment. Ballantyne and Sutherland (1994) suggest
the use of fuzzy set theory to map boundaries of traditional Moari land in New Zealand. The authors indicate that fuzzy representation of culturally or spiritually significant land is more appropriate than traditional mapping methods. An aim of this project was to map Aboriginal clan boundaries in the Central Arnhem Land region of the Northern Territory. As previously suggested, the use of fuzzy representation of these boundaries is worth discussion and consideration. Mapping of these boundaries does have cultural and political implications.

To many people, a map is literally a representation of what does actually exist on the ground (Monmonier, 1991). This perception may be naive but it is common. In an ideal situation a map should therefore attempt to map geographic space in a way best suited to the entity being mapped.

5.4 Generalisation and abstraction of remotely sensed data

Data acquired by satellite remote sensing are in raster format (Pinowar et al., 1990). As described in section 5.2, raster representation is suitable for continuous data. The advantages of using remotely sensed data as an input to a GIS for resource management are described by numerous authors (e.g. Ehlers et al., 1989; Pinowar et al., 1990; Trotter, 1991; Hinton, 1996). During this project a landcover basemap and a saltwater crocodile habitat map were derived from remotely sensed imagery. Derivation of these maps was by classifying the remotely sensed data in an image processing system. It is useful to describe the theoretical basis for the methods used during that process. For the information obtained by remotely sensed images to be useful in a GIS, it must be generalised to homogenous polygons (Otto, 1990; Trotter, 1991). The amount of generalisation required depends on the spectral variation within the remotely sensed image as well as the end application of the image. Remotely sensed data are usually generalised in a digital image processing system by applying classification algorithms to the data (Trotter, 1991). Preprocessing of the remotely sensed image is, however, essential before successful classification can be achieved.

Raw image data obtained by satellite remote sensing techniques have several features that should be corrected before the data are processed. Spectral data recorded by passive remote sensing devices are affected by atmospheric scattering. If this factor is not accounted for during preprocessing stages then classification accuracy will be affected (Wilkinson, 1991). Numerous approaches to remove Atmospheric Path Radiation (APR) are suggested by several authors (e.g. Wilkinson, 1991; Lillesand and Kiefer, 1994). A commonly used method is the dark value method as described by Wilkinson (1991) and Hill and Sturm (1991). The rationale behind this method is that deep water theoretically absorbs all radiation in the infrared part of the electromagnetic (EM) spectrum. If deep water in an infrared band
has a spectral value of greater than 0 then this is representative of the amount of APR in the image. To correct for APR using this method a sample of pixels is selected from deep water in an infrared band of the image. The spectral value of the sample is then analysed. The value obtained is then subtracted from all bands of the raw data, thus correcting for APR.

Preprocessing stages depend largely on what information is required to meet the aims of the study. Image masking may be done to mask out areas in the image that are of no interest to the project. Cloud cover is common on images derived from passive remote sensing devices. It is advisable to remove cloud cover and other unwanted features before classifying the image data. Removal of unwanted data generally reduces computational time during processing stages. Spectral variation within the image data is reduced and classes generated during classification will also be reduced.

Image enhancement is a process whereby the features within the image are made more visually identifiable. This process is useful as it enables the analyst to visually interpret the image and thus recognise features and landcover types. Image enhancement can be achieved by one of several methods (Harrison and Jupp, 1990). All methods involve statistical analysis of the data and subsequent enhancement using one of a range of techniques (Lillesand and Kiefer, 1994). Choice of method generally depends on the aims of the study and more complex enhancement techniques such as edge enhancement may be used to delineate roads and rivers more effectively. However, if the aim of the enhancement is to improve overall visual interpretation of the image then contrast stretching techniques are suitable (Harrison and Jupp, 1990).

Preprocessing steps are designed to prepare the data for processing. The first stage of processing is to classify the image. The classification process is one of generalisation, as pixels with a range of spectral values are grouped into homogenous classes. Choice of classification techniques is important as the outcome of the process depends on the methods used (Langford and Bell, 1997). There are three general methods of classifying an image in digital image processing systems. During unsupervised classification, classes are defined according to spectral variation within the data (Harrison and Jupp, 1990). There is no input from the analyst for this method of classification and the results are objective. From a theoretical point of view the result is better. Disadvantages of this method include the fact that knowledge of the area is ultimately required for aggregation of the classes into super classes. This process is discussed below. Supervised classification techniques rely on the analyst having knowledge of the study area. During this method the analyst selects training areas of pixels. Spectral statistics of these training areas are then used to allocate pixels to
relevant classes (Harrison and Jupp, 1990). This method is subjective and familiarity with the training area can influence results. A third method commonly used has the advantages of both unsupervised and supervised classification methods, as it is essentially a combination of both. This method is commonly used by several authors (e.g. Brondizio et al., 1996; Sader et al., 1995). Hybrid classification methods account for recognisable areas in the image by allowing training areas to be selected (Sader et al., 1995). During the classification pixels are allocated to known classes as defined by the training patches. New classes will be created until the maximum number, as defined by the user, has been attained. Decision rules, used to determine which class a pixel should be allocated to, depend on the classification algorithm applied. Hybrid classification techniques were used during this project to generalise remotely sensed data; the process is described in Chapter 6.

There are several different algorithms that can be applied during the classification process. The best algorithm to use generally depends on the nature of the data (Lillesand and Kiefer, 1994) as well as the intended application (Langford and Bell, 1997). Two algorithms commonly used are the Minimum-Distance-to-Means (MDM) classifier and the Maximum Likelihood classifier (MLC) (Harrison and Jupp, 1988). The MDM classifier calculates the mean value of the training areas in each input band and allocates each pixel to a class by measuring the distance from the mean of the known class (the training patch) to the value of the pixel. Decision boundaries, as preset by the analyst, are used to set the tolerance gate. The tolerance gate determines how close the value of the pixel has to be from the mean before it is included or excluded from a class. If a pixel is not within the specified distance to the mean of any of the known classes then new classes are established. Any pixels that do not fall within a specified distance to the mean of any class when the total number of classes is reached remains unclassified. During this process it is possible to request several iterations. During each iteration the mean value of the class is recalculated to account for pixels that have been allocated to the class during the previous iteration (Harrison and Jupp, 1988). The algorithm used during this project was the MDM as described above.

The MLC classifier is based on probability statistics and assumes a normal distribution (Harrison and Jupp, 1990). During classification this method works on the assumption that each landcover type is found in equal occurrence. This classifier is directed towards supervised or hybrid classification methods. During classification, the variance and covariance of each training patch is evaluated and pixel allocation thereafter depends on the probability that the pixel belongs to a particular class (Harrison and Jupp, 1988). This classifier is computationally intensive and time consuming. A criticism of the method is that land cover types do not occur naturally in a normal distribution for a given piece of land.
Regardless of which classification method or algorithm used, the large numbers of classes obtained during the process is too large to be useful. A method is required to further generalise the information obtained within the image. This process is achieved by determining the spectral range and separateness of the classes that have been generated during the classification process (Harrison and Jupp, 1988). During the process of classification and aggregation the continuous data have been abstracted to a level that is more easily understood. Generalisation of data is essential to allow further analysis, particularly when the data are integrated with ancillary data in a GIS. A measure of the accuracy of the generalisation will provide the end users of the information with the means to assess whether the end result is suitable to their needs.

5.5 Accuracy assessment

The accuracy of the generalisation process and the resultant maps should be assessed and documented (Langford and Bell, 1997). It is only by doing this that the end users can determine if the standard of the map produced is suitable to their needs. However, the cost of field checking the mapped area is usually expensive in time and money (Hord, 1976; Congalton, 1988). For this reason it is essential to work out the most suitable sampling strategy before venturing into the field. Congalton (1988) compared five sampling strategies used to generate error matrices for a landcover map. The sampling strategies included, simple random sampling, stratified random sampling, cluster sampling, systemic sampling and stratified systemic unaligned sampling. The results of that study indicate that stratified random sampling produces good results, and is the best method to ensure that representatives from all classes are included for accuracy assessment. Data collected from the field using the chosen sampling strategy are then generally used to generate an error matrix (Langford and Bell, 1997). Accuracy assessment entails comparing 'true' data obtained from 'ground truthing' an area with image data at the same geographic point on the map produced by classifying a remotely sensed image. This information is then used to compute an error matrix from which overall map accuracy can be ascertained.

During the field component of the accuracy assessment process a Global Positioning System (GPS) is generally used to ascertain the geographic coordinate of a given site. There are numerous sources of error when using a GPS that a researcher must be aware of. Common errors associated with the use of GPS are detailed in texts (e.g. Kennedy, 1996). Kennedy (1996) suggests one method that can account for some of the error inherent with GPS. This method suggests that multiple GPS readings should be taken at each field site visited and
averaged to give a single coordinate. The method is based on the fact that GPS readings obtained are usually close to the true reading but are not exact. Kennedy (1996) uses the principle that large numbers of random errors in this circumstance are self canceling, and an average of multiple readings is more likely to be closer to the true reading than a single measurement. Obviously the more readings taken at a particular site then the more accurate the average of the readings becomes. Time and financial constraints do, however, determine how many readings are feasible at field sites.

5.6 Image rectification and registration
Before remotely sensed images can provide useful information in a GIS they must be registered to a geographic coordinate system. The process of rectifying and registering an image can be successfully done in digital image processing systems. There is a growing trend, however, to use GIS ancillary data during this process (e.g. Papanikolaou and Derenyi, 1987; Trotter, 1991; Hinton, 1996).

Remotely sensed images have inherent geometric distortions that should be accounted for before the data is used for analysis. The nature of the geometric distortions is either platform or orbit related (Harrison and Jupp, 1990). These distortions can be accounted for by applying polynomial models during a rectification and registration process (McGwire, 1996). In a GIS, vector data can be used for image rectification and registration (Hinton, 1996). Coordinates of ground control points are extracted from vector data in a GIS, and used to register the image by applying polynomial models. An advantage of this method is that the vector data can be directly overlaid on the image data to allow visual assessment of the process (Hinton, 1996). Success of rectification and registration processes is largely dependent upon the number and distribution of control points collected (Kardoulas et al., 1996).

5.7 Integration issues
Depending on the level of integration used during a project there are problems that occur during the process of integration. As discussed in section 5.1, integrated GIS has reached the point where GIS and image processing software are available on the one system. For this project, a fully integrated software package was not available and the definition of integration by Trotter (1991) is appropriate. As indicated in this definition, there are logical constraints of moving data between different software. Usually different software store files in different formats and at some point the data must be converted from one file type to another (Hinton, 1996). This process should be kept to a minimum as error is introduced with each file conversion (Trotter, 1991). A common file type may exist between both systems
and should be used where possible. Any process that changes the file structure will introduce some error and this must be considered when assessing the accuracy of the end product.

Even with a fully integrated GIS there are problems that arise due to fundamental differences in data storage. Remotely sensed data acquired for this project were in raster format. GIS data used was in vector format. As discussed in section 5.2 these data formats are fundamentally different. At some point of the project, the data had to be converted from one format to another to make analysis possible (Pinowar et al., 1990).

Conversion of data from raster to vector or vector to raster is not without problems as the process causes further generalisation of features and loss of accuracy (Pinowar et al., 1990; Hinton, 1996). Conversion of raster and vector formats has been well researched for computer graphics (Pinowar et al., 1990). Data conversion for GIS applications is, however, more difficult since spatial relationships between objects must be maintained (Pinowar et al., 1990). Spatial relationships refer to the topological features that were discussed in section 4.2.

It is inevitable that during the data conversion process error will be introduced. Processes of conversion and the resulting generalisation and abstraction of data cause error. If the remotely sensed data are being integrated within a vector GIS, then raster to vector conversion must take place. Before this is possible the remotely sensed data must be generalised to homogenous polygons. Classification and subsequent aggregation of remotely sensed data in a digital image processing system is essentially a process of generalisation. Remotely sensed data can then be converted to vector format. Raster to vector conversion involves the creation of vectors and the assembly of these vectors into relevant polygons (Laurini and Thompson, 1992). The resultant data is often 'blocky', as the polygons will exhibit the rectangular edges of the original raster grid cells (Figure 5.2). A boundary smoothing algorithm may reduce this effect, however, the integrity of the data may not be maintained (Laurini and Thompson, 1992).
If a GIS that can accommodate raster format is being used, then raster to vector conversion is not required. However, since most ancillary GIS data are available in vector format this has to be converted to raster. Conversion of vector data to raster generally causes problems since the borders of the vector polygons do not coincide with the boundaries of raster cells (Figure 5.3). Data represented as lines or points in the vector system are not well represented in a raster GIS. To measure the overall success of a data conversion process it is often interesting to compare area and perimeter measurements of the vector and raster data (Laurini and Thompson, 1992).

During the planning stage of a project that does require integration of vector and raster data the problems associated with data conversion should be considered. Error is introduced during any conversion process and will propagate through the data at each stage of analysis. This present project integrates raster and vector data from various sources. The problems associated with data conversion are therefore relevant and should be considered during each stage of the project.
In a GIS with both raster and vector functionality, the need for conversion can be minimised. In these systems raster information can often be derived directly from vector files. An example of a GIS that can work with both raster and vector data is ArcView. This GIS is essentially vector, however, a spatial extension can support and analyse raster data. In a GIS such as this a raster buffer can be derived from a vector file without any conversion of data. In other GIS a buffer would first have to be made in vector and then converted to raster. Error introduced during the process would thereby be increased.

Awareness of limitations is necessary to ensure that integration processes are planned to reduce error where possible. Careful consideration of data transfer between systems, file conversion and data conversion are necessary throughout the integration process.

5.8 Summary

During the planning stage of this project there are technical issues which should be addressed to ensure data integrity. Decisions regarding data structure are largely dependent upon the software that is already in use within the organisation. Software used for this project is described in the following Chapter. The nature of the entity being mapped also plays a role determining which structure best represents reality. Characteristics of saltwater crocodile habitat and Aboriginal clan boundaries were described in Chapters 2 and 4. Representation of boundaries in a GIS needs careful consideration. This is particularly true when the boundary has political or cultural implications, as have Aboriginal clan boundaries.

During this project GIS and digital image processing techniques are integrated and knowledge of potential problems is useful. The advantages of integration are demonstrated in many previous studies, as briefly described in Chapter 3. During this project careful consideration had to be given to the best method to map Aboriginal clan boundaries and saltwater crocodile data. The methodologies used to meet the aims of this project are described in the next Chapter. Discussion of these methodologies and results of the project is found in Chapter 7.
Chapter 6  Methodology

The methodology used to meet the aims of this project is described in the following Sections. Theoretical basis for the methods used is discussed in Chapters 3, 4 and 5. The GIS and digital image processing components were conducted in a computer laboratory. However, several visits to Central Arnhem Land provided insight into the physical environment and the culture of the region.

6.1 Source Data

During the course of this project data from a variety of sources were input and analysed in both a digital image processing system and a GIS. The software used for analysis of data included microBRIAN image processing system (version 3.41, MPA 1985), ArcInfo (version 7.0.4, ESRI 1997) and ArcView (version 3.0, ESRI 1997) GIS. Data used are described below.

6.1.1 Landsat Thematic Mapper image data

Details of these data are listed in Table 6.1. The data were acquired during April 1994, three years prior to the time of commencement of this project. Time of acquisition is important as seasonal factors influence the spectral signature of vegetation and soil. This factor is further discussed in Chapter 7. Landsat TM bands 1,2,3 and 4 were used to meet the aims of this project. Bands 1 and 2 of Landsat TM data were found to be useful for wetland mapping in a study by Johnston and Barston (1993). Band 2 collects data in that part of the EM spectrum (0.52 – 0.60 microwaves) in which green vegetation reflects microwaves. Photosynthetic plants also reflect strongly in the NIR part of the EM spectrum and band 4 was included for that reason. Table 6.2 describes the spectral bands of Landsat TM and their wavelength on the EM spectrum.

<table>
<thead>
<tr>
<th>path/row/quadrant</th>
<th>104/68/11</th>
</tr>
</thead>
<tbody>
<tr>
<td>scene centre lat/long</td>
<td>11:58:00</td>
</tr>
<tr>
<td></td>
<td>134:08:33</td>
</tr>
<tr>
<td>sun elevation</td>
<td>57.81 degrees</td>
</tr>
<tr>
<td>sun azimuth</td>
<td>91.78 degrees</td>
</tr>
<tr>
<td>date of acquisition</td>
<td>April 1994</td>
</tr>
</tbody>
</table>
Table 6.2 Spectral bands of Landsat TM

<table>
<thead>
<tr>
<th>Landsat TM band</th>
<th>Wavelength of EM spectrum (micrometres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.45 – 0.52</td>
</tr>
<tr>
<td>2</td>
<td>0.52 – 0.60</td>
</tr>
<tr>
<td>3</td>
<td>0.63 – 0.69</td>
</tr>
<tr>
<td>4</td>
<td>0.76 – 0.90</td>
</tr>
<tr>
<td>5</td>
<td>1.55 – 1.75</td>
</tr>
<tr>
<td>6</td>
<td>10.4 – 12.5</td>
</tr>
<tr>
<td>7</td>
<td>2.08 – 2.35</td>
</tr>
</tbody>
</table>

(Source: Barret and Curtis, 1992)

6.1.2 GEODATA AUSLIG TOPO-250K data

These data are a product of the Australian Surveying and Land Information Group (AUSLIG), Department of Administrative Services. AUSLIG data are derived from 1:250 000 scale National Topographic maps for Australia, a map series that was completed in 1988 (Geodata, 1992). The data are in vector format and spatial features are composed of points, lines and polygons. The fundamental differences between GIS data formats have been described in Chapter 5. The data contain three main themes, which consist of layers. The user guide on AUSLIG data defines a layer as a “grouping of features which have compatible spatial objects” (Geodata, 1992, pp18). Each layer has an attached table that contains attribute information on the features represented in the layer. The themes and corresponding layers are briefly described in Table 6.3. AUSLIG TOPO-250K data is tiled. Each tile corresponds to the map sheet in the 1:250 000 National Topographic map series from which the digital data were derived. The study area of this project was covered by two of the AUSLIG tiles, d5302 and c5314.
6.1.3 GEODATA 9 second digital elevation model

The GEODATA 9 second digital elevation model was sourced from GEODATA AUSLIG TOPO-250K data and data supplied from The Australian National Gravity Database (ANGD). The tile used in this project was SD53. Source data for this tile was obtained only from GEODATA TOPO 250-K data, as there were obvious systematic differences between these data and the ANGD data for that area of land. Data derived from the AUSLIG TOPO 250-K data include spot elevation points from the relief theme. The spot elevation data were originally derived from AUSLIG’s national coverage 1:100 000 maps. However when digitised the map is stored in tiles that have a scale of 1:250 000. The density of points used varies from tile to tile (Geodata, 1996). Stream line data and lake boundary data used to derive the 9-second DEM are from AUSLIG TOPO-250K data, hydrography theme. Coastline information was derived from the framework theme of AUSLIG TOPO 250-K DATA. Further information on these data can be found in the User Guide for GEODATA 9 SECOND DEM (1996).

6.1.4 Crocodile nesting data

WMI and Wildlife Division of the Northern Territory Parks and Wildlife Commission provided data on the position and history of crocodile nesting sites for the study area. Data obtained from WMI came in the form of Excel files, text files and raw data obtained in the field during saltwater crocodile egg collection field trips (Appendix 1). Data obtained from the Wildlife Division were in ArcInfo coverage format.
6.2 Creating basemaps of the study area

Previous studies highlight the need for an accurate basemap in a GIS (Tabor and Hutchinson, 1994; Sirait et al., 1994). As suggested in Chapter 3, the use of remotely sensed imagery as a basemap in a GIS is invaluable. The region serviced by BAC is covered by several Landsat TM images. Scope of the project and overall size of the study area constrained the time available to classify remotely sensed images for the whole study area. The Landsat TM scene described in Section 6.1 has been used to create a landcover basemap for a section of the area immediately surrounding Maningrida. A larger topographic basemap that encompasses the whole study area was derived from AUSLG data.

6.2.1 Creating a landcover basemap of the study area from classified remotely sensed imagery

Flowchart 6.1a demonstrates the overall process used to derive a classified basemap for the study area from a Landsat TM quarter scene image. The Landsat TM image was downloaded from tape and imported into the microBRIAN image processing system. Landsat TM bands 1, 2, 3 and 4 were selected and preprocessing of the image was done in microBRIAN to remove Atmospheric Path Radiation (APR). The dark value method as described by several authors (e.g. Wilkinson, 1991; Hill and Sturm, 1991) was used in this project to correct for APR. A sample of pixels was selected from deep water in band 4 of the image data. The spectral value of the pixels was then analysed. Result of analysis indicated that a value of 4 was representative of the APR for the whole image. All bands were adjusted by this value.

The next process was to remove unwanted cloud from the raw data. Spectral digitising was not an appropriate method for this as there is a spectral overlap between cloud and ground covers such as beaches and saline coastal flats. On screen spatial digitising was used as a means of removing unwanted cloud cover. As seen in Figure 6.1 the cloud cover was extensive over the ocean but fortunately did not affect land. Following this the image was enhanced to make features more visually identifiable. For this project contrast stretching as described by Lillesand and Kiefer (1994) was used to enhance the TM image. Visual interpretation of the image was then possible and the image was ready for classifying.

The first stage of processing is to classify the preprocessed image. Many landcover types were recognisable on the enhanced image and hybrid classification techniques described by Sader et al. (1995) were used. The algorithm used to apply the hybrid classification in this project was the Minimum Distance to Mean classifier, described in Chapter 5.
Flowchart 6.1a: Creating a landcover basemap from Landsat TM imagery, Bands 1, 2, 3 and 4.

- Download Landsat TN imagery, bands 1, 2, 3 and 4 from tape.

**Preprocessing stages**

- Correct image bands for APR (dark value method)
- Spatial digitising (to remove unwanted cloud cover)
- Image enhancement (1-99% stretch)

**Image processing**

- Hybrid classification
- Select training patches
- Statistical analysis of patches

- Apply Minimum Distance to Mean algorithm

- 250 classes generated - 75 have less than 150 pixels

- Delete small classes

- Apply Minimum Distance to mean algorithm with different decision parameters

**Spectral Class Aggregation**

- Canonical variants analysis
- Canonical variants plot and minimum spanning tree computed. Gradient of MST low

- Cluster analysis using a dendrogram

- Aggregate classes using PAINTER module in microBRIAN to allocate a nominal number.

- Export from microBRIAN as an ERDAS.gis file
Figure 6.1: Unclassified Landsat TM image, bands 2,3 and 4. Cloud cover can be seen in the top right corner.
During classification of the image for this project a total of 55 training patches was used. The patches represented known land cover types (Table 6.4) in the unclassified image. A decision boundary was defined by applying a tolerance level of 15% with 4 iterations. The maximum number of classes generated during this initial classification was 250, 55 of which were the known classes selected as training areas during the pre-classification process. Table 6.5 indicates the results of that classification.

Table 6.4 Training area collected for hybrid classification of Landsat TM image

<table>
<thead>
<tr>
<th>Landcover type (from AUSLIG topographic maps)</th>
<th>Number of patches obtained with standard deviation of less than 2.5 (Harrison and Jupp, 1988)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deep water (including billabongs)</td>
<td>5</td>
</tr>
<tr>
<td>Medium water</td>
<td>5</td>
</tr>
<tr>
<td>Shallow water</td>
<td>5</td>
</tr>
<tr>
<td>Sedimented water</td>
<td>5</td>
</tr>
<tr>
<td>Eucalyptus woodland</td>
<td>6</td>
</tr>
<tr>
<td>Eucalyptus forest</td>
<td>6</td>
</tr>
<tr>
<td>Swamp</td>
<td>6</td>
</tr>
<tr>
<td>Mangroves</td>
<td>6</td>
</tr>
<tr>
<td>Land prone to inundation</td>
<td>6</td>
</tr>
<tr>
<td>Saline coastal flats</td>
<td>5</td>
</tr>
<tr>
<td>Paperbark swamp</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 6.5: Results of applying minimum-distance to mean algorithm for a hybrid classification.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of classes generated</td>
<td>250</td>
</tr>
<tr>
<td>Number of classified pixels</td>
<td>7557126</td>
</tr>
<tr>
<td>Number of unclassified pixels</td>
<td>33368</td>
</tr>
<tr>
<td>Number of digitised pixels</td>
<td>2713506</td>
</tr>
<tr>
<td>Total number tested</td>
<td>10304000</td>
</tr>
<tr>
<td>Mean within class dispersion</td>
<td>0.84</td>
</tr>
<tr>
<td>Between to within ratio</td>
<td>6.6465</td>
</tr>
</tbody>
</table>
During the classification process a mean image and a residual image were generated. After the initial classification the residual image was noted to have patterns emerging in areas where deep water was evident in the original unclassified image. This pattern in the residual image suggested that some of the unclassified pixels (Table 6.5) resulting from the first classification process formed a homogenous group. Oceanic deep water is not important saltwater crocodile habitat. However, deep water was also noted to occur inland and indicated the presence of billabongs where saltwater crocodiles are commonly found. An aim of the project is to create a GIS that can be expanded to assist with resource management of other resources. For these reasons several new training areas were selected from deep water areas in the unclassified image and the minimum distance to mean classifier applied, again using the same decision boundaries. 75 of the 250 classes generated by this classification process consisted of 150 pixels or less. Classes with less than 150 pixels are too small to be useful. The small classes (<150 pixels) were deleted in microBRIAN and the classification process repeated. The decision boundary was changed during this second classification as the tolerance was increased to 16% with 6 iterations. By increasing the tolerance gate many of the small classes could now be included in the larger classes. 175 classes were generated during the second classification process.

Following the classification process, a method to further aggregate the data is required for reasons previously discussed in Chapter 5. Canonical Variants Analysis was used in microBRIAN for this purpose. The Minimum Spanning Tree (MST) resulting from this analysis had a low gradient and was not useful for class aggregation in this instance. Cluster analysis was achieved by using a dendrogram. The dendrogram used to cluster the classes to produce a basemap of landcover classes for this project is in Appendix 2. Allocating a nominal Number to all classes using the PAINTER module in microBRIAN created the final landcover map. The final landcover map contained 12 broad landcover classes. The classification (mean) channel was then exported from microBRIAN as an ERDAS.gis file. This file was imported to ArcInfo for registration and rectification.

Registration and rectification of the image data was achieved in ArcInfo (Flowchart 6.1b). In ArcInfo a series of links were made between the classified image and a vector coverage derived from the AUSLIG data. In ArcInfo the links were used as control points to compute a six-parameter affine transformation (Table 6.6).
Flowchart 6.1b: Registration and rectification of the classified basemap

Register classified image in ArcInfo (REGISTER command at ArcInfo prompt)

60 links created between the ArcInfo coverage and the image

Register image to ArcInfo coverage (apply 6 parameter affine transformation)

Rectify image in ArcInfo - nearest neighbour algorithm applied (RECTIFY command at ArcInfo prompt)

Root mean square error 9.961
World file created for image

View rectified image in ArcView and convert to GRID format
Table 6.6: Six-parameter affine transformation applied in ArcInfo

\[ x' = Ax + By + C \]
\[ y' = Dx + Ey + F \]

where \( x' \) = calculated x-co-ordinate of the pixel on the map
where \( y' \) = calculated y-co-ordinate of the pixel on the map
\( x \) = column number of a pixel in the image
\( y \) = row number of a pixel in the image
\( A \) = x-scale; dimension of a pixel in map units in x direction
\( B, D \) = rotation terms
\( E \) = negative of y-scale; dimension of a pixel in map units in y direction.
(Y scale is negative as the origins of the image and geographic co-ordinate systems are different)

\( C, F \) = translation terms; \( x, y \) map co-ordinates of the centre of the upper left pixel.

A total of 60 links were made between the image and ArcInfo vector coverages (framework and infrastructure). The Root Mean Square (RMS) error following registration was 9.961. The registered image and the vector coverage were displayed together in ArcInfo so that a visual assessment of the transformation process could be made. The parameters were accepted as the RMS was adequate and when the image and vector coverage were viewed together the result was satisfactory. After registration in ArcInfo the parameters were stored in a world file for the image. The image was then rectified in ArcInfo to transform the image data to real world coordinates. The rectification process has been described in Chapter 5. For this project a nearest neighbour interpolation algorithm was applied to calculate the real world coordinate for each output pixel in the image. This algorithm is recommended in the ArcInfo helpline as the algorithm of choice for continuous data. After rectification the image was converted to grid format in ArcView. Each pixel in the resulting grid had a resolution of 30.8592 metres.

As discussed in Chapter 5 the accuracy of maps should be assessed and documented so that the end users of the maps can determine if the map is suitable to their needs. Accuracy assessment of the basemap produced from the Landsat TM image was assessed by comparing the class allocated to a pixel with the known class on the ground. An error matrix as described by Langford and Bell (1997) was used to determine the accuracy of the resulting map, as well as individual class accuracy. The field survey, described in a later Section, did
not include all classes that were represented in the image data. For this reason information derived from WMI crocodile nesting data was also used in the error matrix.

A second basemap was created for the study area from the remotely sensed imagery. This basemap consisted of bands 1, 3 and 4 of the Landsat TM image. Preprocessing steps had enhanced the image but no other processing was done. As the software available for this project was not integrated, there were some minor problems associated with file transfer from microBRIAN to ArcInfo and ArcView. MicroBRIAN image files are BIL (binary interleaved) format and can be read by ArcInfo. However, to display microBRIAN image files in ArcInfo or ArcView it is necessary to change the image file extension to *.bil and to create a header file for the image. The *.bil file could then be imported into the ArcInfo workspace for registration and rectification as described previously. As a result of the rectification and registration process the resolution of the image pixels was 29.951 x 30.859 metres. The image was not used for further analysis but provided a background point for other data displayed with the image data.

6.2.2 Creating a topographic basemap for the study area from AUSLIG TOPO-250K data

AUSLIG data was used to prepare a topographic basemap of the area serviced by BAC. The data was downloaded from an 8mm tape and then imported into the ArcInfo work environment as ArcInfo coverages. AUSLIG data have a vector format and should have topological properties as discussed in Chapter 5. In ArcInfo the 'CLEAN' or 'BUILD' command are used to create topology for vector files. 'BUILD' creates and updates a feature attribute table for point, line or polygon coverages but cannot accommodate coverages that have overshoots or undershoots. The 'CLEAN' command accounts for intersections whenever one line crosses another by finding arcs that cross and placing a node at each intersection of arcs. 'CLEAN' corrects for undershoots and overshoots within a user defined tolerance. The process of 'building' topology was repeated following any process in the GIS that changed the structure of the vector data. Therefore, the chosen command was used to 'build' topology after editing data or after reprojection of data.

The next part of the process was to join all coverages for each tile imported from AUSLIG data. For example, the drainage coverage for tile c5314 had to be added to the drainage coverage for tile d5302 to create a single drainage coverage. This process was done for all coverages using the APPEND command in ArcInfo. After appending the coverages, each cover was projected from geographic coordinates to Australian Map Grid coordinates (AMG). The coverages were then clipped to the size of the actual study area using the ArcEdit mode in ArcInfo. Following this the coverages were exported to ArcView and
Flowchart 6.2: Deriving a topographic basemap for the study area from AUSLIG TOPO-250K data

1. Download AUSLIG TOPO 250K data from tape
2. Import files into ArcInfo work environment as coverages
3. Build topology (CLEAN or BUILD command)
4. APPEND coverages for tiles c5314 and d5302
5. Generate polygon coverage (exact size of the area serviced by BAC)
6. Clip appended coverages to exact size of the area serviced by BAC using the generated polygon coverage in ArcEdit mode
7. Project clipped coverages into AMG coordinates (from lat/long) using PROJECT command in ArcInfo
8. Convert ArcInfo coverages to shapefiles and display in ArcView. Derive new themes from shapefiles
9. Export coverages from ArcInfo and import into ArcView

* indicates that topology was built after that process
converted to shapefile in that system. Table 6.7 details the resultant shapefiles and the AUSLIG theme they were derived from. The processes used to create the final basemap are outlined in Flowchart 6.2.

Table 6.7: Shapefiles derived from AUSLIG data

<table>
<thead>
<tr>
<th>AUSLIG theme shapefiles were derived from</th>
<th>Shapefile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrography</td>
<td>drainage.shp</td>
</tr>
<tr>
<td>Hydrography</td>
<td>rivers.shp</td>
</tr>
<tr>
<td>Hydrography</td>
<td>wetlands.shp</td>
</tr>
<tr>
<td>Hydrography</td>
<td>mangrove.shp</td>
</tr>
<tr>
<td>Hydrography</td>
<td>offshore.shp</td>
</tr>
<tr>
<td>Infrastructure</td>
<td>roads.shp</td>
</tr>
<tr>
<td>Infrastructure</td>
<td>aero.shp</td>
</tr>
<tr>
<td>Infrastructure</td>
<td>localities.shp</td>
</tr>
<tr>
<td>Framework</td>
<td>studyarea.shp</td>
</tr>
</tbody>
</table>

6.3 Mapping saltwater crocodile habitat

An aim of this project was to investigate the potential of integrating GIS and digital image processing techniques to map the potential habitat of saltwater crocodiles (*Crocodylus porosus*). This Section describes the methods used to meet this aim. The habitat of saltwater crocodiles as described in Chapter 2 was used to create decision rules for application to GIS data.

Decision rules for mapping saltwater crocodile habitat:
1. Saltwater crocodiles are found in tidal sections of rivers
2. Saltwater crocodiles inhabit coastal wetland areas
3. Saltwater crocodiles are found within a specified distance from permanent water bodies and tidal rivers.
4. Elevation is a factor that influences saltwater crocodile habitat.

The rules were then applied to the existing data in the GIS (derived from AUSLIG data) to create a mask. The mask could then be applied to the unclassified Landsat TM image. The process is outlined in Flowcharts 6.3a and b. Prior to application of the decision rules to the GIS data in ArcView, the AUSLIG basemap data were reduced from the size of the total.
Flowchart 6.3a: Applying decision rules to GIS data

Decision rule: Saltwater crocodiles are found in tidal sections of rivers and within 1 Km of permanent water bodies.

Derive shapefile to represent only the tidal sections of rivers from rivers data (A).

Derive shapefile of estuarine areas and permanent water bodies from wetlands data (B).

Merge A and B using an AVENUE script (C).

Distance analysis of C using spatial analyst extension of ArcView (D).

Reclassify D (in raster format) to create a 1Km buffer around tidal sections of rivers and permanent water bodies (E). Value of buffer =

Decision rule: Saltwater crocodiles inhabit coastal wetland areas

Distance analysis of Wetlands data using spatial extension of ArcView (F).

Reclassify E to create a 1 Km buffer around coastal wetlands (G). Value of buffer = 1.

Overlay E and G using mathematical overlay techniques. Resulting grid has 3 values (H).

0 = not suitable for saltwater crocodiles
1 = suitable for saltwater crocodiles
2 = most suitable for saltwater crocodiles

Reclassify to create overall value of 1 for areas suitable for saltwater crocodiles. Resulting grid meets either of the above requirements (I).

Decision rule: Saltwater crocodile habitat is found at an elevation less than 12 metres

Import DEM to ArcInfo and project into AMG coordinates.

DEM is in grid format - reclassify to reduce to two values.
1 = areas less than 12 metres
0 = areas greater than 12 metres

Overlay I and J to create a mask that meets all requirements of saltwater crocodile habitat.

I x J = K

Resulting mask has values of 1 indicating saltwater crocodile habitat and values of 0 indicating unsuitable saltwater crocodile habitat.
Flowchart 6.3b: Applying the crocodile habitat mask to a Landsat TM image

Unclassified Landsat TM image bands 1, 2, 3, and 4

Convert each band to grid format using spatial analyst extension of ArcView

Crocodile habitat mask in grid format. Mask has 2 values: 1 = areas suitable for saltwater crocodiles, 0 = areas unsuitable for saltwater crocodiles

Grids produce: band1, band2, band3, band4

Boolean overlay between each band grid and crocodile habitat mask.
Crocmask x band1 = mask1
Crocmask x band2 = mask2
Crocmask x band3 = mask3
Crocmask x band4 = mask4

Each image band is now reduced in size to cover an area that is known to be suitable for saltwater crocodile habitat. Areas that are unsuitable for saltwater crocodiles are removed from the image data.

Export each mask as *.gis file to microBRIAN digital image processing system.
mask1.gis
mask2.gis
mask3.gis
mask4.gis

Import to microBRIAN as images:
mask1.img
mask2.img
mask3.img
mask4.img

Combine images to form 1 image with 4 bands (1, 2, 3, and 4)

classify image using hybrid classification techniques
Study area to the size of the Landsat image. The spatial analyst extension available with ArcView was used during this part of the study. The spatial analyst increases the functionality of the GIS software and can manipulate and produce files in raster format.

6.3.1 Methodology for applying decision rules to GIS data:

This process is outlined in Flowchart 6.3a.

1. A shapefile was created in ArcView by deriving tidal sections of rivers from the existing river data. Table 2.1 in Chapter 2, indicates tidal sections of rivers within the study area. This information was used as a guideline to create the tidal river shapefile. The distance analysis module in ArcView measures Euclidean distance. Floodplain rivers are not straight and are unsuitable for making Euclidean measurements on. The river vector data is stored in ArcView as a series of sections, which are described in the attached attribute table.

The method used to derive a shapefile, that represented only the tidal section of the river, was to calculate cumulative length of river sections stored in the attributes table.

The structure of AUSLIG data is such that watercourses are not included in the river layer. Since estuarine areas at the mouth of rivers are classed as watercourses this information was extracted from the waterbodies layer. The subsequent layer was merged with the tidal rivers shapefile to provide a complete coverage of tidal rivers. Derivation of the watercourses also provided data on billabongs within the study area.

2. Coastal wetland areas are important crocodile habitat. The thematic layer redwet.shp provided information on suitable crocodile habitat and was used for further analysis in the following processes.

3. Previous surveys in Arnhem land indicate that crocodile nesting sites are found within 7.8 metres of permanent water bodies (Webb et al., 1977). However, observation of crocodile nesting site data compared to river data in the GIS suggested that many of the nest sites were in fact up to one kilometre from permanent water bodies. An arbitrary buffer of 1 kilometre was made around the tidal rivers shapefile and wetland shapefile to account for distance from permanent water bodies where saltwater crocodiles were likely to occur. Buffers were created by distance analysis, which measured Euclidean distance from the rivers and wetlands and then reclassifying the results of distance analysis to create a buffer zone (Figure 6.2). The resultant buffer files were in raster format and were combined using map algebra.

The buffer grids produced by the above processes had been reclassified, so that a value of 1 represented areas where saltwater crocodiles were likely to be found. The value zero indicated areas where saltwater crocodiles were not likely to be found. A mathematical (+)
Figure 6.2: A one-kilometre buffer was created around the tidal sections of rivers. Results of the distance analysis are demonstrated in this figure. The reclassified distance buffer is seen in blue.
overlay of the grids produced an output grid that represented potential saltwater crocodile habitat. In the grid that resulted from this overlay values of 1 and 2 represented potential habitat. Values of 0 represented areas that lay neither within one kilometre of the tidal rivers or wetlands.

4. The highest density of saltwater crocodiles is found in tidal rivers and wetland areas. However, elevation is indicated as a factor that influences crocodile habitat and nesting sites (Messel and Vorlicek, 1987). Analysis of river and nesting site data with a DEM in the GIS indicated that crocodile nesting sites and tidal sections of rivers all occurred in an elevation of less than 12 metres. The DEM was reclassified to produce an elevation buffer of areas of land less than 12 metres elevation.

5. A final mask that could be applied to the Landsat TM image was achieved by combining the buffer zones around tidal rivers and wetlands with the elevation mask. The final mask is illustrated in Figure 6.3. This process was achieved by applying map algebra to the grid as described in Flowchart 6.3a.

6.3.2 Applying the mask to Landsat TM image

The next part of the process was to apply the mask to a raw Landsat TM image. The full methodology for applying the mask and subsequent export and classification in microBRIAN is demonstrated in Flowchart 6.3b.

1. The raw image previously imported into ArcView was converted to a grid format. This process was essential to allow analysis of the image data and thus application of the mask. A grid was made for each of the bands 1, 2, 3 and 4 of the Landsat TM data.
2. The crocodile habitat mask, derived by applying GIS decision rules, was applied to each band grid using mathematical overlay techniques as described in 6.3b.
3. The result of this process was a series of band grids that were reduced in size to that area where saltwater crocodile habitat is more likely to be found.
4. Each band grid was then converted to image format (ERDAS *.gis files) for export to microBRIAN.
5. In microBRIAN the .gis files were combined to form one image file. Channels 1, 2, 3, and 4 had been preprocessed previously as image enhancement was required to allow visual interpretation of the image. Training patches were selected for known cover types using the criteria described previously. The Minimum Distance to Mean algorithm was applied. A decision boundary was defined by applying a tolerance level of 10% with 6 iterations. The tolerance gate around the mean of classes was therefore tightened as the tolerance level had
Figure 6.3: Final mask that is representative of saltwater crocodile habitat is depicted in green. The mask was applied to Landsat TM imagery.
been reduced by 5% when compared to the criteria applied to classify the landcover basemap of the study area. This was done in an attempt to refine the classes and possibly identify a class for paperbark swamps and other landcover types excluded previously. Table 6.8 indicates the results of that classification. The unclassified pixels listed in Table 6.8 did not form a homogenous patch in the classified image.

Table 6.8: Results of applying minimum-distance to mean algorithm for a hybrid classification.

<table>
<thead>
<tr>
<th>Number of classes generated</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of classified pixels</td>
<td>1721977</td>
</tr>
<tr>
<td>Number of unclassified pixels</td>
<td>18558</td>
</tr>
<tr>
<td>Number of digitised pixels</td>
<td>10941103</td>
</tr>
<tr>
<td>Total number tested</td>
<td>12681638</td>
</tr>
<tr>
<td>Mean within class dispersion</td>
<td>1.14</td>
</tr>
<tr>
<td>Between to within ration</td>
<td>4.4275</td>
</tr>
</tbody>
</table>

The number of classes generated during the classification process was too large to be useful. The process of generalisation and reasons for doing so were discussed in Chapter 5. As previously described a dendrogram was used to cluster the 100 classes. The dendrogram used for this process is seen in Appendix 3. The PAINTER module in microBRIAN was used as before to allocate a nominal number to all classes. The classification channel generated by the classification process in microBRIAN was exported to ArcInfo for registration and rectification.

The registration and rectification process described earlier in methodology was used to prepare the saltwater crocodile habitat map. Sixty ground control points were collected, using techniques described in section 6.2.1, to register the image and the six-parameter affine transformation as described in Table 6.6 was applied. RMS after registration of the image was 6.192 and when the data were viewed simultaneously they were a good ‘fit’ as before. The registration parameters were written to a world file and used during the rectification process in ArcInfo. The image was then converted to a grid format in ArcView to enable further analysis of the data. The cell size was 30.8592 metres.
6.4 Mapping saltwater crocodile nesting sites

Data on previous years nesting sites was obtained both from Wildlife Management International and Wildlife Division of Northern Territory Parks and Wildlife. Data received from WMI was in a variety of formats including text files, Excel spreadsheets and maps of the area with saltwater crocodile nesting sites plotted on them. The maps generally corresponded to the text files for records of egg numbers and other details. Data recorded in Excel files included site location, egg numbers, outcome of incubation, as well as details of nest type and site. Geographic location was recorded in a grid format and required conversion to AMG eastings and northings before the data could be mapped in ArcView. The files were edited to remove unwanted data and imported into ArcView. By using a script in ArcView it was then possible to create a point vector file from the tables using AMG coordinates. Data obtained from the Wildlife Division was in ArcInfo coverage format and was easily integrated with existing data. The data cover most of the Northern Territory and had to be reduced to the size of the study area. This was done in ArcView by converting the data to shapefile format and running an Avenue clip script, available with ArcView.

Information obtained from these files included site descriptions and details of eggs collected at these sites.

The information on saltwater nesting sites was now in shapefile format with attached attribute tables. From the overall data shapefiles were derived that contained data for each year. Shapefiles with data from both sources were then merged using the Avenue merge script available with ArcView. The resultant files contained data, which represented information on nesting sites from both sources. The resultant point vector files were in shapefile format and had an attached attribute table. The attribute tables were then edited to include only relevant information for this part of the project, as determined by members of BAC. Original tables have been stored as they may provide information for future analysis.

From this information it was possible to derive information on nesting sites prone to flooding by using select commands within ArcView. Information on nesting sites was also compared with the DEM since topography is suggested as a factor that influences flooding of nests (pers comm B. Ottley, 1997).

6.5 Mapping Clan Boundaries

The nature of clan boundaries is discussed in Chapter 4. From that discussion Aboriginal clan boundaries in Central Arnhem Land have a tendency to follow ecological or geographical natural boundaries. In general Aboriginal clan lands do not have boundaries in
the conventional European sense and the land is more likely to consist of a series of special sites. Overlaps in land ownership are common and more than one clan can have responsibility for a section of land. This is likely to occur in an area where there is a sacred site of special significance. Significance of land ownership declines away from sacred sites but is very strong close to individual sites. Sometimes a clan land is not contiguous but is in fact separated by another clan land.

Mapping of clan boundaries for resource management of saltwater crocodile eggs should attempt to incorporate the features of Aboriginal boundaries. However, it has been suggested that for the initial stages of this project that temporary working boundaries should be mapped rather than Aboriginal boundaries with all of their complexities (pers. comm. Peter Cooke, 1997). Mapping the boundaries in a traditional European way may also help non-Aboriginal Australians understand that boundaries do exist on Aboriginal land (Turk, 1996). Mapping of clan boundaries for this project, therefore, concentrates on mapping boundaries while attempting to encompass some of the indeterminate characteristics of these boundaries. More complex mapping of the boundaries to encompass more of their complexities is possible and is discussed in Chapter 7.

6.5.1 Mapping ‘working’ clan boundaries

As detailed above, Aboriginal boundaries often follow ecological gradients formed by natural breaks in the landscape such as rivers, waterbodies and changes in ecological characteristics of the land. Changes in elevation can also indicate changes in land ownership. The following model for mapping clan boundaries encompasses all of these features. What it does not encompass, is the fact that Aboriginal boundaries are gradients rather than solid lines. The boundaries mapped during the course of this project are hypothetical for the reasons discussed in Chapter 4.

The topographic basemap derived from AUSLIG data contains information on many natural features in the Central Arnhem Land region. Therefore it is feasible to use the geographic information already existing to derive clan boundaries for the study area. Four hypothetical clans were created for this part of the project and boundaries mapped for their lands. The process involved extracting natural features and changes in gradient from existing shapefiles using feature select tools available in ArcView. Selected features were then merged to form a clan boundary shapefile. The resultant clan boundary shapefile for each clan was not in polygon format as they were made up of a sequence of lines. To build topology of the vector files into polygons the shapefiles were converted to ArcInfo coverages in ArcInfo. After this the INTERSECTERR command was used in ArcInfo to determine the extent of intersection
in the boundary data. Since the boundaries are complete polygons, there should be no intersections present. However, during the merge process in ArcView many overshoots and undershoots now formed intersections in the resultant data. The boundary data were edited in ArcInfo to account for some of these problems. Many overshoots and undershoots were identified and removed using edit tools in ArcInfo. Following this process the clean command with the fuzzy tolerance set at 50 metres was used in ArcInfo to build the topology of the files and produce a polygon file. The resultant polygon coverages were then imported to ArcView and converted to shapefiles.

6.6 Field Work

The field component of this project was conducted in October 1997. The objective of the field component was initially to use stratified random techniques as described by Congalton (1988). Field data were collected using a Magellan Global Positioning System (GPS). Information obtained during this part of the project was used to assess the accuracy of both the crocodile habitat map and the broad landcover map previously described. Stratified random sampling techniques in the field would ideally include samples of all classes on the landcover map. This was not possible due to the extent of the study area and the inaccessibility of the land.

6.6.1 Methodology to collect GPS readings in the field

A laptop computer was taken into the field with the classified landcover map in ArcView. This was to be used to detect points on the image for comparison with points on the ground and to compare image landcover type with true landcover type. Unfortunately, the laptop computer failed early in the trip and could not be used thereafter. Figure 6.4 obtained from a paper by Turk (1996) suggests that perhaps this is not an uncommon occurrence. Thereafter points on the ground were recorded on a table (Appendix 4) for comparison with the image later when software and image were available.

Most of the accessible roads in the area were traversed and GPS readings recorded randomly and where distinct changes in vegetation types occurred. Readings away from the roadside were made where possible. A factor that influences collection of GPS readings is the fact that the Magellen GPS 2000 used is line of site (Magellen, 1995) and readings could not be obtained from within dense forest areas. Many readings had to be taken from roadside bounded by different vegetation types to overcome this problem. AMG readings were obtained using the GPS while community structure was assessed at each stop. Community structure assessment used the Specht MKII classification scheme (Appendix 5). Species present and soil characteristics were also obtained at each site. To compensate for some of
the error inherent with GPS's six readings were obtained from each site and averaged to give a single coordinate. This mean coordinate was used to check the field data with image data. The principle of taking multiple readings at the one field site and using an average is discussed in Chapter 5. During the course of this project time and financial constraints as well as other factors limited the number of readings to six at each site. There are numerous sources of errors when using a GPS of which a researcher should be aware. Errors usual for the GPS used in this project are described in detail in the Magellen GPS 2000 user guide (1995) and further explanation is available in texts (e.g. Kennedy, 1996).

Figure 6.4: Laptop computer experiences in the field (Source: Turk, 1996)

6.7 Designing a culturally appropriate GIS
An important aim of this project is to develop a rationale for the development of a culturally appropriate GIS for use by Aboriginal people in the Central Arnhem land region of the Northern Territory. To meet this aim a literature review was completed (Chapters 3 and 4) to identify experiences of other indigenous communities and to identify issues relevant to this aim.

As discussed in Chapter 4 there are several factors that require consideration before a GIS can be adequately designed to meet the needs of indigenous communities. Several authors have identified that indigenous people must be involved in the design stages of a GIS. By involving the end users of the GIS the design can reflect their individual needs and can be used in the community more successfully (Harmsworth, 1997a). The remote location of the study area inhibited the number of visits that could be made to the Maningrida community,
however, four visits were achieved and are outlined below.

The initial visit to Maningrida involved discussion on the needs of the community in relation to a GIS for resource management. A meeting had been organised that involved Ian Munro (CEO of Bawinanga), Dean Yibarbuk (Bawinanga chairperson), Michael Storr (Northern Land Council representative) and several Bawinanga rangers who are responsible for harvesting of the crocodile eggs. During this meeting a visit was made to the Bawinanga research office to meet Robert Handelsmann who was working as a cultural research officer.

The second visit to Maningrida was with Peter Cooke of the Northern Land Council. The purpose of the visit was to attend a meeting on sports fishing. While the subject of the meeting had little to do with this project directly, it was a good opportunity to meet with several landowners of the area. This was useful as it provided an opportunity to discuss the GIS with several members of the wider community and to display maps and images output from the GIS. Maps and images discussed during this meeting are detailed below:

1. An A0 size false colour composite of the unclassified image (bands 1, 2 and 3). The image was without scale bar, grid or north arrow. In effect the image was displayed as a graphic rather than a map.
2. An A0 size false colour composite of the unclassified image (bands 2, 3 and 4). Again no traditional map symbols had been included.
3. An A0 size printout of the classified image created during the process described earlier. No traditional mapping symbols were included with this image.
4. A map of the area as produced by AUSLIG. Map sheets 5773 and 5674.
5. Several A4 size printouts of maps and images.
   a. Map of the immediate area surrounding Maningrida with scale bar, north arrow and grid lines. Produced using classified image in ArcView.
   b. Map as outlined in a but without map symbols.
   c. Map output form GIS showing AUSLIG data only and position of crocodile nesting sites. No map symbols were included.

The maps were passed around during the meeting and opinions on them sought. This was done in an attempt to identify responses to maps produced by a GIS and from remotely sensed data in comparison to the traditional AUSLIG map.

The following visit was to the Bawinanga research office to meet with Peter Danaja (Aboriginal heritage officer) and Murray Garde (research linguist). A laptop computer was used for this visit to demonstrate ArcView and project data. Danaja and Garde had the opportunity to examine the data in ArcView and were encouraged to give feedback, which
they did. Data in ArcView included saltwater crocodile nesting site data, classified basemaps and unclassified Landsat TM imagery. During this visit a meeting was arranged with David Bond and Ian Munro to discuss the future possibilities for the GIS at Maningrida. Results of these visits are discussed in Chapter 7. This Chapter also discusses results obtained and relates them to the overall aims of the project.
Chapter 7 Results and Discussion

7.1 Results

7.1.1 Topographic basemap of study area derived from AUSLIG data

The basemap derived from the AUSLIG data is depicted in Figure 7.1. This basemap covers the geographic extent of that area of central Arnhem Land serviced by BAC. Information in the map includes coastline, roads, position of islands and localities of the area. Mapped wetland classes are floodplain, swamps and mangroves, as described in Chapter 2. Wetland areas provide a habitat for saltwater crocodiles and more detailed mapping of these habitats would be useful for this project. This map does not detail any other vegetation type in the region.

7.1.2 Landcover basemap of study area derived from Landsat TM imagery

The basemap derived by classifying a Landsat TM image is illustrated in Figure 7.2. The overall accuracy of the landcover basemap is 87.93% (Table 7.1). Individual accuracy for those classes mapped varies from 33% to 100%. Classes with highest accuracy include coastal saline flats and swamp areas. The class with the lowest accuracy was grassland. Paperbark (Melaleuca spp.) swamps were not mapped on the image during the classification process. This class was included in the error matrix as the geographic position of paperbark swamps had been ascertained during field survey of the study area (Figure 7.3). Paperbark swamps are of interest as they provide one of the most important nesting habitats for saltwater crocodiles. A comparison between image data and field data indicates that paperbark stands were classified twice as mangroves and once as open eucalypt forest in the landcover basemap.

Errors of omission were found in classes other than the paperbark. Errors of omission indicate that a sample identified as a certain class during field sampling has been excluded from that class in the image data. The classes include grassland, eucalypt forest and land subject to inundation. Field points that had been classified as those landcover types had been excluded from the appropriate class in the image. Two pixels that should have been in the grassland class were wrongly classified as eucalypt woodland. One pixel that should have been eucalypt forest was classified in the image as woodland. Another pixel that had been included in the mangrove class was from field data found to be land subject to inundation. Field classes that are wrongly classified on the image fall into the category of commission errors. Errors of commission were found in two classes, eucalypt woodland and mangroves.
Figure 7.1: Topographic basemap derived from AUSLIG TOPO-250K data
Grid lines are at 10,000 metre intervals of the Australian Map Grid, zone 53, Transverse Mercator Projection.

Produced by Janice Crerar at the remote sensing and GIS lab, NTU, Darwin.

Figure 7.2: Landcover base map derived from Landsat TM imagery.
Table 7.1: Error matrix used to assess map accuracy of the landcover basemap

<table>
<thead>
<tr>
<th>Class identified during field survey</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>Total possible</th>
<th>Omission</th>
<th>Commission</th>
<th>Map Accuracy % per class</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>20</td>
<td>0</td>
<td>16</td>
<td>83</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3</td>
<td>66</td>
<td>0</td>
<td>33</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3</td>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>6</td>
<td>20</td>
<td>0</td>
<td>83</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>6</td>
<td>20</td>
<td>0</td>
<td>83</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td></td>
<td></td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10</td>
<td>0</td>
<td>23</td>
<td>77</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
<td>5</td>
<td></td>
<td></td>
<td>5</td>
<td></td>
<td></td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>Total possible</td>
<td>24</td>
<td>1</td>
<td>0</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>13</td>
<td>5</td>
<td>58</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Overall Map Accuracy = 87.93%

Key to classes:
1 = Eucalypt woodland
2 = Grassland
3 = Paperbark stands
4 = Eucalypt forest
5 = Land subject to inundation
6 = Coastal saline flat
7 = Swamp
In the image, they were classified as such but in reality were eucalypt forest and land subject to inundation. Discussion on the significance of these errors is found in Section 7.2.3. Not all classes in the image could be visited during the field trip or from other data and therefore, were not assessed for accuracy.

Figure 7.3: Typical Paperbark (*Melaleuca spp.*) stand observed during field survey. This stand was close to a permanent waterbody and during the wet season provides a suitable habitat for saltwater crocodile nesting.
7.1.3 Mapping saltwater crocodile habitat

The map of saltwater crocodile habitat that resulted from integrating GIS and digital image processing techniques is seen in Figure 7.4. Overall accuracy improved by 5.03% to 93% when compared with the classified basemap (Table 7.2). Errors of omission occurred in the paperbark class and the eucalypt woodland class. One pixel on the image that should have been included in the eucalypt woodland class had been classed as land subject to inundation. Control points on the ground that had been classified as paperbark were included in the mangrove class in the image. This is in keeping with results of the basemap where paperbark had also been included in the mangrove class.

Overall accuracy has improved when the saltwater crocodile habitat map is compared to the landcover basemap. The preferred habitat of saltwater crocodiles as described in Chapter 2, indicates that coastal wetland areas of the Northern Territory are important habitats for this species of crocodile. The crocodile habitat map is essentially a map of the coastal wetland areas within central Arnhem Land. The favoured nesting sites of this species of crocodile are billabongs with floating vegetation mats and paperbark swamps. Billabongs are included as a class on this image, however, no error assessment has been done due to the inaccessibility of these areas. Paperbark swamps were not able to be identified during the classification process and are not included on the image. Discussion of these results is included in Section 7.2.1.

7.1.4 Mapping saltwater crocodile nesting sites

The geographic position of saltwater crocodile nesting sites harvested from 1990-97 is illustrated in Figure 7.5a. Position of saltwater crocodile nesting sites for those years is mapped in vector point format. The attribute tables for the point data have information that is regarded by member of BAC to be the most relevant for their needs. Figure 7.5b demonstrates the mapped saltwater crocodile nesting sites in ArcView with attached attribute table. Consultation with members of BAC, as described in Chapter 6, indicated that inclusion of the following fields in the attribute table would be suited to their needs.

1. Nest code number
2. River the nest was found on or near
3. Environment (for example swamp, riverbank)
4. Clan estate that nest is positioned on
5. Contact person (clan elder for that estate)
6. Number of eggs collected
7. Number of eggs incubates
8. Number of normal hatchlings
Grid lines are at 10,000 metre intervals of the Australian Map Grid, zone 53 Transverse Mercator Projection.

Produced by Janice Crerar at the remote sensing and GIS Lab, NTU, Darwin.

Figure 7.4: Saltwater crocodile habitat map derived from Landsat TM imagery bands 1, 2, 3 and 4.
Table 7.2: Error matrix used to assess accuracy of the saltwater crocodile habitat map

<table>
<thead>
<tr>
<th>Class identified during field survey</th>
<th>Image classification</th>
<th>Total possible</th>
<th>Omission %</th>
<th>Commission %</th>
<th>Map Accuracy % per class</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total possible</td>
<td></td>
<td>5</td>
<td>0</td>
<td>12</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall map Accuracy = 93%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Key to classes:
1 = Eucalypt woodland
2 = Paperbark stands
3 = Mangrove
4 = Land subject to inundation
5 = Swamp
6 = floodplain
Grid Lines are at 10,000 metre intervals of the Australian Map Grid, zone 53. Transverse Mercator Projection

Produced by Janice Crerar at the remote sensing and GIS lab, NTU, Darwin.

Figure 7.5a: Geographic position of saltwater crocodile nesting sites harvested from 1990 - 1997
9. Number of hatchlings sold
10. Easting for nest site position
11. Northing for nest site position

As demonstrated in Figure 7.5b, the table and the mapped nesting sites are linked and information about a particular nesting site can easily be obtained.

![Table and map of nesting sites](image)

**Figure 7.5b: The spatial nesting site data are linked to attribute tables.**

Flooding of nest sites is an ongoing management problem for this resource. Nest sites commonly flooded in years 1990 - 97 are illustrated in Figure 7.6. As implied by that map, most nest sites prone to flooding are situated on riverbanks. Flooding of nest sites is also related to topography of an area, as discussed in Chapter 2. Figure 7.7 illustrates the result of mapping nest sites in relation to elevation. Nest sites most prone to flooding are found at an elevation of less than six metres.

Charts 7.1 to 7.4 demonstrate graphically numbers of eggs harvested during the 1996 – 1997 season from river systems in the study area. The charts suggest the number of eggs harvested and nests visited are higher in the Liverpool/Tomkinson river system than for Blyth and
Grid lines are at 10,000 metre intervals of the Australian Map Grid, zone 53. Transverse Mercator Projection

Produced by Janice Crerar at the remote sensing and GIS lab, NTU. Darwin.

- Nest sites flooded during the 1996-97 harvesting season

Figure 7.6: Saltwater crocodile nesting sites flooded during the 1996-97 season
Figure 7.7: Saltwater crocodile nesting sites in relation to elevation
Cadell rivers. Discussion of these results and significance to resource management of saltwater crocodile eggs is discussed in Section 7.2.

Chart 7.1: Saltwater crocodile eggs harvested from nests on the Blyth River during the 1996-97 season.

Chart 7.2: Saltwater crocodile eggs harvested from nests on the Cadell River during the 1996-97 season.
Chart 7.3: Saltwater crocodile eggs collected from nests on the Liverpool River during the 1996-97 season

Chart 7.4: Saltwater crocodile eggs harvested from nests on the Tomkinson River during the 1996-97 season
7.1.5 Mapping clan boundaries

Figure 7.8 depicts saltwater crocodile nesting sites mapped in relation to hypothetical clan boundaries. The boundaries are represented in vector format as described in Chapter 5. While this method of mapping is appropriate in the conventional European context, the complexity of Aboriginal clan boundaries is not accounted for. This model does provide a suitable representation of 'working boundaries' as suggested in Chapter 4. Discussion of this method to map Aboriginal boundaries and suggestions for future research are found in Section 7.2.

7.1.6 Designing a culturally appropriate GIS for use by the Maningrida community

The initial visit to Maningrida during February 1997 indicated that the Bawinanga rangers and CEO's were enthusiastic about the potential of a GIS for their resource management problems. During this visit BAC rangers explained the process of saltwater crocodile egg harvesting and the incubation and hatching of the eggs. At that time, David Bond and Ian Munro (CEO's of BAC) discussed the problems of managing the saltwater crocodile egg information in relation to which clan land the nests were found on. The problems that BAC was experiencing were essentially spatial and required a spatial tool to provide the solution. The Bawinanga Aboriginal Corporation viewed GIS as a tool that could resolve some of the resource management problems they were experiencing. During this visit conversations with Ian Munro and Robert Handelsmann (research officer for BAC) indicated that BAC were interested in expanding the GIS, eventually to include all natural and cultural resources within their area. For an initial GIS, however, this meeting concluded that mapping of saltwater crocodile nesting sites and habitat in relation to clan boundaries would be useful for resource management of saltwater crocodile eggs by BAC.

The second visit to Maningrida involved displaying the hardcopy maps, described in Chapter 6, to members of BAC and the Maningrida community. The maps were generally passed around at the meeting and opinions on them sought. Attendants at the meeting included several elders from various clans of the area. Feedback on the maps was interesting as the classified remotely sensed image proved to be unpopular when compared with the unclassified Landsat TM data. The false colour composite of the Landsat TM image bands 2, 3, and 4 was preferred to bands 1, 2 and 3. This image was regarded by most of the participants at the meeting as a photograph of land. On this image many of the participants could point to areas of land and indicate which clan was responsible for that land. The landcover basemap derived from Landsat TM imagery was unpopular and there was a dependency on the legend to interpret the map. The attendants at the fishing meeting easily interpreted the Landsat TM false colour composite of bands 2, 3 and 4 without requiring a legend or further information.
Saltwater crocodile nests harvested in 1996 - 97 season

- Gunbatgarri District
- Guridja District
- Maragulidban District
- Namaidpa District

Grid lines are at 10,000 metre intervals of the Australian Map Grid, zone 53. Transverse Mercator Projection

Produced by Janice Crerar at the remote sensing and GIS lab, NTU, Darwin.

Figure 7.8: Saltwater crocodile nesting sites mapped in relation to hypothetical clan boundaries.
General comments from the group suggested that the classified image looked too much like a map. Rather than by the comment, "it looks too much like a map", this point was made by various gestures. Most participants pointed to the AUSLIG map sheet and commented that the classified image looked like the map sheet. The map sheet was found by most participants to be too 'abstract' and not appropriate to what was actually going on at ground level. On the whole, map symbols such as north arrows, grid lines and scale bars on any of the images were unpopular. The inclusion of these features on maps seemed to be confusing and distracted from the graphic representation of the map.

During this meeting another issue regarding resource management of saltwater crocodile eggs arose. One of the clans in the Central Arnhem Land region has the saltwater crocodile as a totem. This clan cannot receive money directly from the sale of crocodile eggs because of religious and cultural beliefs. The resource management policies of BAC have to consider such beliefs. This issue is highly sensitive, however, and further exploration is not within the scope of this project. It is an indication of other problems that may arise during future research for natural resource management in that area.

The following visit to Maningrida was to the research office to meet with Peter Danaja (Aboriginal Heritage Officer) and Murray Garde (research officer). The outcome of the visit was similar to that obtained during the fishing meeting. Peter and Murray were impressed with the data in the GIS. Discussion of the data concluded that both regarded the false colour composite of the Landsat TM image bands 2, 3 and 4 as the best representation of land in that area. Peter indicated that the most useful basemap for resource management of saltwater crocodile eggs would be the classified crocodile habitat map displayed as a layer over the Landsat TM false colour composite image bands 2, 3 and 4 (Figure 7.9).

During this visit, there was some discussion of the choice of language for the GIS. As described in Chapter 2, Maningrida and the area serviced by BAC are Multilingual. English was nominated as the most appropriate language for the GIS, as this is the language most often seen written in Maningrida. This is supported by the fact that most of the public signs in the community are written in English. The use of classification systems in the GIS was also discussed. It was concluded that over time indigenous knowledge of the area could be included in the GIS so that a local classification system would be incorporated. During the meeting all participants expressed an interest in expanding the GIS to incorporate "everything" (pers. comm. P. Danaja, 1997).
Figure 7.9: Final map produced after consultation with members of BAC. The basemap is a Landsat TM colour composite image, bands 2,3 and 4. Saltwater crocodile habitat map and crocodile nesting sites are displayed with the basemap.
Following the meeting, in the research office, David Bond and Ian Munro (CEO’s) were consulted regarding the GIS. They were given a demonstration of ArcView and comments from them led to the conclusion that they were approving of the comments made during the fishing meeting and at the research office. The community as a whole is supportive of the GIS and look forward to using it at community level.

7.2 Discussion of results in relation to aims and research questions

7.2.1 Investigating the potential of integrating GIS and digital image processing techniques to map the potential habitat of saltwater crocodiles

One of the research questions of this project asks if it is possible to map saltwater crocodile habitat by integrating GIS and digital image processing techniques. To address this question, it was necessary to identify the habitat of this species of crocodile, so that decision rules could be made and applied to GIS data. The most suitable habitat for this species of crocodile was discussed in Chapter 2. Saltwater crocodiles inhabit coastal wetland areas of the Northern Territory. As previously discussed, a review of the literature revealed that no studies were available that had previously mapped saltwater crocodile habitat. The advantages of integrating a DEM and topographic data with remotely sensed imagery, to delineate potential habitat of a species was briefly discussed in Chapter 3.

Sader et al (1995) suggested that the integration of GIS and hybrid classification techniques in a digital image processing system could improve overall accuracy of a classified image. Results of this project do indicate an improvement in overall classification accuracy when GIS and digital image processing techniques are integrated. The map produced by applying GIS decision rules to Landsat TM imagery was of a higher accuracy than the classified landcover basemap. The overall accuracy of the saltwater crocodile habitat map was estimated to be 93%. A map of potential saltwater crocodile habitat is useful for resource management of eggs as potential nesting sites may be established from the map. Furthermore, BAC have recently commenced a project to harvest adults of this species. The map produced during this project will, therefore, contribute to ongoing management of resources other than saltwater crocodile eggs. Another aim of the project was to create a GIS that can be expanded to incorporate a range of cultural and environmental information. The map produced is essentially a map of coastal wetland areas. Other resources are commonly found in wetland areas and the map could be used to derive relevant information for these resources. For example, as described in Chapter 2, mangrove communities provide nursery beds for many fish species. Mangrove communities are mapped with a class accuracy of 83%
in the saltwater crocodile habitat map. The map could be used for management of resources found in mangrove communities.

The aim of applying GIS decision rules to remotely sensed data was to delineate potential saltwater crocodile habitat. This was achieved by applying environmental factors to determine the range where the species is likely to be found. As demonstrated in a study by Palacio-Prieto and Luna-Gonzales (1996), potential spectral overlap of environmental niches is removed and it may be possible to classify vegetation communities at species level. Accuracy of the map did improve, as previously stated, but differentiation of species within the area was not possible with the techniques used for this project. Differentiation of vegetation communities at species level would be useful for resource management of saltwater crocodile eggs. The favoured nesting sites of this crocodile species are paperbark swamps and floating vegetation mats on billabongs. Billabongs were classified in the image data, however no class exists for paperbark swamps. There are two possible reasons for the omission of paperbark swamps in the classified image.

The first reason is that Landsat TM imagery may have unsuitable spatial resolution for mapping coastal wetland areas. A study by Johnston and Barson (1993) indicates that spatial resolution of Landsat TM imagery is to be too coarse for detailed mapping of wetland areas. Resolution of TM data is approximately 30 metres before registration and rectification processes. Whether this resolution is adequate to map wetland areas depends on the detail required in the output map. This resolution may not be sufficient to differentiate between vegetation species in the coastal wetland area studied during this project. The map produced from this study is of an accuracy that is suitable for resource management. However, a more detailed map that included paperbark swamps would be more useful. The saltwater crocodile habitat map has a spatial resolution of 30.8592 metres. The Landsat TM imagery was registered with AUSLIG TOPO-250K vector data, which has a scale of 1:250000 and thus a coarser resolution. Ideally the image would have been registered to data that have a finer resolution. However, the AUSLIG TOPO-250K data was input to the GIS as a topographic basemap and registration of the remotely sensed imagery with this basemap was therefore, advisable (Hinton, 1996).

A second explanation for exclusion of paperbark as an individual class is related to the spectral signature of paperbark in the Landsat TM bands used during the classification process. Paperbark (Melaleuca spp.) may have a spectral signature that is similar to some mangrove species. In the landcover basemap and in the saltwater crocodile habitat map paperbark was more often classed as mangrove than any other landcover type.
indicates that known areas of paperbark, classified during field survey, were twice classified as mangroves in the saltwater crocodile habitat map.

Time of acquisition of the image will influence the results obtained during a classification process. The image used for this project was acquired at the end of a wet season when vegetation would be at its most abundant. As illustrated in the Aboriginal seasonal calendar in Chapter 2, April is at the end of the growth season. By April the paperbark stands have experienced vigorous growth and tree canopies would be thicker than at any other time of the year (Brock, 1993). Landsat TM bands 1, 2, 3 and 4 were used in the process to produce the saltwater crocodile habitat map. Landsat TM bands 2 and 4 absorb EM microwaves reflected by healthy green vegetation. During this season of healthy vegetation the spectral overlap of paperbark swamps and other vegetation could be heightened due to the abundant growth. Future studies could investigate the potential of using remotely sensed imagery from different seasons of the year.

A review of the literature indicates that floating vegetation mats on billabongs provide another favoured nesting site for saltwater crocodiles. Conversations with staff of WMI suggested that compared to other areas of the Northern Territory, saltwater crocodile nests were not commonly found on vegetation mats in that region of Arnhem Land serviced by BAC. The classified saltwater crocodile habitat map does include a class for billabongs. Accuracy of these areas could not be assessed, as they were inaccessible during field surveys of the area.

More detailed mapping of potential saltwater crocodile habitat could result from further studies that use remotely sensed data of a finer spatial resolution. This conclusion is supported by previous studies by Johnston and Barson (1993). Integration of GIS and digital image processing techniques has potential for such studies. Results of this project indicate that it is possible to map saltwater crocodile habitat by integrating GIS and digital image processing techniques. Furthermore, the map produced by applying integration techniques was of a higher accuracy than the map produced from using digital image processing techniques alone.

Accuracy assessment of the map was accomplished by comparing the image classes with field data, data from WMI and AUSLIG data. The number of sampling points used for assessment of map accuracy was less than is advisable (Kennedy, 1996). Future studies should consider the benefits of a more detailed ground survey to check the accuracy of maps derived by classifying remotely sensed imagery. Saltwater crocodile habitat is not easily
accessible and forward planning of the best strategies to ‘ground truth’ these areas have to be sought. One possible strategy to increase the number of GPS readings and surveys in the field would be to equip the rangers of BAC with GPS during their fieldwork to collect the eggs. The rangers could do GPS readings and record the community type that the nest was found in. This would reduce time and cost of field surveys into saltwater crocodile habitat.

Data collected by this means could be extrapolated to other data on the imagery as is done during error assessment techniques already existing. This process would be advantageous for two reasons. First, it would involve indigenous people of the area in information gathering for the GIS. Secondly, this would provide a means to integrate an Aboriginal classification system into a GIS. A further aim of the project is to create a GIS that can be expanded to incorporate a range of environmental and cultural information. Inclusion of an Aboriginal classification system in the GIS would ensure that the system is more appropriate to the needs of the end users.

7.2.2 Investigating the potential for using GIS methodologies to map Aboriginal clan boundaries

To address the research question that is formulated from this aim it was appropriate to identify the nature of Aboriginal clan boundaries and to discuss Aboriginal relationship with land (Chapter 4). The research question emergent from this aim asks, “Can GIS methodologies be used to effectively map the complex and indeterminate nature of Aboriginal boundaries?” In order to answer this question successfully, it is useful to review methods of data representation commonly used in a GIS. In Chapter 5 two widely used data models were discussed. Choice of best model usually depends on the nature of the spatial information being mapped as well as the source the data is derived from. To meet the aims of this project a decision had to be made regarding the best method of representation for Aboriginal clan boundaries in a GIS. The clan boundaries mapped during the course of this project were hypothetical in nature for reasons discussed in Chapter 4. Mapping of hypothetical boundaries provides a basis and example of how the actual clan boundaries could be mapped in the future. This links with another aim of this research project, which is to create a GIS that will assist in resource management of saltwater crocodile eggs in the area serviced by BAC. Discussions with Peter Cooke of the Northern Land Council and Ian Munro (BAC) during visits to Maningrida led to the conclusion that initial mapping of the boundaries should be in vector format. This decision was made on the basis that for resource management of saltwater crocodile eggs ‘working’ boundaries should be mapped initially. This was done so that the usefulness of mapping clan boundaries in relation to saltwater crocodile habitat could be assessed by members of BAC. These ‘working’ boundaries are seen in Figure 7.8.
One factor that influenced the decision to map the boundaries in vector format is that the most suitable representation of crocodile nesting data for this project was as points. In vector format each nest site could have attribute data attached in tables. Some raster systems have the ability to link raster data to tables; this is not possible in ArcView. Analysis cannot occur between raster and vector formats, although they can be displayed together in ArcView with the spatial analyst extension. Further discussion on representing saltwater crocodile nest sites in raster format is included in the next Section (7.2.3).

Another factor that influenced the decision to map the clan boundaries as vector files was the fact that the baseline topographic data was derived from existing AUSLIG data, which is in vector format. In reality, the source data that is used to derive information often determines representation of data in a GIS. Conversion of data from one format to another is possible and is described in Chapter S. However, because there are problems associated with the conversion process it is best to do this as little as possible (Hinton, 1996).

The methodology used to derive the clan boundary information in vector format did consider the complex nature of Aboriginal boundaries to a certain extent. The boundaries as mapped do follow natural features and changes in elevation as described in Chapter 4. Representation of Aboriginal clan boundaries in vector format cannot take into account some of the finer points that describe Aboriginal land. Even use of the word boundaries to describe Aboriginal land is viewed by some authors as inappropriate (Williams in Sutton, 1995). Representation of clan boundaries in a GIS would be better in raster format, since raster represents continuous data and gradients better than vector. Therefore, natural surface features are often better represented in raster format. Traditional Aboriginal lands are closely tied to natural features, therefore, the raster representation is more suitable. Certain aspects are still not well represented by mapping clan lands in raster format. This brings us to the issue of fuzzy boundaries as described in Chapter 5. Most naturally occurring features do not have definite boundaries. This is true of Aboriginal land in Australia. Data representation in a GIS and on most maps involves generalising the data into homogenous polygons. The application of fuzzy set theory, as described in Chapter 5, is a way to accommodate the indeterminate nature of boundaries. Fuzzy set theory can be applied to geographic data in an attempt to map inexact objects more appropriately (Wang and Hall, 1996). Fuzzy boundaries could provide a better representation of Aboriginal clan boundaries as they could account for the indeterminate nature of the boundaries. The full complexities of Aboriginal clan boundaries and relationship with land were discussed in Chapter 4. The model proposed by Leung (1987) provides a possible starting point for mapping Aboriginal clan boundaries in their full complexity. Leung's model represents boundaries as zones with varying degrees of
membership. This model could be applied to Aboriginal clan boundaries. Aboriginal clan lands tend to be made up of a collection of sites where propietral responsibility for the site is strong immediately around the site and then diminishes with distance from the site. Features such as this could well be accounted for by mapping Aboriginal clan lands using the Leung (1987) model. Future research should review the potential of fuzzy boundary theories to map Aboriginal land. In any circumstances where mapping of boundaries has political or cultural significance, serious thought must be given to how the feature should be represented and generalised in a GIS (Ballantyne and Sutherland, 1994).

When the time is right, Aboriginal clan boundaries can be mapped in a GIS and the techniques discussed in Chapter 3 may provide guidelines for that process. Data obtained during GPS surveys were used to map traditional lands in Indonesia and the USA. By involving the traditional owners in GPS survey work in central Arnhem Land the boundaries could be mapped and incorporated into a GIS. Security measures will be necessary when the true boundaries are mapped due to the sensitive nature of this information.

7.2.3 Creating a GIS that will assist in resource management of saltwater crocodile eggs for the study area

"Can a GIS be created to assist BAC with resource management of saltwater crocodile eggs?" This question was asked in the introductory Chapter of this thesis. To create a GIS that can assist with management of this resource, several factors had to be considered. These factors included decisions on what data would be required in the GIS and what format it should be stored in. Inclusion of saltwater nesting site data was necessary and this was obtained from the sources described previously. A basemap was needed for the study area so that the crocodile nesting data would have a reference point in relation to the surrounding region. Aboriginal clan boundaries were mapped, as discussed in the previous Section. Furthermore, the saltwater crocodile habitat map derived by integrating GIS and digital image processing techniques was included in the GIS.

A topographic basemap was derived for the study area from AUSLIG TOPO-250K vector data. A smaller landcover basemap was created for the study area from classified Landsat TM imagery as described in Section 7.1. Past research, described in Chapter 3, demonstrated that the use of basemaps that were less accurate than data derived from GPS survey was a common problem. The accuracy of the landcover basemap produced during this study was 87.93%. Two areas that had been classified as eucalypt woodland in the image were found during field survey to be grassland. This was established by comparing the GPS reading and
field classification with the relevant pixel on the image. The significance of two pixels being wrongly classified as eucalypt woodland is that other pixels on the unclassified image with a similar spectral value could also have been included in the wrong class. Seasonal factors may have influenced the spectral values of these pixels. In the previous Section the effect of seasonal factors on vegetation growth is briefly discussed. At the end of the wet season the grassland would have experienced abundant growth which may have reflected EM microwaves strongly in bands 2 and 4 of the EM spectrum. Another factor that may have influenced the spectral signature of these areas is that at least one GPS survey point the grassland was at the edge of eucalypt woodland. In Chapter 5, the fact that vegetation rarely has exact boundaries is discussed. Inclusion of this pixel in the eucalypt woodland may have been due to the indeterminate nature of the vegetation boundaries. Other errors of omission were found in the mangrove class and the eucalypt woodland class. Land subject to inundation had been wrongly classified as mangrove, this occurred in one pixel only and is possibly due to the position that the GPS reading was obtained at. Landsat TM imagery has a resolution of 30 metres before rectification and registration. In the field much of the land classified as subject to inundation is in close proximity to mangrove communities. Classification of eucalypt forest as woodland in the image is not significant as the difference between these community types is one of canopy density.

Discussions with members of BAC indicate that future plans for the GIS are to incorporate information obtained by GPS survey of the study area. Further assessment of the basemaps used in this study can be achieved when the GPS survey data is integrated in the GIS. The topographic basemap for the whole study area was derived from AUSLIG data at a scale of 1: 250 000. This scale is not appropriate for mapping areas the size of that serviced by BAC in detail. The Landsat TM images used in this project were registered and rectified with the AUSLIG data. Furthermore, the topographic basemap is not appropriate to the needs of the community at Maningrida. Results of discussions with several members of BAC and other community members, indicates that the topographic basemap derived from AUSLIG TOPO-250K data is too much like a conventional European map to represent country in an appropriate way. A basemap derived from unclassified Landsat TM imagery, bands 2,3 and 4 was considered the most suitable representation of country. For the scope of this project, however, the topographic basemap does provide a reference point for other data. Cost, in terms of time and money, is a consideration when acquiring data for a GIS. The use of existing data is less expensive than the surveying of an area.

Saltwater crocodile nesting data were supplied with geographic coordinates, which were used to map the position of the nesting sites in ArcView. Nest sites from previous years were
mapped in vector format as points and linked to attribute tables in ArcView. The data stored in the tables were designed to suit the needs of the end user of the GIS that resulted from this project. The attribute tables for each nest site can be linked to tables for Aboriginal clan boundary data so that analysis between the vector themes is possible. The GIS can then be used for resource management by simply providing a means of data storage and retrieval for yearly egg collection. The GIS could be used to formulate future management strategies for saltwater crocodile eggs. Inclusion of the habitat map in the GIS means that other potential nesting areas may be identified for future harvesting. The map produced by integrating GIS and digital image processing techniques indicates the potential habitat of saltwater crocodiles. Future research could result in a more detailed map of saltwater crocodile habitat. This would be useful to identify potential saltwater crocodile nesting habitats that were previously not exploited.

As demonstrated in Charts 7.1 - 7.4, the majority of nests harvested have been in the Liverpool/Tomkinson River system. Figure 7.8 indicates that most nesting sites harvesting in the years from 1996 - 1997 have fallen within the boundaries of only three clans mapped for the area. This is a hypothetical situation, however, this trend may be noted in reality. Harvesting strategies in the past may have involved visiting river systems known to have saltwater crocodile nest in them. Integration of the saltwater crocodile habitat map and the position of clan boundaries in the GIS will be useful to determine the possible position of other nest sites that could be harvested in the future.

Problems experienced by BAC, in the past, have involved primarily identifying which clan land the nest sites are positioned in so that clan ownership of the eggs harvested can be determined. As suggested by Figure 7.5a, many of the nesting sites fall on riverbanks. As discussed in Chapter 4, the nature of Aboriginal boundaries is such that riverbanks form the natural break between two clan lands. During egg collection, it would be useful for management if consideration was given to the fact that the land on either side of a river will possibly be the responsibility of different clans. Methods to ensure that the position of the nesting site was mapped as accurately as possible in relation to Aboriginal clan lands should be sought. Future egg harvesting strategies could include either the use of a differential GPS, or the egg harvesters could note whether the eggs were collected from the west or east bank of the river. Use of the differential GPS would give the most accurate readings (Kennedy, 1996) regarding the geographic position of the nest sites. Use of either of these methods may assist in resolving resource management problems for saltwater crocodile eggs.
The GIS could also be used to determine nesting habitat that is most prone to flooding. Figure 7.6 indicates that nests on the banks of the Blyth and Cadell rivers have been prone to flooding in the years from 1990-97. Elevation is a factor that can influence the likelihood of a saltwater crocodile nest flooding. The results of this study indicate that most flooded nests in the years 1990 – 1997 lie at an elevation below six metres. As demonstrated in Figure 7.7, most saltwater crocodile nests are found at this elevation. The DEM used in this project is described in Chapter 6. The resolution of the DEM used is unsuitable for analysis of a small Section of Arnhem Land. Use of a DEM that is based on a grid with improved resolution would give more accurate results than those obtained in this project. The methodology described here is worth repeating with a DEM of finer resolution as this may demonstrate in detail the elevation of previous flooded nesting sites. Information of this type could help in the design of harvesting strategies for the future.

The GIS has been designed with the particular needs of the end users in mind. Results obtained from visits to Maningrida mean that the GIS incorporates information that the people of BAC feel is relevant to their needs. This included the use of a Landsat TM false colour composite image as a basemap displayed with the classified saltwater crocodile habitat map and nesting data. Cultural differences such as the use of language or Aboriginal classification systems have been considered during the process. Hardcopy output should be at the discretion of BAC and should represent the country in a way that is appropriate to the needs of the end user. Figure 7.9 illustrates a typical map output that is useful for management of resources such as saltwater crocodile eggs in the region surrounding Maningrida. As demonstrated in this Figure, the map has no traditional map symbols such as map grid, scale or north arrow.

Harmsworth (1997a) stated that it is only by involving the indigenous group during the design stages of a GIS that their cultural imprint will be added. A cultural imprint has been added to this GIS and will develop over time by involving members of the Maningrida community in the process. Meanwhile, the results obtained from this research project indicate that a GIS can be created to assist BAC with resource management of saltwater crocodile eggs.
7.2.4 Creating a GIS that can be expanded to incorporate a range of cultural and environmental information

An aim of this project was to design a GIS that can be expanded in the future to incorporate a range of cultural and environmental information. One of the research questions addressed during this project asked if a GIS could be developed that integrates cultural information appropriate to the needs and interests of indigenous people. Discussion in Section 7.2.3 indicates that a GIS can be created to address the needs and interests of Aboriginal people in central Arnhem Land. During this project, a method to map Aboriginal clan boundaries in a GIS was suggested. The GIS can be used for resource management of saltwater crocodile eggs by BAC and has been designed to meet the needs of the end users. In the future, this GIS will be expanded to incorporate a range of cultural and environmental information.

The GIS was designed so that expansion to accommodate information from a variety of sources is possible. Data was incorporated that was not directly relevant to resource management of saltwater crocodile eggs. The data can be used in the future to derive other information. The landcover base map created a Landsat TM image has several classes that are not relevant to saltwater crocodile resource management. However, many of the classes included in that map can be used in the future for other forms of resource management. There are many natural coastal resources in Central Arnhem Land. Information on coastal patterns can be integrated with other GIS data for future management of coastal resources.

To meet the aims of this project hypothetical clan boundaries were mapped to demonstrate the effectiveness of doing so for resource management of saltwater crocodile eggs. The structure of Aboriginal society is such that larger groups do exist as was described in Chapter 4. Expansion of the GIS to incorporate information for cultural and natural resource management could incorporate the boundaries of these larger groups and information pertaining to them. Expansion of the GIS would also involve integrating unclassified Landsat TM images for the overall region serviced by BAC. As previously discussed, the unclassified image was more useful as a base map than the classified landcover base map or the topographic base map. The inclusion of unclassified satellite imagery in the GIS also means that other information can be obtained by visual interpretation of the image.
7.2.5 Developing a design concept for a culturally appropriate GIS database for use by Aboriginal people in the Northern Territory

As previously discussed, it is only by including a community during the development of a GIS, that it will become unique to that community (Harmsworth, 1997a). Furthermore, overseas experiences demonstrate that indigenous groups who are involved in all stages of GIS development are most successful in using the system (Neto and Neto, 1997). This project explored the potential for a GIS design relevant to the needs of people in Maningrida. Every community in the Northern Territory has individual needs that should be considered during the design stages of their GIS. The results of this project indicate that a GIS suited to a community’s needs can be designed for Aboriginal people in the Northern Territory.

The following guidelines could be adopted during development of a GIS for indigenous communities in the Northern Territory:

1. During all stages of project development the end users of the GIS should be consulted and advice sought from them on their needs and wants. Differences in culture, as described in Chapter 4, should be considered during all stages of GIS development and maintenance. The following list reflects particular issues that should be considered:
   a. More than one language can be incorporated in a GIS. This is useful in multilingual communities.
   b. Hardcopy output – depends on sensitivity of information and should represent country in a way that the community responds well to.
   c. Choice of classification system – indigenous classification system may be more appropriate. This involves incorporation of indigenous knowledge at the request of the community.
   d. Security and sensitivity of information integrated in the GIS should be considered and measures taken to ensure that access is controlled.
   e. Spatial data stored in the GIS should be relevant to the needs of the community and should incorporate the complex nature of their relationship with land.

2. Technical considerations for the implementation of a GIS include:
   a. Choice of data represented in the GIS should reflect the cultural needs of the community.
   b. Source data used for the GIS – depends on availability of data and the detail required in end maps.
   c. Consideration of best processing techniques and software to use.
   d. Accuracy assessment techniques for use in the project, especially in remote areas.
e. Use of remotely sensed imagery.

f. Cost of implementation. This includes cost of hardware, software, data acquisition and training and ongoing maintenance of the system.

3. Ongoing evaluation of the GIS is recommended. Methods of evaluation should be discussed with the community during development stages of the project.

7.2.6 General discussion of the overall project

The overall outcome of the project is a GIS that is designed to suit the needs of BAC and can be expanded to include other environmental and cultural information. Issues discussed in Chapter 4 were addressed during the course of the project and although many of the issues are ongoing, they have been considered at least to some extent. Common languages used in the Maningrida area are described in Chapter 2. Aboriginal languages are traditionally oral and as discussed in Chapter 2, many Aboriginal people do not like to see their language in written form. In the future, a range of Aboriginal languages could be incorporated in the GIS.

After discussion with members of BAC, it was decided that the GIS should include only English meantime, as this is the most commonly written language. Research by Tabor and Hutchinson (1994) indicates that western classification systems are inappropriate to Aboriginal people. During this project, the Specht (1970) classification system was used. This is a western system developed to suit a European rather than an Aboriginal view of Australia. Discussion at Maningrida about the use of indigenous knowledge systems has led to the conclusion that eventually Aboriginal knowledge will be incorporated within the GIS. The inclusion of Aboriginal knowledge is a sensitive issue that needs much thought and consideration (Harmsworth, 1997a). Security issues have to be adequately addressed before inclusion of this knowledge in a GIS can be successfully done.

Another useful aspect of this study was the introduction of remotely sensed technology to an indigenous community. In the literature reviewed for the study there was no discussion on the responses of indigenous people to remotely sensed imagery. With this in mind, it is interesting that people at Maningrida found remotely sensed data to be a better representation of country than conventional maps. This fact indicates that future studies should incorporate remotely sensed imagery as a map form rather than conventional maps.

The methodology used in this project to map clan boundaries is adequate for the 'working' boundaries as requested by BAC. However, it would be possible to map the clan boundaries in a way that would integrate the complexities of the boundaries. Fuzzy boundary methodology as previously described in Chapter 5 could be used to map the boundaries and
their complexities. To map the boundaries would involve an interdisciplinary team that included traditional landowners, an anthropologist who is an expert for that region, and a GIS expert.

7.3 Conclusion

In conclusion, the aims of this project were achieved, as discussed in the previous discussion. The research questions addressed during this project were answered through the above discussion and in previous Chapters. In brief, the following conclusions can be made from this research project:

1. A GIS can be created to assist BAC with resource management of saltwater crocodile eggs.

2. It is possible to map saltwater crocodile habitat by integrating GIS and digital image processing techniques. More detailed mapping to include preferred nesting sites of saltwater crocodiles would be useful for resource management. The methodology used to derive the habitat map in this study could be applied to remotely sensed imagery of a finer spatial resolution to produce a more detailed map of saltwater crocodile habitat.

3. The complex and indeterminate nature of Aboriginal clan boundaries can be effectively mapped using GIS methodologies. Past studies indicate that integration of GPS and GIS techniques have been used successfully to map traditional lands of indigenous groups overseas. During this project, hypothetical clan boundaries were mapped using GIS methods. Future research could investigate the potential of using fuzzy boundary models to map Aboriginal clan boundaries.

4. A GIS can be designed that is relevant to the needs of and usable by indigenous people. Review of the literature indicates that indigenous people overseas are using GIS successfully at community level. The GIS created during this project is relevant to the needs of BAC and will be eventually used at community level in Maningrida. Methods should be sought to measure the ongoing effectiveness of the GIS. Members of BAC should be consulted regarding the most suitable methods of evaluation at community level.

5. A GIS that integrates cultural information appropriate to the needs and interests of Aboriginal people can be developed. This is indicated by a review of the literature and from results of this project. Discussion in Chapter 3 indicates that indigenous people overseas are integrating a range of cultural and environmental information into GIS. During this project hypothetical clan boundaries were mapped to demonstrate the effectiveness of including this cultural information in a GIS.
The GIS created during this project will be installed at Maningrida as a tool to assist with resource management of saltwater crocodile eggs. In time, the GIS will be expanded to incorporate a range of cultural and environmental information. The GIS will become unique to the Maningrida community and relevant to their needs. Security must be maintained to ensure that sensitive information is available only to those with rights of access. Ultimate success of the GIS can only be measured through time.

Ongoing research is advised to explore the potential of GIS methodologies to map Aboriginal boundaries with all their complexities. Methods to incorporate the dynamic nature of the boundaries should be further explored. Fuzzy set theory could provide a GIS methodology suitable for this task. Fuzzy set models could be used to represent Aboriginal land in a way that is more appropriate than the vector model used in this project.

This project is a pilot project to lay foundations for future studies. This relatively new field of GIS has exciting possibilities for the future.
Appendix 1: Raw data from WMI, supplied with text and excel files
Appendix 2: Dendrogram used to aggregate classes in the landcover basemap derived from Landsat TM imagery bands 1,2,3 and 4.

Objective function ranges from 5.9865 to 19.3197 using a log stretch.

These values are scaled from zero (0) to one hundred (100) on the dendrogram.
69 (165767) -
70 (136125) -
71 (1378) -
72 (24786) -
73 (41270) -
74 (111160) -
75 (149302) -
76 (22010) -
77 (14583) -
78 (40307) -
79 (5037) -
80 (10951) -
81 (3415) -
82 (6718) -
83 (4760) -
84 (4940) -
85 (9133) -
86 (3936) -
87 (871) -
88 (83971) -
89 (2865) -
90 (1475) -
91 (684) -
92 (14551) -
93 (533) -
94 (452) -
95 (435) -
96 (1863) -
97 (344) -
98 (1668) -
99 (771) -
100 (2701) -
101 (465) -
102 (471) -
103 (450) -
104 (373) -
105 (361) -
106 (819) -
107 (509) -
108 (504) -
109 (685) -
110 (22519) -
111 (568) -
112 (462) -
113 (214) -
114 (520) -
115 (321) -
116 (419) -
117 (1314) -
118 (145) -
119 (11055) -
120 (32405) -
121 (4199) -
122 (838) -
123 (7707) -
124 (657) -
125 (559) -
126 (278) -
127 (21699) -
128 (502) -
129 (1461) -
130 (1134) -
131 (26893) -
132 (71933) -
133 (480) -
134 (2105) -
135 (403) -
136 (65054) -
137 (120613) -
138 (658) -
139 (1252) -
140 (3219) -
141 (236) -
142 (127816) -
143 (417) -
144 (444) -
145 (987) -
Appendix 3: Dendrogram used to aggregate classes for the saltwater crocodile habitat map derived from Landsat TM imagery

Objective function ranges from 5.9865 to 17.7012 using a log stretch.

These values are scaled from zero (0) to one hundred (100) on the dendrogram.
## Appendix 4: Data obtained during Field survey of the study area.

<table>
<thead>
<tr>
<th>Field Site Number</th>
<th>GPS reading average (AMG co-ordinates)</th>
<th>Community Description</th>
<th>Specht (1970) Community Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.</td>
<td>N 8639741 E 400741</td>
<td>Open woodland ~ 10% coverage comprising of <em>E. miniata</em> and <em>E. tetrodonta</em>. Moderately thick shrub under-storey with thick grasses. Dry light sandy soil.</td>
<td>Open Eucalyptus woodland. Light sandy soil. Thick grass under-storey and shrub in middle storey.</td>
</tr>
<tr>
<td>8.</td>
<td>N 8633092 E 416338</td>
<td>Low open woodland &lt; 10m high (? Acacia). Under-storey thick ~ 1.5m high. Crab skeletons and shells found in soil. Dark muddy clay soil.</td>
<td>Low Eucalyptus woodland.</td>
</tr>
<tr>
<td>Field Site Number</td>
<td>GPS reading average (AMG co-ordinates)</td>
<td>Community Description</td>
<td>Specht (1970) Community Classification</td>
</tr>
<tr>
<td>-------------------</td>
<td>----------------------------------------</td>
<td>-----------------------</td>
<td>----------------------------------------</td>
</tr>
<tr>
<td>11.</td>
<td>N 8651239 E 422813</td>
<td>Open forest. Upper storey ~ 15-20m high, consisting of <em>E. miniata</em> and <em>E. tetradonta</em>. Under-storey was shrubby with leaf litter ++. Reddish sandy soil.</td>
<td>Eucalyptus open forest.</td>
</tr>
<tr>
<td>15.</td>
<td>N 8652958 E 422024</td>
<td>Upper storey consisting of 10-30m eucalyptus (<em>E. miniata</em> and <em>E. tetradonta</em>) forming ~10% canopy. Middle storey of Black Wattle and Livingstonia. Grassy under-storey with leaf litter ++. Soil erosion provides evidence of a wet season watercourse at this site. Pale sandy soil.</td>
<td>Eucalyptus woodland</td>
</tr>
<tr>
<td>16.</td>
<td>N 8653078 E 421986</td>
<td>Upper storey of 10-15m <em>E. miniata</em> and <em>E. tetradonta</em> forming a tree canopy of ~ 10%. Livingstonia and shrubs found in the middle storey. Many saplings and sparse grasses make up the under-storey. Leaf litter + Evidence of a recent bush fire. Pale sandy soil.</td>
<td>Eucalyptus woodland.</td>
</tr>
<tr>
<td>17.</td>
<td>N 8653078 E 421949</td>
<td><em>E. miniata</em> and <em>E. tetradonta</em> (15-20m in height) make up a canopy of &lt;10%. Occasional Livingstonia make up a lush and thick middle storey. Under-storey of sparse grasses with ++ leaf litter. Sandy and stony soil</td>
<td>Eucalyptus woodland.</td>
</tr>
<tr>
<td>Field Site Number</td>
<td>GPS reading average (AMG co-ordinates)</td>
<td>Community Description</td>
<td>Specht (1970) Community Classification</td>
</tr>
<tr>
<td>-------------------</td>
<td>----------------------------------------</td>
<td>-----------------------</td>
<td>---------------------------------------</td>
</tr>
<tr>
<td>19.</td>
<td>N 8654284 E 432421</td>
<td>Canopy of ~ 10% of 20m tall trees. Middle storey of Acacia species with occasional 'screw pine'. Sparse grassy under-storey with +++ leaf litter. Evidence of old bush fires. Occasional Cathedral termite mounds and Grevilla species 'she oaks'.</td>
<td>Eucalyptus woodland.</td>
</tr>
<tr>
<td>20.</td>
<td>N 8654171 E 432354</td>
<td><em>Eucalyptus miniata</em> and <em>tetradonta</em> Trees 10-15m high comprising a canopy of &lt;10%. Under-storey of lush Acacia species with sparse grass. Leaf litter ++++. Pale red sandy soil.</td>
<td>Eucalyptus woodland</td>
</tr>
<tr>
<td>21.</td>
<td>N 8654290 E 432336</td>
<td>Upper storey consists of <em>E. miniata</em> and <em>E. tetradonta</em> (~ 20m in height) in a &lt;10% canopy. Middle storey consists of Pandanus and various Acacia. Sparse grasses and some herbaceous plants make up the under-storey. Small amount of leaf litter. Pale sandy soil.</td>
<td>Eucalyptus woodland</td>
</tr>
<tr>
<td>22.</td>
<td>N 8658373 E 430892</td>
<td>Canopy of &lt;10% of 10-15m thin trees in upper storey. Middle storey plants consists of Pandanus trees, with a small number of Acacia. Under-storey was sparse and grassy. Leaf litter ++. Dry, pale red sandy soil.</td>
<td>Eucalyptus woodland</td>
</tr>
<tr>
<td>23.</td>
<td>N 8664565 E 424323</td>
<td><em>E. miniata</em> and <em>E. tetradonta</em> (~10-15m in height) make up the upper storey with a canopy of ~15%. Middle storey comprises of Acacia and shrubs. Saplings occur in under-storey. Leaf litter ++. Cathedral termite mounds. Red sandy gravel / soil.</td>
<td>Eucalyptus woodland</td>
</tr>
<tr>
<td>Field Site Number</td>
<td>GPS reading average (AMG co-ordinates)</td>
<td>Community Description</td>
<td>Specht (1970) Community Classification</td>
</tr>
<tr>
<td>------------------</td>
<td>---------------------------------------</td>
<td>-----------------------</td>
<td>---------------------------------------</td>
</tr>
<tr>
<td>25.</td>
<td>N 8662842 E 424604</td>
<td>Melaleuca stand near waterhole and Eucalypt forest</td>
<td>Paperbark stand</td>
</tr>
<tr>
<td>26.</td>
<td>N 8662842 E 424503</td>
<td>Tall Eucalyptus community (20-30m in height) contribute to a ~50% canopy coverage. Pandanus and Acacia make up the middle storey. Grassy under-storey. Dry sandy red soil.</td>
<td>Eucalyptus forest near Melaleuca stand</td>
</tr>
<tr>
<td>28.</td>
<td>N 8642382 E 400125</td>
<td>Open grassland near Melaleuca stand</td>
<td>Open grassland</td>
</tr>
</tbody>
</table>
**STRUCTURAL FORMATIONS IN AUSTRALIA - SPECHT MKII**

<table>
<thead>
<tr>
<th>Life form of tallest stratum</th>
<th>Foliage Projective Cover of tallest stratum</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100 - 70% (4)#</td>
</tr>
<tr>
<td>Trees* &gt; 30 m</td>
<td>(T)# Tall closed-forest</td>
</tr>
<tr>
<td>Trees 10-30 m</td>
<td>(M) Closed-forest</td>
</tr>
<tr>
<td>Trees &lt; 10 m</td>
<td>(L) Low closed-forest</td>
</tr>
<tr>
<td>Shrubs* &gt; 2 m</td>
<td>(S) Closed-scrub</td>
</tr>
<tr>
<td>Shrubs 0.25 - 2 m</td>
<td>(Z) Closed-heatland</td>
</tr>
<tr>
<td>Sclerophyllous</td>
<td>(C) -</td>
</tr>
<tr>
<td>Non-sclerophyllous</td>
<td>(D) -</td>
</tr>
<tr>
<td>Shrubs &lt; 0.25 m</td>
<td>(W) -</td>
</tr>
<tr>
<td>Sclerophyllous</td>
<td></td>
</tr>
<tr>
<td>Non-sclerophyllous</td>
<td></td>
</tr>
<tr>
<td>Hummock grasses</td>
<td>(H) -</td>
</tr>
<tr>
<td>Herbaceous layer</td>
<td></td>
</tr>
<tr>
<td>Graminoids</td>
<td>(G) Closed (tussock) grassland</td>
</tr>
<tr>
<td>Sedges</td>
<td>(Y) Closed-sedgeland</td>
</tr>
<tr>
<td>Herbs</td>
<td>(X) Closed-herbland</td>
</tr>
<tr>
<td>Ferns</td>
<td>(F) Closed-fernland</td>
</tr>
</tbody>
</table>

* A tree is defined as a woody plant usually with a single stem; a shrub is a woody plant usually with many stems arising at or near the base.

# Symbols and numbers given in parentheses may be used to describe the formation, eg tall closed-forest - T4, hummock grassland = H2.

‡ Senescent phases of Tall forest.
References:


Brock, J. (1993). Native Plants of Northern Australia, Reed Books, N.S.W.


Otto, J. E. (1990). "Integration of remote sensing and GIS for tropical forests monitoring." *ACSM ASPRS Annual GISLIS, USA.*


