Towards Exploring Future Landscapes using Augmented Reality

This thesis is submitted in fulfillment of the requirements for
the degree of Master of Applied Science by Research

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April 2008

Declaration

I certify that except where due acknowledgement has been made, the work is that of the author alone; the work has not been submitted previously, in whole or in part, to qualify for any other academic award; the content of the thesis is the result of work which has been carried out since the official commencement date of the approved research program; any editorial work, paid or unpaid, carried out by a third party is acknowledged; and, ethics procedures and guidelines have been followed.

Craig N. Feuerherdt
8th December, 2008

Acknowledgements

Firstly and most importantly I'd like to thank Professor William (Bill) Cartwright for being my primary supervisor. His initial thrust to lure me into post-graduate study was backed by his enthusiasm to keep me moving in the right direction. Michael Black, my secondary supervisor, must also be thanked for ensuring that Bill's ideas were interpreted into practical output. The time and effort put in by both supervisors is greatly appreciated.

In addition to my formal supervisors there are additional people who assisted. Mark Imhof from the Department of Primary Industries (DPI) who provided me with the photographs used in the prototype interface. Craig Beverley also from DPI for providing me with references for the Catchment Assessment Tool (CAT). Tim Hailes from Aviation Data Systems (Australia) Pty Ltd, a knowledgeable friend who assisted in verifying the positioning aspects of my theoretical mobile Augemented Reality (AR) system. Wayne Piekarski from the University of South Australia who spent some time chatting and showing me the Tinmith mobile AR system. The six participants who evaluated the prototype and provided constructive feedback also need thanking. The time and effort spent by both reviewers needs to be acknowledged. Their comments, feedback and suggestions have improved the structure of the thesis.

The quest to design a mobile outdoor AR system based solely on open source software mandated that open source software also be used for writing this thesis. To this extent I would also like to acknowledge all the programmers who have contributed their skills to develop the following applications. This thesis was written and compiled solely within OpenOffice (http://www.openoffice.org/) office software suite. Bibus (http://bibus-biblio.sourceforge.net/) was initially used for bibliographic reference management prior to moving to Zotero (http://www.zotero.org/), both of which integrate flawlessly with OpenOffice. Inkscape (http://www.inkscape.org/) was used for vector editing and GIMP (http://www.gimp.org/) for image manipulation.

The prototype user interfaces were produced with the Axure XP Pro software (http://www.axure.com/). This software was provide free-of-charge under the Axure Good Student Program. The free Beneton Movie GIF software (http://software.benetonfilms.com/Beneton_Movie_GIF/) was used to create the animations in the prototype. Silk Icons (http://www.famfamfam.com/lab/icons/silk/) were used on the mapping interface.

Last, but by no means least, my wife and children must be thanked for enduring my study years. The birth of my three sons took place during the writing of this thesis and while Lachlan, Luke & Joshua have provided plenty of distractions, they compelled me to get it finished so I could spend more time with them. Maree provided substantial input into this thesis by finding those small but important grammatical errors. Their patience will be repaid, with interest!

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Acronyms

2D	Two dimensional
3D	Three dimensional
6DOF	Six Degrees Of Freedom
ACD	Activity-Centered Design
ALUM	Australian Land Use and Management
APRIL	Augmented reality Presentation and Interaction Language
AR	Augmented Reality
ASCII	American Standard Code for Information Interchange
BARS	Battlefield Augmented Reality System
CAT	Catchment Assessment Tool
CD-ROM	Compact Disc Read-Only Memory
COTS	Common Off-The-Shelf
CRC	Cooperative Research Centre
CSIRO	(Australian) Commonwealth Scientific and Research Organisation
DART	Designers Augmented Reality Toolkit
DB	Database
DEM	Digital Elevation Model
DGPS	Differential Global Positioning System
DPI	Department of Primary Industries
DSE	Department of Sustainability and Environment
DSS	Decision Support System
DVD	Digital Versatile Disc
EDA	Exploratory Data Analysis
ETA	Estimated Time of Arrival
FOV	Field Of View
GIS	Geographic Information System
GLONASS	Global Navigation Satellite System
GML	Geography Markup Language

GNSS	Refer to GLONASS
GPS	Global Positioning System
GUI	Graphic User Interface
HCD	Human-Centered Design
HCI	Human-Computer Interface
HID	Human Interaction Device
HMD	Head-Mounted Display
HREC	Human Research Ethics Committee
HTA	Hierarchical Task Analysis
HTML	Hyper-Text Markup Language
HUD	Heads-Up Display
IBM	International Business Machines
ICM	Integrated Catchment Model or Integrated Catchment Management
IDE	Integrated Development Environment
IEEE	Institute of Electrical and Electronics Engineers
IT	Information Technology
KML	Keyhole Markup Language
LAN	Local Area Network
LBS	Location Based Services
LCD	Liquid Crystal Display
MAGIC	Mobile Augmented Group Interaction in Context
MARS	Mobile Augmented Reality System
MBR	Minimum Bounding Rectangle
MDB	Murray-Darling Basin
MDBC	Murray-Darling Basin Commission
NAP	National Action Plan (for Salinity and Water Quality)
NASA	National Aeronautics and Space Administration
NCCMA	North Central Catchment Management Authority
NHT	Natural Heritage Trust
NRM	Natural Resource Management
OGC	Open Geospatial Consortium
PDA	Personal Digital Assistant
PHP	Hypertext Preprocessor
PUI	Perceptual User Interface
PSP®	Playstation Portable
RAID	Redundant Arrays of Inexpensive Disks
RAM	Random Access Memory
RCS	Regional Catchment Strategy

RDBMS	Relational Database Management System
SBD	Scenario-Based Design
SDIO	Secure Digital Input Output
SLD	Styled Language Descriptor
SQL	Structured Query Language
SUS	System Usability Scale
SVGA	Super Video Graphics Array
TBL	Triple-Bottom Line
TUI	Tangible User Interface
UCD	User-Centred Design
UI	User Interface
UMN	University of Minnesota
VE	Virtual Environment
VDT	Visual Display Terminal
ViSC	Visualization in Scientific Computing
VR	Virtual Reality
VRD	Virtual Retinal Display
VRML	Virtual Reality Modeling Language
WFS	Web Feature Service
WIMMIS	Wearable Immersive Multi-Media Information System
WIMP	Windows, Icons, Menus and Pointing devices
WLAN	Wireless Local Area Network
WMS	Web Mapping Service
WOZ	Wizard Of OZ
XLST	XML Stylesheet
XML	eXtensible Markup Language

Thesis summary

With increasing pressure to better manage the environment many government and private organisations are studying the relationships between social, economic and environmental factors to determine how they can best be optimised for increased sustainability. The analysis of relationships are undertaken using (sometimes) complex computer-based models known as Integrated Catchment Models (ICM). Many of these models have focused on environmental factors due to the greater understanding of the linkages and availability of appropriate data however social and economic factors are being increasingly used to provide a holistic "picture". The availability of low cost, high performance computer systems has increased the use of such models.

The vast majority of models are capable of generating scenarios depicting alternative land use alternatives at a variety of temporal and spatial scales, which present (potentially) better Triple-Bottom Line (TBL) outcomes than the prevailing situation. Dissemination of this data is (for the most part) reliant on traditional, static map products however, the ability of such products to display the complexity and temporal aspects is limited and requires additional explanation (either verbal or written) to fully understand the inherent complexities. Attempting to communicate the detail of such models to large, heterogeneous stakeholder groups often results in the outcomes being simplified and targeted at the lowest perceived intellectual capacity. This undervalues both the knowledge incorporated in the models and the capacity of stakeholders to disseminate the complexities.

Geovisualization provides tools and methods for disseminating large volumes of spatial (and associated non-spatial) data. Virtual Environments (VE) have been utilised for various aspects of landscape planning for more than a decade. While such systems are capable of visualizing large volumes of data at ever-increasing levels of realism, they restrict the users ability to accurately perceive the (virtual) space. Augmented Reality (AR) is a visualization technique which allows users freedom to explore a physical space and have that space augmented with additional, spatially referenced information.

Mobile outdoor AR systems support the visualization of virtual features within a mobile, interactive augmented environment. The creation of such systems is complex and whilst some mobile AR systems have been commercialised, the vast majority are on-going research within educational institutions. The collection and processing of data needs to be done in near real time for augmented graphics to be perceived as 'reality'. Mobile AR relies on utilising small, portable hardware however such devices typically have reduced computational processing power limiting the ability to process sensing data and render graphics. A review of existing mobile AR systems forms the basis for the development of a theoretical mobile outdoor AR system.

A User Interface (UI) is the medium through which users interact with a computer system and dictates a systems functionality and effectiveness. User interfaces for AR are, for the most part, based on desktop computing metaphors. Some aspects of these metaphors are restrictive in AR systems due to the mobility of the user and alternate interaction devices. The core contribution of this research is exploring the potential of AR for better understanding landscape processes through the development of user interfaces for creating, interacting with and disseminating land use scenarios within a mobile augmented environment.

The specific requirements of visualizing land use scenarios in a mobile AR system were derived using a usability engineering approach known as Scenario-Based Design (SBD). The SBD approach is utilises hypothetical stakeholders (based on target stakeholder groups) and (theoretical) problem scenarios to develop realistic (yet hypothetical) use scenarios which explore user interface requirements to form the basis for developing the required user interface(s).

The user interfaces were evaluated using participants from two targeted stakeholder groups. Evaluation tasks based on the hypothetical use scenarios were developed with participants asked to complete them. Feedback from participants was collected using the cognitive walk-through technique whereby verbal feedback from the participant about their progress (both envisaged and actual) was documented as they progressed through the task. This information was supplemented by evaluator observations of participants physical actions. In addition, the System Usability Scale (SUS) questionnaire was completed by each participant, providing qualitative feedback about their perception of the user interface.

Results from this research suggest that the prototype user interfaces did provide the necessary functionality for interacting with land use scenarios. While there were some concerns about the potential implementation of “yet another” system, participants were able to envisage the benefits of visualizing land use scenario data in the physical environment. In addition, the research has raised further research questions which need to be considered in creating better user interfaces for outdoor AR systems. This research could be extended through further development and testing of the prototype user interfaces and implementing the user interfaces within a working mobile AR system.

Chapter 1

Introduction

1.0 Chapter overview

This chapter outlines the purpose of the research, with particular emphasis on catchment management, its context and importance within Australia. The underlying questions which are to be addressed are then discussed. The research methodology is outlined along with the scope of research including the specific inclusions and exclusions followed by an overview of the thesis structure.

1.1 Introduction

Many government departments are undertaking projects looking at the trade-offs between social, economic and environmental factors, commonly referred to as 'triple-bottom line' (TBL) accounting. This approach, recognised across Australia as Integrated Catchment Management (ICM) (The State of Victoria, 1999; Murray-Darling Basin Commission, 2004b), is essential to the long-term sustainability of a region (The State of Victoria, 2004b; Bryan, 2003).

In looking at trade-offs between various landscape elements, most natural resource projects are now heavily reliant on complex, computer-based models. Such models have the capability to generate large quantities of scenarios. These scenarios provide land use alternatives which can be used to assist land managers determine a more appropriate solution for a specific area given, a particular issue or set of issues (such as decline in water quality or erosion).

ICM frameworks have become more robust with the availability of cost-effective computational devices and a continually improving understanding of the landscape systems being conceptualised. Despite the improved accuracy of model output, dissemination of such outputs is often done using static, thematic maps. Such products require detailed explanation in order to be understood by diverse stakeholders and as a result, land managers do not necessarily fully understanding the long term benefits of the land use changes being suggested. It is argued that these artefacts are incapable of showing the real complexity of the generated scenarios. As many of these models require expert knowledge to build, execute and visualize outputs, it is important that the final visualization 'works', eliminating possible scepticism amongst stakeholders. With communication becoming increasingly wireless and technology becoming more robust and accessible, mobile augmented reality may provide an appropriate interface between models and stakeholders.

1.1.1 Clarification of terms

For the purpose of this research, catchment is used to define a geographic area in which water is collected by the natural landscape. The term catchment manager refers to those people who manage the natural resources (such as water, land and biodiversity) within a catchment (or group of catchments). Land managers are those people that are directly responsible for the management of the land including farmers, land owners and reserve managers. Management practices carried out by land managers not only impact on the immediate area but on all points downstream of their property thus defining the connection of a land manager to a catchment.

Catchment information, in the context of this research, is data and information relating to the management of the resources (land, water, social, economic and biodiversity) which has been derived from measured data such as census, survey and monitoring programs. Catchment information has many relationships and complex interactions.

Landscape scenario and land use scenario are typically used interchangeably, however there is a slight difference. Landscape scenarios encompass social, economic and environmental aspects while land use scenarios are predominantly biophysically based. In reality, economic aspects are difficult to model in respect to land management, resulting in many catchment models focussing on biophysical aspects.

1.2 Research problem and aims

This research is focussed on the development of user interfaces for a mobile Augmented Reality (AR) system to facilitate landscape scenario development and dissemination. The objective is to utilise AR as a method of disseminating land use scenarios in addition to providing an interface to complex catchment models.

Virtual Environments (VE) are seen as an alternative to traditional static maps for disseminating the complexity of land use scenarios to land managers. While VE allow users to interact with land use scenarios in a wholly virtual environment, the true implications of a scenario are difficult to realistically interpret given the differences in space (virtual) and time (virtual). Augmented Reality (AR) has the potential to provide an interactive environment for viewing land use scenarios while located in the physical (real) environment. The application of AR for integrated catchment management is yet to be explored. The research outlined in this thesis evaluates the effectiveness of using mobile devices as an interface between integrated catchment models, the scenarios they output and the envisaged users of such systems.

While the user interfaces of catchment models become increasingly user friendly, the inherent knowledge required to understand the underlying complexities of the model result in them remaining the domain of experts. This not only restricts the extent to which such models are applied but contributes to scepticism amongst critics as to the robustness of such models. The complexity of comprehensive models necessitates high performance computing to generate outputs in sensible time frames, however simplistic models can be deployed on most computing devices to provide timely feedback about the potential magnitude of issues relating to a landscape.

(Orland, 1992) suggests that visualization systems must 'think globally' whilst providing the functionality to 'act locally'. This research is focused on the development of User Interfaces (UI) for interacting with catchment models within a mobile, outdoor AR system and specifically UI's which allow a wide range of users to address and disseminate scenarios in such an environment to facilitate Orland's (1992) vision. The research also touches on other areas of research including the impact of visualization on knowledge discovery within AR environments, the effectiveness of visualizations on small format, low resolution displays and collaboration within augmented environments.

Many technological issues have prevented AR becoming more widely adopted. The availability of higher performance, lower cost hardware and peripherals, has not simplified the implementation of AR systems due to the complex technical and scientific problems associated with such systems (Azuma, 1997; Romao et al., 2004). Accurate registration of synthetic images with real world features (Azuma, 1997; Gelenbe, Hussain & Kaptan, 2004; Hollerer et al., 2001; Romao et al., 2004) continues to be the main issue with AR, severely compromising its effectiveness (Azuma et al., 2001). Tracking the users location and viewing orientation is crucial for accurate image registration, and although more accurate in prepared indoor environments, mobile outdoor applications continue to pose significant challenges (Feiner et al., 1997; Romao et al., 2004).

A range of other issues continue to limit the applicability and acceptance of AR including information retrieval, data dissemination (both through Head-Mounted Displays (HMD) and on small, portable devices such as Personal Digital Assistants (PDA)) and user interaction methods (Romao et al., 2004). While these technical issues provide context, the core contribution of this research is the development of suitable User Interfaces (UI) for mobile outdoor AR which facilitate the exploration and dissemination of complex landscape processes.

1.3 Research questions and methodology

The core question for this research is “Can suitable user interfaces for small, hand-held devices be developed that allow for the creation, examination and dissemination of land use scenarios within a mobile augmented reality environment?”. Such a question requires a thorough understanding of the requirements of the envisaged users and the capability of an AR system to deliver those requirements. A series of subsidiary questions are posed to assist answer the core research question and determine the applicability of AR to such an application, including; “What components might a suitable AR system be comprised of?”, “How would data be managed within such a system?”, “How do users collaborate?” and “Can the system be used in a variety of ways to accommodate different users?”.

To answer these questions and determine whether AR has the potential to provide an interface between complex catchment models and various stakeholders, the following methodology is proposed. Several AR systems will be reviewed with their functionality and UI elements examined. This will form the basis for the development of a theoretical mobile outdoor AR system which coalesces the necessary components into a single system.

Suitable UI elements will then be developed by documenting the processes undertaken in land use scenario development and dissemination. Theoretical use scenarios will be developed describing how the objectives may be attained in a mobile outdoor AR system with a focus on the specific functionality required by users creating and disseminating land use scenarios. A realistic, computer-based, low-fidelity prototype user interface based on the findings will be developed utilising suitable rapid-prototyping software.

The user interfaces will be evaluated by a small number of participants undertaking specific tasks derived from the envisaged use scenarios. In addition, each participant will complete a post-evaluation questionnaire providing a 'big picture' assessment of the interfaces. A qualitative analysis of the recorded results will determine the effectiveness of the prototype user interfaces. The results will be discussed and where necessary, alternative interface solutions offered to overcome the major shortcomings highlighted by the participants evaluations.

1.4 Research scope

The scope of this research is restricted to the development of prototype user interfaces that enable users to interact with and create alternative land use scenarios. The specific inclusions and exclusions are listed below.

1.4.1 Inclusions

The scope of this research includes:

- A review of selected mobile AR systems and their applicability to landscape visualization;
- Documentation of a conceptual mobile (visual) AR system capable of being used outdoors;
- Development of prototype user interfaces which enable the development, interaction with and dissemination of land use scenarios;
- Evaluation of the user interfaces using a small group of participants with a natural resource background; and,
- An evaluation of the appropriateness of mobile AR as a tool for assessing and developing land use scenarios.

1.4.2 Exclusions

The scope of this research explicitly excludes:

- The development of a working mobile AR system;

- The implementation of the user interfaces on a suitable device (PDA);
- The integration of any integrated modelling framework;
- Comprehensive testing of the prototype user interfaces with a large and varied user base; and,
- Iterative development of the prototype user interfaces through the incorporation of any alterations resulting from the issues found during the evaluation.

1.5 Thesis structure

Chapter 2 has been structured to give the reader an appropriate background to visualization. This is developed into more detail relating to the applicability of Virtual Reality (VR) and Augmented Reality (AR) to geographic visualization. Visualization for knowledge construction is also discussed. The realisation of ubiquitous computing (ubicomp) is also outlined with specific reference to its linkage with AR. A section is devoted to current user interfaces metaphors.

Chapter 3 details the core components of visual AR systems and how they are integrated to provide an immersive, portable visualization environment. The complex technological issue of mobile AR are outlined with reference to future research requirements. This chapter also outlines some of the mobile AR systems documented in the literature, focussing on systems built for a purpose similar to land use scenario depiction. A brief overview of software libraries and authoring frameworks for developing AR applications is included.

Chapter 4 introduces catchment modelling with a hypothetical scenario. Appropriate interpretation of model outputs through interaction and community engagment is discussed. Reference to the multitude of inputs required to build accurate, computer-based representations of the landscape is made with the inputs and outputs of one such model described to better highlight the diversity.

Chapter 5 describes a theoretical AR system created from readily available hardware components. Data management is critical in outdoor AR applications and more so at a landscape level. A conceptual framework for the storage and delivery of data (based on open standards), utilising wireless networks is provided as a stimulus for further research.

Chapter 6 details the development of the prototype user interfaces. After an introduction to usability engineering design, the user interfaces of the AR applications reviewed in Chapter 3 are summarised. The prototype user interfaces are developed using the Scenario-Based Design (SBD) methodology which relies on the development of scenarios to understand the requirements of the user interfaces. The scenarios are developed using knowledge gained from many years working with various natural resource scientists (soil scientists, hydrogeologists, modellers, catchment managers) creating alternative landscapes. Three distinct user interfaces catering for various users and methods of land use scenario are developed.

Chapter 7 is focused on evaluating the user interfaces. Qualitative and quantitative techniques are described prior to outlining the selected evaluation process. The cognitive walk-through evaluation method is described and a post-evaluation questionnaire chosen to gain a better understanding of the overall effectiveness of the developed user interfaces. The performance of participants undertaking each task is assessed with the specific issues documented. Responses from the questionnaire are analysed prior to the results being discussed and potential improvements for user interface elements provided.

Chapter 8 outlines the conclusions deduced from the research along with recommendations for those wanting to utilise AR technology for visualizing land use scenarios. A series of further research questions are also documented as a means to progress the development and use of such technology in the NRM field.

1.6 Chapter Summary

This chapter has provided an introduction to the challenges associated with natural resource management. The broad research problems relating to AR were documented along with the specific aim of this research. A methodology was developed to assist in answering the core research question “Can suitable user interfaces for small, hand-held devices can be developed that allow for the creation, examination and dissemination of land use scenarios within a mobile augmented reality environment?”. The inclusions, and more importantly exclusions of this research were documented to focus the extent of the research with the structure of the thesis outlined.

Chapter 2

Scientific visualization

2.0 Chapter overview

This chapter outlines scientific visualization, highlighting its usefulness for personal and collaborative knowledge construction. Geovisualization, the application of scientific visualization to spatial data will be explained with reference to its benefits and shortcomings as the next evolution of cartography. An explanation of Virtual Environments (VE) and Augmented Reality (AR) as paradigms for geovisualization is given, along with a comparison of their strengths and weaknesses.

Physical interaction with visualizations is a significant factor in determining the effectiveness of geographical visualization applications by allowing users to develop an understanding of the data and concepts they are portraying. Visualization interaction methods will be discussed with reference to Human-Computer Interfaces (HCI) with specific reference to the metaphors that have been applied to Augmented Reality. The linkages between Augmented Reality and ubiquitous computing will also be discussed.

2.1 Introduction

The increasing volume of data being collected and stored necessitates the application of novel approaches to disseminate it in meaningful ways to gain an understanding of it. Visualization as a science has existed for nearly three decades with a variety of tools and protocols developed for manipulating large volumes of data into visual representations.

Visualization of spatial data, commonly known as geovisualization, provides unique challenges due to the large volumes of data and the complexity of displaying the inherent relationships that exist within and between different data sets. These issues are exaggerated by the methods used for displaying the output and the high computational requirements for generating realistic detail. These restrictions have resulted in an evolution of visualization and resulted in it being applied in increasingly novel ways.

Augmented Reality (AR) is a novel visualization paradigm that renders computer generated graphics over real world images. This reduces the computational requirements and provides a level of realism unobtainable from computer generated graphics.

2.2 Visualization

Visualization attempts to represent relationships graphically and is targeted at providing tools and methods for analysing, discovering and understanding relationships within data (Kraak & Ormeling, 1996a). Visualization applies techniques from computer graphics, image processing, computer vision, computer-aided design, signal processing and user interface design studies to transform existing data from (potentially massive) data repositories and computational models into computer generated images for interpretation (Rhyne, 1997, 2000b).

McCormick, DeFant & M. Brown (1987) outlined the many potential applications for visualization in the 1980's, defining a robust representation (Figure 2.1) describing the relationships between the various inputs, processes and transformations applied to generate computer visualizations. Although some of the terminology is a little outdated, the diagram highlights the typical flow of data beginning at the input devices (or collection stage). These input devices could include Global Positioning System (GPS), scanners or keyboards which are used to collect or create data. The data is accessed and manipulated with software applications by users using interaction devices (such as keyboards, mice or Personal Digital Assistants (PDAs)). This interaction results in additional data written to output devices whether they be hard drives, CD-ROM, DVD, displays or a combination.

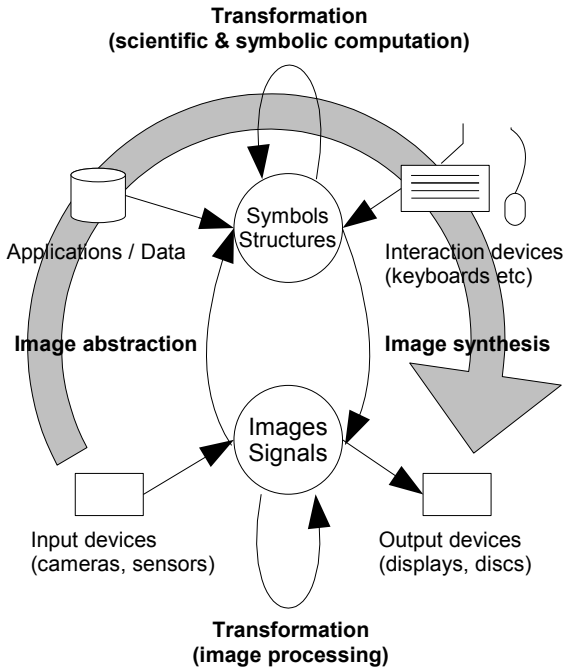

Figure 2.1 - Representation of visualization from input to output, after McCormick, DeFant, & Brown (1987, p.15).

Visualization has been defined by (McCormick, DeFant & Brown, 1987) (cited in Buckley, Gahegan & Clarke, 2001, p. 3) as;

> *A method of computing…a tool both for interpreting image data fed into a computer, and for generating images from complex multi-dimensional data sets…to leverage existing scientific methods by providing new insight through visual methods.*

Visualization therefore provides a methodology for generating and interpreting graphical representations of digital and potentially multi-dimensional data (Rhyne et al., 1994). However, this implies that visualization is wholly a process of computing. MacEachren et al. (1992) (cited in Buckley, Gahegan & Clarke, 2001) argued that visualization is assisted by the power of computing, but, initially, it is an act of cognition, the human ability to develop mental representations for identifying patterns and ordering vast amounts of information. This view is supported by Kraak & Ormeling (1996a) who stated that the capacity for abstraction of visualizations allows humans to perceive connections, patterns or structures.

Card, Mackinlay & Shneidermann (1999) (cited in Tory & Moller, 2002, p. 6) has succinctly combined both the computational and cognitive aspects of visualization, stating visualization as "...the use of computer-supported, interactive, visual representations of data to amplify cognition".

The increase in the amount of digital data, combined with the need to address complex scientific challenges, makes it increasingly difficult to explore, understand, analyse and communicate information. Visualization techniques can provide a variety of methods to overcome these problems while ensuring the users remain focused on solving particular issues. The processing and graphic capabilities of computers can be used to display data in innovative ways that allow hidden patterns to be visualized thereby providing users with a greater understanding of the problem (Buckley, Gahegan & Clarke, 2001). Effective visualization requires access to a variety of data sources (Rhyne et al., 1994) which, when combined with effective tools, assist in understanding complex patterns and relationships by allowing them to better manipulate and interrogate the data they are exploring (N. Andrienko & G. Andrienko, 2001; McCormick, DeFant & Brown, 1987). The manipulation of (raw or input) data into a displayable image is represented by Szalavari et al. (1998) as a visualization pipeline (Figure 2.3).

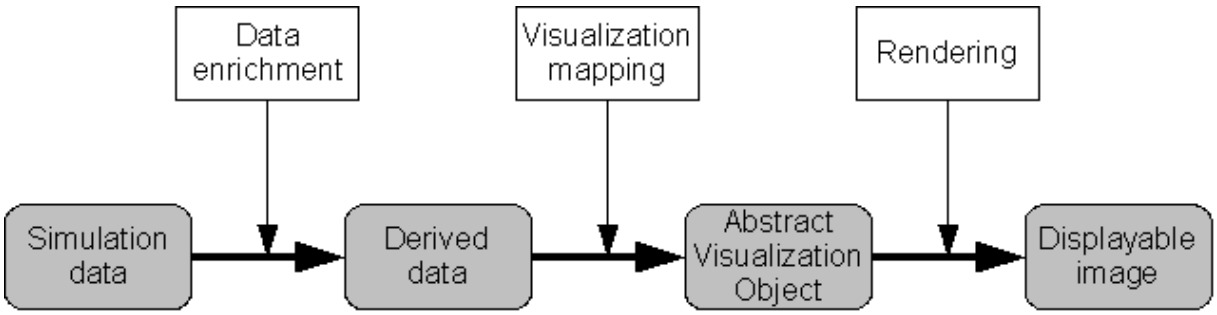

Figure 2.2 - Visualization pipeline depicting the process of visualization from collection and transformation of data through to a displayable image, after Szalavari et al. (1998, p.38).

Early definitions of visualization (including Edward Tufte's book *The Visual Display of Quantitative Information* (1983) and the 1987 report by the (USA) National Science Foundation, *Visualization in Scientific Computing*) made no distinction between scientific and information visualization (Rhyne, 2003). Separate definitions began appearing in the early 1990s, with Rhyne (2003) arguing that the separation was necessary to evolve and broaden the appeal, application and recognition of the importance of visualization. Munzner (2002), on the other hand, believes the distinction was simply an "accident of history", and argues that the continued separation of visualization is detrimental to the progression of visualization as a science (Rhyne, 2003 ; Rhyne et al., 2003).

Information visualization focuses on non-spatial, abstract data (web pages, bank transactions etc) while scientific visualization focuses on data with a physical or dimensional component (geographical, molecular etc). Scientific visualization focuses on analysing relationships in a graphical sense and targets the discovery and understanding of those relationships. Scientific visualization was once distinguished from information visualization because the tools allowed users to interact with the data, while information visualization traditionally provided users with a pictorial display (Rhyne, 1995). This point of difference is outdated as both forms of visualization (or rather the tools) allow users to interact with data.

As (Munzner, 2002, p. 2) clearly highlights, “information visualization isn't unscientific and scientific visualization isn't uninformative”. Both visualization domains share the common goal of communicating data, concepts, relationships and processes through visual forms however, they have evolved separately for more than a decade, with little interaction. This has resulted in each community developing powerful tools for interrogating and displaying data for knowledge development with little or no integration. This division has ultimately resulted in a substantial knowledge gap in analysing large-scale scientific data sets that have characteristics from both domains (Rhyne et al., 2003).

Visualization in general has evolved into a highly interdisciplinary science utilising expertise from a diverse range of sciences (Szalavari et al., 1998). Both domains should therefore combine to develop integrated capabilities that leverage their specific strengths, which have been developed in relative isolation over the last decade (Rhyne et al., 2003), to result in a strong, flexible and robust science. Despite the increasing momentum to dissolve the arbitrary division between the fields of information and scientific visualization, visualization remains divided (Kraak & Ormeling, 1996a; Rhyne, 2003; Rhyne et al., 2003; Tory & Moller, 2002).

2.2.1 Learning and knowledge construction

Effective learning occurs when meaning is taken from experience. Exploration can enhance creativity and when combined with physical engagement with a subject creates an involvement that increases cognitive interaction, interest and motivation of the user that passive listening or watching does not (Price & Rogers, 2004).

Maps, traditionally presentation devices, are now recognised as both an interface and active tool in the thinking process that support information exploration and knowledge construction (MacEachren & Kraak, 2001). The primary goal of visualization is to provide insight into complicated problems through exploring and understanding large amounts of data in a graphical manner (Szalavari et. al., 1998). Visualization, in association with human vision and spatial cognition, provides the environment for enabling thinking, learning, problem solving and decision making (MacEachren & Kraak, 2001) by simplifying large, complex data sets into graphical representations. Visualization can be applied to all stages of problem-solving from hypothesis development to data presentation and evaluation (Buckley, Gahegan & Clarke, 2001).

The “continuum of understanding” as defined by Shedroff & Jacobson (1994), is represented in Figure 2.3. In general, data is not an adequate product for communication and is relatively worthless by itself as it doesn't represent the complete story. The transformation of data into information occurs through the appropriate organisation and presentation of data within the right context, forming the stimulus for knowledge. Knowledge is participatory, created by interacting with tools and humans to learn the patterns and meaning inherent in the information. Knowledge can be personal (unique to a persons experiences and thoughts), local (developed through shared experiences between a group of people) or global (general and limited). Wisdom is the result of digesting knowledge and combining it with personal experiences (Shedroff & Jacobson, 1994).

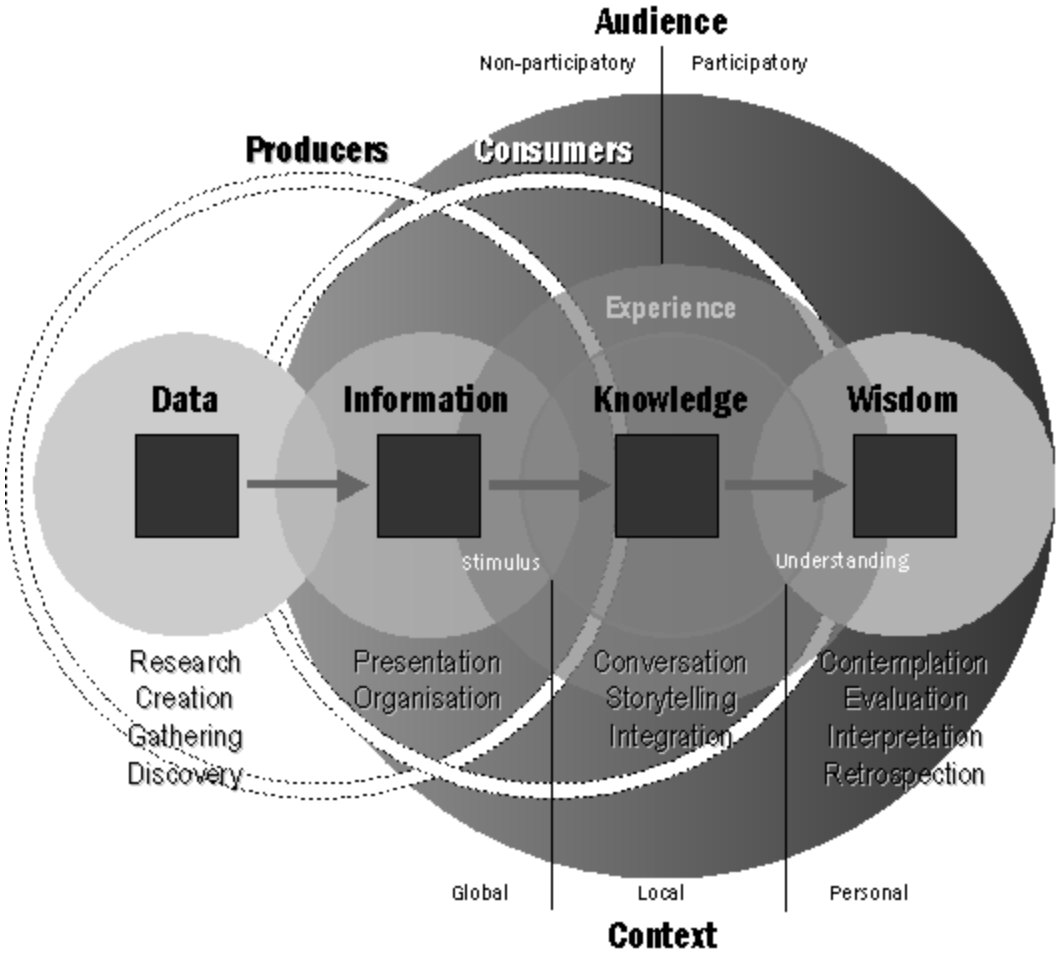

Figure 2.3 - The "continuum of understanding" showing the evolution of data through various contexts (global, local and personal) and audience participation resulting in the creation of wisdom, after Shedroff & Jacobson (1994, p.3).

According to Kraak (2003), visualization plays two distinct roles "public visual communication" (non-participatory) and "private visual thinking" (participatory) as shown in Figure 2.3. Shedroff & Jacobson (1994) make a clear distinction between participatory and non-participatory audiences, suggesting that wisdom is only gained by those that actively engage with knowledge. While this distinction is correct, MacEachren & Kraak (2001, p 3) suggest that participation is required at every phase, stating;

> *Human vision and domain expertise are powerful tools that (together with computational tools) make it possible to turn large heterogeneous data volumes into information (interpreted data) and, subsequently, into knowledge (understanding derived from integrating information).*

Both scientific and information visualization are focused on the creation of knowledge through visual representations of data that stimulate thought and user interaction (Rhyne, 2000a) liberating the human brain from information retrieval and manipulation, allowing it to be applied to analysis and synthesis of the images (Buckley, Gahegan & Clarke, 2001). Human vision alone can not be successful in extracting meaning from large data sets and consequently, construction of knowledge from complex data is more likely to occur if the advantages of computational processing and vision are combined (MacEachren & Kraak, 2001). MacEachren & Kraak (2001) advocate "visually enabled knowledge construction tools" that provide the ability to locate and provide potential explanations of the patterns and relationships being displayed.

MacEachren et al. (2004) argue the distribution of visualization will enhance the construction of real-world knowledge by promoting active learning techniques allowing users to gain and improve their understanding of complex issues. Active learning has several key aspects (Price & Rogers, 2004):

- Experienced-based learning – actively engaging in meaningful real-world activities;
- Collaboration – making learning a social experience; and
- Reflection – the need to experience, construct, test and revise knowledge. Interpretation and transformation of the knowledge allows understanding and creation of personal meaning.

Knowledge therefore grows through a process of hypothesis and theory testing with learning being the result of exposing errors in our theories (Hearnshaw & Unwin, 1994). According to Rhyne (2000b), the construction of knowledge would be greatly enhanced by the creation of interactive global virtual environments for exploring representations of scientific phenomena. Google™ Earth (Google, 2007a), Google™ Maps (Google, 2007b), NASA World Wind (NASA, 2006) and Microsoft® Virtual Earth™ (Microsoft Corporation, 2007) are examples of successful Internet applications that provide the basis for such global virtual environments (Kraak, 2006). While these and a multitude of other applications provide access to large volumes of data, the related knowledge is not stored nor represented, making the task of knowledge construction difficult (MacEachren & Kraak, 2001).

2.2.2 Collaboration

Interacting with other humans underpins learning and development, with its effectiveness defined by engagement and interaction (Price & Rogers, 2004). Buckley, Gahegan & Clarke (2001) suggest that in order to better understand earths complexities, research in the area of geovisualization should focus on improving communication and collaboration between domain and data experts. Collaboration provides a means by which users can interact to increase their understanding of complex issues and is an essential element for the construction and sharing of knowledge. Computers are being increasingly used to support collaboration and communication between users (Azuma et al., 2001).

Understanding complex, integrated systems requires decision making and knowledge sharing through interaction and collaboration between individuals (Azuma et al., 2001; Buckley, Gahegan & Clarke, 2001; MacEachren, 2001). Decision making also requires the ability to simultaneously interact with data objects to explore issues in real-time or at different times (Buckley, Gahegan & Clarke, 2001; MacEachren, 2001). These individuals may be located in disparate locations, with varying knowledge of the subject being explored and have a varying understanding of the computing systems being used.

The development of effective tools for communicating concepts, methods and knowledge to scientists and stakeholders in collaborative virtual environments is a key challenge in visualization (MacEachren & Kraak, 2001; Rhyne et al., 2001). Both real-world knowledge construction and decision making can be supported by distributing visualization tools, methods and outputs across software components, hardware devices, people and places (Brodlie et al., 1999; MacEachren et al., 2004). Improvements in networking, displays and interfaces are providing the fundamentals for real-time, collaborative visualization systems (MacEachren & Kraak, 2001).

Collaboration requires the distribution of each users 'state' to all users of the system (Reitmayr & Schmalstieg, 2004a). The representation of each user within the virtual space and the representation of each users perspective (required for distant or remote users) pose many challenges for collaborative visualization (MacEachren, 2001). Collaboration can be implemented in several ways. Domain experts could be readily accessible, whether that be physically or virtually, to provide input, knowledge and answers. Alternatively, collaboration could be implemented through interface agents that provide personalised assistance for users to interrogate the data appropriately (Schiaffino & Amandi, 2004).

2.3 Cartography and visualization

Cartography is concerned with communicating spatial information and relationships efficiently (through maps) to aid the visual thinking process (Gartner, Cartwright & Peterson, 2007; Kraak, 2003; Kraak & Ormeling, 1996a). Maps (and their various derivatives) are regarded as a form of scientific visualization (Kraak & Ormeling, 1996a). They are used for analytical and communicative purposes, assisting in the portrayal, synthesis, analysis and exploration of spatial data and it relationships (Kraak, 2006; Kraak & Ormeling, 1996a). Board (1990) (as cited in Kraak & Ormeling, 1996, p. 43) defines a map as "…a representation or abstraction of geographic reality. A tool for presenting geographic information in a way that is visual, digital or tactile."

The wealth of geographic data represented in static representations cannot be fully realized when information implicit in the data is not represented or difficult to discern (Buttenfield et al., 2000). A well designed map represents a complex of understandings rather than simply data (Francis & Williams, 2007) however, an interactive map that provides users with a flexible interface for interacting with the data and providing access to related information distinguishes geovisualization from traditional cartography (Kraak, 2006; MacEachren, 2001).

Geographical visualization (or geovisualization as it is commonly called) is a specific branch of scientific visualization focused on visualizing geographic data. It has emerged from a variety of sciences including spatial analysis, image analysis, cartography, GIS, visual analytics and information visualization G. Andrienko et al., 2007; Buckley, Gahegan & Clarke, 2001; MacEachren et al., 2004 ; Rhyne, MacEachren & Dykes, 2006). The integration of approaches from these domains have developed theories, methods and tools for the exploration, analysis, synthesis and presentation of geographic data in a visual manner (MacEachren & Kraak, 2001).

Geovisualization relies on cartographic principles to develop maps that use visualization methods (Rhyne, MacEachren & Dykes, 2006), representing the evolving nature of cartography through the utilisation of technological advances (Kraak, 2006). The relationship between scientific visualization (or geovisualization) and cartography is represented in Figure 2.4. While cartography fits wholly within the spatial context and information visualization is solely about exploration of non-spatial data, scientific visualization crosses spatial and non-spatial divide. It could be argued that both forms of visualization are capable of presenting data.

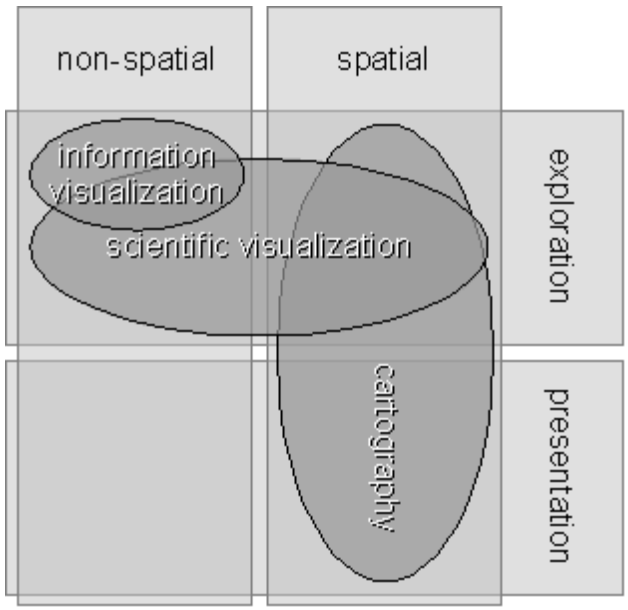

Figure 2.4 - The relationship between scientific visualization, information visualization and cartography, after Kraak (2006, p.34).

According to (MacEachren et al., 2004), the term geographic visualization was first mentioned in the 1987 report by the (USA) National Science Foundation (McCormick, DeFant & Brown, 1987), but research and practice in geographic visualization had begun almost a decade earlier. Geovisualization has been defined in various ways. An early definition by MacEachren, et al. (1992) (cited in MacEachren et al. (2004, p.312)) states geovisualization as;

> *The use of concrete visual representations – whether on paper or through computer displays or other media – to make spatial contexts and problems visible, so as to engage the most powerful human information-processing abilities, those associated with vision.*

A more recent definition by MacEachren & Kraak (2001, p.3) states;

> *Geovisualization integrates approaches from Visualization in Scientific Computing (ViSC), cartography, image analysis, information visualization, Exploratory Data Analysis (EDA), and Geographic Information Systems (GIS) to provide theory, methods, and tools for visual exploration, analysis, synthesis, and presentation of geospatial data.*

Geovisualization provides tools which allow maps to be used as an interface to geospatial data supporting information access, exploration and a presentation device. This functionality is strongly influenced by advances in other fields, allowing scientists to link diverse data to view patterns and relationships for solving spatial problems. The integration of these diverse approaches requires that cartographic (geovisualization) design integrates Human-Computer Interaction (HCI) techniques to ensure the products are usable (Kraak & Ormeling, 2003).

Geovisualization is both a process for leveraging vast amounts of spatially referenced digital data and an area of research for developing tools and methods to support spatial data applications (MacEachren et al., 2004). Geovisualization attempts to represent spatial relationships graphically and is targeted at analysing the relationships to develop hypotheses, gain insight and generate knowledge through understanding, interaction and displaying results (Buckley, Gahegan & Clarke, 2001; Kraak & Ormeling, 1996; MacEachren et al., 1999). Geovisualization spans both visualization domains (scientific and information) while contributing knowledge and methods from decades of research (Rhyne, 2003). Visualization techniques are employed at various stages during the analysis and manipulation of spatial data (Kraak, 2003) with various tools being used to display and analyse spatial relationships and patterns (Cartwright, Peterson & Gartner, 1999) in an interactive manner (White, 1997).

Geovisualization (and visualization in general) can allow users to participate in data exploration. MacEachren, Gahegan, & Pike (2004) represent the three main functions (task, interaction and users) of geovisualization as a cube (Figure 2.5). Each side of the cube depicts a continuum of each function from static to interactive, public to specialist. The space defined by the cube represents the multitude of roles that visualization can play. The 'explore-analyse-synthesis-present' diagonal represented on the geovisualization cube directly correlates to Shedroff & Jacobson's (1994) continuum of understanding (data-information-knowledge). Geovisualization therefore forms the basis of knowledge construction through interaction with spatial and non-spatial data, allowing users to explore data at a deeper level, both spatially and conceptually (Cartwright, Peterson & Gartner, 1999). Geovisualization is a process for leveraging large and diverse data resources through interactive and exploratory methods to meet the needs of science and society by providing insight into structures and relationships through portals into complex phenomena and processes (MacEachren & Kraak, 2001; MacEachren et al., 2004).

Many geovisualization methods and tools are unable to handle the extremely large data sets being collected (MacEachren & Kraak, 2001) however there is an urgent need for improved methods and tools that can intelligently and automatically transform geographic data into information and, furthermore, synthesize geographic knowledge (Buttenfield et al., 2000). Even though the creation of tools and methods for scientific visualization accelerated during the 1990's, visualization has yet to be fully exploited with geographic data (MacEachren & Kraak, 2001) although the expanding prevalence of digital globes is expanding such possibilities.

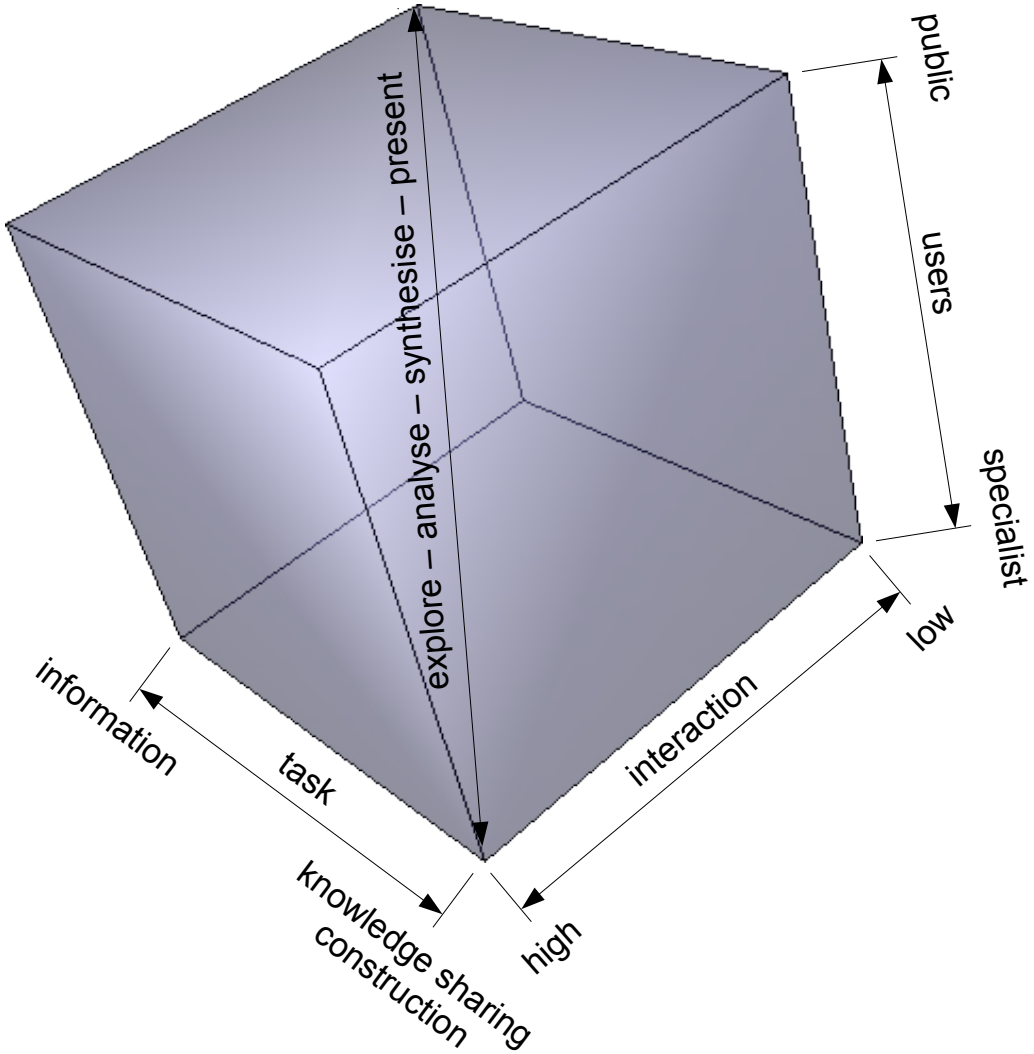

Figure 2.5 - Functions of geovisualization, after MacEachren, Gahegan & Pike (2004, p.13).

2.3.1 Applications of geovisualization

Geovisualization techniques can be applied to all stages of a products development from data exploration through to information presentation (Kraak, 2006) as represented in Figure 2.6. As a result, geovisualization has been applied to a diverse range of scientific domains including public health, environmental science (O'Connor, Bishop & Stock, 2005), crisis management (MacEachren et al., 2004; Mills & Noyes, 1999), military (Appleton & Lovett, 2003) and molecular chemistry (MacEachren & Kraak, 2001) and is increasingly used in environmental decision-making to facilitate dialog between stakeholders (Appleton & Lovett, 2003).

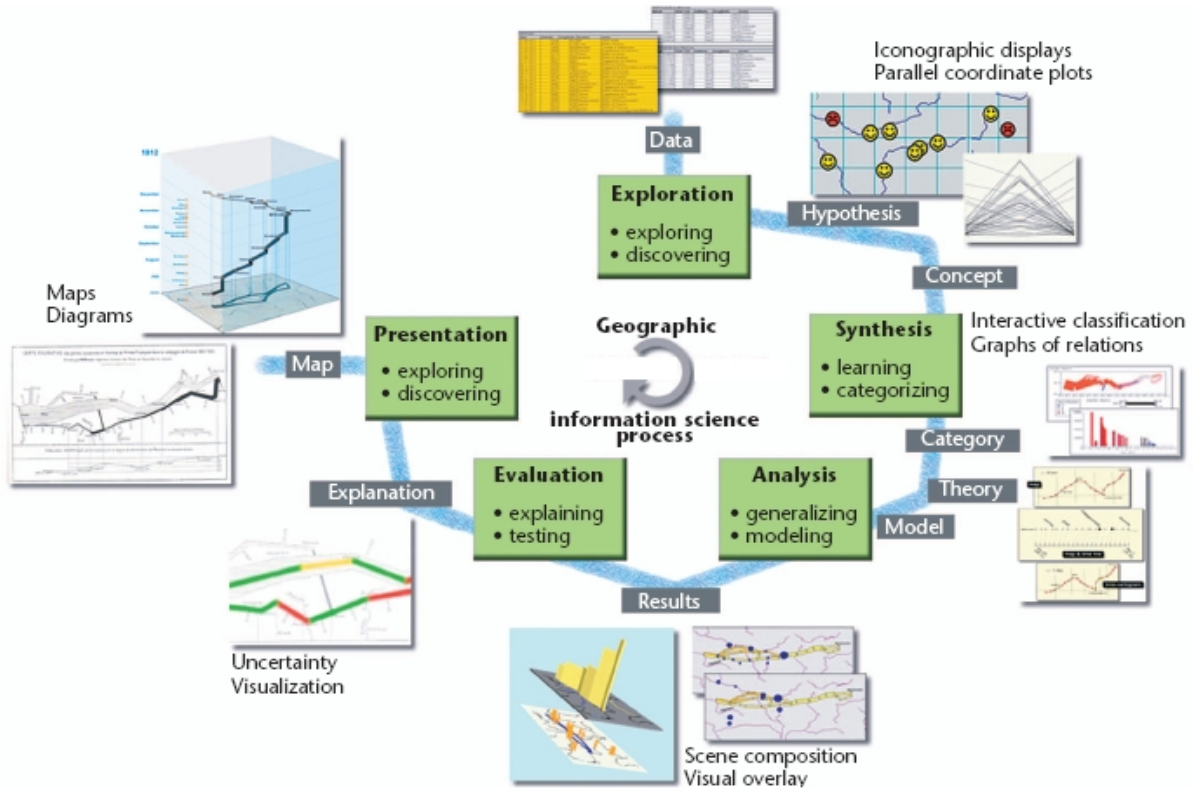

Figure 2.6 - A diagram representing the variety of diagrams and maps required at the various stages, after Kraak (2006 , p.7).

Previous research has found “accurate and realistic” 3D visualizations are an effective means of communicating with a wide range of stakeholders (Daniel & Meitner, 2001) and as a result, visualization has been described as the common currency of planning as it encourages participation and increases understanding amongst the community (Orland, Budthimedhee & Uusitalo, 2001). Effective methods of communicating environmental complexity are being driven by the need for increased transparency and public participation in making landscape-scale decisions (Appleton & Lovett, 2003).

2.3.2 Current limitations and issues

The ability to generate realistic visualizations has become increasingly easier given the availability of cost effective hardware and software, however such visualizations are not common (Meitner et al., 2005) due to the lack of suitably detailed data (Appleton & Lovett, 2003) and differing data requirements (MacEachren & Kraak, 2001; Rhyne, 1997). While mobile computing and GPS have assisted in the collection of field data, the issues relating to data storage, maintenance and access have not been fully resolved (Rhyne, 1997). This has resulted in large amounts of duplicate spatial data (of varying standard), due to it not being readily findable nor seamlessly accessible.

Data visualization tools and standards have evolved independently of spatial data standards resulting in inefficiencies in transforming data for different applications. Some geovisualization environments allow data to be imported from GIS data stores, however it is generally not possible to undertake complex spatial data analysis or data mining once the data is rendered (Rhyne, 1997).

MacEachren & M. Kraak (2001) highlight four additional limiting factors relating to spatial data and its visualization, these are:

- Geospatial data are structured in several aspects (location, elevation, time) while unstructured in regards to non-spatial attributes;
- Space is represented as two dimensional (2D) and occasionally attributed with a height (2.5D) with time being treated as an attribute of space. (Current software such as gOcad (gOcad research group - ASGA, 2008) and GeoModeller (Intrepid Geophysics & BRGM, 2008) are now capable of storing and representing true, 3D objects);
- The descriptive (non-spatial) attributes associated with features are meaningful and useful, however explicit matches between features and attributes are sometimes difficult; and,
- Geospatial data sets are often collected at various scales with different attributes and nomenclatures making them difficult to collate and interrogate.

Due to the inherent differences of geospatial data sets, current geovisualization tools have not taken advantage of georeferencing to link data from disparate sources (MacEachren & Kraak, 2001; Rhyne, 1997). The combination of all these factors make it difficult to make compelling visualizations without substantial effort in data collation and consolidation, resulting in geovisualization being seen as a time consuming task.

Rhyne (1997) suggests that a functional integration between GIS and visualization tools will only occur if appropriate software links are developed and standard, open formats are adopted for storing spatial data. However, more than a decade after Rhyne (1997) predicted advances in online digital libraries, access to high speed networks and the convergence of visualization disciplines would combine to support community decision making. The increasing popularity of eXtensible Markup Language (XML) (OASIS, 2008) and its various implementations have provided the catalyst for such integration. The Open Geospatial Consortium (2008d) has promoted a variety of XML-based standards for spatial data such as Geographic Markup Language (GML) (Open Geospatial Consortium, Inc, 2008a) for data storage and interoperability and Keyhole Markup Language (KML) (Open Geospatial Consortium, Inc, 2008b) for the visualization of spatial data in a variety of desktop and web-based applications.

Viewers' perceptions of accuracy and certainty are affected by the realism portrayed in visualizations. Realistic foreground vegetation and ground surfaces have been found to be important factors in communicating the appearance of landscapes in visualizations (Appleton & Lovett, 2003). Methods of representing information also affect the effectiveness of any visualization. The current consensus is that abstraction (simplifying/generalising complex features) is necessary for geovisualization, however new technologies and techniques are allowing a greater level of realism (MacEachren, 2001; MacEachren & Kraak, 2001). Understanding the advantages and disadvantages of abstraction, the context in which it should be applied and how to effectively combine abstraction and realism are continuing challenges for all forms of visualization (MacEachren, 2001).

Interaction with features within visualization environments is a recurring issue. The typical division between those creating the visualization (and its user interface) and those using it result in many inconsistencies. According to (Buckley, Gahegan & Clarke, 2001), data exploration by domain scientists is often separate from the development of geovisualization methods (typically undertaken by data practitioners). As a result the techniques and methods developed for interacting with data become overly complicated and confusing to the domain scientists.

2.4 Visualization paradigms

Milgram & Kishino (1994) describe a virtuality continuum (Figure 2.7) that represents the real environment at one end and completely virtual environments at the other. Geovisualization is applicable across the whole virtuality continuum from Virtual Environments (VE) (that being totally virtual and existing wholly within the computing environment) through to AR (where physical reality is augmented with computer graphics). With the progress of technology it may become more difficult to determine whether the world being perceived is predominantly real or virtual (Milgram & Kishino, 1994). The following sections provide more detail on Virtual Environments and Augmented Reality.

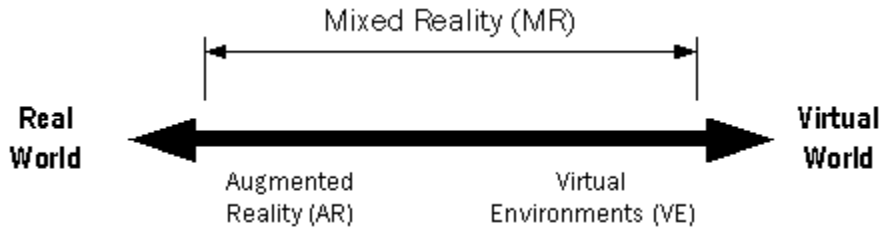

Figure 2.7 - Simplified “virtuality continuum”, after Milgram & Kishino (1994, p.1322).

2.4.1 Virtual Environments (VE)

Virtual Reality (VR) and Virtual Environments (VE) immerse the user in a computer-generated replica of the real world (Azuma, 1997) replacing the real world with a wholly virtual world (Feiner, MacIntyre, Hollerer & Webster, 1997). The terms Virtual Reality (VR) and Virtual Environments (VE) are commonly interchanged although Mills & Noyes (1999) suggest that Virtual Environments is less contradictory and will be used throughout the remainder of this thesis.

VE's provide increasingly experimental modes of accessing and manipulating information (MacEachren & Kraak, 2001). VE's combine computer systems, displays and interface devices to represent space in a simulated three-dimensional (3D) environment and potentially provide user interfaces allowing users to interact with (typically move or fly through the virtual world) and experience the synthetic reality (Kaur, Sutcliffe & Maiden, 1998; Mills & Noyes, 1999; Orland, Budthimedhee & Uusitalo, 2001). Such systems are typically implemented in desktop environments which provide a more conducive 'space' for implementing collaborative functionality, due to familiar Human Interaction Devices (HID) (such as keyboards and mice) for interaction and inputting text.

In order to accurately represent the real world, highly complex models of real world objects need to be generated (Mills & Noyes, 1999). VE's and visual simulation applications typically concentrate on visual fidelity (Reitmayr & Schmalstieg, 2003) which requires a significant investment in high performance graphics hardware for high-end, intensive graphic rendering (Danahy, 2001; Rhyne, 1997). This has resulted in skepticism about the cost effectiveness of VE's (Mills & Noyes, 1999) and the software required to create the visualizations, although hardware is becoming more affordable. Anecdotal evidence of this is provided by (Wilox, 2007) who stated the cost of a new 3D, immersive VE being commissioned by Minerals & Petroleum Victoria was in the order of AUD$200,000, less than half the price of an equivalent setup installed by Geoscience Australia 2-3 years prior.

Virtual Environments are suited to those people who learn through exploration, however, while VE's provide an enjoyable experience they don't necessarily assist in learning (Mills & Noyes, 1999). VE's have typically lacked a coherent approach to user interaction design with users becoming disorientated and confused about potential interaction methods resulting in perceptual misjudgments and user frustration (Kaur, Sutcliffe & Maiden, 1998). Additional limitations of screen-based virtual environments include a lack of peripheral context and lack of immersion (Danahy, 2001).

2.4.2 Augmented Reality (AR)

Augmented Reality (AR) is a visualization paradigm that supplements (typically) vision with computer generated information, superimposed on the users view (Schmalstieg & Reitmayr, 2007). AR is focused on the presentation of information for enhanced situational awareness and perception within a temporal and spatially structured manner, allowing users to browse, filter, search and interact with data in the real world (Behringer, 1999; Ledermann & Schmalstieg, 2005). Schmalsteig & Reitmayr (2007) state that AR is the natural progression of cartography.

It is also possible to remove (occlude) existing objects from reality and while this is known as mediated or diminished reality, (Azuma et al., 2001) classifies it as a subset of AR. Augmenting the real world with computer generated graphics provides users with an experience not possible in just the real or virtual world (Price & Rogers, 2004). Augmented Reality (AR) resides between Virtual Environments (VE) (or virtuality) and reality on Milgram & Kishino's (1994) continuum (Dix et al., 1998; Mills & Noyes, 1999) (Figure 2.7).

The field of modern AR has existed for well over a decade (Azuma et al., 2001), with origins back to the 1960's when Sutherland (1968) developed Sketchpad, a man-machine graphical communication system. AR systems are defined by their ability to spatially integrate virtual objects into the physical world in real-time, immersing the user in an information-rich, interactive environment (Azuma, 1997; Feiner, MacIntyre, Hollerer & Webster, 1997; Hollerer et al., 2001; MacIntyre, 2002; Romao et al., 2004; Reitmayr & Schmalstieg, 2003). AR can be applied to any human sense (Azuma et al., 2001), although vision is most commonly augmented. Head-Mounted Displays (HMD's) are typically used to display spatially registered computer generated images onto the real world for the user to see (Reitmayr, 2004).

AR is useful in any situation where additional information is required (Schmalstieg & Reitmayr, 2007). Known application areas of AR include medicine (Azuma, 1997; Traub et al., 2004; Y. Wang & Samaras, 2003), manufacturing (Azuma, 1997; Dangelmaier et al., 2005), construction (Malkawi & Srinivasan, 2005), automotive maintenance (Anastassova et al., 2005), environmental management (Romao et al., 2004), tourism (Reitmayr & Schmalstieg, 2004a), entertainment (Azuma, 1997), architecture (Webster et al., 1995, 1996) and military (Azuma, 1997). In many critical applications such as medical operations and military simulations, it is advantageous to conduct simulations within safe augmented environments that are physically accurate and visually realistic (Gelenbe, Hussain & Kaptan, 2004).

In many AR applications (such as automotive or aircraft heads-up displays) the (virtual) graphics being displayed are not connected to the real objects resulting in a weak link between virtuality and reality. A real sense of the virtual and real worlds meeting is achieved when the graphics are spatially aligned to real world objects which requires accurate real-time tracking of the users position and orientation (Dix et al., 1998).

The diversity of applications to which AR has been applied makes a consensual definition difficult (Renevier & Nigay, 2001). Rather than an explicit definition, Azuma (1997, p.356) defines AR as a computer system which; combines real and virtual objects, is interactive in real-time and registered in three-dimensional (3D) space. While this statement is not perfect – as highlighted by Schmalsteig & Reitmayr (2007) – it is generally inclusive of all augmented reality derivatives.

The specific focus of this research is mobile augmented reality, which has been defined by Renevier & Nigay (2001, p.316) as "...one in which augmentation occurs through available knowledge of where the user is (the users location and therefore the surrounding environment)."

Augmented Reality has been identified as providing an excellent user interface for mobile computing applications as it facilitates location-based information browsing by augmenting the users senses with additional information, however it is difficult to achieve (Reitmayr & Schmalstieg, 2004a; Schmalstieg & Reitmayr, 2007). As with Virtual Environments (VE), detailed digital models representing real world features are required for appropriate graphics (and shadows) to be rendered, determination of visible objects and therefore what interactions are possible and valid (Reitmayr & Schmalstieg, 2004a).

The distinction between the Human-Computer Interface (HCI) and the real world is blurred in augmented reality (Reitmayr, 2004), with the computer playing an unobtrusive yet assistive role (Thomas et al., 2000). Interaction within an AR environment happens in real-time, diminishing the distinction between what is real and what is virtual (Reitmayr & Schmalstieg, 2004a), providing a natural user interface (Reitmayr, 2004) for exploring real world phenomena and improved understanding (Romao et al., 2004).

Mobile AR systems rely on ubiquitous computing infrastructure for connectivity to enable a range of novel applications including navigation, situational awareness and geo-located information retrieval (Azuma et al., 2001). Mobile AR can also be classed as a Location-Based Service (LBS) as the position of the user must be known to provide the appropriate contextual information (Gartner, Cartwright & Peterson, 2007). Such systems can be applied to a broad range of applications including mobile context-sensitive information systems and in-situ visualization of various data (Szalavari et al., 1998; Reitmayr & Schmalstieg, 2003).

Current mobile AR research has focused on the building of prototypes, investigating technical issues and exploring user interfaces (Reitmayr & Schmalstieg, 2004b). However, the development of viable, real-world mobile outdoor AR systems for disseminating complex data is currently limited by inefficient storage of large 3D models, access to and rendering of that stored data, ubiquitous and accurate tracking, availability of high performance computing hardware, hardware costs and bandwidth limitations of current wireless networks (Feiner et al., 1997; Reitmayr & Schmalstieg, 2004b; Renevier & Nigay, 2001; Romao et al., 2004).

MacIntyre et al. (2001) believes that AR will not evolve from specialised, research-based applications until it is seen as a new medium and the systems created provide rich, engaging, dramatic and personal experiences for the users. AR provides a personal interface with capabilities not available in other medium. In personal AR systems, users control their own experience through their movement and interaction with the system. Users of new media lack established expectations about how the media operate, however this can be leveraged to encourage a more emotional and subtle relationship with the environment. The adaption of earlier media conventions can assist in defining new conventions for AR from which meaningful information experiences can be created (MacIntyre et al., 2001).

2.4.3 Collaborative AR

Collaborative AR systems enable many (potentially disparate) users to interact or perform a task (Renevier & Nigay, 2001). Renevier & Nigay (2001, p.317) define a collaborative AR system as "...one in which augmentation of the real environment of one user occurs through the actions of other users and no longer relies on information pre-stored on the computer."

The concept of collaboration can be incorporated into mobile AR systems, resulting in mobile collaborative AR being defined as (Renevier & Nigay, 2001, p. 319) "...one in which augmentation occurs through available knowledge of where the user is and what the other users are doing".

Typical remote collaboration technology adversely affects user communication. Face-to-face virtual collaborative interfaces suffer several shortcomings related to displaying the real world and real objects which play a key role in spatial collaborative tasks. Audio interfaces remove the visual cues of communication while video conferencing removes the spatial cues necessary for efficient communication between participants (Billinghurst & Kato, 2002). Such interfaces create spatial, temporal and functional seams forcing user to shift among various spaces or operations (Ishii, Kobayashi & Arita, 1994). A group of people looking at a desktop monitor or large screen are less able to refer to specific virtual objects nor communicate naturally due to a lack of software support and input devices for such collaborative environments (Billinghurst & Kato, 2002). Interactive touch tables (such as DiamondTouch (Dietz & Leigh, 2001) among others) can allow multiple users to simultaneously interact with the interface in a physically collaborative environment.

As AR is being made increasingly accessible it offers promising collaborative capabilities which exceed the collaborative capabilities of current remote collaboration technologies (Fjeld, 2003). Billinghurst & Kato (2002) suggest that the greatest potential for AR is the enhancement of face-to-face and remote collaboration by providing a suitable interface for remote collaboration by immersing the user in the physical space and blending the remote users into the same space. Collaborative AR interfaces allow remote attendees to become part of the users surroundings, increasing the sense of social presence found in typical desktop audio or video conferencing. The benefits of using AR for collaboration include the ability to control the visual size of the users, the number of users being seen and the position of those users in the viewing space to ultimately improve the perception of non-verbal visual cues (Billinghurst & Kato, 2002).

Renevier & Nigay (2001) have defined three categories of collaborative AR systems:

- Remote collaboration in one augmented reality – includes systems where one user is physically next to an object and the other user(s) are distant. (The physical environment is augmented by the distant user(s) actions (such as Mobile Augmented Group Interaction in Context (MAGIC), section 3.4.4));
- Remote collaboration in augmented realities – includes systems where there are several remotely linked but physically present objects. (The real environment of all users share common attributes and/or objects ie a collaborative augmented whiteboard); and
- Local collaboration in one augmented reality – represents systems where all users are together with their physical space augmented by information and actions of the other users. (The augmented environment of each user is different because it is being viewed from a different perspective (such as Tourist Guide, section 3.4.7)).

Transparency and ubiquity allow computer-based tools to be integrated in to the physical environment, allowing them to be accessed from anywhere, at any time. Both are essential for collaborative AR (Nigay et al., 2002). Transparency provides a seamless interface through which the user can remain focused on the task to be undertaken rather than the interface while ubiquity allows users to access information and collaborate with experts at any time.

Implementing collaboration in mobile AR applications is difficult because, unlike VE's, mobile AR users don't have access to familiar Human Interface Devices (HID) for input. Despite this, collaboration has been explored to varying degrees in several projects including Mobile AR System (MARS), Tinmith, MAGIC and Tourist Guide (refer to 3.4 for further details). These projects implemented a variety of collaborative techniques including mobile to mobile user, mobile to stationary users and between multiple mobile users.

Supporting collaboration requires the user interface state of all users to be shared, with the information displayed being dependent on the parameters of other users and the current interaction. Providing mechanisms to join or leave collaborative sessions ensures individual users have control over their own system (Reitmayr & Schmalstieg, 2004b).

Incorporating collaboration into an AR system should not increase the cognitive load of the user, nor require them to gain more knowledge in order to use it (Reitmayr & Schmalstieg, 2004b). The necessity for mobile AR systems to concentrate on multiple tasks has meant that few AR systems combine mobility and collaboration (Renevier & Nigay, 2001). Collaboration between mobile AR users will become the norm as systems move from research prototypes to production systems (Reitmayr & Schmalstieg, 2004b).

2.5 Comparing AR with VE

This section highlights the advantages and disadvantages of Augmented Reality systems when compared to Virtual Environments. It is an attempt at documenting the comparative strengths and weaknesses of each visualization paradigm.

2.5.1 Advantages

The advantages of AR systems compared to VE systems include (Azuma, 1997; Feiner et al., 1997; Romao et al., 2004):

- The reduced computational resources for generating realistic images. (VR systems require intensive computations to generate a realistic, synthetic image of reality. On the other hand, AR systems only have to generate the augmented graphics (typically vectors));
- The use of reality as the image background provides the most realistic view of the environment;
- The user remains connected with the real world because they are immersed in it; and
- AR provides the ability to utilise a variety of devices including PDA's and mobile phones for delivering the AR in a non-immersive manner.

AR supports efficient information retrieval allowing common tasks and those task being undertaken for the first time, to be done with minimal errors (Haringer & Regenbrecht, 2002). The main advantages of AR over traditional VE's include reduced computational resources for graphics rendering, a fully immersive environment and enhanced spatial perception by users (Azuma, 1997). The benefits of AR are realised when location-based information is available, creating a spatially-aware, information rich environment (Reitmayr & Schmalstieg, 2004a). Although any AR application can be presented in a VE, AR increases the level of realism by immersing the user in an augmented, realistic environment.

2.5.2 Disadvantages

While a substantial amount of research has been done, the inherent difficulties in combining data from a variety of sensors, in real-time, is a continuing problem in modern AR (Schmalstieg & Reitmayr, 2007). Creating high quality renderings that are indistinguishable from reality, in real-time, is not yet possible. (MacIntyre, 2002) outlines a range of common tasks which include highlighting, labelling, adding new objects and providing visual clues when manipulating objects in a physical space that are not easily implemented in AR systems. Augmenting the real world with such virtual information can also result in cluttering the display and making it unreadable (Azuma et al., 2001).

The lack of processing power in small computing devices makes it necessary to distribute complex tasks (such as image recognition and 3D rendering) to remote servers. In a mobile AR system, this requires access to a wireless network for transferring the necessary data between the server(s) and client(s). As computational power in such devices increases the reliance on additional remote resources will reduce (Geiger et al., 2001). Data for AR applications are more difficult to produce and maintain because it is being used in a dynamic environment (Reitmayr & Schmalstieg, 2003).

The accuracy of registration greatly affects the realism of the augmented experience (Schmalstieg & Reitmayr, 2007). In order to view data relating to landscape in an augmented manner it is necessary to align virtual graphics with real features on surfaces (ground, wall, ceiling etc). In terrain with little topographic definition, the impact of AR can be lost given the low viewing perspective which may result in minimal amounts of augmented data being visible. While this can also occur in virtual environments, the user has the capability to alter their perspective by increasing their elevation or easily moving to a different location.

In order to make AR systems common place the systems have to be intuitive to use by untrained people (Ledermann & Schmalstieg, 2005). System therefore need to incorporate appropriate Human Interaction Devices (HID) which are familiar and commonly used. In addition, the current (commercially available) HMD's lack resolution and are not adequate for outdoor use.

2.5.3 Interacting with augmented environments

Interaction, control and the presentation of information in AR applications are continuing research problems (Azuma et al., 2001). Screen size and layout, background colours, lighting conditions and methods of user input need to be considered when designing User Interfaces (UI) for AR applications (Thomas et al., 2000).

Creating 3D Graphical User Interfaces (GUI's) for VE and AR requires a number of computational decisions to be made for each and every frame. These are: the creation/display of objects with appropriate properties; the arrangement of those virtual objects in the scene; determining the visibility of each object; adjustment of the lighting effects and determining the available methods of interaction (Bell, Feiner & Hollerer, 2001). Due to the computational requirement of rendering complex, spatially referenced object geometries, most AR systems display simplified or low complexity objects (Haringer & Regenbrecht, 2002).

2.5.4 Human-Computer Interaction (HCI)

Human-Computer Interaction (HCI) is a study of human interaction with computer systems and is a culmination of many disciplines including computer science, psychology, ergonomics, engineering and graphic design (Stone et al., 2005). An interface serves as the mediator between the wishes of the user and the abilities of the machine (Francis & Williams, 2007).

According to Fjeld (2003), a variety of questions relating to HCI need to be asked when designing AR applications, including: who the users are and their particular needs; how to design an effective and efficient system for the specific users; how this efficiency and effectiveness will be measured; whether users prefer an AR system or an alternative to undertake tasks; and, how the usability of the AR system can be tested.

A recent goal in HCI has been the extension of computer systems to combine reality with virtuality to assist users in interacting with the physical environment (Renevier & Nigay, 2001). The increased power of computing and availability of smaller devices has resulted in the technology being creatively applied to augmenting the power of the user. Development of interaction paradigms has generally occurred to enhance interaction with advancing technological capabilities. More usable systems are the result of creative paradigm development however, these paradigms are not typically well defined and exactly how they support users accomplish a task is not clear. Dix et al. (1998) go on to state that the repeated use of an interaction paradigm will not result in a more usable system.

The design of interactive systems relies on a complementary approach whereby creativity results in new interaction paradigms that are supported by the development of principles for its repeated application (Dix et al., 1998). There have been significant advances in UI research relating to virtual environments, mobile computing and the combination of the two (Feiner et al., 1997). The usability standards that are available must be maintained on mobile ubiquitous devices, however the shear diversity of these devices pose new constraints that are not well handled by the current paradigms. As a result, different approaches to prototyping and evaluation are essential in the design process (de Sa & Carrico, 2006).

Pedersen, Buur & Djajadiningrat (2003) argues that an understanding of the underlying technology is not sufficient to develop professional AR tools but needs to be complemented by design approaches that: provide insight into the users, their work practices and use context; and, support the alignment of viewpoints between designers and the experienced reality of the users. The effective development of an AR User Interface (UI) requires interface (system) designers to have a intimate understanding of the context in which the system will be used, something that is hardly possible given the complexity of some tasks (Pedersen, Buur & Djajadiningrat, 2003).

2.6 Current User Interface (UI) metaphors

A User Interface (UI), is the 'layer' that exists between a user and a computer. In the common computing environment the user interface is comprised of windows, icons and menus which are interacted with using a cursor. The Windows, Icons, Menus and Pointing devices (WIMP) interface was invented over 40 years ago (Baber & Baumann, 2002) and is one of the most successful interface paradigms ever developed (Billinghurst, 2003). This interface metaphor was made popular by the *Macintosh* computer and later imitated by Microsoft© *Windows*® and other operating systems (Taylor, 1997).

Good UI design provides an easy, natural and engaging interaction between a computer and its user (Stone et al., 2005). Interfaces for AR are moving away from traditional desktop metaphor and are beginning to use heterogeneous designs and tangible interfaces (Azuma et al., 2001). With Buckley, Gahegan & Clarke (2001) suggesting that the interface in AR is in fact the visualization as it provides the only method of interacting with the data.

Three-dimensional (3D) interfaces are being explored in the desktop environment. Project Looking Glass (Sun Microsystems, Inc, 2008a) is an attempt to revolutionise Linux and Solaris (Sun Microsystems, Inc, 2008b) desktops by moving them into the third dimension. Aside from incorporating additional functionality within a 3D context, the Looking Glass user interface continues to use the WIMP metaphor.

There is a general consensus that the traditional WIMP interface is not appropriate for future user interfaces (Baber & Baumann, 2002; MacEachren & Kraak, 2001), redundant and clumsy when applied to map-based applications (Francis & Williams, 2007) and are particularly detrimental for wearable and mobile systems (Azuma et al., 2001; Rhodes, 1997) because they require the user to focus on a single task or object at a time (York & Pendharkar, 2004). (Gentner & Nielson, 1999) suggest that the WIMP interfaces were optimised for people to learn personal computers and highlights that current users are willing to do additional work to extract extra functionality. They go on to suggest that todays user interface metaphors be replaced by reality, something that AR is capable of.

Despite the suggestion of adopting alternate interfaces, new interfaces will continue to utilise the core components of WIMP-based interfaces (Broll et al., 2001) and adapt them to support future technologies (Baber & Baumann, 2002), including AR. These new interface paradigms will need to support interaction with advanced data sets, allow multi-modal methods of interaction and support individuals working alone or collaboratively (MacEachren & Kraak, 2001).

WIMP interfaces are considered a form of direct manipulation interface, although they typically allow objects to be manipulated by controls (such as buttons and menus) rather than directly (Azuma et al., 2001; Taylor, 1997). Azuma et al. (2001) believe it is appropriate for AR interfaces to have real components rather than remaining totally virtual. True direct manipulation interfaces or Tangible User Interfaces (TUI's) allow users to manipulate virtual objects by using a representative object (a paddle for moving and manipulating objects or a representative item like a cube for interacting with a box). TUI's are well suited to desktop AR applications (Fjeld et al., 2002), examples include 'Sandscape', 'Sensetable' and 'Audiopad' (Massachusetts Institute of Technology, 2005). Tangible User Interfaces utilise the core features of WIMP interfaces implemented in a different manner.

2.6.1 User interfaces for AR

Natural, intuitive interfaces are vital for disseminating information within AR environments (Broll et al., 2001) however significant challenges exist in creating user interfaces for wearable computing environments that present information clearly and allow interaction with that information. The majority of current wearable applications adopt WIMP interfaces optimized for desktop use however these are less than ideal due to the unique input and output devices (Billinghurst et al., 1998).

Adapted WIMP interfaces utilise the four elements in slightly different contexts. The computer desktop (window) is replaced by the real world, the icons are replaced by objects in the real world and while traditional menus may still be present it is more common for menus to be shown when interacting with specific objects. In mobile augmented reality systems the methods for capturing user input are limited. Mice and keyboards are clumsy and inefficient methods of input in mobile AR systems (Piekarski & Thomas, 2001). Interfaces based on speech, gestures and facial expressions are being perfected (Broll et al., 2001; York & Pendharkar, 2004), but input devices including chording keyboards, touchpads and data gloves are the norm.

Examples of mobile AR systems, relying on these adapted WIMP interfaces, include the 'Touring Machine' and 'ANTS' project (refer to section 3.4). Both systems allow information visualization through Head-Mounted Displays (HMD's) and rely on Personal Digital Assistants (PDA's) for collecting user input. Current interfaces are cumbersome and often based on heavy and obtrusive equipment (Broll et al., 2001). 'SignPost' is a lightweight handheld AR system that utilises a PDA for both user input and visualizing the data resulting in a highly transportable AR systems (Wagner, 2003).

Increasing computing, graphics and network capacities are enabling a range of alternate interface techniques and devices, dominated by interactive interfaces. These innovative interfaces are being influenced by trends in AR, Perceptual User Interfaces (PUI) and Tangible User Interfaces (TUI), resulting in a move towards post-WIMP interfaces (Billinghurst, 2003).

Perceptual User Interfaces (PUI) provide the computer with human perceptual capabilities through the use of sensors and cameras, allowing it to react to the user. Tangible User Interfaces (TUI) allow users to interact with digital information by manipulating physical objects (Billinghurst, 2003). TUI are highly intuitive, however the displaying information is difficult and confined to projection onto the tangible surface or an alternative display space, resulting in the task space and display space being disconnected (Billinghurst & Kato, 2002).

AR allows the physical world to become the UI, allowing users to view, interact and potentially modify electronic information (Hollerer et al., 1999; Schmalstieg & Reitmayr, 2007). Combining AR with tangible interaction techniques provides an intuitive interaction metaphor, allowing interaction with physical objects and the virtual graphics to be treated with equal importance (Billinghurst & Kato, 2002). Tangible Augmented Reality (TAR) allows the user to interact with physical objects to control and manipulate virtual content, resulting in the interface moving from the screen space into real space (Billinghurst, 2003). “View management” decisions for applications with a fixed viewing specification are easily determined however, this is problematic when applied to dynamic scenes rendered through HMD because of continual changes of the viewing angle. These issues are magnified in AR applications with virtual and physical objects being displayed in the same 3D space (Bell, Feiner & Hollerer, 2001). Bell, Feiner & Hollerer (2001) overcome these issues by attributing objects with various constraints based on the visible portion of an objects two-dimensional (2D) Minimum Bounding Rectangle (MBR) determined from the users viewing direction.

2.7 Ubiquitous computing

> *The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it (Weiser, 1991, p. 19).*

The term “ubiquitous computing” was coined by Mark Weiser in the late 1980's to describe an invisible computing infrastructure that would eventually replace the Personal Computer (PC) (Weiser, 1991). Weiser's concept was to augment people and their surrounding environment with computing resources and capabilities through a less obvious, unobtrusive user interface (Abowd & Mynatt, 2000; Dix et al., 1998). Technology has advanced to a point where computer use permeates life, with generally everyone using a computer system directly or interacting with an embedded computer system everyday (Stone et al., 2005).

Ubiquitous (or location-aware) computing provides the infrastructure to allow users to move away from the desktop and still access vast amounts of information from disparate computing resources using various modes of interaction in a totally seamless manner (Dix et al., 1998; Hollerer et al., 1999). Context-aware computing is typically restricted to location-aware computing applications such as in-car Global Positioning System (GPS) and Augmented Reality (AR) however context is broader than location (or position) alone. Context can also include the feelings, intentions and future behaviour of the user (Dix et al., 1998).

The convergence of various technologies including wireless networking, voice recognition, camera and vision systems, hand-held computing devices and positioning systems is bringing ubiquitous computing closer to reality (Dix et al., 1998). The recent proliferation of such technologies enables new interaction paradigms and applications that constantly leverage distributed computational, visualization and information resources (Abowd & Mynatt, 2000; Broll et al., 2001). As a result, the feasibility of mobile, wearable computing applications is becoming increasingly real with increasing computational speed and network bandwidth in combination with the decreasing size of computing devices (Hollereret al., 1999).

A wearable computer is comprised of a portable computing device, a Head Mounted Display (HMD), an input device and wireless connectivity that is controlled by the wearer, always on and always accessible (Billinghurst et al., 1998). Wearable computers are "always on", allowing users to access information and computing resources from anywhere. Wearable computing has three essential criteria (Suomela & Lehikoinen, 2000):

1. Eudaemonic – the system is seamless with respect to the user;
2. Existential – control of the system is within the users domain and is an extension to the user; and
3. Ephemeral – the system is always active and works in real-time.

Ubiquitous computing is revolutionary because of the resulting applications and its ability to support active learning (Dix et al., 1998; Price & Rogers, 2004). It attempts to conceal computing infrastructure within the physical world whereas augmented reality seeks to add to the experience of reality, creating new forms of interaction (Reitmayr, 2004). Augmented reality provides a user interface well suited to disseminating information accessed through ubiquitous networks, by combining it with location and orientation information, enabling information to be viewed and interacted with in a natural way (Hollerer et al., 1999; Reitmayr & Schmalstieg, 2003).

Ubiquitous computing will result in another interaction paradigm shift due to rapid improvements in technology, however truly ubiquitous computing remains experimental with Dix et al. (1998) suggesting that current ubiquitous applications lack an understanding of the technology because they utilise existing interaction paradigms.

2.8 Chapter summary

This chapter provided an overview of scientific visualization and specifically geovisualization. Visualization provides the tools to transform data into information products which can subsequently support users develop knowledge and eventually wisdom. Visualization is the result of many processes accumulating data from a variety of sources to generate a digital, graphic representation of that data, ranging from purely visual through to immersive and interactive. The display of complex information in novel ways provides users with the ability to explore the display to gain a better understanding of the subject matter. While the process of generating the visualization is computational, the interpretation of the visualization is reliant on the cognition of the audience.

Over a decade ago researchers started distinguishing between scientific and information visualization. Information visualization focuses on non-spatial, abstract data while scientific visualization is about the representation and analysis of spatial relationships. While there is conjecture regarding the reason for the separation between the two domains, the distinction is seen as detrimental to the continued progress of visualization as a science. Ultimately, both domains utilise knowledge from external scientific fields and pooling knowledge would result in the strengthening of visualization as a science.

Visualization can be participatory or non-participatory. Participation is essential to underpin learning and the construction of knowledge, whether personal, local (group) or global (general). Visualization promotes active learning by immersing the user in the data providing an environment that is conducive to constructing knowledge. Collaboration between experts and users also underpins the acquisition of knowledge.

The application of visualization to the spatial sciences is referred to as geovisualization. Some authors suggest that geovisualization is the natural evolution of cartography. As with cartography, geovisualization is focused on the representation of spatial relationships in a graphic manner. As a result, visualization techniques can be applied at all phases of a mapping products development.

Virtual Environments (VE) and Augmented Reality (AR) are two paradigms for visualization. VE's represent space in a wholly graphical sense using computer monitors or screens and can be immersive or non-immersive. In contrast, AR supplements real features with computer graphics and can also be immersive or non-immersive. Vision is the most commonly augmented sense however advances in technology will allow other senses to be augmented.

While common computer interaction paradigms can be applied to virtual environments, augmented reality poses unique interaction issues. Interaction and collaboration within augmented environments is constrained by the users ability to interact while situated in a real, physical location. While various devices have been developed to assist users interact in such environments, they require substantial practice to become efficient in their use. Interaction is therefore one of the largest factors limiting the wide-spread adoption of augmented reality. Determination of appropriate interaction metaphors for augmented reality is essential.

The following chapter outlines the components required for a mobile, outdoor AR system. Management of data required to generate augmented graphics is also examined prior to reviewing a variety of existing (primarily research-based) AR systems which have been developed. Some of the available software libraries available for connecting the various components and frameworks for authoring augmented content are also examined.

Chapter 3

Existing Augmented Reality (AR) systems

3.0 Chapter overview

This chapter describes the five necessary components required for mobile outdoor Augmented Reality (AR) applications. The limitations and issues associated with each component are also discussed. The current issues and limitations associated with AR are outlined, with an emphasis on data management which is especially important given the context of this research.

Several mobile outdoor AR systems developed over the last decade and described in the research literature are outlined with regard to the hardware components used, software they are reliant upon and their domain of application. This will provide a foundation for answering several of the research questions posed in the Chapter 1, including "What components would a suitable AR system be comprised of?", "How is data managed within such a system?" and "How do users collaborate?". Finally, the various development frameworks capable of assisting in the development of AR applications are summarised.

3.1 Introduction

All AR systems blend real and virtual objects in a real environment, registered in three dimensions (3D) and support real-time interaction (Azuma et al., 2001). In order to achieve this, AR systems rely on various components including displays, registration and tracking devices, input devices, a wireless network and a computational platform (Azuma et al., 2001; Hollerer & Feiner, 2004).

While AR is typically defined as utilising only Head-Mounted Displays (HMD), AR systems can be defined by their ability to combine real and virtual objects within an interactive 3-D space in real-time (Azuma, 1997). While this broadens the application of AR, the focus of this research is mobile outdoor AR either immersive (HMD) or non-immersive (screen-based).

3.2 Components for mobile outdoor AR systems

Most wearable computer systems are comprised of disparate computing components, cobbled together, resulting in initial negative first impressions by users (Suomela, Lehikoinen & Salminen, 2001). It is relatively easy to connect hardware components together, but substantially more difficult to integrate the multitude of hardware components required for an AR system into a cohesive unit. There are a range of issues associated with current AR applications that limit its application, including image registration, display clutter, latency, depth perception and adaptation (Azuma et al., 2001).

A major issue with mobile AR is that the systems have to be worn by the user (Azuma et al., 2001). The necessary hardware components for mobile augmented reality systems must therefore be considered for a variety of factors including: size and weight – smaller and lighter components allow users increased flexibility when moving around; component robustness – outdoor systems are exposed to the elements (dust, moisture, sunlight) and must sustain continued jolting and movement; and processing capability – the components generating the various inputs (orientation and location) are relatively simple, however the processing required to generate the necessary graphics in real-time are intensive. The availability of suitable hardware components that meet these high performance requirements (processing power, resolution, accuracy) while satisfying size and weight limitations is major constraint for developing mobile AR applications.

Mobile outdoor AR systems require five core elements (Azuma, 1997; Hollerer & Feiner, 2004) (each of which are explained in further detail in the subsequent sections):

1. Display – a head-mounted display (HMD) allows the user to view the generated graphics. (The resolution of such devices can be relatively low due to the relatively simple graphics being generated and the close proximity to the eye);
2. Tracking – tracking devices are required to ensure the rendered graphics are correctly registered with real world objects. (Tracking can be done through the use of markers and/ or a range of sensors to determine the users location and viewing direction/angle);
3. Input devices – these devices allow the user to interact with virtual objects, control what is being displayed and to allow the user to interact with one another;

4. (Wireless) Networking – provides users with access to remote data and information resources and can be utilised for transferring data to remote processing platforms; and
5. Graphics/computational platform – used to generate the appropriate overlays. The complexity of the graphics is minimal as they are only augmenting the reality that already exists. (The computational platform is responsible for receiving and processing input from the tracking devices and generating the necessary graphics).

3.2.1 Displays

Displays are required to superimpose the computer generated graphics onto the real world. Mobile outdoor AR is primarily targeted at augmenting vision using HMD (Hollerer & Feiner, 2004), but can also be achieved using hand-held computers. Although this research is focused on visual augmentation, AR is not confined to the visual sense. Systems have been developed that augment touch (haptic augmentation) and hearing (aural augmentation) (Sundareswaran et al., 2003).

According to a 2001 survey, a variety of attributes can be used to distinguish and compare HMD's including; resolution, weight, field-of-view, stereo capability, colour depth, refresh rate and focus (or collimation) distance (Computer Graphics Systems Development Corporation, 2001). The survey documents 25 commercially available HMD's (circa 2001), but does not pass judgment on which device is most suitable for a given application area.

According to Azuma et al. (2001), the most significant limiting factors in HMD's for mobile AR applications are size, weight and cost. The ability to adjust the brightness and contrast of the device also needs to be considered in outdoor applications where various lighting conditions can be encountered. Since Azuma et al. (2001) published an update to the original Azuma (1997) paper, the diversity and capability of commercially available HMD's has increased dramatically (Bungerts 2006) web site contains a comprehensive list of more than 140 HMD). Top-end devices, targeted at military use, have overcome many limitations, however their size and weight is restrictive and their cost results in their adoption for civilian and research applications being prohibitive.

There are two types of HMD available, optical (Figure 3.1) and video see-through (Figure 3.2), each have advantages and disadvantages. Optical see-through HMD's allow users to see the real world with virtual objects superimposed on top, similar to Heads-Up Displays (HUDs) common in military and automotive applications. The superimposed image is achieved by placing a partially see-through lens in front of the user's eyes onto which virtual objects are projected and reflected into the user's eyes by head-mounted projectors (Azuma, 1997). These devices act like sunglasses, with the lenses allowing a portion (approximately 30%) of the real-world light through.

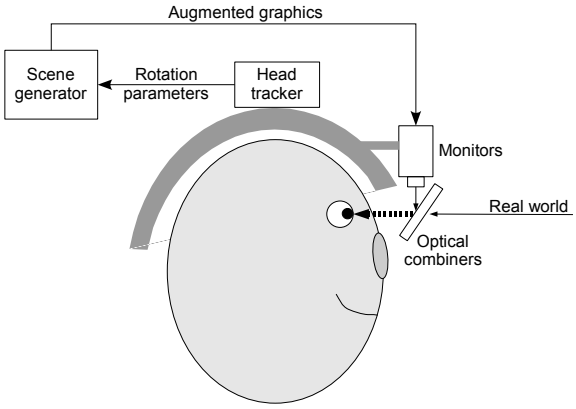

Figure 3.1 - Conceptual diagram of an optical see-through HMD, adapted from Azuma (1997, p 11).

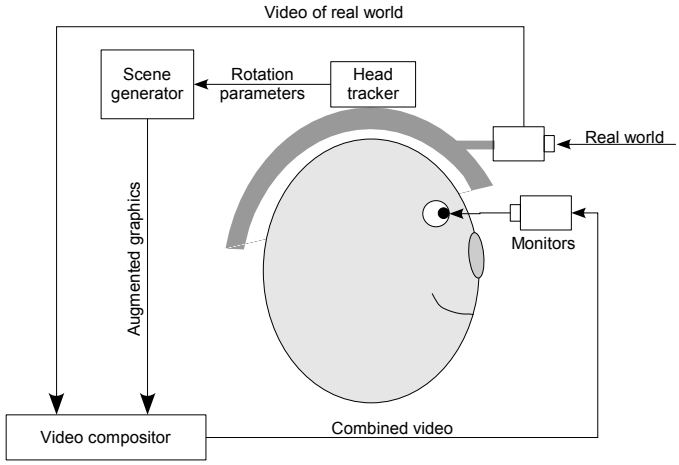

Figure 3.2 - Conceptual diagram of an video see-through HMD, adopted from Azuma (1997, p 11).

In an update to the comprehensive 'Survey of Augmented Reality' (Azuma, 1997), Azuma et al. (2001) concluded that optical see-through displays lacked sufficient brightness, contrast, stereo output, resolution and field-of-view to provide realistic AR experiences. While many of these devices aren't suitable for bright outdoor situations, the lens opacity of some optical see-through HMD's can be adjusted (ie SONY *Glasstron* PLM-S700) (Behringer, 1999). Displays supporting binocular stereo capability (where video is captured by two cameras, one for each eye) are typically expensive, however Behringer (1999) argues this capability is only required when visualizing objects in close proximity. Although recent technological advances have improved many former limitations, the ability to totally occlude (Figure 3.3) real objects behind virtual objects remains a shortcoming (Azuma et al., 2001) and results in real world objects remaining partially visible behind virtual objects, creating a ghosting effect.

Virtual Retinal Displays (VRD) are a variation of optical see-through HMD's and work by drawing an image directly onto the users retina using low-powered lasers (Figure 3.4). Due to the combination of their high brightness and contrast, large depth-of-field and low power consumption, VRD's are a potential solution for creating effective optical see-through outdoor AR applications (Azuma et al., 2001; Behringer, 1999).

Figure 3.3 - Demonstration of occlusion. The brown cow and trees are virtual, the other objects are real, (source: Azuma et al. (2001, p 7)).

Video see-through HMD's are the alternative to optical see-through displays and work by displaying a video of the real world, overlayed with appropriate graphics, on monitors in front of the users eyes (Azuma, 1997) (Figure 3.2). While most commercially available video see-through devices are targeted at video and game playing applications, they are sufficient for research AR systems (Azuma et al., 2001).

Figure 3.4 - An artists impression of a Virtual Retinal Display (VRD) (source: Hughey (1999)).

Shortcomings common to both types of HMD also exist. The majority of AR systems only use a single video camera for capturing the real-world scene, resulting in parallax. These issues can be overcome by using two video cameras (one for each eye) (Figure 3.5) and ensuring they share the same optical path (eye base) as the user's eyes. Depth-of-field (or accommodation) is the ability to focus your eyes on objects at varying distances. In see-through HMD the accommodation distance is fixed (defined by the video camera), resulting in incorrect image alignment and focus, except at the apparent distance of the video camera. Both issues cause eye-strain and visual artifacts (Azuma et al., 2001).

Figure 3.5 - A HMD with multiple cameras for video capture (source: Azuma (1997, p 12)).

3.2.2 Registration and Tracking

Image registration is related to tracking a users position and orientation with accurate tracking and image registration essential for creating a realistic and immersive augmented reality system (Dixet al., 1998; Suomela & Lehikoinen, 2000; You, Neumann & Azuma, 1999) by ensuring correct alignment of real and virtual objects (Rolland, Davis & Baillot, 2001) in Six Degrees of Freedom (6DOF) (Figure 3.6) (Jiang, You & Neumann, 2004). Both location and head orientation (of one or more users) needs to be accurately tracked, at interactive speed (Rolland et al., 2001) for appropriate images (and potentially feeling or sound) to be generated, registered and displayed (Hollerer & Feiner, 2004; Rolland, Davis & Baillot, 2001; You, Neumann & Azuma, 1999). While this has been done successfully in indoor environments prepared with markers or sensors, tracking users in unprepared outdoor environments remains a challenge (Dix et al., 1998; MacIntyre, 2002).

Rolland et al. (2001) outlines six types of tracking – time of flight (GPS), spatial scan (image recognition), inertial sensing (gyroscopes and accelerometers), mechanical linkages (eg Sketchpad (Sutherland, 1968)), phase-difference sensing and direct-field sensing. The real-time nature of AR requires fast and efficient algorithms to interpret and process incoming signals (Rolland et al., 2001).

The robustness of any one tracking device or methodology is inversely proportional to its accuracy (M. Jiang et al., 2004). Most orientation devices require constant calibration to compensate for errors (or drift), this is normally accomplished by using various devices in a hybrid configuration reducing error propagation and improving registration accuracy (Azuma et al., 2001; Behringer, 1999; Rolland, Davis & Baillot, 2001). Hybrid tracking techniques are employed to compensate for errors with various device combinations used with varying degrees of success (Azuma et al., 2001; Behringer, 1999; Jiang, You & Neumann, 2004). To increase the accuracy of positioning using hybrid tracking systems, the devices need be synchronised, something not easily achieved (M. Jiang et al., 2004).

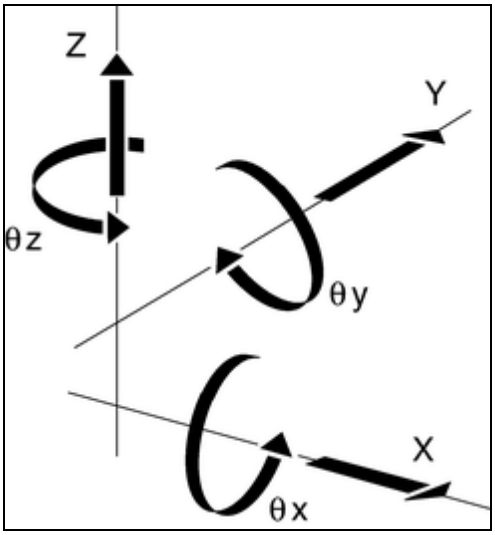

Figure 3.6 - Illustration of the six degrees of freedom, 3 translational (X, Y, Z) and 3 rotational (θx, θy, θz) (source: Newport Corporation (2008)).

The most common orientation devices used for AR are gyroscopes, magnetometers and inclinometers (Azuma, 2004). In order to determine the yaw, pitch and roll of the users head three devices are required (one for each rotation). The rotational accuracy of the devices varies from 1-3 degrees for magnetometers, 0.5 degrees for inclinometers and 0.2 degrees for mechanical gyroscopes (Rolland, Davis & Baillot, 2001).

Robust tracking and registration techniques have been accomplished in indoor environments (Azuma et al., 2001) as they are easily calibrated with the addition of landmarks (fiducial markers) and have better lighting control which ensures accurate user tracking and image registration (You, Neumann & Azuma, 1999). This level of calibration is currently unrealistic for 'unprepared' environments (for example outdoor) (Behringer, 1999; You, Neumann & Azuma, 1999) and further work is required to improve the accuracy and robustness of such tracking and registration methods in natural environments (Azuma et al., 2001).

While GPS is suitable for outdoor AR applications, registration errors between graphics and reality become more perceivable when visualizing graphics in close proximity of real features (less than 50 metres) (Azuma et al., 1999; Thomas et al., 2000). This is due to insufficient accuracy (5-10 metres) and resolution, especially in urban and covered areas, making GPS a less than perfect ubiquitous tracking device (Rolland et al., 2001). Differential GPS can be utilised (providing a base station can provide real-time corrections to the AR system) improving the locational accuracy to less than 50cm (Gleue & Dahne, 2001). Scott-Young (2004) applied new generation GPS constellations to increase positioning accuracy in outdoor environments and combined it with dead-reckoning (estimating the current position by advancing the previously known position, speed and direction) techniques to provide accurate tracking when insufficient signals are available. Current wireless networking technology could be used for determining location, removing the need for a GPS and therefore reducing the weight and bulk of mobile systems (Azuma et al., 2001).

Natural feature (or vision-based) recognition can provide an alternative, precise and cost-effective method of tracking in outdoor environments (Azuma et al., 2001; Behringer, 1999). Model-based vision tracking techniques are accurate for indoor applications (using artificial markers), but are typically unsuitable for mobile outdoor applications due to their computational requirements, algorithm instability (M. Jiang et al., 2004) and lack of unique recognisable features (Behringer, 1999). Research systems have been developed that recognise natural (horizon silhouettes) (Behringer, 1999) and man-made objects (building recognition) (M. Jiang et al., 2004). Combining this method with other devices ensures more accurate tracking when suitable, recognisable features are not available (Behringer, 1999; Jiang, You & Neumann, 2004). Handheld devices do not have the functionality to support multiple tracking devices and must therefore rely on marker-less tracking techniques (Beier et al., 2003).

A major limitation of current registration and tracking methodologies is the acquisition and transfer of data from the devices (latency), which affects the ability to render the appropriate graphics at “interactive-speed” (Azuma et al., 2001; Rolland, Davis & Baillot, 2001). Sufficient computational resources and network bandwidth are required to minimise lag and improve refresh rates to reduce the possibility of motion sickness (Rolland et al., 2001).

Hybrid tracking systems will overcome the current limitations of single device systems by improving the accuracy and speed, resulting in more robust AR systems (Azuma, 1997; Broll et al., 2001). Obviously this is reliant on the devices being integrated into an appropriate form and size that is suitable for mobile AR applications.

3.2.3 Input devices

Input and interaction devices enable a user to interact with virtual objects in the augmented space. A multitude of devices have been tested and adopted within AR applications. Such devices include:

- Chording keyboards – small format keyboards with a minimal number of keys. (Users input text by using certain key combinations.);
- Data gloves – special gloves fitted with various sensors allowing a user to interact with the system through various finger and hand gestures;
- Physical objects – these objects have unique patterns attached allowing it to be recognised by the AR application. (Examples include virtual pointers, human digits and small palates used to move objects within an augmented space.); and
- Small format computers – depending on the application these can range from PDA's through to tablet or laptop computers. (These devices are familiar to users and provide greater input options ie on-screen or physical keyboards.)

The application of one or more of these devices is dictated by the purpose of the AR application, its context of use and user ability.

3.2.4 (Wireless) Networking

Access to a network increases the volume of data and information that can be accessed by any application and user. Rapid development of wireless protocols including IBM's *Bluetooth*® and Wi-Fi (801.11a/b/g) is providing the necessary networking infrastructure for mobile AR through increased bandwidth and ease of access (Behringer et al., 2000; Renevier & Nigay, 2001).

Utilising such resources can reduce the requirement for carrying large and bulky storage devices and potentially remove the need for a high performance computational device to be transported. Wireless networking also allows AR systems to communicate and retrieve additional or updated data from remote repositories without being physically connected.

3.2.5 Computational Platform

Ultimately a robust computational platform capable of processing data from the tracking, registration, video and input devices is required to generate the relevant graphics for display. The continuing miniaturisation of computing hardware is enabling AR systems to migrate from large backpacks to being worn on a belt (Behringer et al., 2000). Future systems may have the necessary hardware components embedded in clothing, vehicles or even our bodies (van Dam, Laidlaw & Simpson, 2002; Lehikoinen & Suomela, 2002) making them truly ubiquitous (Baber & Baumann, 2002).

The computational platform also requires sufficient disk space for storing the various configuration files, input data and data calculated by the system. In addition, space is also required for storing device and system configurations, application state for restoration and/or collaboration and user preferences.

Availability and longevity of batteries are necessary for real-life applications (Behringer et al., 2000). Not only are batteries required for running the computer but additional batteries may be required for powering the display(s) and tracking device(s). Batteries contribute significantly to the weight of any mobile AR system.

3.3 Data management in AR

The majority of research AR applications work with small data sets that have been specifically collected and manually collated (Reitmayr & Schmalstieg, 2004a), however any real-world application of mobile AR requires a substantial amount of spatially referenced data, including detailed models of semantic and contextual data relating to the physical space in which it is applied (Reitmayr & Schmalstieg, 2003). As the area of interest increases, the data required to augment the space increases, thereby increasing the resources to create, update and maintain the data sets (Reitmayr & Schmalstieg, 2004b).

Detailed data, existing in various systems and formats need to be extracted and transformed to be useful in AR applications. Such data is also used for other purposes including occlusions, shadows, possible user interaction and vision-based tracking of objects. The data used in augmented reality applications is therefore difficult to compile, create and maintain because of the need to maintain currency and accuracy to match the environment in which the system is being used (Reitmayr & Schmalstieg, 2003).

While application specific data formats and management strategies are typically adopted in research AR systems, Reitmayr & Schmalstieg (2004a) believe this inhibits the reuse of data and increases the complexity of application development and maintenance. The most common technology for storing data are Relational DataBase Management Systems (RDBMS) however,Reitmayr & Schmalstieg (2004b) believe the hierarchical data structures used by XML are better suited to the 3D requirements of AR applications.

Various functions within an AR system may require the same data in different forms (Reitmayr & Schmalstieg, 2004b). Such issues are typically overcome in computer-based systems through the use of multi-tier architectures. Such architectures are typically comprised of three tiers; presentation, logic and data. Each tier is developed and maintained separately, allowing computing resources to be shared appropriately and individual tiers to be upgraded independently of the others (Carnegie Mellon Software Engineering Institute, 2007).

The data model described by Reitmayr et al. (2004) uses an object-oriented approach, implemented using a commercial XML database. XML is self-descriptive and self-organising through schemas and namespaces and is therefore not bound to any particular visualization tool or technique. Utilising a common data model (data tier) reduces redundancy and provides a single, centralised data repository (Reitmayr & Schmalstieg, 2004b) facilitating the management and visualization of data.

The second (logic) tier is capable of transforming data into the various formats required. Populating the data model and utilising data within the database requires three tasks to be performed: importing data into the database using existing parsers; maintaining or editing the data using filters; and transformation of existing data into appropriate structures for the various applications (Reitmayr & Schmalstieg, 2004b). The presentation tier is responsible for displaying the data to the user.

The multi-tiered approach to application development appears to be well suited to AR applications. Parts of this approach will be adopted in the following chapter when a hypothetical AR system is designed.

3.4 Reviewed mobile Augmented Reality systems

The majority of AR systems have been created for research purposes and have generally been assembled to demonstrate and test the application of AR for a particular purpose. Mobile AR systems are typically demonstrated using navigation or information browsing applications (Reitmayr & Schmalstieg, 2004a). While many commercial AR systems (manufacturing, medical and military) utilise specialised hardware (ie miniature wearable computers, specialised HMD's) (Geigeret al., 2001). Research systems are generally assembled using inexpensive, Common Off-The-Shelf (COTS) hardware and software (Behringer, 1999; Behringer et al., 2000; Thomas et al., 2000). This reduces the overall cost of the hardware and provides sufficient capabilities to demonstrate their applicability while allowing system components to be easily replaced or upgraded as required (Behringer et al., 2000).

To provide context and background to this research, a variety of AR systems are outlined in the following sections. The systems have been chosen because they have features and functionality relevant to this research or have been applied in similar environments. While each system has functionality relevant to this research, several systems comprise individual elements that, when brought together, would be beneficial to users. A table summarising the hardware and software configuration of each system is provided in section 3.4.10. A matrix highlighting the functionality provided by each system is located in section 3.4.11, with section 3.4.12 providing an overall summary of the reviewed systems.

3.4.1 Augmented Environments (ANTS)

ANTS (Augmented Environments) is an environmental application of AR for exploring and studying physical and natural structures (Romao et al., 2004). The project was developed by the University of Evora, Portugal and the New University of Lisbon, Portugal. The system is based on a client-server model and provides the flexibility of migrating various modules between the client and server depending on the computational capacity of the client (Danado et al., 2003).

The ANTS architecture also considers the use of PDAs and mobile phones (Figure 3.7) for delivering non-immersive AR applications (Romao et al., 2004). These devices free the user from the traditional large, cumbersome devices that typically restrict movement and time consuming setup. The ANTS project is researching the technological limitations imposed by these small devices including screen resolutions, limited computational power, wireless network capability, network latency and minimal data transfer rates.

Figure 3.7 - PDA interface (source: Danado et al. (2003, p 6)).

ANTS has been evaluated using several environmental management applications, validating the original research objectives of defining an overall AR architecture, developing new methods for image registration, exploring various navigation paradigms and testing the infrastructure (Romao et al., 2004). ANTS has been applied to various domains including:

- Monitoring water quality using pollutant transport models. The application is implemented on a PDA and allows users to view real-time water quality data from a pollutant transport model. Implemented on a Compaq (HP) *iPAQ* with a GPS, video camera, orientation tracker and wireless networking capabilities. The users are tracked in real-time allowing the system to download and display the water quality in the vicinity. The user is provided with two interfaces. The first being a map of the users location allowing the user to alter the model parameters by selecting from pre-defined lists. This interface also allows the user to input pollutant source. The second interface allows the user to visualize the pollutant dispersion on the PDA through non-immersive AR.
- Visualizing the temporal evolution of physical structures and natural elements. This application allows users to roam through an environment and have contextual information about particular features and structures displayed on the screen. It was designed for use on both a laptop computer and a PDA.
- Visualizing sub-surface features. This application is targeted at finding sub-surface features such as pipelines and telephone cables at the users current location. These features are visualized through a PDA or laptop.

3.4.2 AR-PDA

The AR-PDA project provides a framework for delivering non-immersive mobile AR applications using Personal Digital Assistants (PDAs) or mobile phones with video capture capabilities. The framework is targeted at general consumers to assist them with tasks such as shopping, sightseeing and understanding technical devices. The application was implemented by porting portions of the ARToolKit software (3.5.2) to the Pocket PC (Geiger et al., 2001).

The majority of existing PDA's (with the capability of adding a video camera into the expansion slot) and video mobile phones have the capability of delivering non-immersive AR applications, based on a 'magic lens' metaphor (Figure 3.8) (Geiger et al., 2001). Augmentation of an object is achieved by pointing the devices camera at a specific object. The aligned augmentations (annotations, avatars etc) are then displayed on the screen of the mobile device.

Figure 3.8 - AR-PDA being used to augment a digital camera (source: Geiger et al. (2001, p 182)).

In this application, object recognition is achieved by analysing the image collected by the devices camera. Straight edges are extracted from the image and compared to 2-D views of 3-D objects stored in the database. This process is supplemented by texture mapping techniques allowing the application to distinguish between objects with similar geometries (Beier et al., 2003).

The system is reliant on a wireless network to send the images to a remote server for processing. The complete time to capture, transmit, process and return the augmented image for a standard PDA resolution (320x240 pixels) is approximately 300 milliseconds, however this has been improved through parallel processing techniques, resulting in a frame rate of 10-12 frames per second – sufficient for the application domain (Geiger et al., 2001).

3.4.3 ARCHEOGUIDE

The ARCHEOGUIDE (Augmented Reality-based Cultural HEritage On-site GUIDE), an archaeological AR application, bridges the gap between recreation, education and scientific research (Vlahakis et al., 2002). ARCHEOGUIDE is a custom, mobile outdoor AR system implemented at Olympia, an archaeological site in Greece, across an area of approximately 300m by 500m.

The system is comprised of four components (Vlahakis et al., 2002):

1. Server – The Site Information Server (SIS) administers a range of multimedia that can be accessed by the mobile units. The SIS also allows virtual and augmented tours to be created.

2. Mobile clients – Three types of mobile clients are supported, including a laptop (supports immersive AR through a HMD), pen-tablet and PDA. Each mobile unit requests multimedia from the server based on their location. Each client handles tracking and rendering and provides users with a controller and data manager through various user interfaces. This results in a thick client architecture but minimises network traffic and server load when there are many concurrent users.

3. Tracking – Determining the users location is achieved using a hybrid tracking system. A Differential GPS (DGPS) base station is used to calculate GPS signal corrections which are transmitted to each client allowing them to be located within <1 metre accuracy. A digital compass (30' accuracy) provides an initial viewing angle which is further refined by image tracking (when the laptop is used) to determine the users exact viewing orientation. At each point of interest, the users field-of-vision (captured by video) is compared with still images stored in the database to determine their viewing angle. Transformation parameters are calculated from the comparison of the images and applied to the virtual 3D models to correctly render them on the chosen device. Information corresponding to each point of interest is downloaded as the user approaches the point of interest.

4. Network – A Wireless Local Area Network (WLAN) (802.11b @ 11 Mbits/sec) is used for transmitting data to the mobile clients and is capable of supporting up to 50 simultaneous users. Data is transmitted to each client (if the data is not already present on the device) as it approaches a point of interest. The majority of information is uploaded to each device at the beginning of the tour with only updates being transmitted across the network, minimising network traffic. Three permanent wireless Access Points (AP) with directional antennas provide complete coverage of the site. Additional point-to-point antennas are used for communication between AP's. Each AP is fitted with solar panels and batteries for power supply.

The ARCHEOGUIDE system can be personalised at the beginning of the tour, ensuring the content being viewed is relevant to the users knowledge and interests. Each mobile client also delivers audio narration syncrohnised to the video stream (Vlahakis et al., 2002).

Each of the mobile clients provide various methods of interaction. The laptop is combined with a HMD and supplemented with a game-pad that allows the user to interact with the various interface shown in the HMD, including a map, detailed object descriptions and related topics. The pen-tablet computer is predominately used to display multimedia specific to the feature and can also be used to display a non-immersive AR presentation by holding the tablet computer vertically and changing its direction (Vlahakis et al., 2002).

The PDA only allows for position tracking and displays information similar to a paper map guide. In addition, a variety of multimedia including panoramic views, video, audio narration and augmented images are automatically presented to the user when approaching each point of interest. The interface is deployed using the device's Internet browser (Vlahakis et al., 2002).

3.4.4 Mobile Augmented Group Interaction in Context (MAGIC)

The MAGIC (Mobile Augmented Group Interaction in Context) system (Renevier & Nigay, 2001) is a mobile collaborative AR system that supports archaeologists to take notes, sketch objects, record photographs and communicate in an augmented environment (Figure 3.9). The objective of the MAGIC project is the creation of tools to make archaeological field work more efficient by allowing analysis of data in-situ, reducing the time taken to understand and document the artifacts (Renevier & Nigay, 2001).

The system makes use of a pen (tablet) computer with the interface based on a paper-based metaphor. The application was developed using the Presentation-Abstraction-Control (PAC) Amodeus software structure organisation with the user interface organised around the Clover Model, offering components for coordination, communication and production (Renevier & Nigay, 2001).

Figure 3.9 - The MAGIC system (source: Renevier & Nigay (2001, p 320)).

As per the Clover Model, the coordination aspect of the interface is provided by a base map of the archaeological site. This map provides a common point for interacting with the system and other users. The location of other users are shown on the map with the colour of the symbol corresponding to the availability of the user for interaction/collaboration. Aside from the detailed site map, a simplified 'radar' map provides an overview, highlighting the current area of interest. The maps are also used to show who is connected to the system; users who have lost connection with the network are displayed as gray circles that progressively blur depending on the time they have been disconnected. On the screen of the user who has lost connection all other users are shown as gray stationary circles (Renevier & Nigay, 2001).

Multiple communication techniques are provided including virtual post-it notes (posted on the screen from another users) which can contain voice recordings and a chat room enabling users to interact by sharing images and discussions. Text is entered through a virtual (on screen) keyboard available on the tablet computer. Users are informed of arriving communications by sound and visual queues displayed in the HMD (Renevier & Nigay, 2001).

The production components provide the core functionality, allowing users to describe and analyse archaeological objects. Archaeologists enter details about each object using standard forms, and can include sketches and photographs where necessary. The GPS (5 centimetre accuracy) used for locating the user can also be used to record the position of newly-found objects. The details of the new object remain on the local tablet computer until validated. Once validated, the data is replicated into the shared database to be shown on the map and made accessible for other users (Renevier & Nigay, 2001).

The system allows users to capture photographs of reality and store them in the system with a user entered description (referred to as 'clickable reality') and photograph direction collected using a digital compass (accuracy of 30'). This allows a north arrow to be placed on the photograph for future contextual reference. Users can access these stored images based on their location and orientation, providing the functionality for an 'augmented stroll' (Renevier & Nigay, 2001) where images in the database can be superimposed on reality for comparison.

3.4.5 Mobile AR System (MARS) / Battlefield AR System (BARS)

The Mobile Augmented Reality System (MARS) (Figure 3.10) (Hollerer et al., 1999) has been developed by the Department of Computer Science at Columbia University to test the applicability of augmented realities as an interface for interacting with spatialized hypertext attached to physical objects using ubiquitous computing infrastructure. The system began life as the Touring Machine (Feiner et al., 1997) regarded as the first complete, self-contained outdoor AR system (Julier et al., 2000).

Figure 3.10 - The MARS hardware (source: Hollerer et al. (1999, p 780)).

The Touring Machine annotated real world buildings with the names of the resident academic departments. Access to additional multimedia information was available through a handheld display (tablet computer or PDA). Over time, the Touring Machine evolved into a system that rendered models of historical buildings that no longer existed on the university campus, displayed routes for users to reach designated locations and played historical documentaries (Feiner et al., 1997).

User interfaces for different display types (HMD and tablet computer) were the core focus of this continuing research. Utilising various interfaces, two prototype applications were developed, a campus tour and a storytelling (narrative) application. MARS, the successor of the Touring Machine, has subsequently implemented four user interfaces (Hollerer et al., 1999).

- Immersive outdoor AR - a wearable backpack that allows a mobile outdoor user to be tracked by real-time kinematic GPS in combination with inertial and magnetometer orientation sensors. (The user has access to additional information that can be viewed (and listened to) through the see-through HMD. Users can also highlight features for indoor users to view);

- Non-immersive outdoor – a hand-held (tablet) computer that provides a map-based UI enabling the user to interact with and view information. (This can be used stand-alone or in conjunction with the wearable backpack);
- Non-immersive desktop – this is predominately an administrative UI allowing users to create virtual objects, highlight and annotate virtual objects for mobile outdoors users to see using a 3D model of the environment. (This UI can also be used to record and replay the activities of outdoor users); and
- Immersive indoor AR – an extension of the desktop UI allowing users to see and manually interact with objects in the 3D model. (This utilises see-through HMD, hand and object trackers to manipulate the model over a physical desk).

The outdoor user interfaces were implemented on an area of the Columbia University campus that was: within range of the GPS base station (providing real-time error correction parameters); within range of the wireless network; and within the area for which the 3D model existed. The indoor interfaces were only constrained by the extent of the 3D model (Hollerer et al., 1999).

The interfaces were developed using a combination of the University's Coterie platform (based on Modula-3, a now redundant programming language) (Feiner et al., 1997; Hollerer et al., 1999) and Java/Java 3D for the immersive indoor application and interfacing with the database. The interfaces displayed on the hand-held computer were coded using Coterie, however they could have been delivered through a generic Web browser (Hollerer et al., 1999).

Subsequent research and development of MARS resulted in the development of the Battlefield Augmented Reality System (BARS) (Julier et al., 2000). BARS extended the basic functionality of MARS to provide relevant and critical information for the users context within a battlefield situation.

3.4.6 Tinmith

The Tinmith (Piekarski, 2007) wearable computer has been under constant evolution, with the current version comprised of a small belt-worn computer (based on hardware extracted from a Toshiba TECRA laptop), wireless data gloves for user input and a customised helmet incorporating a HMD (*i-Glasses*), GPS antenna, video camera, headphones and an orientation sensor (Piekarski, 2007) as depicted in Figure 3.11. The system provides accurate tracking using vision-based optical tracking of fiducial markers (using the ARToolkit software (see section 3.5.2)) when used indoors and a sub 50 centimetre GPS and a magnetic compass when used outdoors.

Figure 3.11 - Tinmith 2006 hardware (source: Piekarski & Thomas (2003b, p 3)).

One of the initial applications was the adaptation of a first-person shooting game, *Quake* from Id Software, into a mobile AR application that was operational both indoor and outdoors, known as ARQuake (Thomas et al., 2000). ARQuake was implemented across a 100x150 metres section of the Mawson Lakes campus of the University of South Australia, encompassing buildings and large, open outdoor areas. Users of the system wandered the area collecting virtual items while defending themselves from virtual monsters. The monsters were attacked by looking at them and shooting them using an plastic toy gun.

The ARQuake application was developed using custom software developed at the Universtiy of South Australia, Tinmith-evo5 (see section 3.5.5). The whole system was implemented on the Tinmith-Endeavour hardware (circa 2002) (Piekarski, 2007). The Tinmith system has subsequently been commercialised by the University (Piekarski & Thomas, 2003b) and is available for purchase for approximately $100 000 (Piekarski, 2007, pers. comm., 5 February 2007).

Additional AR applications have been developed using the Tinmith system, including Tinmith-Metro an application that supports architectural design (Piekarski & Thomas, 2003a).

3.4.7 Tourist Guide

The Tourist Guide (Reitmayr & Schmalstieg, 2004a) is a collaborative, mobile Augmented Reality system developed by the Interactive Media Systems group at the Vienna University of Technology and implemented in the City of Vienna. The system is targeted at tourists who typically have a limited knowledge of the area they are visiting yet have a strong interest in the location, both in regards to navigating the area and finding out information about the surroundings. The Tourist Guide is a navigation aid that can direct the user(s) to various locations within the historic City of Vienna and deliver contextual information, collated from a wide variety of sources. The system supports collaboration between multiple mobile users by allowing users to highlight points of interest for others to view and providing a method for locating and meeting one another (Reitmayr & Schmalstieg, 2004a).

The system was created using Studierstube (Szalavari et al., 1998) (see section 3.5.4) and implemented as a three-tier architecture: a central database (that stores the data); a transformation tier that converts the data into application specific structures; and the application (interface) tier. This implementation leverages eXtensible Markup Language (XML) and its associated standards for data storage, transformation and display (section 3.3) (Reitmayr & Schmalstieg, 2003).

Each user interacts with the system using a touch pad to control menus displayed in the HMD (Figure 3.12). Generic information including current location, target location, distance to specified target and a compass are displayed in a panel along the bottom of the HMD (Reitmayr & Schmalstieg, 2004a).

Figure 3.12 - Tourist Guide hardware (source: Reitmayr & Schmalstieg 2003, p 47)).

The system implements three distinct user interfaces (Reitmayr & Schmalstieg, 2004a):

- Navigation mode – allows the user to select a point of interest using a specific address or type (ie pharmacy) and be navigated to it along the shortest path using virtual markers and connecting lines displayed in the HMD. (The system is responsive to deviations from the path and recalculates the shortest distance to the point of interest on-the-fly. This mode also allows users to guide, follow or meet other system users.);

- Information mode – shows virtual icons at specified locations representing the availability of additional information. (The virtual icons are selected using "ray intersection" where the user looks directly at an object through the HMD to select it. This results in contextual information including text, images, video and other multimedia being displayed in the HMD). The user can restrict which icons are visible by specifying a keyword thus reducing clutter in the display. This mode can support multiple users allowing the sharing of selected topics between users or a tour guide to control what is selectable.); and
- Annotation mode – allows users to associate virtual icons with physical features for sharing among other system users. (Users visually specify (using ray intersection) the object to be annotated and can control the colour and shape of the icon, but they are unable to associate multimedia elements with features).

3.4.8 WalkMap

WalkMap is the main application developed as part of the NetWalk wearable computing research project undertaken at the Nokia Research Centre in Finland (Suomela & Lehikoinen, 2000). WalkMap is an AR application designed for navigating a walking user through a physical environment while providing context sensitive information. The WalkMap system was assembled using Common Off-the-Shelf (COTS) hardware (Figure 3.13) with the interfaces built using Message Exchanger (MEX) (Lehikoinen & Suomela, 2002).

Figure 3.13 - WalkMap hardware (source: Lehikoinen & Suomela, (2002, p 36)).

Several interface components were developed for the WalkMap system, including: a compass representation along the top of the screen (ContextCompass (Suomela & Lehikoinen, 2000)); an opaque, full screen map; and a semi-transparent vector map. The various interface components provide users with a choice of locating information that suits their particular context (Lehikoinen & Suomela, 2002).

ContextCompass is a simple linear compass interface extension to WalkMap which provides easy access to contextual data (Figure 3.14) (Suomela & Lehikoinen, 2000). Rather than render spatially aligned augmented graphics, the interface displays the location of virtual objects on the compass – objects directly in front of the user are in the centre of the compass. The centered object can be selected and additional information will be displayed. Upon making a selection, the distance to the object and its name is displayed. This approach overcomes the lack of accuracy inherent in tracking technology and the resultant inaccuracies of aligning virtual graphics with physical objects.

Figure 3.14 - WalkMap interface showing ContextCompass and potential interactions with the N-Fingers device (source: Lehikoinen & Suomela (2002, p 40)).

All interaction with the WalkMap system is done using the N-Fingers haptic device, developed at the Nokia Research Centre (Figure 3.15) (Lehikoinen & Suomela, 2002). This device provides four discrete 'buttons' per hand that can be used in various combinations to control the system.

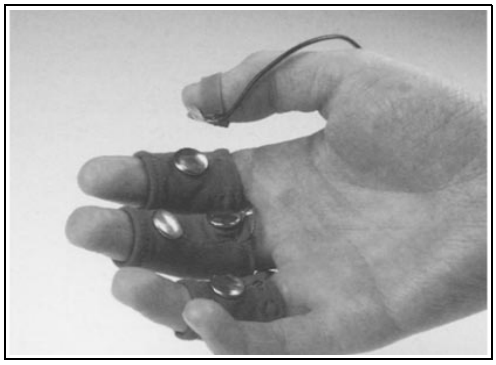

Figure 3.15 - The N-Fingers interaction device (source: Lehikoinen & Suomela (2002, p 41)).

All objects (points of interest) are stored in a database. The user retrieves the contextual information by defining a context. The context is a combination of the users position and a user defined filter (ie all historic buildings), reducing the amount of data retrieved and displayed.

3.4.9 Wearable AR Testbed

This AR system was created using Common Off-The-Shelf (COTS) hardware and designed to provide the necessary computational resources necessary for AR whilst remaining lightweight. The primary goal of the research was to test mobile AR applications (Behringer et al., 2000).

The system is deployed on a wearable computer, with hardware and batteries carried in a vest. In addition, a HMD and tracking device are located on the users head. The system uses *Windows 98*® as the operating system (due to the large number of hardware drivers available at the time of development). The system supports two HMD's, a monocular device which provides a colour display at a resolution of 640x480 pixels and the Sony *Glasstron* PLM-S700 with a resolution of 800x600 pixels. While neither are particularly suited for outdoor use, Sony's device allows the user to alter the opacity of the lenses, improving its usability in bright, outdoor environments.

Two applications have been implemented on the system (Behringer et al., 2000). The first is a military application, known as the Intelligent Tetherless Wearable Augmented Reality Navigation System (itWARNS) (Behringer et al., 2000) that provides context and location-sensitive navigation information to provide warnings of possible hazards to the user. The system displays graphics found in typical Heads-Up Display (HUD), including pitch and roll, artificial horizon, cardinal directions and topographic feature labels. The horizon silhouette is generated on a remote computer using the GPS coordinate and a Digital Elevation Model (DEM).

The second application, Wearable Immersive Multi-Media Information System (WIMMIS) (Behringer et al., 2000), was developed to demonstrate and experiment with various Human-Computer Interation (HCI) modalities. The system allows various sensor data to be visualized and auralised, while speech recognition allows users to interact with the system. This application can output to a variety of displays including PDAs, desktop and large-screen projections. The WIMMIS acts as a server, updating the various displays based on the location and orientation of the user wearing the AR unit.

3.4.10 Main component summary

The previous sections outline the diversity of applications to which Augmented Reality (AR) has been applied. Table 3.1 summarises the hardware used by each AR system, specifically the computing device, Head-Mounted Display, orientation and location devices. In addition, the operating system(s) used by each AR system is shown.

The processor speed of each system varies greatly (ignoring the PDA's and heldheld computers). These variations can be attributed to the age of the AR system, with the more current systems utilising 2GHz machines.

Various HMDs have been utilised in the reviewed systems however the most popular is the Sony *Glasstron*. This device projects the augmented graphics onto a semi-transparent screen allowing reality to be seen through the augmented graphics. Unfortunately Sony no longer produce this optical see-through HMD (refer to Figure 3.1) meaning that such systems will have to find alternative HMDs into the future. The remaining systems utilise video see-through HMDs (refer to Figure 3.2) which require a video capture device (camera) and sufficient computational capabilities to incorporate the augmented graphics onto the video prior to being displayed.

The vast majority of systems have been implemented on the *Windows®* platform. This could be attributed to several factors, including: the popularity and availability of the operating systems; and the availability of proven Integrated Development Environments (IDE) which aid application development. The continued maturation of the Linux operating system should see it become more widely used in a variety of computing applications, including AR.

There is no real standout device when it comes to determining orientation. Those applications that rely solely on portable devices typically use image recognition (either of the real world and/or fiducial markers) to determine the camera orientation. The other systems rely on a variety of digital compasses, magnetometers and orientation sensors, sometimes used in combination to minimise error propagation.

The Global Positioning System (GPS) is the common method of determining the users position (except in the case of AR-PDA which does not require the users explicit location). With worldwide (outdoor) coverage and no service costs it is the ubiquitous positioning system. The accuracy of the GPS receivers used varies from several to tens of centimetres depending on the application. Other positioning systems (typically used for Location Based Services) do not provide the accuracy necessary for positioning users and accurately aligning the augmented graphics, however they do provide ubiquity when roaming inside and outside.

System name	***Computing device***	***Head-Mounted Display***	***Operating System***	***Orientation device***	***Location device***
ANTS	Unknown	Daeyang E&C *Cy-Visor* DH-4400VP	Unknown	*InterSense*® *Intertrax* 2	PRETEC– *CompactGPS*
AR-PDA	Compaq (HP) *iPAQ* 3630	N/A	*Windows CE*®	Image recognition	N/A
ARCHEOGUIDE	Laptop, 800MHz Fujitsu pen-tablet, 500MHz	nVision VB-30 Sony *Glasstron*	*Windows*® *Windows CE*®	Image recognition, digital compass	DGPS
BARS[1]	Laptop, 366MHz	Sony *Glasstron*	Unknown	*InterSense*® IS-300 Pro	Ashtech *GG24-Surveyor* GPS
MAGIC	Fujitsu pen-tablet, 450MHz	Sony LDI D100 BE (semi-transparent)	*Windows* ®	Honeywell HMR3000[2]	Garmin GPS III+
MARS	Laptop, 133MHz Handheld, Mitsubitshi *AMiTY* CP, 166MHz	Virtual I/O *i-Glasses*	*Windows NT*® *Windows* 95®	Magnetometer	Trimble DSM GPS
Tinmith	Laptop, Pentium-M, 2GHz	Virtual I/O *i-Glasses*	Linux – *RedHat* 7.3	*InterSense*® IS-300	Trimble Ag132 GPS
Tourist Guide	Laptop, 2GHz	Sony *Glasstron* PLM-700e	*Windows* XP®	*InterSense*® *InertiaCube2*	Trimble *Pathfinder* Pocket differential GPS
WalkMap	Plug'n'Run Wearable, 333MHz	Sony *Glasstron* PLM-700e	*Windows 98*®	Leica DMC-SXZ digital compass	Trimble *Nav-GUIDE* GPS
Wearable AR Testbed	*Xybernaut*© MA-IV, 233MHz	Sony *Glasstron* PLM-700	*Windows* 98®	*CyberTrack*® II, *Intersense*®[3]	GPS

Table 3.1 – Summary of hardware and software from reviewed AR systems. (The hyphens indicate that specifications were not provided in the literature).

1 Note that this system is described with MARS

2 This is a digital compass used to record the orientation of photographs taken in the field

3 The Intersense® sourceless tracker was to be implemented at a later time to provide improved accuracy

3.4.11 Functionality matrix

Table 3.2 summarises the functionalities provided by each of the AR systems (as documented in the literature), grouped into system functionality, tracking method, system capabilities and collaboration. The absence of a functionality does not necessarily mean it was not present, but rather it was not mentioned in the reviewed literature, with some functionality being inferred from the literature. In the case of MARS and the Wearable AR system (which are two specific yet related systems), the combined functionality is shown.

The first section of the matrix highlights functionality provided by the particular AR system. Several AR systems provide multiple modalities for interaction including HMD and handheld devices. These systems are distinguishable in the table where both the immersive (HMD) and non-immersive (handheld device) AR boxes are marked. Wireless connectivity refers to the ability of the system to communicate with remote information sources using wireless communication protocols. In some instances the wireless communication is used to transfer data for processing on remote servers, minimising the computational requirement of the hardware being transported. Three of the systems also allow some level of personalisation by defining a context of use.

Only two types of position tracking have been adopted in the reviewed AR systems – GPS and image. The AR-PDA system relies solely on image tracking to determine the location of the handheld device to generate the aligned augmented graphics. The other systems rely predominantly on GPS for determining the users location.

There are a variety of capabilities provided by the various systems, many of them dependent on their target audience and application. Some of the capabilities, including data replication and preemptive downloads, reduce network bandwidth and ensure the availability of current data. Real-time routing is available in the two systems targeted at navigating users through urban environments. Virtual selection allows users to select objects by looking at them through the HMD. This capability is used to assist users collect information and annotate features. Two AR systems are directly linked to modelling applications, the output from which can be visualized. Another two systems allow remote users to view the augmented world as seen by the users with the HMD.

Each of the AR systems has a User Interface (UI), however a common theme has been the adoption of a 'world in miniature' (2D map) orientated to the users position allowing them to locate themselves easily. Several systems support collaboration with the MAGIC and Tourist Guide systems allowing AR users to communicate and share information. In addition MAGIC allows allows users to communicate with off-site users.

		System functionality					Tracking		Capability							Collaboration			
		Immersive AR	Non-immersive AR	Wireless connectivity	Personalisation	Remote processing	GPS tracking	Image tracking	Real-time routing	Data replication	Virtual selection	Information collection	Pre-emptive download	Scenario visualization	Off-site visualization	Multi-user	User-user communication	Off-site communication	Information Sharing
System name	ANTS		X	X		X	X							X					
	AR-PDA		X	X		X		X											
	ARCHEOGUIDE	X	X	X	X	X	X	X					X			X			
	MAGIC	X		X			X			X		X				X	X	X	X
	MARS	X	X	X	X		X		X						X	X			
	Tinmith	X					X	X			X			X		X			
	Tourist Guide	X		X			X		X		X	X				X	X		X
	WalkMap	X		X	X		X												
	Wearable AR	X	X	X		X	X	X							X				

Table 3.2 – Matrix highlighting the functionality provided by the reviewed AR systems ('X' denotes that the feature exists for the given system).

3.4.12 System summary

Each of the AR systems reviewed has a combination of features that make it unique. This section will summarise the points of difference amongst each of the reviewed systems with a particular emphasis on their relevance to this research.

All but three of the reviewed systems utilise a PDA or tablet computer for user input or as a display device. Utilisation of such devices provides users with a familiar interface for interacting with the system and objects. In the case of the ANTS system the PDA is the sole piece of hardware, providing a non-immersive AR experience using a looking glass metaphor whereby the object is combined with the augmented graphics on the screen of the PDA. The MAGIC system provides users with a page metaphor (similar to many data input systems) for entering data relating to archaeological objects.

The need to interact with and select virtual objects within an AR systems depends on the context of the application. The Tourist Guide application provides a 'ray-picking' functionality which allows users to point a virtual beam at an object by looking at it and then interact with the objects attributes through a touchpad device. The WalkMap application uses a compass metaphor, displaying the location of objects that are with a certain periphery of the viewing angle. Once the users has rotated themselves to look at the object they can interact with it using their N-fingers haptic device.

The ANTS system has a particular relevance to this research as it allows users to manipulate the parameters of a (pollutant transport) model and visualize the output. This functionality is provided on a PDA with connectivity to a wireless network for remote processing of the model. AR-PDA also makes use of wireless connectivity, transmitting the video captured through the PDA to a remote server for processing. The Wearable AR system also utilises remote processing for rendering a representation of the horizon for display.

ARCHEOGUIDE utilises an extensive wireless network for transmitting data and GPS correction information allowing users to be located with a high level of accuracy. The preemptive downloading of resources, based on the users preferences, to each mobile client ensures users have up-to-date multimedia resources and audio narration. This system can be used as an immersive or non-immersive AR environment depending on the preference of the user.

The MARS (and associated systems) and Wearable AR system provide a variety of visualization modalities. This allows users to experience and explore the environment in various contexts (immersive, non-immersive, desktop, large-screen) potentially providing them with a better understanding of the environment. Narrative applications can also be built with MARS, allowing users to be guided through an environment by the system.

Tinmith is the only system to provide seamless tracking indoors and outdoors using a combination of tracking techniques. This has provided the flexibility to create unique AR experiences. The small size and weight of the Tinmith system, combined with its haptic interface and application to urban planning make it stand out in the context of this research.

Two systems allow collaboration amongst users. Users of the MAGIC system can interact with other system users or remote users, allowing them to resolve issues immediately. The Tourist Guide application allows users to locate and navigate to one another. It also allows users to tag features with virtual notes that other users can read.

Various portions of each system can be applied to this research however some of the systems have been built for comparatively simplistic tasks when compared to the land use scenario modelling. For instance, the ANTS system requires the user to input a single point on the PDA representing the location of a pollutant source. ARCHEOGUIDE uses a large touchpad to assist field workers enter data about archaeological objects and is predominantly focussed on the context existing objects rather than visualizing modelled objects. The functionality of these reviewed systems will be further discussed and adapted during the development of the proposed land use AR system in Chapter 5 and Chapter 6.

3.5 Software libraries

The diversity of systems outlined in the previous section, has resulted in various software libraries, development frameworks and standards being created for authoring AR applications. Whilst AR technology is maturing, the lack of AR-specific development frameworks (Geiger et al., 2002; MacIntyre et al., 2001), authoring languages and agreed techniques for structuring content are preventing AR from being exposed to a broader audience (Ledermann & Schmalstieg, 2005). Creating robust development frameworks for non-programmers which hide the complexity of underlying AR systems, whilst allowing access to sufficient system functionality is difficult (Geiger et al., 2002; Ledermann & Schmalstieg, 2005; Piekarski & Thomas, 2001).

Well-designed development environments that are universally available, increase the quality and variety of applications built within a particular paradigm. This is illustrated by the evolution and success of WIMP interfaces (MacIntyre et al., 2001). Ledermann & Schmalstieg (2005) argue that any AR development framework must support a comprehensive range of established devices, tools and paradigms. While individual devices and tools are relatively easy to accommodate, the various AR paradigms (head-mounted displays, immersive projection environments or portable devices) require unique and complex hardware setups comprised of many displays and input devices connected by computing networks and other devices (ie mobile phones, PDA's etc) which may be running disparate operating systems (Ledermann & Schmalstieg, 2005). Ledermann & Schmalstieg (2005) suggest that some of this complexity can attributed to the systems being research prototypes but state the increasing ubiquity of computing will result in increasing numbers of heterogeneous development environments.

MacIntyre et al. (2001) suggest that progress and evolution of AR development tools can be accelerated by involving graphic designers and content creators while the medium is still in its infancy. In turn, this would result in a positive influence on development of the underlying technologies used to implement such systems. Below is a selection of development environments and software libraries that can be used to develop AR applications.

3.5.1 ARLib

The aim of the ARLib project was to create a comprehensive and easily implementable toolkit for creating marker-based, indoor AR applications (Diggins, 2005). ARLib is a single, static programming library that runs on *Windows* and *Linux* operating systems. Simple applications can be easily implemented with two lines of code and a Web camera. ARLib applications are configured using external, text-based configuration files and can be extended using built-in functions or extended with additional programming.

The algorithms used for distinguishing markers, calculating user orientation and camera calibrations are simplistic. This ultimately affects the quality and accuracy of the graphics being rendered, however it results in a computationally light-weight system that works in real-time at 25 frames-per-second refresh rates (near video quality) (Diggins, 2005).

3.5.2 ARToolKit (JARToolKit)

ARToolKit is a set of computer libraries capable of calculating camera position and orientation, in real-time, relative to physical makers (Thomas et al., 2000). ARToolKit is implemented as a C-library targeted at low-level programmers (C or C++) and is not object-oriented. An object-oriented version of ARToolkit has been implemented in Java (JARToolKit), providing programmers with an alternative way of building AR applications (Geiger et al., 2002). Features of the software include fiducial tracking from simple markers, pattern matching software, calibration code for video and optical see-through applications and fast performance (Thomas et al., 2000).

3.5.3 Message EXchange (MEX)

MEX is an open and dynamic software architecture for developing wearable computing applications built specifically for mobile computing platforms and is capable of connecting to other information sources. MEX is built on an open application interface, flat model hierarchy and services architecture and as a result is suitable for creating small, mobile applications requiring connectivity (Suomela & Lehikoinen, 2000).

MEX provides a simple programming interface for a wide range of components (both programs and devices) to communicate to one another in an anonymous manner. Each component has an interface that allows it to be registered with the MEX server and subsequently accessed by other components (Suomela, Lehikoinen & Salminen, 2001).

3.5.4 Studierstube and StbLight

Studierstube is a runtime environment and Application Programming Interface (API), written in C++, for developing AR applications (Szalavari et al., 1998). It incorporates existing standards and applications including *Open Inventor*®, an object-oriented 3D graphics API and OpenGL for rendering graphics. Although it is a capable prototyping system, it does not natively incorporate any database functionality (Reitmayr & Schmalstieg, 2004), requiring additional programming to access and manipulate data.

Studierstube provides a flexible multi-user, multi-application environment that supports many display devices and Six Degrees of Freedom (6DOF) interaction (Reitmayr & Schmalstieg, 2004b). It was specifically designed for AR applications in a fixed location (eg in a room). Applications are developed as object-oriented structures that arrange the logical and spatial representations of a graphical scene – known as a scene-graph (Szalavari et al., 1998). Studierstube also has a light-weight implementation called StbLight, capable of running on PDAs.

3.5.5 Tinmith-evo5

Tinmith-evo5 is an architecture which describes the design and implementation processes for creating virtual environments (Piekarski & Thomas, 2001). Tinmith provides a set of libraries and modules that support outdoor AR applications running on the Linux operating system (Piekarski & Thomas, 2003b). It is the result of several iterations of the Tinmith software and includes a software library of components and development applications within an object-oriented structure written in C++. The developers at the University of South Australia purposely developed the architecture to enable development of highly complex virtual environments (particularly mobile AR applications) in a simple manner (Piekarski & Thomas, 2001). A data flow methodology is the core concept behind the architecture, handling data from various sensors, processing it in order to render graphics to the chosen display.

3.5.6 Software library summary

All of the software libraries reviewed above are low-level programs that ultimately require programming knowledge to implement AR applications. Each library provides the programmer with suitable program interfaces through which they can control the various components (see section 3.2).

For those with no programming experience, alternative options for creating AR applications exist. The next section reviews several AR authoring frameworks that provide simple interfaces to the complex AR software libraries.

3.6 Authoring frameworks

The development of AR applications typically involves extensive programming, detailed content creation and an intimate knowledge of cameras, trackers and 3D geometries making it difficult for non-programmers (Berry et al., 2004; Grimm et al., 2002; MacIntyre et al., 2003). The primitive state of AR and the lack of tools to support application development makes it difficult to support rapid prototyping and incremental testing in experience-based applications (MacIntyre et al., 2003). Much of the current research is focused on developing applications for specific domains rather than developing a structured authoring framework with reusable components (Grimm et al., 2002). MacIntyre et al. (2003) go on to argue that making AR more accessible to designers will result in more powerful applications and dramatic experiences being developed.

Authoring environments hide the complexity of the underlying software, while providing access to the necessary properties in a simple framework. Generic application development frameworks rely on agreed techniques and practices for developers however the development and provision of authoring frameworks for AR is a non-trivial task, because of the infancy of the science, lack of agreed techniques and diversity of the data sets required (Ledermann & Schmalstieg, 2005). The construction of detailed models for AR environments is a time consuming exercise (Haringer & Regenbrecht, 2002) however, effective authoring frameworks can reduce the effort required to create AR presentations.

Early attempts at Virtual Reality (VR) authoring frameworks were based on text-based scripting files such as Virtual Reality modelling Language (VRML) and its successor X3D (Web3D Consortium, 2008), however they have no in-built support for AR nor do they provide the necessary control over the temporal structure and interactive behaviors required in AR (Ledermann & Schmalstieg, 2005). The following sections outline some of the AR authoring frameworks that have been developed.

3.6.1 AMIRE

AMIRE was a technical project sponsored by the European Union (EU) Information Society Technologies (IST) program (LABEIN, 2004). The overall objective of the project was to implement software to provide content experts with the ability to design and implement AR applications with no knowledge of the underlying technologies (Grimm et al., 2002). The AMIRE framework is based on ARToolKit (section 3.5.2) (Thomas et al., 2000).

The AMIRE framework (Figure 3.16) allows a variety of users to contribute to the creation of an AR application by separating the process into various tasks. This broad framework makes use of an AR-specific component library which can be extended through the creation and registration of further components (Grimm et al., 2002). The project was successfully completed and evaluated in 2004 (LABEIN, 2004), with the software being made available on SourceForge.net (a web site hosting almost 180 000 Open Source software projects) (SourceForge Inc, 2008).

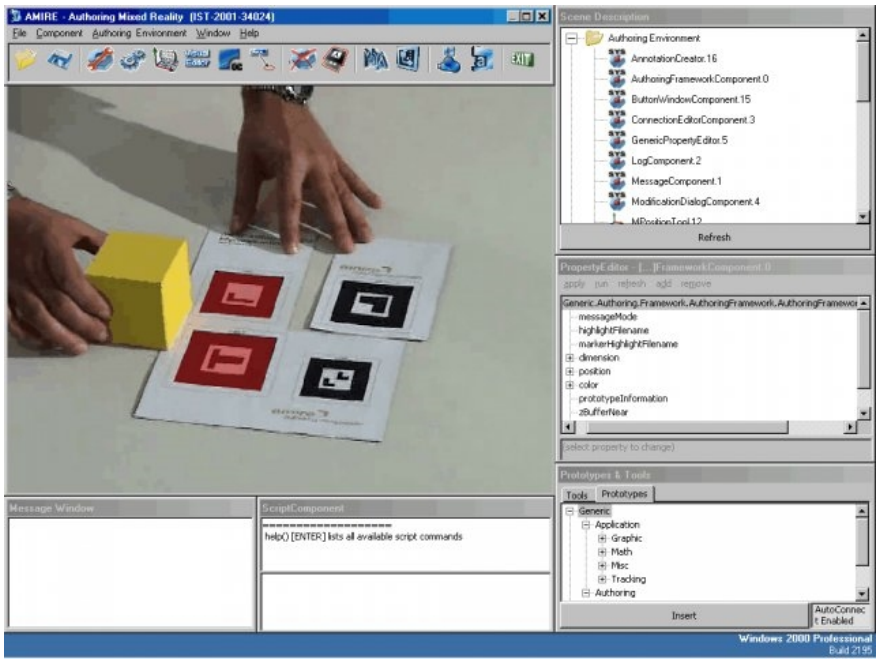

Figure 3.16 – The AMIRE framework (after http://sourceforge.net/project/screenshots.php?group_id=110240)

3.6.2 APRIL

The development of this authoring framework was underpinned by identifying the key concepts of authoring compelling AR presentations. The Augmented reality PResentation and Interaction Language (APRIL) framework is specifically designed for authoring AR presentations for distributed hybrid projective AR systems (Ledermann & Schmalstieg, 2005). APRIL focuses on providing a high level of abstraction for authoring AR applications rather than providing a Graphic User Interface (GUI) for authoring applications. It achieves this by describing content independent of the output device(s) and providing templates and best practices for presenting information.

APRIL uses XML to describe hardware setup, the presentations content and their temporal organisation and interaction capabilities. This methodology not only separates content from the system specific setup, ensuring authored presentations are reusable, but allows components to be reconfigured for different devices and/or operating systems, without modification. The authoring process can be undertaken by an individual or distributed amongst various domain experts. This also allows rapid application prototyping. Prototypes can be tested on desktop PCs (using simulated tracking data) prior to implementation on AR devices.

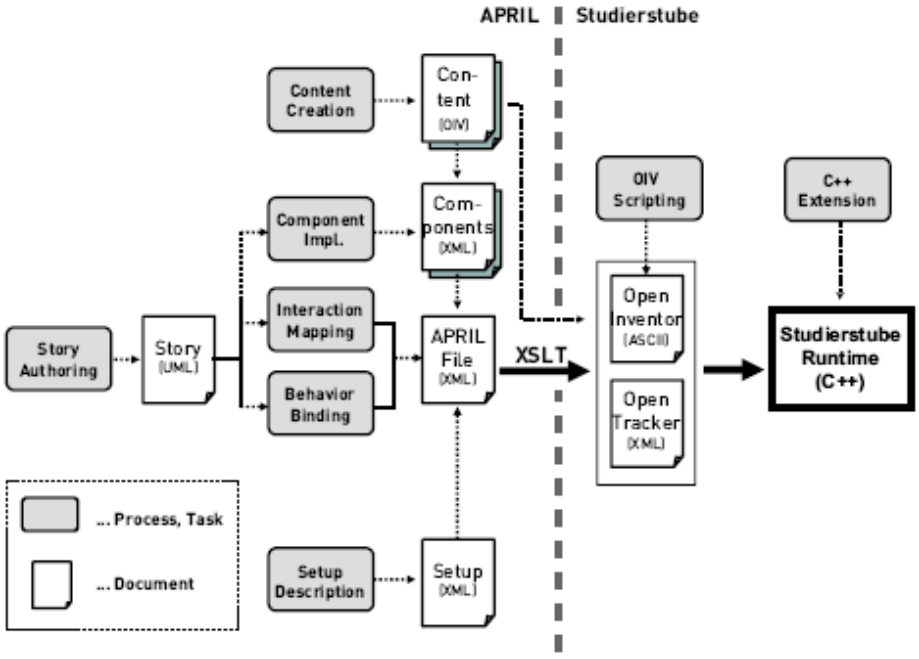

Figure 3.17 – Schematic view of the APRIL transformation process (after Ledermann & Schmalstieg, 2005, p. 192)

APRIL utilises existing industry standards, tools and practices where they already exist. Studierstube (Szalavari et al., 1998) (see section 3.5.4) is used as the run-time environment (although other run-time platforms could be used) as depicted in Figure 3.17. OpenTracker XML is used for configuring tracking devices and embedded in APRIL elements to provide semantics of the tracking data. Components are inserted within XML tags as host-specific ASCII text expressing the platform-specific content, allowing multiple, platform-specific components to be defined in the one file, increasing it's portability. The APRIL presentation files are transformed into application-specific configuration files using XLST.

3.6.3 DART

DART is built on the popular Adobe *Director* (Adobe Systems Incorporated, 2008) multimedia development application, allowing familiar paradigms to be used for creating rich AR applications (Figure 3.18). DART is focused on supporting rapid prototyping of AR applications by designers, allowing continued refinement and evolution of content using familiar practices and tools (MacIntyre et al., 2003).

It was developed to provide university students at the Georgia Institute of Technology with the ability to create AR applications with the primary purpose being to enable designers to work directly with AR to create new media experiences (refer to section 2.4.2). The goals of the research were; the identification and support of appropriate design activities for AR, the creation of robust tools to support those activities and, solving fundamental research problems to create the tools (MacIntyre & M. Gandy, 2003).

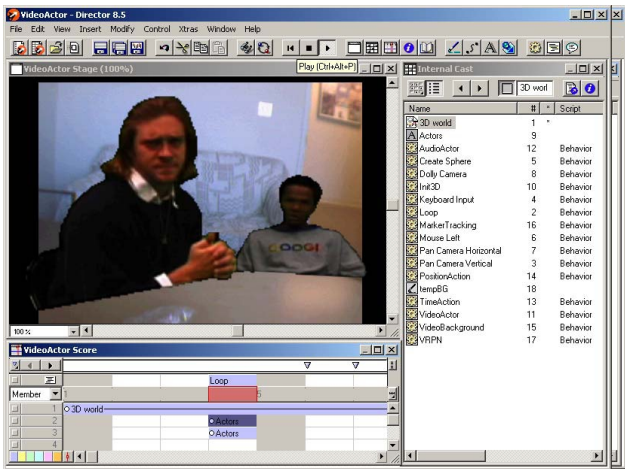

Figure 3.18 – DART framework within Adobe *Director* (after MacIntyre et al., 2003, p. 2)

DART is implemented as a combination of *Director* behaviours to allow graphical creation of content (including virtual objects and triggers) and Xtras that support AR services including video capture, tracking and fiducial registration (MacIntyre et al., 2003).

3.6.4 Powerspace

This application utilises Microsoft® *PowerPoint* for authoring AR content (Figure 3.19). It was created to assist in the migration of automotive repair procedures from CD-ROM format to AR content, with the target audience being technical documentation editors unfamiliar with AR. It is specifically targeted at authoring small-scale AR presentations.

The application separates AR authoring task into three main tasks, with a clear distinction between editing (or creation of content) and the presentation of content (Haringer & Regenbrecht, 2002). The first is the generation and arrangement of elements (text, images, multimedia) in 2D using *PowerPoint*. The elements order of appearance is determined by the slide order. The presentation is then exported from *PowerPoint* into an XML file.

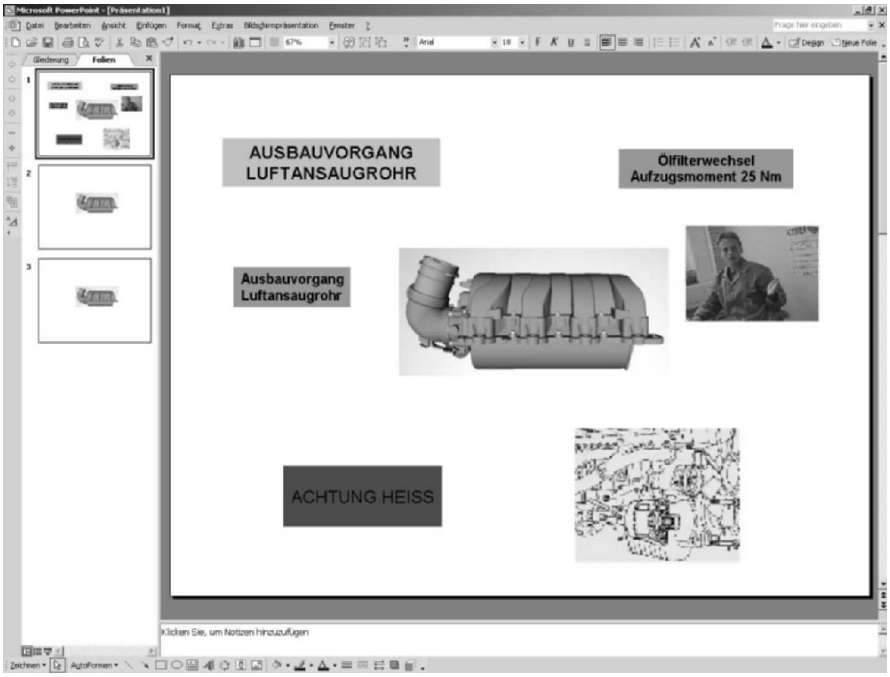

Figure 3.19 - Adding annotations to a PowerPoint slide for importing into the PowerSpace editior (after Haringer & Regenbrecht, 2002, p. 2)

The second task involves importing the presentation into the PowerSpace Editor for spatial arrangement and development of the 3D (position and orientation) geometries and definition of the order and relationships between the imported slides. Finally, the presentation can be evaluated using the AR viewer integrated into the PowerSpace Editor prior to export and use in the PowerSpace Viewer application. The content can be displayed on a variety of outputs including Head-Mounted Displays (HMD), large projection screens (monoscopic or stereoscopic) and desktop monitors.

3.6.5 Authoring framework summary

AR authoring frameworks provide non-programmers with the ability to create AR applications in a windows environment. Several frameworks are built on existing applications (including DART and PowerSpace) providing users familiar with the underlying software with the functionality to create AR applications.

The majority of AR authoring frameworks have been developed for creating narrative AR applications. The major shortcoming of AR authoring frameworks is their inability to accommodate large-scale, applications (Haringer & Regenbrecht, 2002). This significantly limits their applicability for creating outdoor, immersive AR applications.

3.7 Chapter summary

A wide variety of mobile AR applications have been developed in the past decade with most systems being the result of applied research in educational institutions. Current AR applications are generally targeted at navigation and multimedia presentation of information in urban environments. The other predominant area of application is history, where AR has been used to display representations of architectural and archaeological features that no longer physically exist. While these current applications display factual information, none of the systems reviewed display abstract scientific data, nor do they allow users control over the visualization and its representation. In general, AR has not been applied to visualizing natural resource data.

While some of the reviewed systems are quite old, Table 3.1 highlights the hardware components used and the similarity between systems. The computational power, reduced size and increased battery life of current hardware is increasing the usability of AR from a weight perspective (as highlighted by the Tinmith system, section 3.5.5). Continuing improvements in size and weight will greatly enhance the usability of wearable computing systems, while the capability and accuracy of registration, tracking and networking will enable mobile AR systems to move towards adoption by mainstream application developers for use in new and innovative applications.

The reviewed systems utilise various strategies for managing data including file-based, databases, remote databases and XML. As discussed, data management within AR is critical and will be discussed further in Chapter 5. Collaboration has also been implemented in various ways as highlighted in Table 3.2 and this will be further explored during the development of the user interfaces in Chapter 6 and Chapter 7.

Chapter 4

Context of application

4.0 Chapter overview

This chapter provides the underlying context for the development of user interfaces for a hypothetical AR system targeted at manipulating and visualizing land use scenarios. This chapter is divided into three main sections, beginning with an introduction and hypothetical scenario outlining a typical situation faced during a landscape reconfiguration project.

The second section broadly outlines the application of visualization to landscape planning. Visualization is an important method of engaging communities to understand local phenomena and allows decision-makers to refine model inputs. The third section looks at one such model to demonstrate the variety of spatial and aspatial inputs required and some of the possible outputs generated, thus providing a context for future chapters.

4.1 Introduction

Many areas across Australia are at risk of severe environmental degradation. While Australia has a diverse range of farming systems, many of them have created environments out of balance with the natural systems in which they are applied (The State of Victoria, 2004e). As a result, severe environmental degradation has occurred in many areas causing a decline in the productivity of agricultural land and ultimately declining rural communities. The implementation of sustainable farming systems is required to recreate healthy ecosystems for the benefit of all.

The ability to communicate and engage landholders and the public affects the way in which land managers and scientists respond to environmental degradation (Orland, 1992). While land managers have an intimate physical knowledge of their particular area of interest they are generally less knowledgeable about the complex scientific interactions that occur between the contributing processes.

Large-scale environmental management requires the combined effort of government, industry, special interest groups (for example Landcare in Australia) and the public. Environmental change will rely on the action of these groups in conjunction with changes in individual behaviour (Orland, 1992).

What follows is a hypothetical scenario which provides a context for discussing the complexities of creating a holistic model from conceptualisation, collection and generation of spatial and aspatial data sets, through to executing the model and communicating the results to a range of stakeholders.

4.1.1 A hypothetical scenario

A computer model demonstrating the interaction between rainfall, land use and groundwater levels has been developed by scientists and modellers. After many months of refining and checking the model the modellers are wanting to show their findings to all interested stakeholders.

In the past, outputs from such models were shown through a Microsoft PowerPoint® presentation comprised of static thematic maps, explanatory text and complicated mathematical equations justifying the results. Although effective with scientists, this format was found to be less beneficial for landholders and catchment managers whose interest is focused on the impact of the scenarios on their current land management practices.

This time the results are being shown through an Augmented Reality (AR) system, with a meeting organised at a property in the catchment where the modelling was undertaken. All stakeholders involved in the development of the model and affected by its output have been invited to attend, including:

- The Department of Sustainability and Environment DSE – Victoria's leading government agency responsible for promoting and managing the sustainability of the natural environment;
- The Department of Primary Industries DPI – responsible for the sustainable development of primary industries through strong economic activity, high quality natural resource base for the long term and resilient industries and communities;

- Catchment Management Authorities CMA – responsible for implementing the Catchment Management Framework, which involves the sustainable use and management of land and water resources at a catchment level; and,
- Landholders – People responsible for managing the land in accordance with the above policies for future generations.

The meeting is held outdoors in a paddock which provides a good outlook across the catchment. It begins with a brief introduction by a CMA representative who describes the general topography of the catchment and the main issues currently affecting the catchment. An explanation of the AR system to be used for disseminating the results is given by the system developer.

Each stakeholder present at the meeting is provided with the chance to interact with the model and its outputs through the AR system. This 'hands-on' approach, in the 'real world' provides the user with an experience not possible in a meeting room, allowing users to visualize the interactions between model components and dependencies amongst the various elements. The other advantage of the system is its ability to store the user-generated scenarios, which allows catchment managers and modellers to gain an understanding of how the landholders see their area into the future. These user-generated scenarios can be modelled at a finer resolution to determine whether they provide a plausible, alternative solution to the one offered by the scientists.

4.2 Landscape visualization

Visual communication is a common part of environmental decision-making, used to facilitate dialogue between policy-makers and non-experts to increase understanding and improve decision making (Appleton & Lovett, 2003). As environmental decision-making continues to move towards the combined goals of increased transparency and greater public participation, there is a corresponding need for effective ways of communicating environmental information to non-experts (Hearnshaw & Unwin, 1994) (cited in Appleton & Lovett, 2003). This becomes particularly important when the decisions to be made have impacts at the landscape scale, and it makes sense for such potential changes to be communicated visually.

Orland (1992) describes visualization as the common currency of planning stating that it opens the process to participation, increases understanding and improves the quality of decision-making. However, there is a clear need for careful evaluation of current visualization technology to assess whether increases in capability actually enhance the usefulness of visualizations for environmental decision-making (Appleton & Lovett, 2003).

Some visualization systems output very realistic images, implying defensibility and accuracy to many viewers, however potential limitations can actually be camouflaged by details which have been inferred by the producer (Sheppard, 2001). Often, the greater the realism, the weaker the link to underlying data or scenarios (Orland, 1994) which provides opportunities for biased representations and potentially undermines many of the advantages of such visualization (Appleton & Lovett, 2003). A certain degree of realism is still needed if viewers are to relate to a landscape and make decisions based upon it as high degrees of abstraction have been found to be inadequate (Appleton & Lovett, 2003; Daniel & Meitner, 2001). Ultimately the accuracy of any visualization is directly related to the data – if suitable data is available at the right (spatial and temporal) scale, the final representation will be accurate.

The need for a critical eye is particularly apparent when considering the advances in realism, since opportunities for realistic visualizations are rarely matched by the availability of suitably detailed data, and viewers' perceptions of factors such as accuracy and certainty are also affected (Appleton & Lovett, 2003). Even as technology develops there will probably always be a degree of realism which is desired but unattainable (Appleton & Lovett, 2003; Ervin & Hasbrouck, 2001).

Environmental visualization is affected by three issues (Rhyne et al., 1994):

- The large volume of data which can affect performance and analysis times;
- Complex and heterogeneous data represented by multiple formats, scales, resolutions and dimensions; and
- The increasing requirement for multiple people, from a wide range of disciplines, needing to interact with the data to define solutions.

These issues have prevented geovisualization from being integrated with existing data storage and analysis tools (MacEachren, 2001). Scientists and other stakeholders want to visualize multiple data sets simultaneously, made difficult by varying sources, data types, spatial resolution and coordinate systems (Rhyne et al., 1993).

Visualization can assist managers and scientists to interpret impacts and relationships as well as providing a method to motivate landholders to implement change. Geovisualization can be used to represent the extent, severity, rate-of-change or experience of varying land uses and management regimes and allow them to be compared with the 'no change' scenario (Orland, 1992), however visualization has largely ignored representing error and uncertainty (Rhyne et al., 2004).

The increasing number of tools capable of creating and representing virtual worlds has increased the ability to visualize and communicate environmental issues to various stakeholders. Such visualizations can be efficiently authored and edited using a variety of commercial and open source software systems (Orland, Budthimedhee & Uusitalo, 2001).

4.2.1 Interacting with landscape models

The delivery of model outputs has evolved from static images (or image sequences) to applications in which users are free to explore, interrogate the output and (perhaps) undertake "what-if" scenarios (Orland, Budthimedhee & Uusitalo, 2001). Analysis and modelling tools must be integrated with powerful graphic capabilities to create realistic virtual environments enabling real-time interaction with data and allow visualization of the results in an abstract or realistic form. Visualization systems must allow decision support at various scales in a seamless manner (Meitner et al., 2005; Orland, 1992).

Decision Support System (DSS) is the common name given to a system that integrates data from disparate sources to allow querying, manipulation and visualization of data in order to solve a specific issue. Such systems facilitate decision-making by providing the user with the "right knowledge to the right decision-makers at the right times in the right representations at the right costs" (Holsapple, 2008, p. 21). Modern DSS are sometimes referred to as knowledge management systems as they support the capture and explanation of existing knowledge as well as incorporate learning capabilities (Burnstein & Carlsson, 2008) allowing the system to evolve as more information becomes available.

In supporting scientific and technical decision-making, DSS empower stakeholders with the ability to test scenarios and view the (modelled) consequences, both positive and negative. DSS are comprised of three major components; visualization, predictive modelling and communication with Orland, Budthimedhee & Uusitalo (2001, p.145) going on to state that;

> *A successful DSS would be one that integrated these three techniques into an environment that immersed users…with a set of tools that enabled them to play out future scenarios and display those to themselves and others in a variety of flexible and interactive formats.*

4.2.2 Community engagement

Tabular and verbal information is being rapidly replaced with graphic visualizations however, these visualizations are often provided to stakeholders with minimal context and provide limited opportunity for users to interact, react and provide feedback. DSS also suffer these same issues by not providing greater context to the issues they are portraying. This severely inhibits a user gaining a thorough understanding of the information being portrayed. Orland, Budthimedhee & Uusitalo (2001) suggest that, prior to allowing naive users access to a DSS, an introduction to the issues be provided to context their interaction with the system. Even more sophisticated users may benefit from understanding the system prior to use.

The direction of policy relating to environmental planning is increasingly influenced by the public and as a result, planning processes have become more participatory. Scientists, policy-makers and land managers work on behalf of citizens to bring about responsible changes in magnitude, distribution and consumption of (environment) benefits and services by integrating knowledge communicated by the public.

Complex products requiring detailed explanation typically complicate the participatory process. Environmental planning has migrated from purely explanatory to exploratory. DSS and associated interactive, virtual environments have been confirmed to increase participation, improve understanding of the issues and assist decision-making. This allows the logic of catchment planning to be better understood and ultimately applied in alternative ways to deliver tangible benefits. Facilitating such interaction within a networked, collaborative environment allows highly complex and interrelated environmental problems to be solved (Orland, Budthimedhee & Uusitalo, 2001; Rhyne et al., 1994).

4.3 Catchment modelling

Government departments (and private businesses to a lesser extent) are responsible for managing the natural landscape, including the people and economies that rely on it. Natural Resource Management (NRM) is the sustainable management of natural resources. In Australia, NRM is typically driven by government and, in recent years, has been funded federally by two national initiatives; the National Action Plan for Salinity and Water Quality (NAP) (Commonwealth of Australia, 2008a) and the Natural Heritage Trust (NHT) (Commonwealth of Australia, 2008b). These initiatives are supported by a range of additional initiatives funded by state government, local government or private investment.

The application of computer-based models in NRM supports (ICM) (Murray-Darling Basin Commission, 2004a; The State of Victoria, 2004b). At a government level, Integrated Catchment Management (ICM) is one method of approaching NRM projects to improve land and water management (The State of Victoria, 2004b). ICM has been defined by the Murray-Darling Basin Commission (2004, p.1) as;

> *A process through which people can develop a vision, agree on shared values and behaviors, make informed decisions and act together to manage the natural resources of their catchment. Their decisions on the use of land, water and other environmental resources are made by considering the effect of that use on all those resources and on all people within the catchment.*
>
> *The decision to manage our natural resources on the basis of catchments reflects the importance of water to the Basin environment, and to the people who live and work within the Basin.*

As the definition states, includes social, environmental and economic aspects. Determination of specific social, economic and environmental values important for a given catchment is essential for delivering a holistic and sustainable outcome. This approach, commonly referred to as Triple Bottom Line (TBL) reporting. TBL reporting is targeted at understanding the (sometimes) complex relationships between environmental, economic and social (or community) factors in order to arrive at a synergistic solution that is sustainable in the long term (Environment Australia, 2003).

The ICM process attempts to maximise (or improve) environmental aspects while minimising the negative social and economic impacts. ICM in Australia is attempting to achieve a multitude of outcomes, including: healthy rivers, ecosystems and catchments; innovative, competitive and ecologically sustainable industries; and health regional communities (Murray-Darling Basin Commission, 2008).

The inherent complexity of managing the social, economic and environmental aspects (and their composite factors) requires an integrated solution (or framework) based on an understanding of the system (from an individual to a catchment and beyond) (CSIRO Land and Water, 2004) to underpin the long-term sustainability of a regions (Bryan, 2003; The State of Victoria, 2004a). As a result, NRM projects are now heavily reliant on complex, computer-based modelling frameworks that provide a robust and repeatable method of applying various rules to biophysical data sets to predict responses to land use change strategies (Beverly et al., 2005).

Natural resource managers have 4 key roles: identify and interpret complex environmental systems; communicate these complexities to stakeholders; provide the tools for stakeholders to evaluate alternative scenarios; and implement management plans as a result of these evaluations (Orland, 1992). These roles are undertaken with limited and finite resources and as a result, natural resource managers require tools to develop cost effective, targeted investment strategies to maximise catchment health (Beverly et al., 2005). Ecosystem interactions are being increasingly modelled as knowledge of the underlying processes increases with the numerical models providing insight into the current state of the environment while allowing the testing of alternate scenarios (Orland, Budthimedhee & Uusitalo, 2001).

The complex interactions within natural resource systems has resulted in the development of various modelling frameworks to assist in determining the implications of various scenarios. Early models allowed only single-cell simulations but this has evolved into complex models, integrating a variety of individual models and allowing spatial interaction between cells (Orland, Budthimedhee & Uusitalo, 2001). Models must be scalable and robust in order to output defensible results, even with the increase in computational ability, (spatially) large models can only be run using generalised data, reducing their ability to model and realistically represent local-scale impacts without subsequent localised analysis (Orland, 1992).

Many modelling frameworks are typically created by, and targeted at, domain experts (typically computer or natural resource scientists). In addition, the number of spatial and aspatial data sets required as input into such models is non-trivial, requiring data management strategies for effective storage, documentation and retrieval. If catchment models are to be accepted and used more widely they will have to evolve to accommodate non-specialist users (Orland, Budthimedhee & Uusitalo, 2001).

There are a range of catchment modelling frameworks in use across Australia. Catchment modelling is primarily focused on water quality and quantity, a topical issue in Australia given the availability and reliability of such a critical resource. While catchment models may be focused on one aspect (such as water), they can incorporate a variety of other data sources in an attempt to more accurately model the real world. While not a comprehensive list of all catchment models, the Catchment Modelling Toolkit web site (http://www.toolkit.net.au/) lists a variety of models developed as part of the eWater Cooperative Research Centre (CRC) (eWater Limited, 2007b) that have been widely adopted such as E2 (Argent et al., 2005) and the suite of Catchment Scale Multiple-Landuse Atmosphere Soil Water and Solute Transport Model (CLASS) products (Tuteja et al., 2004).

Scientists at the Department of Primary Industries (DPI) Victoria, in conjunction with the CRC for Plant Based Management of Dryland Salinity (subsequently eWater CRC), have developed a catchment modelling framework known as the Catchment Analysis Tool (CAT). The CAT connects existing physically-based biophysical predictive models (both commercial and public) together to determine the impacts of various land use scenarios on the water as both a resource (water yield in reservoirs) and a threat (recharge and eventual discharge) to link paddock scale actions to catchment scale environmental outcomes (The Cooperative Research Centre for Catchment Hydrology, 2002; The State of Victoria, 2005).

Some of the models that CAT utilises include: plant growth models such as 3-PG (CSIRO Forestry and Forest Products, 2005) and GRASSGRO (CSIRO Australia, 2007); and various groundwater flow models including MODFLOW (United States Geological Survey, 2005), FEFLOW (Schlumberger Water Services, 2007) and BC2C (eWater Limited, 2007a).

To allow users to interact with the input spatial data and model outputs an interface has been built using MATLAB® (The Mathworks, Inc, 2008) (Figure 4.1). The interface ensures the input data is free from errors, allows thematic visualization of data, generates appropriately formatted inputs for the model. Interaction with a command line interface is necessary to run the model which, depending on the size of the study area and resolution of the input data, can take many days of processing time (the limitation of many catchment models).

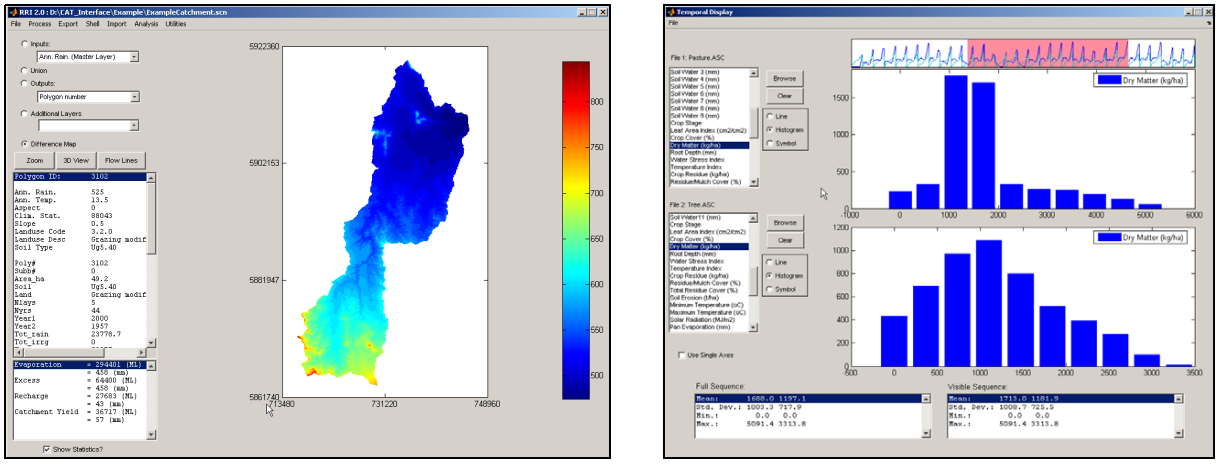

Figure 4.1 - Sample screen captures from the graphic user interface developed for CAT a) Initial interface with the capability to visualize model input and output b) Interface enabling the display and comparison of temporal data (Beverly et al., 2005).

While user interfaces for complex models have been developed many are complicated and require specialist knowledge to use and ultimately interpret the data being displayed. This makes it difficult for non-expert users to understand as the exact input requirements are not necessarily clear. Attempting to replicate such interfaces in an AR system would result in their complexities being magnified due to the low resolution displays, restrictive interaction methods and other environmental factors (such as variable lighting conditions). Balancing all these issues to create a robust and functional AR system which allows users to interact with complex catchment models to generate, interact with and visualize land use scenarios is the challenge of this research.

Catchment models require various biophysical and climatic data to model water movement through the landscape. The required data is dependent on the temporal and spatial resolution required by the underlying models and the clients requirements. The following sections broadly describe some of the inputs and outputs of these models, using the CAT as an example.

4.3.1 Model inputs

A diverse range of data, both spatial and aspatial, representing the various social, economic or environmental factors being modelled is a requirement for any catchment model. Data sets relating to the environment are often large, sometimes temporal or multi-dimensional and potentially consolidated from various sources (Rhyne et al., 1993). Most catchment models have historically dealt with environmental (or biophysical) data however this is being widened to include social and economic data. While the interactions between the various data sets (such as soils and recharge to groundwater aquifers) are complex, the relationships are (typically) well known and documented enabling natural resource scientists to build conceptual representations.

Consideration of complex interactions between various factors requires large amounts of data and the relationships between data must remain consistent at all scales of analysis (Orland, 1992) to allow comparison, a challenge which is yet to be met. Due to the differences in data collected at different spatial scales (state, regional or local), the output of the model is ultimately affected by the accuracy and consistency of the data. For this reason most catchment models are relevant to a specific spatial scale, dependent on the availability of relevant spatial data and attributes.

The CAT model is capable of running at a variety of spatial and temporal resolutions depending on the requirements of the client. The availability of relevant data (and attributes) and its spatial resolution (both the cell size and the complexity of the conceptualisation) determines the number of cells and the potential interactions between the cells and the various layers.

Spatial data sets required by the CAT (and other such models) include: a Digital Elevation Model (DEM); extent and depth of various groundwater aquifers; soil units; climatic data including rainfall and evaporation; and scenarios representing land use, both current and alternate. All these spatial layers must be converted into grids with the same cell size and alignment (although some models can handle multi-resolution data). In addition a range of aspatial data is required to paramaterise underlying models and input data, including: plant physiology and water use patterns; land use coding; soil hydraulic properties; and possible interactions between each of the layers (such as groundwater aquifers). While data preparation is time consuming a comprehensive repository of data resources is built over time, which subsequent models can utilise.

4.3.2 Model outputs

Integrated modelling frameworks utilise temporal data to model changes over time. As a result, they create an output for each temporal step however these outputs are rarely visualized unless there are obvious anomalies in the final output, and then only by a catchment modeller. Visualizations of model output is often abstract, enabling scientists to extract a greater understanding of the processes involved (Orland, 1992).

Model outputs are generally disseminated as static products including: thematic maps representing areas of recharge; tables highlighting the increase or decrease in a value (such as water quantity); and graphical representations of values over time (such as plant water use). Many of these products often require further explanation, either by modelling experts or by reading the final report to be correctly interpreted and understood by stakeholders. The complexity of the model outputs (and difficulty in interpreting them) occasionally results in scepticism among stakeholders regarding the validity of the output and the land practice changes recommended.

4.4 Chapter summary

Providing land managers with a range of tools to improve their understanding of environmental issues may enable them to make better decisions regarding their land management practices to ultimately reduce their impact on the environment. Rather than provide access to complex modelling applications, scientist typically provide them with simple static products which include maps, graphs and tables. While these are sufficient for providing an overview, land managers are not able to gain a better understanding of the issues through exploration of the model inputs and outputs.

In the case of the CAT, a desktop application has been created to allow land mangers to explore the model inputs and resulting outputs. However, users are limited by the capability of the application. Another shortcoming of this approach is the lack of environmental context of the issues and their modelled solutions. AR has the ability to immerse the user in a landscape, providing a physical context for visualizing both model inputs and outputs. The various system components and functionality from the previous chapter in addition to the context described in this chapter provide the basis for developing a theoretical AR system.

Chapter 5

A theoretical Augmented Reality system

5.0 Chapter overview

This chapter will outline a theoretical mobile outdoor augmented reality system, specifically designed for land use scenario visualization. This chapter is divided into two main sections covering each of the core elements of any AR system: hardware components; and, software and data management. Within each section, the ideal requirements to deliver an effective mobile outdoor AR experience will be discussed. Based on the requirements, suitable hardware components and software applications (available at the time of writing) have been identified with their specifications listed.

The review of existing AR systems (as described in Chapter 3) provided the basis for selecting (theoretically) suitable components that were available at the time of writing. Various alternatives for each component are explored with pros and cons stated prior to a specific component being selected. Detailed specifications of the selected component are provided. A comprehensive assessment of all possible components has not been undertaken as the focus of this research is on the interfaces rather than the system, as a result there may be alternative components that are better suited. All component models and prices quoted in this chapter are approximate and were valid at the time of writing.

5.1 Introduction

Applications of mobile immersive outdoor Augmented Reality (AR) are wide and varied, however each system has common components and functionalities. With the majority of systems being developed in educational institutions to explore functionality and user interface paradigms, they are constrained predominantly by cost, potentially impacting the systems performance or other factors.

A theoretical AR system for natural resource management aimed at providing an alternative method of disseminating a variety of natural resource data, including outputs from Integrated Catchment Models (ICM) is described. It is envisaged that such a system would promote greater interaction between modellers, scientists and stakeholders. The AR system would allow users to experience and explore ICM output in-situ, input alternative land use scenarios, visualize the results and explore (query) the implications of implementing those scenarios.

All mobile AR systems previously developed, whether they be commercial or research, rely on the user to carry all the necessary hardware, typically in a backpack (Haringer & Regenbrecht, 2002) or on a belt (Piekarski, 2007). The theoretical system described in this chapter uses current (at the time of writing) Common-Off-The-Shelf (COTS) components and proposes the use of wireless communication protocols to stimulate thought into how such technology can be utilised to minimise the hardware being carried and potentially expand the diversity of applications. Although no formal criteria were defined to assess the components of the conceptual system, each component was assessed on the functionality documented in the reviewed AR systems (refer to Chapter 3).

5.2 Hardware components

Hardware components form the basis of any AR system. Current hardware limitations including weight (Azuma et al., 2001), cost, power consumption (Danado et al., 2003) and accuracy of tracking systems (Billinghurst, Grasset & Looser, 2003) all affect an AR systems usability. Some of these limitations can be overcome by shifting the computational load to remote servers (Azuma et al., 2001), made possible through the evolution of wireless networking. Additionally, any outdoor AR system must be weather-proof and robust enough to withstand every-day use in such environments (Davies et al., 1998) to ensure it provides a viable solution for data and information dissemination.

Five core components necessary to implement a mobile augmented reality system which include; displays, registration and tracking, input devices, networking and a computational platform (Azuma, 1997; Hollerer & Feiner, 2004). The specific requirements of each hardware component in relation to a mobile outdoor AR system for viewing land use scenarios are described in the following sections. For each component a suitable suggestion is made.

The majority of existing mobile AR systems, as described in section 3.4, are designed for a single user and require the user to carry all the necessary hardware. The system described in this chapter would be capable of operating with multiple users and operate in a variety of modes (discussed in Chapter 6) with several users seeing a visualization defined by a master user (an augmented presentation) or individuals controlling their own visualizations. Each user would carry a HMD, orientation sensors and PDA to interact with the system.

The theoretical system comprises a remote computer (or processing engine). All mobile components would communicate through the wireless network, enabling users freedom to explore the surroundings whilst carrying minimal hardware. The 'hub' (or central processing engine) has been designed with portability in mind. A minimal amount of hardware would allow the system to be deployed with relative ease at any location and enable users to begin exploring the landscape.

5.2.1 Display

As discussed in section 3.2.1, the capability of a HMD delivering an immersive augmented reality experience is determined by a range of factors, including; resolution, weight, Field Of View (FOV), stereo capability, colour depth, refresh rate and focus (or collimation) distance (Computer Graphics Systems Development Corporation, 2001). Due to the system being used outdoors, a see-through HMD with a high contrast display would be required to ensure the augmentations were visible in all lighting situations. Associated with this, the HMD should have a wide FOV to reduce eye strain and improve the perception of immersion.

In the theoretical mobile outdoor augmented reality system, a see-through HMD would be desirable. The Sony *Glasstron* see-through HMD (which is no longer produced) is the predominant display used in research systems however Dahne & Karigiannis (2002) found that it was not comfortable to wear for prolonged periods, as a result they selected a hand-held video see-through display, the nVision VB-30 (similar to a pair of binoculars). While the nVision VB-30 HMD would be suitable for many applications, it is not suitable for the application described in this research as it would severely limit their ability to interact with the PDA as at least one hand would have to hold the HMD.

The majority of manufacturers now focus on video see-through displays and, as a result, see-through HMDs are predominantly targeted at military applications (such as NVIS nVisor ST, Rockwell Collins ProView XL40 / 50STm or SAABtech AddVisor 150 (Inition, 2008)) and cost in excess of AUD$50,000.

Monocular see-through HMDs exist, including the Icuiti M920, Trivisio Monocular M3 (Figure 5.1) and the Liteye series (LE-500, LE-700 or LE-750) (Inition, 2008). The benefits of such devices include lower cost than biocular HMDs, low weight and low power consumption and allow one eye to remain fixed on the surrounding environment to scan for dangers or obstacles. The FOV of these devices is typically less than 30° and the collimation distance is low resulting in several perceptual issues including binocular rivalry, visual interference, depth of focus, unnatural eye movements, and eye dominance (York & Pendharkar, 2004). For these reasons, monocular devices are better suited to maintenance applications were access to generally textual information (such as manuals and plans) is required.

Figure 5.1 - Trivisio Monocular M3 (source: Inition (2008)).

Video see-through displays are more widely available as manufacturers (and users) have more control over the viewing environment. The are a variety of video see-through HMDs available, predominately targeted at the gaming and virtual reality markets. Units such as the Cybermind Visette Pro, Cybermind hi-Res800 and 5DT HMD 800 cost around AUD$5,000 (Inition, 2008). Video see-through HMD requires a camera (or cameras) to capture video of the environment which are digitally combined with the augmented graphics before being displayed to the user on small screens mounted in the HMD (see Figure 3.2). The majority of research systems (described in Section 3.4) have used web cameras to capture the video.

An alternative to typical HMDs is the Virtual Research WindowVR product (Figure 5.2) which is essentially a 17 inch LCD screen with an in-built tracking device. This device provides a semi-immersive environment and allows users to interact using the buttons on the handles and via menus on the touchscreen. Although better suited to fixed displays such as museums and galleries, it could be utilised in outdoor environments if mounted on a stable platform (such as a tripod) which could easily be moved. This device costs approximate AUD$15,000 (Inition, 2008).

Figure 5.2 - Virtual Research *WindowVR* (source: Inition (2008)).

Suggested device and specifications:

The ARvision-S stereo video see-through HMD from Trivisio (Trivisio Prototyping GmbH, 2007) has been identified as a suitable HMD for the theoretical AR system. The device has two in-built video cameras (one per eye) that can be manually adjusted for focus and eye-distance, minimising eye strain. The displays are SVGA with a refresh rate of 120Hz and can be adjusted to suit the users eye base. The HMD has a 32° horizontal and 24° vertical FOV and weighs approximately 380 grams (including the battery). The battery unit which has an approximate life of 2 hours allows the user to manually adjust the brightness and contrast of the displays. The battery can be fully recharged in 50 minutes. At the time of writing, the cost of the HMD was approximately AUD$9,000 (Inition, 2008).

5.2.2 Registration and tracking

Tracking the real-time location and movement of users within an AR system is essential to ensuring that the virtual objects are correctly aligned with reality (Rolland, Davis & Baillot, 2001; Suomela & Lehikoinen, 2000; You, Neumann & Azuma, 1999). Rolland, Davis & Baillot (2001) outline several tracking methods suitable for AR, many of which are used together to minimise errors. Geographic Positioning System (GPS) is most commonly used for positioning in outdoor AR applications however it has limitations in urban areas and dense vegetation where signals from the GPS satellites are difficult to receive and distorted by multi-path errors.

Determining location within wireless networks is an increasing field of research which has been adopted within the commercial marketplace (Meunier, 2004) and underpins the concept of Location Based Services (LBS). LBS applications utilise the knowledge of a users location to deliver a range of services including nearest feature, proximity notification and targeted advertising (Gumuskaya & Hakkoymaz, 2005). Mobile AR systems are a form of LBS as it utilises the location of the user(s) to provide location specific information. Each users location can be determined by triangulating their position within a wireless network (5.2.4). Connelly et al. (2005) attest that Wi-Fi positioning is an increasingly attractive solution for determining user location, however the locational precision remains poor when compared to differential GPS.

The accuracy of positioning in wireless networks is between 3 and 30 metres (Figure 5.3), comparable to handheld GPS, without the requirement for an additional device (Vossiek et al., 2003). The locational precision required in outdoor augmented reality, when applied to landscape scale visualizations, is low due to other factors contributing to the accuracy of rendering graphics including computation lag and bandwidth for transferring graphics (Azuma et al., 2001; Rolland, Davis & Baillot, 2001). The horizontal position of the user will be determined by processing the strength of Wi-Fi signals received from each transmitter (section 5.2.4). Once the users horizontal position has been determined their elevation can be calculated from a Digital Elevation Model (DEM).

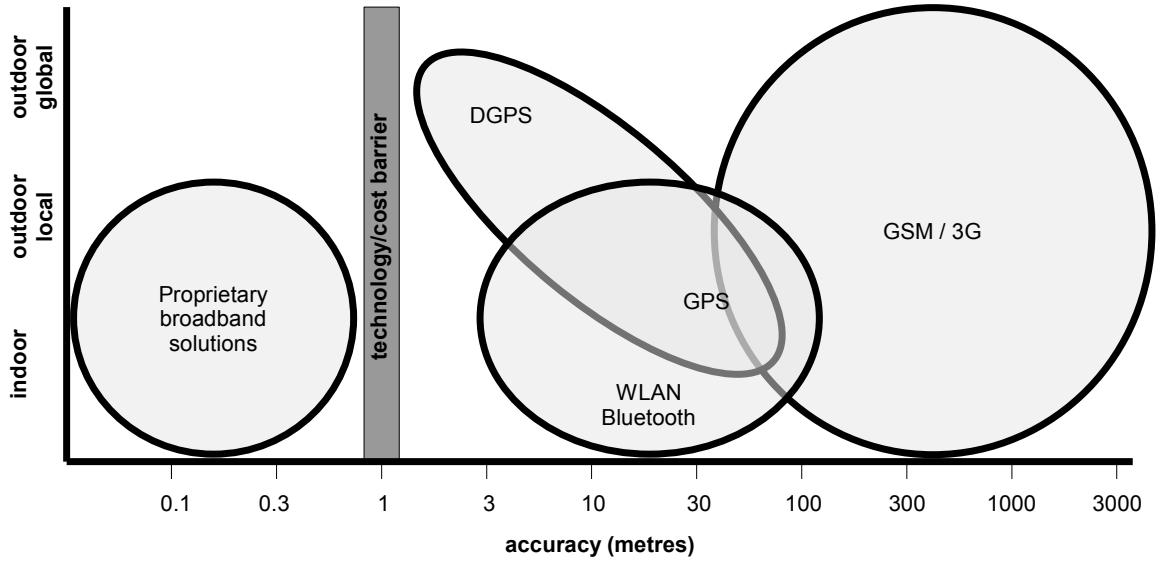

Figure 5.3 - Accuracy of various positioning techniques, adapted from Vossiek et al. (2003, p 221).

In order to determine the location of each user within a wireless network several techniques can be used. While some techniques require specific infrastructure, the triangulation method can determine location as a by-product of the generic networking service (Meunier, 2004). Triangulation locates a user by measuring the strength of the signal received from each transmitter and processing this data to determine the most likely position within the network (Figure 5.4). A minimum of three transmitters are required for triangulation, however the accuracy increases with additional transmitters. A greater number of antennas also increases the wireless reception coverage, providing users with the flexibility to explore a larger area.

While it is possible to locate users within an established wireless network, the time and cost of establishing such a network in an outdoor, rural environment is no small undertaking as each transmitter requires additional hardware to operate, including; a power source and mast or tripod (Vlahakis et al., 2002). When combined with the need to accurately locate the position of the antennas and provide sufficient power to run the network, it is not a feasible solution within a remote rural landscape.

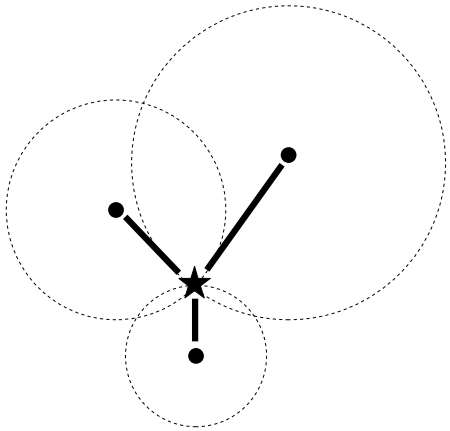

Figure 5.4 - Triangulation of a mobile users position within a wireless network, adapted from Hightower & Borriello (2001, p 2).

The area of application for this research (discussed in Chapter 4) is well suited to the use of Global Navigation Satellite System (GNSS). GNSS is the combined term used to describe various satellite navigation systems including Global Positioning System (GPS), GLObal NAvigation Satellite System (GLONASS), Galileo and other future positioning systems (Questex Media Group, Inc, 2005). For the purpose of this research GPS has been selected for determining the position of the users due to its maturity and availability of suitable hardware.

Each roaming person would have a small GPS receiver collecting location information from the GPS satellite constellation. A base (or reference) station would transmit correction data via the wireless network to each of the roaming users. The raw GPS data and correction data would be processed by each client, providing their position with an accuracy of approximately one metre – more than sufficient for the purposes of a rural, outdoor AR application where augmented graphics are some distance from the user (Thomas et al., 2000) and given the accuracy of most ICMs, locating a environmental asset (such as a tree plantation) with such an accuracy would have little effect on the result.

As discussed in 3.2.2, there are a variety of methods for determining the orientation of a users head. Devices that can accurately track head rotation are required as small rotational errors are noticeable when visualizing distant objects. The size and robustness of the orientation device is also important as it will be attached to the AR display and located on the users head.

Suggested device and specifications:

Location: For each roaming user a NovAtel *SUPERSTAR II*™ receiver is required at AUD$270 per unit. These GPS receivers are small (46x71mm) and consume less than 1 Watt while providing a positional accuracy of 1 metre or less when combined with a DGPS base station to transmit correction signals at a cost of AUD$1600.

Registration: InterSense *InertiaCube3* provides 3DOF tracking with an angular resolution of 0.03° and RMS accuracy of 1° for yaw and 0.25° for pitch and roll. The unit weighs 17 grams, has a minimum latency of 2 milliseconds and costs AUD$3175 (Mindflux (Jasandre Pty Ltd), 2007).

5.2.3 Input devices

The availability of a wide variety of Personal Digital Assistant (PDA) devices (including smart-phones) make them an obvious choice as an input device. The limiting factor of such devices is their small screen size and low screen brightness/contrast which makes it difficult to see in bright outdoor lighting. A PDA with a large screen size and resolution (capable of VGA quality output) would be most appropriate to provide the largest possible screen area making it easier to see and interact with. Other limitations of PDA's include slow and restrictive input methods (ie on-screen keyboard), low bandwidth, reduced storage capacity, limited battery capacity and slow computing speeds (Gulliver, Serif & Ghinea, 2004). Some of these limitations are negated if the device is treated as a thin client (connects to a remote computer via a wireless network).

While there are video-out cards capable of being attached to the Secure Digital Input Output (SDIO) interface of a PDA, the computational and video rendering capabilities of current PDAs are inadequate for AR. Two alternatives exist to overcome this issue. Firstly, the AR-PDA (3.4.2) method of using a remote server for rendering the augmented graphics could be adopted. This approach has been tested in a single user instance but may have shortcomings when adopted in a multi-user environment where network traffic and computational requirements of the server are high. Secondly, an additional computation device could be carried by the roaming users to render and deliver the images to be displayed in the HMD. This approach has been adopted in the majority of AR systems and while it burdens the user with additional weight, it provides the most robust solution. A device such as the fit-PC (fit-PC, 2008) would be perfectly suited to this task due to its small size, weight and multitude of USB ports and wireless connectivity.

Handheld gaming platforms could provide an alternative to a PDA. Sony's Playstation® Portable (PSP®) (Figure 5.5) is an integrated portable entertainment system predominantly targeted at gaming (Sony Computer Entertainment America Inc, 2008). The PSP® has built-in Wi-Fi allowing it to connect to wireless networks, although at the time of writing, the PSP® only supported the slower 802.11b Wi-Fi connection (11 Mbits/sec). With dimensions of 17x7.5x2.2cm, a 11cm LCD screen and weighing less than 300 grams it could be an alternate device for user input. The limitation of the PSP® is the minimal input control, based on a series of individual buttons rather than a touch-screen as on PDAs.

Figure 5.5 - Sony's handheld entertainment system, the *Playstation*® Portable (PSP) (source: Colourful Zone (2008)).

A potentially novel method of interaction with interfaces displayed in the HMD is the Nintendo® *Wii* entertainment system. The Wii remote (Figure 5.6, right) uses accelerometers and infrared detection to sense linear motion in three dimensions as well as tilt. An optical sensor located in the gaming console can determine the pointing direction of the remote. In addition, the Nunchuck (Figure 5.6, left) can be attached to the Wii remote, allowing alternative interaction through the analogue stick and buttons, similar to a gaming joystick. The combination of both devices allow physical gestures in combination with button presses to control games and other activities available through the Wii console.

Figure 5.6 - The Wii entertainment system from Nintendo® with the Wii remote (right) and Nunchuck (left) (source: Revolution Report (2006)).

While the PSP® has the potential to be used as a non-immersive AR platform or an input device, the innovative controllers of the Nintendo® *Wii* has the potential to provide users with simple methods of interacting with User Interfaces (UI) that are displayed in the HMD. Both systems are capable of running Linux (Mo, 2008; WiiBrew, 2008) and could therefore support several of the AR software libraries (see section 3.5).

Suggested specifications:

A HP iPAQ 200 Enterprise Handheld with dimensions of 75.4x17.5x133.9mm weighing 190 grams is provided as a suitable input device for the purpose of the theoretical AR system. It has a 624MHz processor, 128MB SDRAM, 4" Transflective Thin Film Transistor (TFT) 640x480 pixels, 65k colour display. The device has both SDIO and CF memory card expansion slots, allowing gigabytes of data to be stored (rather than transmitted via the network). The device also supports 1 bit SDIO, allowing other devices to be connected. It has a variety of wireless connectivity options Infrared, Bluetooth and WiFi 802.11b/g. Battery life is dependent on screen brightness and use of wireless communications, exceeding several hours at a minimum. The unit would come with the Windows® Mobile® operating system and cost AUD$599 (Hewlett-Packard Development Company, 2008).

Fit-PC (fit-PC, 2008) as the portable graphic processing engine and wireless data transfer. This PC is pre-installed with (Gentoo and Ubuntu) Linux. It has 512MB of memory, 802.11b/g wireless connectivity, 3 USB ports and comes with an upgradable 60GB hard drive for storing data and weighs approximately 380 grams. In addition, this PC runs on 4-6 Watts of power which would require a minimal battery to run.

5.2.4 Networking

The network used to link the various hardware components would be wireless and use the 802.11x wireless protocol (Wi-Fi) (IEEE Computer Society, 2003). This protocol provides a set of standards for Wireless Local Area Networks (WLAN) and has undergone various amendments to improve its range and speed with the 802.11g modulation being the most recent (and backwards compatible with 802.11b). The various amendments to the 802.11 protocol have resulted in increased security and higher data transfer rates with the net throughput of the 802.11g modulation being 24.7 Mbits per second, with an indoor range of approximately 30 metres, while outdoor coverage can exceed kilometres with appropriate antennas (Wi-Fi Alliance, 2008). The wireless network would be used to transfer a variety of data from the computational platform (5.2.5) to the PDA (5.2.3) for display and interaction and the roaming input devices along with correction data for the GPS devices.

Suggested specifications:

Any number of omni-directional wireless antennas would be suitable for this application. A HyperGain® HG2407MGU antenna with a gain of 7dBi is compact and weatherproof and capable of transmitting a wireless signal several kilometres – more than sufficient for this research. The antenna also has sufficient vertical coverage (Figure 5.7, left) to compensate for elevation differences found in the area of application (Chapter 4). With its magnetic base the antenna would be attached to the top of the vehicle and be connected to the computational platform (laptop).

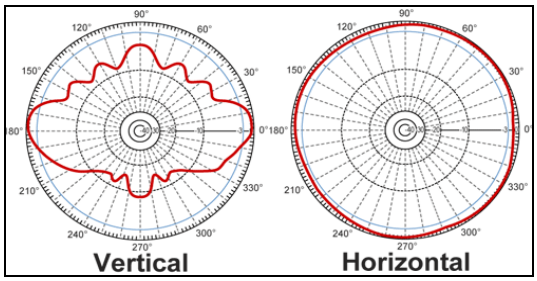

Figure 5.7 - Antenna patterns for the HyperGain® HG2407MGU omni-directional antenna (source: Hyperlink Technologies, Inc (2008)).

5.2.5 Computational platform

The central computational platform (server) serves a variety of roles within the AR system. This includes data server (5.3.4), wireless network hub (5.2.4) and data processor for the registration and tracking devices (5.2.2) and model processing. Many of these functions will be undertaken simultaneously, dictating the requirement for a 'high specification' computer with substantial Random Access Memory (RAM), processing power and ample storage capacity.

To maximise system portability, a laptop computer would provide the best solution. The laptop would be positioned in close proximity to the wireless network antenna. The weight and robustness of the laptop is therefore not a great issue, as there is no need for the mobile user(s) to carry it. The compromise between battery capacity and performance is a factor in any mobile AR system (Dahne & Karigiannis, 2002). Given the intensive computational requirements the computer will be set to run on full power, resulting in higher than normal battery consumption. Dahne & Karigiannis (2002) suggest a minimum running time of two hours, which could be provided through an additional battery for the laptop. The other alternative is to connect the laptop to an auxiliary battery (such as the vehicles battery), through an inverter, potentially extending the battery life for many hours.

The predominant role of the computational platform is to generate the augmented graphics to display through the HMD. Using input from the registration and tracking devices (5.2.2), the AR software (5.3.2) will generate the augmented graphics and stream them back to each HMD for display. The system must be capable of generating graphics for several HMD's simultaneously to create a multi-user AR system.

Screen size and resolution of the laptop is important as it will be used for disseminating various graphics including an evaluation interface and viewing the location of each user and what they are viewing. The addition of a wireless mouse would enable the system coordinator to interact with the laptop more efficiently.

While solely using the PDA would increase the portability of the AR system, such devices do not have the necessary computational requirements for complex modelling and visualization tasks (Rosson & Carroll, 2002). Therefore, in addition to the central server, each roaming user requires access to a suitable processing platform to generate the relevant augmented graphics. The approach taken by (Piekarski & Thomas, 2003b) for the Tinmith AR system would provide a comfortable and affordable solution to deliver the necessary computational power for each mobile user and provide SVGA output to the HMD.

Suggested specifications:

Server: For less than AUD$6,000, Alienware (Alienware, 2008) are capable of delivering a high-end laptop with sufficient resources, including; 2GB RAM, dual 100GB hard drives (RAID (Redundant Array of Inexpensive Drives) level 0 (striped)), dual 512MB graphic cards, with Wi-Fi, Bluetooth® and gigabit ethernet networking capabilities.

Roaming user: A mid-range laptop (less than AUD$2000) would provide sufficient capabilities, while being reasonably light weight (less than 3 kilograms). The core components of the laptop could be extracted and reassembled, as per the Tinmith system (3.5.5), however it would also be viable to carry the laptop in a backpack.

5.2.6 Other

The other major requirement is a reliable power source for running the laptop and charging batteries for the various hardware devices. Visualization of rural landscapes is typically undertaken in 'remote' locations, far from reliable power supplies. Because a vehicle would be used to transport the AR equipment to the site, this requirement would be implemented by connecting a power inverter to a vehicle by way of the cigarette lighter. This method would require the vehicle to be fitted with an additional car battery, ensuring the primary battery was not run down to a level which prevented the vehicle from being started again.

Another significant hardware component is a suitable headset to allow users to communicate with remote and distant users. Due to other hardware being worn on the head (including the display, GPS antenna and registration device), a behind-the-head (rather than over-the-head) headband would be ideally suited. The addition of a microphone will enable users to communicate orally and record notes and messages.

Suggested specifications:

Inverter: For less than AUD$100 a 150W 12VDC to 230VAC inverter capable of recharging the batteries of the laptop computer, the PDA and those in the HMD could be purchased.

Headphones: AUD$100 will purchase the Koss CS 80 communications headset.

5.3 Software and data management

Software covers everything from the operating system through to the software used to process the orientation parameters and generate the appropriate graphics. The proliferation of Open Source software since 2000 has broadened the diversity of software and operating systems. The various software licensing models have promoted an evolution of software, allowing it to be freely distributed, with its source code. The various licensing models allow anyone to alter and develop the software to suit their needs and, if they wish, incorporate their alterations and improvements back into the original (source) product thereby improving it for everyone.

With the current availability of high quality Free and Open Source Software (FOSS) it is possible to build an immersive mobile outdoor AR system without relying on costly software. In addition, open standards (such as Open Geospatial Consortium (OGC)) would be used for data storage and manipulation. This approach would ensure improved system functionality through continuing software and standards development, allowing the system to be expanded or integrated with other systems with minimal alterations. Each major software component is described in the following sections. Suggested solutions are made for implementing a robust mobile augmented reality system.

5.3.1 Operating system

The operating system forms the foundation on which all the individual hardware and software components together are integrated into a cohesive system. An essential aspect of any operating system is the availability of relevant hardware drivers that provide an interface for communicating with various hardware components ie HMD, orientation sensors and input devices.

Linux is capable of running on most computing hardware devices ranging from PDA's, mobile phones and gaming platforms through to large computing clusters. Its increasing popularity has resulted in a plethora of open source utilities, drivers and applications being ported or specifically created for Linux, making it a viable alternative to the commonly used Microsoft Windows® operating system.

There are a variety of open source operating systems available however Linux is the most recognised. The continuing development and improvement of the Linux kernel has seen a proliferation of Linux distributions (an integrated package of software applications and operating system), the majority of which can be viewed and compared on Distrowatch.com (2008). While there are hundred's of individual Linux distributions, many are variations (additional or reduced software applications, compiled differently etc) of larger distributions ie Ubuntu (Canonical Ltd, 2008), Fedora (Red Hat Inc, 2008), Debian (SPI, 2008), openSuse (Novell, Inc, 2008), etc.

Most Linux distributions (or distros) are capable of booting and running from a CD-ROM (DVD or other removable media) making it possible to have a totally portable operating system with all the necessary drivers and software applications for a particular purpose. Given the relative novelty of Augmented Reality (AR) and its reliance on a variety of software libraries and drivers, the ability to carry a complete system on a portable device, insert it into any compatible computing device and begin an AR session is an attractive option.

The current size of portable flash drives (memory sticks) means that almost any Linux distribution can be loaded onto them with sufficient space remaining for saving and editing files. There are several Linux distributions designed for booting and operating from USB memory sticks including SLAX (Slax, 2008) and Knoppix (Knoppix, 2008). SLAX is particularly well developed and has a modular structure that allows additional modules to be installed, increasing its functionality. While this would enable (almost) any computer to be utilised as the computational platform, it would not be optimally compiled for the specific peripherals.

Gentoo Linux (Gentoo Foundation, Inc, 2008) has a user-friendly software management application called Portage (Gentoo Wiki, 2008) which allows users to compile, install and upgrade software (using small text files known as ebuilds) while maintaining the necessary software dependencies. Hundreds of ebuilds exist for a wide variety of Linux applications and it is possible to create an ebuild for other applications (such as ARToolKit).

Suggested specifications:

Gentoo Linux (Gentoo Foundation, Inc, 2008), compiled for the specific computational platform (5.2.5) would be installed on both the server and roaming users laptop. PostgreSQL, University of Minnesota Mapserver, ARToolkit and PostGIS would be installed (with all their required dependencies) to deliver the user interfaces and visualization capabilities. Each of these are explained in further detail in the following sections.

5.3.2 AR software

The purpose of the AR software has been explained in section 3.5. AR software is capable of calculating the position and orientation of a camera by interpreting the visible scene (Billinghurst, Grasset & Looser, 2003) (through the position of markers or other physcial objects including the horizon) or by utilising the input from other orientation devices. The AR software processes the users orientation from the orientation sensors and location parameters being supplied by the wireless network (section 5.2.2) to accurately determine each users position and viewing direction at any given time, ensuring the additional graphics are correctly aligned with reality (captured by video) before being rendered through the HMD.

Both Studierstube (Graz University of Technology, 2005) and ARToolKit (HIT Lab, 2008) have been proven to operate on Linux. Both applications have been released under the GNU General Public License (GNU Project, 2008), allowing modification, development and use without the need for licensing or payment of royalty fees.

Suggested specifications:

Tinmith-evo5 (see section section 3.5.5) would be selected for the theoretical AR system. This software library has been recently applied to urban planning (including the placement of indivudal features such as trees and urban furniture) and is therefore most appropriate. The software runs on Linux, the selected operating system for the conceptual AR system.

5.3.3 Data management

The large quantities of data required for real world AR systems require efficient storage in a common structure (Reitmayr & Schmalstieg, 2003). While many applications rely on flat, file based data storage, Reitmayr & Schmalstieg (2003) has implemented an eXtensible Markup Language (XML) solution with benefits including text-based, human readable files and easy transformation into alternate structures using eXtensible Stylesheet Language Transformation (XSLT). XML solutions have many benefits for navigation applications however, a substantial amount of effort is required to convert data from existing spatial formats ultimately resulting in some loss of the inherent spatial relationships. It is therefore an inefficient methodology for applications incorporating other spatial functionality.

Data would be stored and managed in a spatially enabled Relational Database Management System (RDBMS) providing efficient data storage, querying and analysis. Many of the major database vendors have spatially enabled their databases. Oracle® Express is a free version of their 10g database technology and has support for spatial features. It has several limitations including a maximum of 4GB data storage. MySQL® (MySQL AB, 2008) is a popular open source database which also has support for storing and querying spatial objects, however the spatial industry typically uses PostgreSQL (PostgreSQL Global Development Group, 2008) and the PostGIS (Refractions Research, 2008a) extension.

PostgreSQL is a robust open source RDBMS (PostgreSQL Global Development Group, 2008) and Refractions Research (Refractions Research, 2008b) has developed the PostGIS (Refractions Research, 2008a) extension that spatially enables the database, providing methods for interacting, manipulating and analysing spatial data (geometries). PostGIS has recently gained compliance from the Open Geospatial Consortium, Inc® (OGC) (Open Geospatial Consortium, Inc, 2008d) which ensures the product complies with OpenGIS® (Open Geospatial Consortium, Inc, 2008d) standards. Ensuring systems are built using open standards enables them to be interoperable with other standards-based systems (Open Geospatial Consortium, 2003b).

All the base data (including extents of groundwater aquifers, hydrological data, current land use, modelled land use scenarios and associated water use parameters) would be stored in the database. Other data including that used to calibrate the model and scenarios generated by the model would also be stored in the database. Due to the current short-comings of storing raster data in databases (including Digital Elevation Model (DEM), aerial photography and satellite imagery), such data layers would be stored as files on the laptop with their extent and other contextual information stored in the database to enable some rudimentary spatial comparisons.

Where necessary, data will be extracted from the database and transformed into the appropriate format using XML and XLST for the specific application.

Suggested specifications:

The PostgreSQL (PostgreSQL Global Development Group, 2008) database would be used, spatially enabled using the PostGIS (Refractions Research, 2008a) extension. The combination should provide a robust and proven solution for storing spatial data, with the ability to query (spatially), select and output data in a variety of formats including Scalable Vector Graphics (SVG) and Geographic Markup Language (GML) allowing it to be accessed and used by the AR software.

5.3.4 Data delivery

There are various methods that could be used to deliver data to the client(s). The preferred method would be to deliver and render the data using OGC (Open Geospatial Consortium, Inc, 2008d) standards including Web Map Service (WMS), Web Feature Service (WFS) and Style Layer Definition (SLD). There are several open source software applications capable of doing this. While some allow retrieval and delivery of spatial data others allow for editing of data.

Spatial data is required for two purposes in the AR system including: rendering the augmented graphics for display in the Head-Mounted Display (HMD); and display in the user interface on the Personal Digital Assistant (PDA). Rendering augmented graphics requires the data to be 3-D to allow height to be appropriately displayed.

The PDA provides the only means for the user to interact with the application, data and scenarios. The various user interfaces could be written using any number of Internet-based programming languages (ie Java, PHP, Ruby on Rails etc) allowing them to be implemented through the Internet browser on the device, communicating with the computational platform (section 5.2.5) via the wireless network (section 5.2.4). The device is therefore a thin client, requiring minimal processing power and bandwidth to function.

The core of the user interface can be implemented through an Internet-based mapping application. Every GIS vendor has their own map server and most of them are capable of delivering data using OGC standards however they are generally restricted to displaying proprietary data formats. The University of Minnesota has created an open source, Internet mapping application called MapServer (http://mapserver.gis.umn.edu/). This software has evolved to become a robust and reliable application capable of rendering maps from a variety of spatial data formats, including PostgreSQL (section 5.3.3) while allowing user interaction and integration with other applications.

Suggested specifications:

UMN MapServer (Mapserver, 2008) would be used to deliver the spatial data to the roaming input devices (5.2.3). A custom interface would need to be implemented to accommodate the small form factor of the PDA device (discussed in further detail in 6.4.3).

5.4 System summary

Various alternatives for each of the required components have been outlined above with a specification provided for a cost effective option that delivers the necessary requirements. Based on the suggested components, the total cost of the AR system described (for a single user system at the time of writing) would be approximately AUD$22,000. To create a multi-user system, each additional roaming user would require a HMD, PDA, roaming computing platform and GPS receiver, costing approximately AUD$13,300. In addition, programming and technical expertise (excluding data preparation and loading) would be required to integrate the components into a cohesive system. It is anticipated that this would be in the vicinity of 4-6 weeks of effort for a knowledgeable person and add a once-off AUD$20,000-$30,000 to the system cost. A single user system would therefore cost between AUD$40,000-$50,000. While this seems initially expensive, the commercial version of the Tinmith system for instance costs around AUD$100,000.

Given the COTS approach to the conceptual systems, individual components of the system could be utilised for other purposes when not being utilised in the AR system (such as the PDA and laptop computer), thereby distributing the costs. The cost of each roaming user could also be offset if users supplied their own laptop and/or PDA (feasible due to the large ownership (either personal or company) of PDAs and laptop computers, especially in government departments which is a key audience for such a system). Provided the devices had Wi-Fi capability, they could be utilised, with the addition of a HMD, GPS receiver and suitable backpack. In conjunction with configuring the HMD and GPS receiver on the supplied hardware, the appropriate AR software would also need to be installed and configured prior to use.

Regardless of the source of the roaming hardware, Figure 5.8 shows the linkages between the hardware components for the conceptual mobile augmented reality system. The PDA is used to send and receive data to the remote laptop (from the display, registration and tracking devices) via the wireless network as indicated by the dashed lines. All this data is controlled by the Tinmith-evo5 AR software. The user interacts with the system through the web browser interface which communicates via the wireless network to UMN Mapserver, as represented by the solid lines.

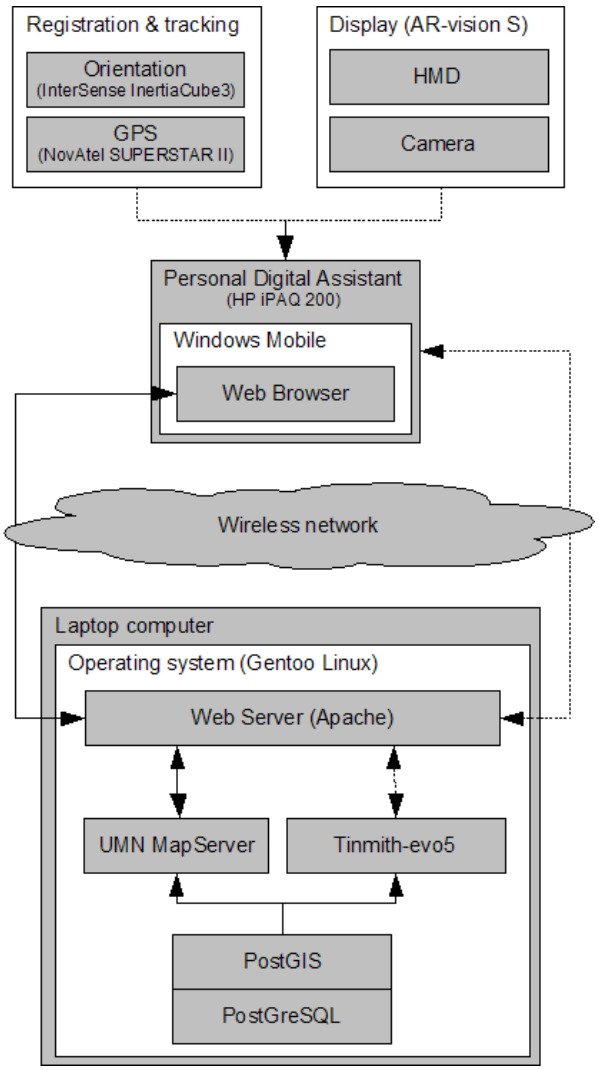

Figure 5.8 - Architecture and information flow of described AR system.

5.5 Chapter summary

The application domain ultimately dictates an 'ideal' AR system. The conceptual mobile immersive outdoor AR system described in this chapter has utilised the review of existing systems (Chapter 3), answering the question, “What components would a suitable AR system be comprised of?”. The system (theoretically) allows multiple users (the actual number being dependant on the capacity of the wireless network and centralised computational platform) to interact with, interrogate and visualize land use scenarios at various scales within a wireless network.

Commercial AR systems do exist however they are predominantly targeted at viewing static information resources such as technical manuals in-situ, rather than immersing the users in a real-time, augmented environment. While the conceptual system has been created for a specific application, many of the individual components could be adopted for other applications.

The complexity of individual components required for a mobile outdoor AR system are very low, however the complexity is introduced when integrating the individual components into a cohesive system to provide a seamless and realistic AR experience. The mobile immersive outdoor AR system described in this chapter is a purely conceptual. A substantial amount of technical effort would be required to combine the individual components, at both a physical and systems (or programming) level. While each of the components have been thoroughly tested in their own right by the manufacturers, the reality of using them in an integrated system as proposed is untried and untested.

The following chapter describes the development of specific user interfaces suitable for land managers to develop, explore and visualize land use scenarios and their impacts within a mobile outdoor AR system. To provide a context for developing the user interfaces the Bet Bet catchment of central Victoria has been selected. Extensive data collection and monitoring has been (and continues to be) undertaken in this catchment, providing access to sufficient resources for user interface mock-ups.

Chapter 6

User Interface development

6.0 Chapter overview

This chapter describes the development of several interfaces interacting with landscape models within an AR context and is central to answering the research question posed in Chapter 1. This chapter is divided into three main sections. The first section outlines various usability engineering design methods currently used for developing computer applications and their interfaces. After a brief overview of techniques a specific method is chosen for developing the user interfaces for the purpose of this research.

The second section describes the development of the interfaces, following the process of the chosen methodology. This section includes prototypes of the user interfaces which incorporate the required requirements determined as part of the process. The final section describes the need for usability evaluation and its importance in determining the usefulness of user interfaces with respect to a variety of factors. The actual evaluation of the interfaces is documented in following chapter.

6.1 Introduction

A User Interface (UI) consists of "all the hardware, software, screens, menus, functions and features" (Shelley, Cashman & Rosenblatt, 2003, p 304) affecting how users interact with a computer. The UI is therefore the most important aspect of any computer system, determining its functionality and how users ultimately perceive its effectiveness (Stone et al., 2005). An understanding of Human-Computer Interaction (HCI) (the relationship between computers and their users) and design principles are required when designing user interfaces (Shelley, Cashman & Rosenblatt, 2003).

UI design is the seamless integration of content organised by navigational and interactive controls which allow a system to be navigated and interacted with (Khan, 2005). Good interface design is the combination of ergonomics, aesthetics and interface technology that results in an "easy to use, attractive and efficient" (Shelley, Cashman & Rosenblatt, 2003, p 310) interface which engages users and allows them to complete a specific task (Stone et al., 2005). The best user interfaces are those that are not noticed because they operate as the user expects them to (Shelley, Cashman & Rosenblatt, 2003; Stone et al., 2005). Shelley, Cashman & Rosenblatt (2003) list eight guidelines for interface design: focus on basic objectives; easy to learn and use; promote efficiency; access to help; minimise data input problems; provide feedback; attractive design and layout; and, using familiar terms and images.

The information displayed to the user and the functionality offered through the user interface determines the design, interaction methods and overall effectiveness of any computing system (Khan, 2005; The Open University, 2008). The underlying principle of user interface design relies on mapping user input to a computing output through an appropriate interaction metaphor (Billinghurst, Grasset & Looser, 2003), as shown in Figure 6.1. Metaphors allow new concepts to be taught by applying terms already familiar to the user (Dix et al., 1998).

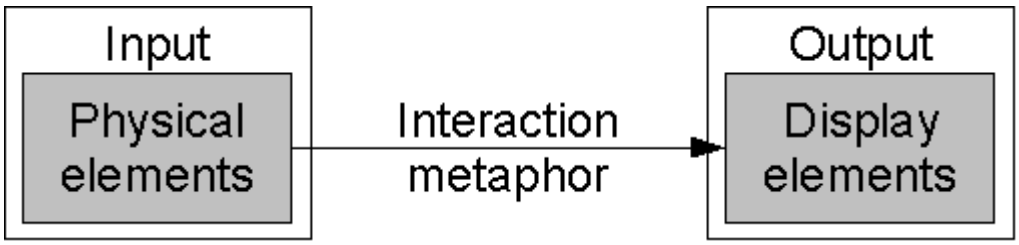

Figure 6.1 - The key interface elements, adapted from Billinghurst, Grasset & Looser (2003, p 17)

User interfaces for AR are still considered as an emerging field and as such are regarded as being immature (Wang & Dunston, 2006). Challenges posed by the inherent limitations within AR systems are well documented (Azuma et al., 2001; Bell, Feiner & Hollerer, 2001; Billinghurst, Grasset & Looser, 2003; Thomas et al., 2000), and many of these make it difficult to create usable and effective user interfaces. To date, developers of AR systems have been predominantly focused on the technical integration of the necessary hardware and software, with minimal attention being given to designing user-centered applications tested by formal usability evaluation techniques (Wang & Dunston, 2006).

According to Billinghurst, Grasset & Looser (2003), designing UI's for AR is dependent on selecting appropriate input and output devices and linking them through an appropriate metaphor. This ultimately creates a UI that is easy to use and facilitates user learning while remaining responsive and appropriate for the given task. There are many interface design principles for two-dimensional (2D) and three-dimensional (3D) interfaces, and while some are applicable to AR, few have been explicitly developed for AR environments (Billinghurst, Grasset & Looser, 2003). Billinghurst, Grasset & Looser (2003) outline the four stages through which new interface mediums evolve:

1. Prototype demonstration;

2. Adoption of interaction techniques from other interface metaphors;

3. Development of new interface metaphors appropriate to the medium; and

4. Developed of formal theoretical models for predicting and modelling user interactions.

Billinghurst, Grasset & Looser (2003) goes on to argue that AR interfaces have barely progressed to stage 2, stating that most AR systems developed provide intuitive methods for viewing 3D data but provide limited (if any) support for the creation or modification of content displayed. New interface metaphors for AR are being explored, based on real-world objects, known as Tangible User Interfaces (TUIs) (Ishii & Ullmer, 1997). Such interfaces are moving into the third stage of interface evolution.

6.2 Usability engineering design

Usability engineering is defined as “the concepts and techniques for planning, achieving, and verifying objectives for system usability” (Rosson & Carroll, 2002, p 14). It was originally applied only to user interface design however it has since been applied to various other aspects of software development (Rosson & Carroll, 2002) by considering the user requirements, collaboration, activities, tasks, work flows and context of usage (de Sa & Carrico, 2006). Adopting a usability engineering approach should ultimately optimise the usability of a computer system (Stone et al., 2005) through the provision of “strategies, guidelines and procedures” (de Sa & Carrico, 2006, p 695).

Designing software is a poorly structured activity and often the final state or goal is not known (Carroll, 2000). Carroll (2000) defines six design issues which make it difficult to develop software, they are: incomplete description of the problem to be addressed; lack of guidance on possible design options; the design goal or solution state can not be known in advance; trade-offs among many interdependent elements; reliance on a diversity of knowledge and skills; and, wide-ranging and ongoing impacts on human activity. To assist software designers overcome these issues a wide variety of usability engineering design approaches have been created and applied to information systems development.

User-Centered Design (UCD) (sometimes referred to as Human-Centered Design (HCD)) is a design approach which focuses on users and the tasks they are to perform through the planning, design and development phases for a product or system. UCD is an internationally recognised approach (International Standard ISO 13407) involving four core activities: specifying the context of use; specifying requirements; creating design solutions; and evaluating the designs (G. Andrienko et al., 2006; Stone et al., 2005; Usability Professionals' Association, 2008).

Several authors (Francis & Williams, 2007; Norman, 2004) argue that Activity-Centered Design (ACD) is a superior technique to UCD as it analyses and focuses on the task to be accomplished rather than the human requirements specifically. Norman (2004) states that designing for the activity results in other factors being considered and designed for which would have otherwise been ignored using a UCD approach.

Carroll (2000) states that the standard design methodologies (those outlined above) are ineffective in addressing the six design issues and offers Scenario-Based Design (SBD) as an alternative. Rather than attempt to control the complexity of the design process by filtering information and de-constructing problems into small tasks, SBD attempts to exploit the complexity of design by gaining a deep understanding of the problem from various perspectives (Carroll, 2000). The SBD methodology requires all aspects of the environment (physical, technical and social) to be evaluated to understand the successful work practices and identify current limitations (Nigay et al., 2002). This is achieved through the development of user interaction scenarios which underpin the design process. Scenarios are described as a:

> *...modest but pervasive element of design practice...understanding peoples current needs and preferences, envisioning new activities and technology, designing systems and software, and evaluating and drawing general lessons from systems as they are developed and used. (Carroll, 2000, p 13).*

While SBD shares many features of other usability engineering techniques (including user interaction scenarios), SBD uses them to unify the complete design process, building on them through each of the design phases, to provide insight into the users requirements (Carroll, 2000; Rosson & Carroll, 2002). Another common element between many of the methodologies is iterative design.

Iteration is a way of ensuring new information and knowledge gained through the design process is considered and incorporated where appropriate (Stone et al., 2005) and is a particular focus of the SBD methodology. As a result the SBD methodology has been selected as the basis for designing and prototyping the proposed user interfaces for a mobile AR system targeted at landscape visualization.

In many cases, the design approach adopted by the developers of the reviewed AR systems (section 3.4) is not stated, however (Nigay et al., 2002) have found field study and Scenario-Based Design techniques useful for designing the MAGIC (section 3.4.4) AR application, specifically related to archeology. While scenario's provide a way of engaging users to determine the actual and potential activities of the system (Nigay et al., 2002), Pedersen, Buur & Djajadiningrat (2003) have adopted an approach known as 'field design sessions' to develop their AR interfaces. Rather than solely relying on user interviews and familiarisation with the tasks, the SBD approach is extended by undertaking an analysis, synthesis and evaluation of tasks in the environment where the AR system is to be implemented, with the person(s) who typically undertakes the task. The field design method allows system designers to experience the full context of eventual system use, rather than relying solely on abstractions. As Pedersen, Buur & Djajadiningrat (2003) state, one can not understand the environment without the help of the user and one can not understand the users work practices and problems when outside the actual work environment.

While the field design session method is particularly relevant to tasks involving manipulation of physical objects (such as frequency converter maintenance as described in Pedersen, Buur & Djajadiningrat (2003)), the approach is less applicable when designing a system for manipulating conceptual objects (such as creating and manipulating land use scenarios as described in this research) because the user has no physical attachment with the objects, apart from being physically located in the environment.

6.3 AR system user interfaces

Table 6.1 shows the functionality provided by each of the AR systems evaluated in Chapter 3. the table is divided into four main sections. The first represents the fixed interface elements such as menus and position information which are displayed in the augmented space. The second shows the types of augmented graphics presented to the user. The interaction methods are represented in the fourth section with the final section highlighting additional capabilities.

		Interface elements						Augmented graphics						Interaction				Capability			
		Position details	Navigation target	Pitch / roll display	Menu(s)	Compass rose	Camera metrics	Feature wireframe	Selection areas	Navigation aids	Annotation	Place / edit objects	Occluded objects	Ray intersection	Haptic gloves	Controller	PDA / Tablet	3rd person view	World-in-miniature	Communication	Intelligent agent
System name	ANTS									X	X						X				
	AR-PDA										X		X				X				X
	ARCHEOGUIDE	X			X								X				X		X		
	MAGIC	X			X								X				X		X	X	
	MARS				X					X	X		X				X		X		
	Tinmith	X			X	X	X	X				X	X		X			X	X		
	Tourist Guide	X	X	X	X			X	X	X		X	X	X			X				
	WalkMap	X				X									X				X		
	Wearable AR			X		X										X					

Table 6.1 - Functionality provided by the AR researched systems. The absence a feature does not mean it is not available in the particular system, but rather no explicit mention was made in the references. (X represents that the capability can be viewed as either fixed or user oriented).

There are several interesting observations to come out of Table 6.1. Firstly, several augmented reality systems don't display any augmented graphics (namely WalkMap and Wearable AR). The table also highlights that interface elements within the augmented viewing area are not required to deliver an interactive augmented experience, or they are difficult implement and provide appropriate methods of interaction with.

The majority of the systems researched use a PDA or Tablet computer for user input. Only two systems (Tinmith and Tourist Guide) allow users to place virtual or augmented objects into the environment. Tinmith is the only system that allows users to select and edit virtual objects. Surprisingly few systems display augmented annotations. Annotating objects would appear to provide a computationally simple method of highlighting an object to the user, provide the position of the object was known in advance, something that is only typically the case in urban environments.

6.4 Scenario-Based Design (SBD) methodology

SBD attempts to manage the inherent complexity of design by what Carroll (2000) calls "concretization" rather than the typical design process of "abstraction". This is done using scenarios which are concrete (real or actual) or fact-based (based on reality) stories about the use of a product. Scenarios are somewhat of a contradiction: based on fact, but actually fiction; tangible yet flexible; allowing all stakeholders to access, explore and manipulate them to explore "what-if" possibilities to determine the best possible design outcome (Carroll, 2000).

According to Carroll (2000, p 255), scenarios "...must raise and illuminate key issues of usability and usefulness or suggest and provoke new design ideas". The SBD methodology allows scenarios to be created prior to system development and are used to manage trade-offs between various requirements of the system (Rosson & Carroll, 2002). Rosson & Carroll (2002) suggests three core components of the SBD methodology: analyzing the requirements of the users; designing the system and interfaces using scenarios; and prototyping and evaluating the resultant system. Figure 6.2 represents these core components as an information flow.

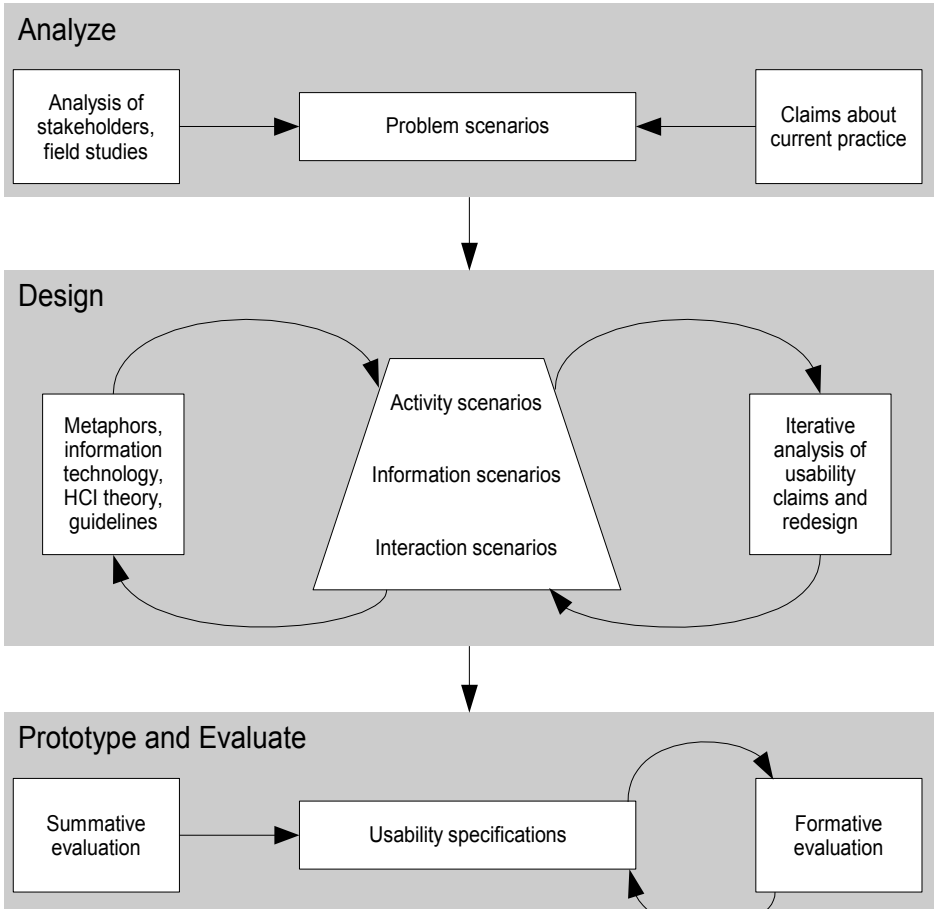

Figure 6.2 - Overview of Scenario-Based Design method, adapted from Rosson & Carroll (2002, p 25).

A theoretical background for each of the three core aspects (analyze, design and prototype and evaluate) of the SBD methodology is provided under each of the following sub-sections. For the purpose of this research, an adapted version of the SBD methodology was undertaken. Unless otherwise stated, the author's previous experience with land resource managers (including (Bluml & Feuerherdt, 1999a, 1999b) amongst others) and involvement in the development of spatial data layers (including hydrogeological, soil, present and alternative land use scenarios) for ICMs will be utilised in place of physical observations and interviews.

Orland, Budthimedhee & Uusitalo (2001) outline a system that supports shared exploration of environmental scenarios that incorporate real time interactivity between models and spatial data, the incorporation of qualitative and quantitative decision aids and where necessary voting, ranking and group interaction. The focus of this research is the application of AR to landscape planning and specifically the interfaces through which users would interact with a landscape model. As a result, this research assumed that an AR system was appropriate (and wanted by the users) for visualizing and altering land use scenarios. The SBD methodology was therefore applied to the development of the user interfaces and not the complete AR system. The detailed development of the user interfaces for developing and exploring land use scenarios is provided in section 6.4.2.2.

6.4.1 Analyse requirements

This component of the SBD framework analyses the needs of the users in the context of the proposed project, resulting in a requirements specification which lists the minimum functionality the system must deliver. The users, their needs and work practices must be understood in detail to deliver a successful system. The analysis component involves determining the activities to be undertaken by the system (typically through Hierarchical Task Analysis (HTA)), specifying the information and tools required to undertake the activities (using ethnography), and determining the various roles of the system users (Rosson & Carroll, 2002).

Interaction principles depend on an understanding of the users rather than the technology (Dix, Finlay, Adowd & R. Beale, 1998). Determining the users or stakeholders of a system is important, as each has their own perspective on what the system is and how it should be used. Under a thorough SBD approach, analysis of stakeholders is typically done by interviewing or photographing stakeholders undertaking their role using current practices and techniques. For the purpose of this research, past experiences of the author (as previously documented) will be used to generate the stakeholder profiles. Each profile summarises the generic characteristics of the stakeholder including their background, expectations of the proposed system and Information Technology (IT) preferences. A stakeholder diagram is also created showing the relationships between the different stakeholder groups. These profiles form the basis for generating hypothetical stakeholders which are used in the scenarios.

Once the stakeholders have been determined their current work practices are analysed. This is done using Hierarchical Task Analysis (HTA), where tasks and sub-tasks are identified and organised into a hierarchy. Specific artifacts used to achieve the work practices will be known. The purpose of each artifact is classified into information and/or procedures. Analysis of all this information results in a summary of themes which highlight underlying patterns across the various stakeholders, activities and artifacts. The problem scenarios are critically informed by the themes (Rosson & Carroll, 2002).

6.4.1.1 Stakeholder profiles

For the purpose of this research five main stakeholder groups were identified (see Table 6.2). Each stakeholder group has a varying understanding and interest in catchment modelling, their output and implementation implications.

Stakeholder	*Profile*
Natural resource scientist	Background: Extremely proficient in the use of computing applications. Able to integrate various software applications by coding their own programs. Can conceptualise complex natural resource systems with input from other natural resource scientists (hydrogeologists, hydrologists) to model the relationships and interactions between the various elements. With the assistance of spatial scientists can create spatial layers that represent the elements for input into the model. modellers also verify the developed model utilising data that was excluded during the creation phase. Expectations: A tool to assist in validating their application and the conceptual models it relies on. Preferences: Want control over all aspects of the application and the ability to make changes to the base (conceptual) data when errors are found.
Extension officer	Background: Good understanding of computers including office software, Internet and email applications. Spend a large amount of time assisting landholders implement practical land use change through government support (grants) and community contacts. Expectations: A system that shows the impact of the on-ground works that have been (and are planned to be) completed and where changes have had the greatest impact. Preferences: Want to visualize individual property data aggregated to a sub-catchment level.
Landholder (farmer)	Background: Minimal computing experience with modest exposure to the Internet and email. Are typically proactive in the local Landcare group, making contributions to the understanding of natural resource processes that affect their region. Landholders are often involved in creating land use scenario visions which assist catchment managers and scientists develop land use scenarios that can be input into models. Farmers, with financial assistance from various government departments, implement land use change based on documented policies. Expectations: A system that enables them to visualize the proposed land use scenarios along with their positive and negative aspects, both natural resource and financial. The system must be targeted at a paddock scale. Preferences: Require assistance to operate and understand the system. Prefer a 'guided tour' highlighting the natural resource issues and various alternative solutions proposed. The interface for inputting alternative land use scenarios must be intuitive and make common-sense assumptions to assist in creating scenarios quickly.

Stakeholder	*Profile*
Community member	Background: General computing experience with regular exposure to the Internet, email and other *Windows®*-based applications. Don't own rural land but have a real interest in its management and off-site impacts. Expectations: A system that allows them to better understand the multitude of factors (environmental, social and economic) that are contributing to land degradation issues. Preferences: A flexible 'guided tour' approach that allows users to pause the presentation and ask further questions and research issues. The ability to visualize one of several 'pre-built' scenarios. The visualizations should show the economic impacts (in relative terms) of changes to the landscape.
Policy maker	Background: Involved in the development of policy relating to setting goals for landscape, catchment and entire jurisdictions. Able to understand and interpret specific scientific findings into general rules applicable to large regions. Use the Internet, email and other *Windows®*-based applications on a daily basis. Expectations: To compare the results of various land use scenarios to aid policy creation. Preferences: Interested in landscape-level implications rather than specific, local management practices. Want to see data aggregated to a landscape scale to help write and implement new policies to resolve local and catchment-scale degradation.

Table 6.2 - Profiles of various stakeholders

6.4.1.1.1 Stakeholder relationships

The stakeholders are not isolated from one another, but rely on input and feedback from various other stakeholders to assist develop, verify or implement a land use or land use scenarios. There is no formal interaction between the stakeholders. Communication takes place through the outputs (such as policy and scenarios) generated by the stakeholders. Policy underpins the whole process, forming the basis for the scenarios, which in turn inform the policies from which they were derived through an iterative process. Once an appropriate scenario has been selected the extension officer is responsible for communicating it to the landholder. The landholder then implements the land use scenario, using the expertise from the extension officer and accessing funding resources provided as part of the policy. While the landholder benefits from the land use implementation, the larger community is the ultimate beneficiary of improved amenity, environmental and (potentially) economic factors. Figure 6.3 depicts the relationships between the stakeholders (Table 6.2) and their outputs.

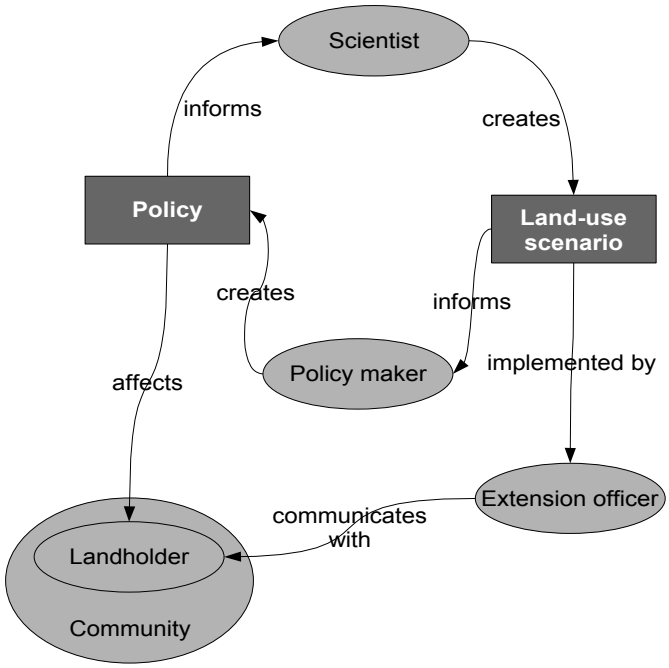

Figure 6.3 - Relationships between stakeholders developing land use scenarios

6.4.1.2 Task documentation

This step documents the typical tasks carried out by the various stakeholders involved. Table 6.3 summarises the various tasks undertaken by each of the stakeholders (Table 6.2) as part of developing, implementing or reviewing land use scenarios.

Stakeholder	*Tasks*
Natural resource scientist	Reviewing scientific literature; conceptualising complex natural resource systems; collating various spatial data layers; building and verifying the integrated model; presenting results to stakeholders.
Extension officer	Interpreting policy and communicating at Landcare meetings; assisting landholders implement practical land use change; reporting land use change implemented.
Landholder (farmer)	Implementing on-ground works; attending Landcare meetings.
Community member	Reading governmental reports about land use change and its impacts; attending Landcare meetings.
Policy maker	Developing policy; reviewing integrated model output; developing policy based on model output.

Table 6.3 - Tasks undertaken by stakeholders as part of land use scenario process

6.4.1.3 Problem scenarios and claims analysis

Problem scenarios depict a use scenario of common practice by describing new activities (grounded by current activities) in a specific problem domain through fictional yet believable and evocative stories. They are developed to reveal aspects of stakeholders and activities that have implications for the design of the application (Rosson & Carroll, 2002). Scenarios can be derived empirically, through observing stakeholders undertaking existing roles and tasks or alternatively through an analytical approach where conceivable scenarios for the proposed system are documented (Carroll & Rosson, 1996). Ultimately, the development of problem scenarios is essentially a creative task (Rosson & Carroll, 2002).

Each problem scenario is suggestive rather than exhaustive and make use of hypothetical stakeholders who have characteristics from a specific stakeholder group. One or more of these fictional characters serve as actors in each problem scenario and assist designers understand the tasks from the perspective of the characters. Stakeholders should be re-used in the various problem scenarios, highlighting relationships between creating the stakeholders and developing a cohesiveness (Rosson & Carroll, 2002).

Scenario development is always complemented by claims analysis which identifies the features of a situation that have an important effect on the actors. Claims highlight trade-offs with a given scenario and are tied to specific artifacts and activities with a hypothesis made about the positive and negative effects of each feature. Claims analysis has several roles in SBD: isolating the most important features of the problem scenarios, highlighting the effects of a particular feature in a different scenario, promoting a balanced view of a situation and, explaining the impacts of a feature on the hypothetical stakeholders. Claims features are anything (object, procedure and other actor) in the problem scenarios that notably affect the experience of the actor. Claims analysis identifies key functionality requirements highlighted in the problem scenarios and assists designers determine the consequences of implementing them. The ultimate goal is to maintain or enhance positive consequences while minimising or removing negative consequences (Rosson & Carroll, 2002).

6.4.1.3.1 Hypothetical stakeholders

Seven hypothetical stakeholders, representing 5 unique roles, were developed for this research. Two stakeholders represent landholders, each with a different perspective on land ownership; one earning a living from it, while the other views it solely as an environmental asset. A hypothetical stakeholder representing a community member with an interest in improving the environment has also been included acknowledging that better management of the environment is the result of collaboration between all members of a community (Orland, 1992). Both types of landholders are typically represented by people with (generally, but not always) low computing skills, an important factor in the development of an AR system and its user interfaces. The profiles of all hypothetical stakeholders are outlined in Table 6.4.

Edwina Gardner	is a catchment modeller working for a government department. She has been actively involved in the modelling community for the last decade, promoting the benefits of integrated models. To this extent she has developed her own application which integrates several discreet modelling applications to assist policy makers and catchment managers better understand the connectedness of the environmental processes contributing to continuing landscape degradation. The application was thoroughly tested and certified by a national government department two years ago. Edwina is close to finalising the conceptual groundwater model of the Bet Bet area, utilising input from a variety of scientists and locals.

Karl Schmidt has been working with the agricultural government department for more than 23 years assisting farmers understand and implement the tangible aspects of policy. He has worked in various regions across the state during his long career, but has been located in central Victoria for more than 10 years. In this time he has gained a great deal of knowledge about his region and is well respected by the farming community for his common-sense, down-to-earth way of implementing policies. His local knowledge has been utilised by Edwina to 'reality-check' her conceptual model of the area.

Lachlan Smith is a third generation farmer. He currently farms 763 acres, made up of land originally owned by his grandfather and a recent acquisition of part of a neighboring property. Lamb and wool production are the core of the farming enterprise with the occasional grain crop planted. Lachlan is aware of the land degradation taking place across the region thanks to his involvement in the local Landcare group. On several parts of his property there are large erosion channels and dryland salinity discharge sites. Over the last 5 years he has begun fencing and re-vegetating some of these sites with funding assistance from Landcare and the Catchment Management Authority. While this effort has minimised continuing degradation Lachlan would like to focus on fixing the cause rather than the resultant issue while ensuring his farming enterprise remains viable.

Doris Parker is from the city and having worked in a high paying, high stress job for the last 15 years decided she needed a 'tree change'. With no more knowledge about farming than what she had read in the city newspapers she purchased a portion of a farm that was sold 2 years ago. She is friends with her neighbour Lachlan and his wife who have been there to provide valuable farming knowledge and assistance when required. Doris does consultancy work, making use of broadband Internet and the telephone to work remotely, while owning a few horses and cattle. Her grand vision is to return her property to a natural state through direct seeding of indigenous species and natural re-generation. This is a time consuming and costly task due to minimal indigenous seed being available, something she hopes to rectify by becoming a member of the local Landcare group to expand her seed collecting areas onto neighbouring farms.

Peta Richards has lived in the local town all her life. She helps run her mothers news agency. Being born in the 1970's, Peta is part of generation 'X' and very interested in seeing positive changes made to the environment. Although living in a rural community and constantly seeing the physical signs of land degradation, she is not directly associated with farming. With very little scientific knowledge about the processes involved in the degradation, she finds it difficult to reconcile why landowners can't re-vegetate large areas of land to minimise erosion and salinity.

Luke van Eyk	is a senior environmental policy maker for the Catchment Management Authority (CMA). He commissioned Edwina to develop the conceptual model of the Bet Bet area to assist the CMA understand the major factors contributing to the visible environmental degradation. Luke and his colleagues have developed several theoretical land use scenarios, based on documented policies. These scenarios will be run through the model with the outputs analysed to determine the impact of the proposed changes and, ultimately, inform new and alternate policy.
Joshua Reynard	is a GIS operator who has worked with the government for 8 years. Having an excellent understanding of the many spatial data layers available in the government department, Joshua has been involved in incorporating various spatial data layers to create spatial representations of proposed land use scenarios for use in the integrated model.

Table 6.4 - Hypothetical stakeholders involved in developing, communicating and implementing land use scenarios.

6.4.1.3.2 Problem scenarios

Describing problem scenarios is the most difficult yet important task of the SBD methodology. Generation of sufficient scenarios provides "guidance for specifying, prototyping and evaluating designs" (Carroll, 2000, p 283), however the number of scenarios depends on the application being designed. Scenarios can never be complete, however the number of scenarios should be balanced between those describing typicality (frequent and representative) and criticality (rare). They are recognised as adequately detailed when they enable claims to be identified and should include "...significant uses of a system and the major types of agents, goals, actions, events, obstacles, contingencies and outcomes that constitute these uses" (Carroll, 2000, p 256).

For high-level design problems four is seen as sufficient, while detailed design may require twenty or more scenarios. Carroll (2000) outlines seven methods that can be adopted to ensure good, unbiased scenarios are developed, including: ethnographic field study, participatory design, reuse of prior analyses, scenario typologies, theory-based scenarios, technology-based scenarios and transformations. Carroll (2000) goes on to suggest that employing each method, either separately in each scenario or to varying extents in the same scenario will minimise the potential distortion of any one method.

The problem scenarios in Table 6.5 represent the current method of developing land use scenarios, inputting the scenarios into an integrated model and disseminating the results for communication to various stakeholders. These scenarios have been derived empirically through the authors previous involvement in creating and disseminating land use scenarios. The scenarios highlight the four primary roles of environmental managers, namely (Orland, 1992): identification and interpretation of complex environmental systems; communication of the implications of those systems; testing alternative scenarios by experts and non-experts; and implementing the plans resulting from the scenarios.

The first three problem scenarios are provided as context to the inherent complexities of developing land use scenarios, however they will not be referred to in subsequent sections of this chapter because the AR system and its user interfaces are not well suited to small scale analysis and manipulation of data.

1. Joshua develops various land use scenarios

   Edwina has asked Joshua to provide the necessary ASCII files for input into the integrated model, one representing the current land use and two alternate land use scenarios for the Bet Bet catchment. Joshua has undertaken this task for other catchments in the past and is aware of the particular requirements of the model. A vector layer representing the current land use is derived bi-annually by another section of the government and will be used to depict the 'current' land use and form the basis of the alternate land use scenarios. The alternate scenarios require various spatial layers to be analyzed and processed within a GIS to depict a spatial land use scenario representing the current CMA policies relating to re-vegetation, dryland salinity and erosion.

   Joshua's first task is to create a set of rules which represent the CMA policy document. Not wanting to read and interpret the policy document from the CMA he spends several hours with Luke van Eyk the senior policy maker at the CMA. During this meeting Joshua asks Luke to summarise the policy document, paying particular attention to those statements relating to changes relating to the landscape. As each point is highlighted, Joshua attempts to formulate a rule set which can be applied in the GIS. During their time together Luke and Joshua develop and prioritise many rule sets which are generic to the whole CMA. The following day Joshua analyses and processes a variety of departmental spatial layers to extract and create (vector) layers indicating the spatial extent (or influence) of the CMAs policies.

   The integrated model accepts ASCII files representing a raster data set, with each line of the ASCII file representing a unique point in the landscape. The requirements of the integrated model are quite particular and all layers must be precisely aligned for it to work. To ensure correct alignment, a raster file of appropriate resolution is created from the vector layer representing the project area. This raster layer then forms the basis for creating the subsequent layers.

   Additional ASCII files representing fundamental physical attributes of the project area are also provided, including rainfall, temperature, soils and a DEM. All the files are

compressed and emailed to Edwina for incorporating into the integrated model.

2. Edwina Gardner runs the integrated model

Having received the data from Joshua via email Edwina extracts the ASCII files from the compressed file and begins loading them into a custom-built GUI. The GUI allows Edwina to view the various data sets, determine if they are correctly aligned and output additional composite data files required by the integrated model. Once the data has been validated and the additional output files generated, Edwina opens a command window and executes the integrated model. The model prompts Edwina for the location of the necessary files and additional information before processing.

The model has been coded for parallel processing, enabling it to be run on a 'farm' of computers, reducing the run time from several weeks to several days. At the final prompt, Edwina presses the enter key, giving the program approval to process the data for the current land use scenario. Over the subsequent weeks the other two scenarios are run through the integrated model, generating a vast number of ASCII files, each representing a variety of information, aggregated into weekly, monthly and yearly time periods from 2005 to 2050.

3. Edwina Gardner summarises the model outputs

By the end of the month all land use scenarios have been run through the integrated model and the output has been checked to ensure there are no obvious anomalies. Edwina now begins the process of interpreting the results. She begins by looking at the summary ASCII file which shows, that if no change to the landscape is made now, the recharge into the groundwater aquifers will result in increasing salinity discharge, both locally and into the Murray River. The results confirm what Edwina and others had already guessed. Edwina generates a few maps using the GUI along with a few tables summarising the modelled output to highlight the pertinent issues attributed to keeping the land use 'as is'.

The results from the alternate land use scenarios require substantially more effort on Edwina's part. Following the same process as the current land use scenario, Edwina views the summary ASCII file for each alternate scenario in turn. To her surprise the results are only marginally better than leaving the landscape 'as is'. Further investigation is required to undercover why the results are only marginally better.

Edwina begins by loading the annually summarised model output for one of the proposed land use scenarios into the GUI. During the first 5 years of the simulation the recharge amounts are almost identical to the 'as is' scenario which can be explained by the establishment of vegetation. Over the modelled time period the recharge decreases to a certain point then plateau's out. The same occurs for both alternate land use scenarios. Some further investigation reveals that there are differences between the two alternate land use scenarios relating to surface water run-off and therefore erosion. While both scenarios had similar areas of trees planted and more deep-rooted perennial pastures established, the location of the trees were different. One scenario had them planted on the crests of the hills while the other focused the tree planting around existing erosion gullies, resulting in better erosion control.

While the results were somewhat disappointing, Edwina could draw some positives from

the modelling. A variety of information, including representative maps, graphs and tables is put into *PowerPoint* for a presentation to various stakeholders the following week.

4. Edwina Gardner communicates the results to stakeholders

Approximately a dozen people representing various government departments and statutory bodies are present for the meeting at the regional government department offices. Some, like Karl, are interested in the practical output of the modelling exercise while others, like Luke, are interested in the determining whether the model could have benefits for their landscape.

Edwina begins with a summary of the Bet Bet catchment, highlighting the major issues being faced by the area relating to social, economic and environmental factors. After a brief explanation of the integrated model, its inputs and generalised workings Edwina starts presenting the results of the modelling exercise.

She begins by displaying a map depicting the current land use. The next slide presents a table summarising the model output with total values for a variety of parameters including recharge, discharge, salt loads etc. She continues onto the first alternate land use scenario, showing a map depicting the land use if current CMA policies were adopted across the whole area. This is followed by another table highlighting specific parameters and compared to the 'as is' land use scenario. Several people in the audience query Edwina about the marginally lower figures. Edwina responds with a summary slide highlighting the key reasons that she ascertained from studying the various model outputs. The other alternate land use scenario, a variation on the CMA policies, results in similar questioning from the audience.

A healthy debate, facilitated by Luke van Eyk follows Edwina's presentation, with conjecture about the models validity and robustness. Edwina defends the model, stating that it had been verified and certified at a national level, suggesting the current policies, while seeming to be substantial improvements are well below that required to significantly slow environmental degradation, let alone improve the situation. After further discussion it was agreed that another land use scenario needed to be created which was dramatically more ambitious than the others.

5. Luke reviews the environmental policies of the CMA

Having assisted Joshua develop an 'extreme' land use scenario and discussing the results with Edwina, Luke could see that it was the only possible way to reduce environmental degradation and return the water quality in the Bet Bet catchment to the desired level. However, he recognised the cost of implementing such dramatic change was excessive and the social and economic impacts on landholders in the catchment would be unacceptable. Luke decided that some minor alteration to the existing policies would improve the environmental benefits while minimising the financial cost to both the CMA and landowners.

6. Karl Schmidt explains the landscape plan to Lachlan Smith

Having been at Edwina's presentation back in December, Karl was surprised to see a revised environmental policy document from the CMA so soon. The covering letter from

Luke outlined the reasons for the alterations and recognised the importance of providing the revision prior to the coming spring to ensure grants and funding were spent in the most cost-effective and environmentally beneficial manner. Karl had already begun assisting several landholders develop farm plans and took the time to read and compare the new policy document with the existing one to familiarise himself with the changes. To his surprise there were very few changes, considering the discussion that had followed Edwina's presentation. Most of the changes affected the location of tree plantings, rather than concentrating on the crests of the hills, plantings were to be focused on the mid-slopes and around existing salinity discharge and erosion gullies. Although minor, Karl needed to revise some of the farm plans he had been working on with landholders in the past month. Having made the changes suggested by the revised policy document Karl met with Lachlan Smith to discuss his revised plan. After introducing the major policy changes, Karl started explaining his plan for Lachlan's farm. Lachlan could immediately see some issues with the new plan – much of his most productive land was to be planted to trees, while the less productive areas were to remain in production. Lachlan told Karl that the current plan would severely impact the viability of his farming enterprise. Over the next 30 minutes Lachlan manually altered the plan according to his knowledge of the landscape. With no way of determining whether the changes were positive or negative, with respect to the modelled issues, the plan suggested by Lachlan was agreed to.

Table 6.5 - Problem scenarios illustrating the current practice of developing, communicating and implementing land use scenarios.

6.4.1.3.3 Claims analysis

Claims analysis emphasises the causal relationships which may be suggested by the scenarios, resulting in propositions and hypotheses about usability. Claims are not a simplification of the scenarios but highlight issues, conflicts and contradictions that were not necessarily explicitly stated. Claims analysis is an iterative process which highlights core issues and design possibilities through revision and refinement (Carroll, 2000).

While each of the problem scenarios represented in Table 6.5 outline the current sequence of developing alternative land use scenarios, the complexity and computational power required for the first three problem scenarios make it unrealistic to suggest that an AR system is suitable and practical in such scenarios. The claims analysed in Table 6.6 reflect this decision.

Situation feature	*Possible pros (+) or cons (-) of the feature*
Meeting held at government office	+ central to the majority of attendees + appropriate facilities for computers and projectors – attracts predominantly government employees
Creating the presentation in PowerPoint	+ familiar environment for developing presentations + easily incorporate existing spreadsheet resources – presentation utilises the generic functionality found in PowerPoint and does not engage the audience – some elements of the presentation are complex and require detailed explanation – lack the ability to drill-down into the data being represented in graphs and tables
Scenario development is purely theoretical	+ can quickly develop rules based on scientific knowledge + rules can be easily manipulated and added to – difficult to determine the metrics of the scenario rules ie how many additional hectares of vegetation will that result in? – the only way to determine the implications of the scenario is to develop a spatial representation and run it through the model
One-on-one presentation to landholders	+ encourages landholder to be open about environmental issues on their property + personalised analysis of the landholders property – have to provide the background information multiple times – proposed changes are not appropriately documented – difficult to assess implications of proposed changes

Table 6.6 - Claims from problem scenarios which much be considered in the design phase.

6.4.2 Design

The core portion of the SBD methodology is the design phase which integrates three distinct aspects of design – activity, information and interaction. A comprehensive SBD methodology would iteratively build on the problem scenarios (Table 6.5), adding the relevant elements to build a complete narrative of the envisaged system. For the purpose of this research, only the activity scenarios have been fully developed into narratives. Rather than continually develop the activity scenario for the information and interaction design phases, the essential elements for the proposed user interfaces are discussed.

6.4.2.1 Activity design

Activity design is the first phase of the design process, transforming the current problems and applications by exploring various metaphors and technologies that could be utilised. The goal of activity design is to specify the system functionality (also know as conceptual or task-level design). This involves designing the system within a context of usage while considering their support for human goals and activities. Ultimately, activity design determines what the system is required to do, prior to designing the user interfaces (Rosson & Carroll, 2002).

6.4.2.1.1 Activity scenarios

The purpose of activity scenarios is to specify typical and critical services which users seek from the proposed system. As with problem scenarios, this is achieved through narratives that focus on functionality rather than explicit details of how the system will look or how it is manipulated (Rosson & Carroll, 2002). The activity scenarios described in Table 6.7 have been developed using an analytic technique where conceivable scenarios for altering and visualizing land use scenarios with an AR system have been developed. Naturally the scenarios are informed by the problem scenarios (Table 6.5) documented using empirical knowledge.

1. Luke van Eyk communicates the results of the landscape planning exercise to landholders
   Through an evaluation process, the catchment manager has chosen a landscape design that has the greatest impact in reducing and ameliorating the proven natural resource issues of an area. A small Landcare group has been approached by Luke van Eyk, the catchment manager, to review and assist in refining the proposed landscape design.
   The meeting with the Landcare group begins with Karl Schmidt giving a brief introduction about the project before introducing Luke van Eyk. Luke begins by handing out a small scale overview map of the catchment showing the proposed landscape design to the 12 attendees. Luke provides some further background information about the project and the processes undertaken prior to detailing the key features of the proposed land use scenario.
   The attendees pose several questions to Luke regarding the proposal relating to the implications of implementing the proposal on their properties. Luke explains that the proposal should be seen as a master plan that can be locally adapted, however the overarching principles highlighted in the proposal are necessary to ameliorate the severe degradation that has, and that continues to occur.
   Karl returns to the front to explain the new system available to farmers that allows them to explore and query the proposal and allows the user to input an alternative option. The use of the system and Karl's expertise is offered to all interested landholders. Karl closes the meeting but invites those interested in staying to see the system in action while they have their post-meeting coffee.

The interested landholders make their way outside the small hall with their coffee to see the system on offer. Karl has bought several AR units, loaded with some sample data for the area immediately surrounding the hall. Over the hour the AR system is tested by the interested landholders.

2. Karl Schmidt explains the landscape plan to Lachlan Smith

Lachlan is a proactive member of the Landcare group and is interested in using the new system to analyse the proposed landscape design suggested by Luke van Eyk. Karl arrives at Lachlans property early one afternoon, and after some discussion they decide to view the suggested landscape changes around the area of severe gully erosion. After driving to a suitable location, Karl spends a few minutes turning on the necessary computers and peripherals and erecting the GPS base station.

Karl has bought along two of the new AR systems, one for himself and one for Lachlan. Having seen and experienced the system at the Landcare meeting only a few weeks ago, Lachlan was keen to see its application in a real-world scenario. While it is possible to have multiple people exploring, analysing and planning alternate landscape designs, Karl has switched his system into a view only mode, allowing him to see the changes being suggested by Lachlan.

With both systems switched on and comfortably worn, both men see nothing but the actual landscape with a small icon in the HMD indicating that the GPS is still initialising and locating the necessary satellites. A small dialog is displayed prompting Lachlan to enter his name. After another 30 seconds the icon disappears and some text indicating the readiness of the system is displayed in the HMD.

Karl reminds Lachlan that all interaction with the system takes place through the PDA. Lachlan holds the PDA up and sees a map of the immediate area with two small icons which he recognises as being his and Karls current location. There are several recognisable icons shown on the map and a couple of ones Lachlan has never seen before. Karl informs Lachlan that one of the icons is for selecting the layers you want to see through the HMD, while the other one allows him to create his own landuse scenarios.

Having selected the proposed landscape design to be displayed in the HMD, Lachlan wanders around for a few minutes familiarising himself with the physical feel of the system while making some minor adjustments to the helmet ensuring he can see the graphics suitably in the bright afternoon light.

According to the proposed land use scenario, Lachlan and Karl can see a large portion of the area immediately surrounding, and up-hill from the erosion gullies is ear-marked for re-vegetation. Further investigation through the PDA by Lachlan highlights that the modelled positive impacts that the trees would have if planted, include: reducing groundwater recharge, which would subsequently reduce the dryland salinity scalds on his neighbours property further down the slope and, reducing the volume and velocity of surface-water run-off which has resulted in the large erosion gullies and increased sediment in the streams below. While this information is acknowledged by Lachlan he also knows that this is some of his more productive land, supporting good pastures for fattening lambs and without it, his farming enterprise would be severely reduced.

Lachlan decides to make some alterations to the proposed landscape design. Utilising the mapping interface on the PDA he alters the area to be re-vegetated to better accommodate his farming enterprise. After completing the alterations, Lachlan is prompted whether he'd like to compare the two scenarios. Selecting yes, a comparison of the changes and their implications are displayed on the PDA within 20 seconds.

3. Karl and Lachlan seek an expert opinion on the alternate scenario

Karl is impressed by how quickly Lachlan has come to terms with the system and can see Lachlan's point of view from an economic sense. Karl asks Lachlan if Luke van Eyk is online. Unknown to Lachlan it is possible to connect with remote users. Karl verbally guides Lachlan through the process and find that Luke is online. Having accepted the invitation Luke is able to see a map of Lachlan Smiths proposed landscape and communicate with the roving user verbally.

The three men have an online discussion regarding the changes proposed by Lachlan. Through their discussion, Luke can see Lachlan's issue of planting trees on his productive land. Comparing the original scenario with Lachlan's suggestion, Luke makes some changes to Lachlan's proposal and verbally tells Lachlan to refresh his map to see the changes. After refreshing his map, Lachlan can see the new landscape design.

Lachlan is comfortable with the changes suggested by Luke, but is interested to see if they made any significant difference. Lachlan selects his and Lukes proposal and asks the system for a comparison. After a short amount of time a comparison of all three scenarios is shown. While Luke's altered scenario is well below the ideal landscape in all the key areas it is somewhat better than Lachlans proposal.

4. Doris Parker explores the relevance of her property with the catchment

Doris was not at the recent Landcare meeting due to other commitments, however Lachlan Smith had mentioned the presentation given by Luke van Eyk during their weekly catch-up. Lachlan pointed out the key issues using the map from the meeting as a reference and mentioned that a new system was available for community members to explore the proposed land use scenarios. That afternoon Doris contacts Karl using the number provided by Lachlan. She organises a get together for Saturday morning to accommodate her busy work schedule.

Following a handshake and some discussion of the continuing dry weather, Doris invites Karl inside for a cup of tea. Karl brings his laptop, a PDA and some maps of the catchment. Over a cup of tea Karl provides some further context to the proposed landscape changes and explains that the recommended scenario is to be seen as a framework for landscape improvement rather than a definitive plan. Comparing the current situation with the planned landscape, Doris is pleased to see an increase in vegetation. She quizzes Karl to determine why there are not substantially more trees planned.

Rather than try to explain it, Karl switches on his laptop and hands the PDA over to Doris. Having used PDAs in the past, Doris picked it up, extracted the stylus and studied the screen. She recognised the map of the catchment displayed in a web browser window with several icons. Selecting the magnifying glass she intuitively dragged the stylus over the region of her property. The map display changed, showing more detailed information. Karl

prompted her to stop for a minute so he could explain a few things. Showing her the screen of the laptop he explained that he was seeing the same map as displayed on her screen. He then explained the functionality provided by each of the icons. Karl suggested she may want to explore the landscape design at a regional level to gain an understanding as to why more vegetation was not present.

Doris selected the relevant icon, and was displayed graphics depicting broad environmental, social and economic factors. She started manipulating the area of vegetation and noticed the values of the other factors changing. Karl explained that the interface was depicting the relationships between the various factors and that some of the factors had specific thresholds, beyond which they could not be altered. The thresholds, including water yield (or run-off), had been determined by external agencies to ensure any proposed landscape was realistic.

Doris was fascinated by the complexity of the interface. Having created what she deemed a perfect scenario, a new map was displayed, depicting a spatial representation of the scenario. Zooming in on her property, Doris could see that the representation of her perfect scenario did not include vegetation on her whole property. Karl explained this may have been due to a number of factors but was most likely due to the underlying model viewing the landscape as production-based rather than environmental.

5. Peta Richards gains an understanding of complex landscape processes

Peta had introduced herself to Karl at the last Landcare meeting and had contacted him a few days later. While she had not tried the AR system after the meeting, she was interested in knowing whether it was only available for use by landholders and whether it had an educational aspect. Karl informed her that while it was predominantly a tool to assist landholders make decisions regarding landscape changes, it did have an educational mode that he was keen to utilise.

Karl picks Peta up from the newsagent one morning. Karl had asked Lachlan Smith if he was comfortable with letting Peta explore his property and the proposed landuse changes. Lachlan said he was comfortable and also interested in finding out more about this alternate mode of the system he had used only a few days ago.

With the introductions complete, the three headed out to the large erosion gullies, with Peta and Lachlan chatting while Karl sets up the system. All three are issued with an AR system, with Karl carrying the controlling PDA. Once the system was initialised, Karl put it into educational mode and selected the soil erosion option from the list. A voice telling each of them to follow the arrow displayed in the HMD was heard through their ear phones.

The arrow lead them to the top end of an erosion gully. As each user arrived within a certain proximity, further audio telling the user to stop was heard and a video narrative supplemented with an audio description on soil erosion began.

During the narrative various graphics were shown in the HMD, assisted by a navigational arrow indicating which direction the user should move or look. The whole narrative took about 10 minutes, guiding each of the users from the top of the erosion gully to the main stream. Through audio and various graphics the processes that caused the erosion, the

impacts on the environment and the various methods of ameliorating the issue were explained.

Table 6.7 - Activity scenarios for the development of land use scenarios using AR.

6.4.2.1.2 Claims analysis

Rosson & Carroll (2002) state that incremental changes to existing practices are more easily understood and adopted by users but concede that innovation can transform tasks and process in "exciting and satisfying ways". The activity scenarios detailed in Table 6.7 are significantly different to the problem scenarios outlined in Table 6.5. The activity scenarios therefore represent an innovative leap in landscape or land use scenario design. rather than incremental step. The claims from the activity scenarios are detailed in Table 6.8. The design of the user interface will attempt to consider the negative claims while ensuring the positive claims are not turned into negative ones.

Proposed activity design feature	*Hypothesized pros (+) or cons (-)*
Meeting held at local hall	+ encourages landholders to attend – high quality presentation facilities may not be available – location may be some distance from all attendees – presentation may not be clearly visible by all attendees
Presentation facilitated by PowerPoint	+ presentation is customised for the local area + each attendee receives a hardcopy map in conjunction with the PowerPoint presentation + presentation is more organic, allowing for greater discussion – lack the ability to drill-down into the data being represented in graphs and tables
Landholder can analyse existing scenarios	+ encourages landholder to be open about environmental issues on their property + personalised analysis of the landholders property – have to provide the background information multiple times – proposed changes are not appropriately documented – difficult to assess implications of proposed changes
The ability to input alternate landuse scenario	+ allows users to explore various options and compare them against the suggested one + explore issues at various scales – users with low computer literacy may be overwhelmed – complex spatial alterations may be tedious and time consuming on a small PDA screen
Explanation of complex natural resource process through narratives	+ incorporates practical visual examples with scientific facts + integrates various issues into a cohesive story – doesn't allow the user to query the information being displayed – the temporal speed of the narrative is not controlled by the user

Table 6.8 - Claims from activity scenarios which much be considered in the design phase.

6.4.2.2 Information and interaction design

For the purpose of this research the information design phase of the SBD process has been combined with the interaction design phase because of the inherent link between the design of the UI and the interaction with that UI in an AR environment. The relationship between these design elements are represented in Figure 6.4. Information design is focused on the organisation and presentation of data by transforming it into something valuable and meaningful, underpinning the success or failure of interactive products. Shedroff & Jacobson (1994) includes sensorial design as a design element to encompass the various techniques with which humans communicate such as writing, graphic design, photography, voice and music.

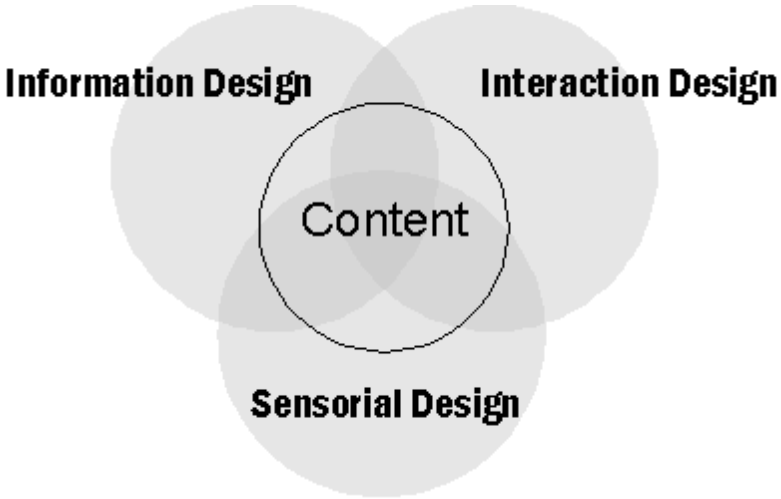

Figure 6.4 - The relationship between information design, interaction design and sensorial design, adapted from Shedroff & Jacobson (1994, p 1).

The information design phase elaborates on the documented activity scenarios (Table 6.7) through the addition of further narrative detail relating to information provision. Shedroff & Jacobson (1994) highlights the fact that information design neither ignores nor focuses on the aesthetic requirements, stating that it builds the structure for designing the final product. This phase utilises various design principles to build a visual language by applying; familiar metaphors (such as language), realistic and refined images where appropriate (such as icons), and making necessary actions obvious to users (Rosson & Carroll, 2002).

Relating knowledge to detect and interpret patterns is central to understanding a user interface. The ability of a user to make sense of a user interface relies on them utilising existing knowledge about other systems to integrate the information being displayed. This process is guided by consistent use of visual elements, adoption of familiar visual metaphors, clear and consistent information models that allow users to navigate large volumes of information and dynamic displays that reduce and filter content appropriately (Rosson & Carroll, 2002).

The computer literacy of the target users was a major consideration in the overall interface design. Bowman & Hodges (1995) state the lack of adoption of AR as a mainstream interface is related to the poor interfaces and user interaction metaphors that are "...inconsistent, imprecise, inefficient and perhaps unusable" (pp. 1). Tangible devices such as haptic gloves, chording keyboards or tagged objects are typically provided for user interaction in AR systems, however they require significant training and practice before they can be used in any real sense. Combine these factors with reduced area available for displaying augmented graphics in the HMD, AR systems become difficult to use (efficiently).

The user interface for an AR system designed for visualizing landscape (or land use) scenarios would provide several user interfaces, allowing a variety of options for interacting with spatial data and visualizing outputs at different spatial scales. The limitations of displaying user interfaces within the HMD of a mobile immersive outdoor AR affects the amount and quality of information displayed and the users ability to interact with it. Creating a user interface that provides the necessary auxiliary information in an uncluttered manner while allowing the user to see the augmented visualizations is a central challenge.

These issues resulted in the decision to separate the user interface and visualization interface. Rather than consume significant portions of the HMD with a user interface, the user interfaces for the AR system would be implemented on a Personal Digital Assistant (PDA), allowing users to interact with a variety of relevant and contextual spatial layers using a familiar (desktop) metaphor, leaving the HMD solely for visualizing augmented data. Shifting the user interface to the PDA (section 5.2.3) clearly defines the HMD as a visualization interface by maximising the area for displaying graphics, minimising visual clutterd in the HMD and removing the need for unfamiliar interaction devices (section 3.2.3).

In order to provide familiar and functional methods for interaction, the user interfaces will be developed using the familiar WIMP metaphor, providing familiar, point-and-click functionality on the PDA. The conflict of allowing users to interact with the PDA and viewing the augmented landscape through the HMD must be taken into consideration when designing the interface. This could be overcome in a number of ways. Firstly, the PDA could be tagged with a unique marker (as done in many indoor AR systems), allowing the AR system to determine when the PDA is in view (for instance the user is holding the PDA up in their line-of-sight or they are looking down at the PDA), removing (turning off) the augmented graphics to provide an uninterrupted view of the interfaces on the PDA. Alternatively, the AR system could be programmed to cease the HMD augmentation when the users head tilts below a certain angle (ie looking down at the PDA). Both methods require no input from the user to switch between viewing mode and interface interaction mode. The first option is preferred as it provides the user with the greatest flexibility, allowing them to hold the PDA in a position that is comfortable without having to look in a certain direction.

Within a natural resource context, each data set is relevant to a particular scale. Providing users with the necessary visual cues and interfaces for interacting with data sets at a specific scale is essential. The metaphor adopted by current Internet mapping applications, where the interactions with a data set (or layer) are restricted by the map scale, will be applied to the user interfaces to provide unambiguous feedback regarding the appropriateness of visualizing any given layer.

For a computing system to be effective it must be as flexible as the user and be capable of changing tasks (Dix et al., 1998). As G. Andrienko et al. (2006) state, the objective of the interfaces is to present data which is unfamiliar to the target users by providing the relevant geovisualization tools with the appropriate Exploratory Data Analysis (EDA) methods and principles to assist develop hypothesis and therefore begin to understand the key concepts of the particular domain.

Allowing the user to toggle between interfaces (regional versus context (or local) scale) also provides this flexibility and allows them to gain a rudimentary understanding of what layers are appropriate at a given selected scale. In addition to controlling what spatial information is being displayed through the HMD, additional contextual information (such as annotation and informative icons) may be required. The contextual information available for display would be dependent on how the AR system was being used. The user should have the option to control the display of such information.

The majority of AR systems reviewed in 3.4 were developed for a single purpose and typically displayed simplistic spatial data with attached multimedia comprised of documents, images and annotations providing narrative information. None of the AR systems reviewed allowed users to control the spatial layers being displayed in the HMD, nor did they allow the symbology of visible layers to be altered. Given the differing abilities of various users to distinguish colours and line weights (especially under the variable lighting conditions experienced outdoors), the functionality to customise the symbology to suit their requirements is seen as essential. Many desktop-based computing applications allow users to adjust their visual settings (colours, font size) to suit their particular needs. Providing this functionality in the user interface would provide each user the ability to customise the visualization to suit their needs and the environment in which they are operating.

The interaction design phase of the SBD methodology utilises interaction scenarios that encompass the complete design vision of the system, including: the users and tasks being supported, the information required, the actions taken to interact with the provided information and the system responses (Rosson & Carroll, 2002).

Users find it easier to understand and embrace new and innovative ideas when they are based on familiar and recognisable concepts. To assist with this, designers utilise metaphors when designing systems and user interfaces. While metaphors simplify a system or interface they may also limit the expectation of what the system can deliver. Rosson & Carroll (2002) suggests that designers must go beyond existing metaphors to develop new and improved interfaces.

For the purpose of this research, the narrative of the activity scenarios in Table 6.7 will not be expanded to highlight the envisaged information and interaction design aspects of the AR user interface, as per the typical SBD methodology because the application of the information and interaction design aspects are easily placed into the activity scenarios. As alluded to in the activity scenarios, there are two distinct modes of operation for the AR system; narrative learning and exploration of alternate land use scenarios. The following sections discuss the two modes in more detail and outline the specific user interface requirements. Illustrations (storyboards) of the interfaces and specific information regarding their implementation can be found in section 6.4.3.

6.4.2.2.1 Narrative learning user interface

This role is best illustrated by activity scenario 5 in Table 6.7. The purpose of this user interface within the AR system is the provision of a simple, user-friendly method of explaining complex natural resource issues and the interactions between various environmental processes to users. MacIntyre et al. (2001) have explored the concept of narratives within AR, principally based on (virtual) human actors interacting with the user of the AR system. Their research formed the basis for the development of the narrative interface (or role). This role is predominantly targeted at users with little knowledge of environmental issues (but has purpose for a wide range of users) with users controlling the narrative by their location within the environment, as in MacIntyre et al. (2001).

By way of example; the lack of vegetation on the surrounding hills have resulted in increased water run-off causing gully erosion and increased recharge into the shallow groundwater aquifers resulting in dryland salinity on the lower slopes. An observer can see the physical impact (salt scalds), but may not understand the processes that caused them. The AR system could be utilised to educate the user about these processes through augmented narratives. The information used in the narratives could also be packaged into a help system (similar to desktop applications) allowing users to familiarise themselves with issues when using the AR system in other ways (such as exploring scenarios 6.4.2.2.2).

This role requires physical input from a single user (the supervisor) to select a narrative from the options displayed on the PDA (Figure B.1a). Rather than each individual user controlling the narrative (stop, start, pause, fast-forward etc) using the PDA, each educatee controls the narrative by physically locating themselves within a narrative hot-spot. A narrative hot-spot is a physical space around a specific feature (or set of features) in which the narrative has context (Figure B.1b). The feature may be a point (such as a location that maximises the view of a specific landscape feature) or a linear or areal feature (such as a watercourse or erosion gullies). While each narrative is broken into succinct chapters (associated with a spatial location) with an optimal sequence, each user has the ability to move through the chapters in any order by locating themselves within a narrative hot-spot (determined by the GPS (section 5.2.2)), prompting the narrative to begin. This allows users to traverse the whole narrative in an adhoc manner if they choose but provides them with sufficient structure without being restrictive. If a user already has knowledge of a specific chapter, they can easily move onto the next chapter.

“Story-worlds” that feel real and unconstrained, while providing an environment for a narrative experience is difficult within augmented spaces as the “author” must ensure the user is in the correct place at the correct time and ensure the user has an understanding of how they can interact with the narrative. The author of the narrative can not physically re-locate or re-orientate the user within AR and must therefore rely on providing the user with cues on how to interact with the narratives and account for unexpected behaviour (MacIntyre et al., 2001). While these issues can't necessarily be overcome, the provision of visual cues can assist users navigate the narrative appropriately.

This interface requires several key elements, the first being a 'world-in-miniature' map depicting the spatial extent of the narrative and the location of the narrative hot-spots. While the system could be programmed to automatically display the map, providing control to the user allows them to determine when to display it. The pitch of the users head (determined by the orientation sensor, section 5.2.2) could provide a simple mechanism for displaying/hiding the map when the user chooses. When the pitch of the users head exceeds a certain (negative) angle the 'world-in-miniature' map, oriented to the real world, would be displayed and any visual or audio presentation paused. Returning their head to its natural orientation would hide the 'world-in-miniature' and continue the audio and visual presentation (if previously playing).

Appropriate representation of the map features is necessary to ensure the user can avoid obstacles on the ground if they are in motion while viewing the map. The objects represented on the 'world-in-miniature' map would be opaque, with the background being transparent. Features on the map would include the location features referred to in the narrative (such as a watercourse, vegetation and salinity discharge extent) and the narrative hot-spots, colour-coded according to whether they had been visited by the user. The current location of the user would also be shown as an arrow, indicating the direction of travel, to assist the user orientate themselves.

The second requirement of the interface is a visual prompt indicating the direction to the next narrative hot-spot in the sequence. The Tourist Guide (Reitmayr & Schmalstieg, 2004) AR system uses virtual way points and connecting lines displayed in the HMD to navigate users between locations. This approach is appropriate in urban landscapes where the next location is typically occluded by buildings. Given the relatively small spatial extent of a narrative and its application within a rural environment where the narrative hot-spots are probably within line-of-sight. Suomela & Lehikoinen (2000) ContextCompass provides a novel method of showing the locations of points of interest, but reduces the visible display and is not very effective when the points-of-interest are along a linear feature which is being followed (such as a watercourse).

Virtual icons representing each narrative hot-spot would provide a simple navigation tool (Figure B.1c). The next hot-spot in the narrative sequence would be shown as an opaque icon, while other hot-spots would be shown in decreasing opacity. Visited hot-spots would be displayed in a different colour. The icons would be shown in the HMD once a user leaves a narrative hot-spot and remain visible until arriving at the next narrative hot-spot. Each icon could be annotated with the name of the narrative chapter (such as groundwater recharge, groundwater discharge) to assist users in selecting the chapters that are of relevance to them.

Once the user is physically located within a narrative hot-spot, the relevant visualizations will be automatically displayed in the HMD (Figure B.1d). It is envisaged that the visualizations will be predominantly augmented graphics, supplemented with rich multimedia (such as photographs, audio, animations or movies) to assist the explanation of specific environmental processes. As suggested by MacIntyre et al. (2001), users need guidance on where (the direction) to focus their attention to ensure they gain the maximum from the narrative.

The narratives may require the user to stand in a single location or require them to move along or around the feature. A simple way of achieving this would be to display an arrow in the HMD, to indicate the direction to turn (left and right arrow) or move forward (up arrow). These cues would allow the user to move themselves to an appropriate position where the augmented graphics match the audio narrative. The arrow would be located in a corner of the display, providing a subtle directional cue while allowing users to explore the whole panorama if they desired. The arrow would be hidden when the users viewing direction was within a certain threshold of the correct direction, accommodating peripheral examination of the visualization.

6.4.2.2.2 Scenario exploration user interface

This mode of the AR system allows users to undertake three specific tasks, including; creating alternate land use scenarios using the PDA, analyzing qualitative and quantitative differences between scenarios and visualizing land use scenarios (both on the PDA and through the HMD). Each user in the scenario exploration mode operates as an individual and is supplied with a complete AR system (as described in Chapter 5). The PDA provides the user interface for interacting with the system.

Creation of (alternate) land use scenarios would be possible at two spatial scales; regional (or landscape) scale and context (or local) scale. The two scales allow users to choose an interface appropriate to their computing ability, environmental knowledge (refer to Figure 2.3) and the time they have available. The regional-scale interface allows users to manipulate social, environmental and economic factors in a simplified manner, while the context-scale interface allows users to input detailed land uses. Each interfaces is describe below.

6.4.2.2.2.1 Regional-scale user interface

Specifically targeted at broad areas (such as a catchment), this interface is aimed at catchment and natural resource managers who want to gain an understanding of policy implications for instance, “What are the implications on water yield if there was an X% increase in biodiversity plantings as specified in a Regional Catchment Strategy (RCS)?” or users who want to generate a variety of scenarios quickly and view the results in the immediate area.

There are significant challenges in providing a user-friendly interface which provides the necessary functionality. Simplifying the complex relationships (or trade-offs) involved in landscape planning is relatively easy, however transforming the simplified inputs into viable land use scenarios for analysis is no trivial exercise.

Users would develop scenarios by altering the proportion of a landscape factor to be included. Landscape factors include a variety of defined social (such as population), economic (such as food or fibre production etc) and environmental (such as water quality and water yield) issues. Depending on the area of application, factors could be added or removed to ensure the interface was relevant.

The complex relationships at a regional scale have been simplified using a ‘radar chart’, with each axis representing a key aspect of the landscape. For the purpose of interface prototyping, the landscape was simplified to five core factors (or axis); fibre, food, biodiversity, water and social. Although this provides a highly generalised view of the landscape, it provides a sound basis to test the effectiveness of the interface through the prototypes.

To manipulate the defined factors, a radar chart with each axis representing a single factor or composite grouping of factors would be used. When first opening the regional interface, the axis' on the graph will display the current situation. The functionality to show the current situation and/or return the chart axes back to the current situation will also be provided. This will provide the users with a reference from which they can create a new land use scenario (Figure B.2b).

The user would be able to adjust each factor (or axis of the graph) separately, creating their own personalised vision of the landscape. The interface would be implemented through a web browser and provide several methods of manipulating the axis of the radar chart. The obvious method is to allow users to select a factor and then drag the end of the bar to a new position along the axis. Another alternative would be to provide users with a text entry interface, allowing them to input values for each factor.

While an infinite number of land use scenarios could possibly be generated (using either the graphical or text-based interface), there are certain requirements (dictated by policy or social responsibility) that must be met. These requirements and the inter-connectivity between the various factors (or trade-offs) would be visible when adjusting an individual factor to a desired level, with other factors being automatically adjusted to accommodate the proposed change (such as increasing the area of vegetation for environmental purposes would result in the water yield axis reducing, representing the decreased run-off and increased water use of the vegetation) or a factor being constrained to a pre-defined range (such as the number of people in the landscape representing landowners in an agricultural landscape).

Once the user has defined their preferred landscape using the radar chart, a spatial layer representing the landscape needs to be generated. Basic layers (such as tree cover, extent of dryland salinity, Digital Elevation Models (DEMs), watercourses and the like) will have been spatially pre-processed (through buffering, selecting and simplification) to save time and to create various vector layers. These vector layers would be overlaid in a certain order to generate a scenario that best represents the users desire. By way of example, increasing biodiversity will be achieved by applying hierarchical vegetation rules (applicable to the region) including the planting of riparian (stream-side) vegetation, increasing the extent of existing remnant vegetation and improving the connectivity of existing remnants by planting vegetation corridors.

Visualization of the resultant scenario would occur using the mapping interface on the PDA (Figure B.2a and B.2c) and through the HMD. Refer to section 6.4.2.2.4 which outlines the various visualization methods.

6.4.2.2.2.2 Context-scale user interface

A specific interface is required to analyse the immediate area around the user (equating to part of a farm). The context-scale interface is a lot more detailed than the regional-scale interface, accommodating an infinite number of possible land use scenarios. This interface is targeted at landholders and catchment officers who are interested in the implications, both positive and negative, of altering specific land use on their property and potentially the visual amenity of the suggested land use change. The context scale interface would provide users with appropriate tools to edit the placement and extents of various land uses at a local scale using their (local) knowledge (see Figure 2.3). The regional-scale interface could be used to create an initial scenario capable of being fine tuned through this interface. The resulting scenario would be visualized through the HMD and PDA.

Land use scenarios would be create on the PDA by selecting existing land use polygons and altering their existing land use (such as changing annual pastures to perennial pastures) or by adding new polygons representing alternate land uses (such as additional vegetation corridors and proposed farm forestry plantations). Several methods of creating new polygons (buffering, freehand digitising) would be offered (Figure B.3a and B.3b). Each polygon would be attributed with the envisaged land use and submitted to the ICM for analysis prior to the results being visualized through the HMD.

6.4.2.2.3 Analyzing scenarios

The ability to compare the land use scenarios created (using the interfaces described above) with the current situation or other alternate scenarios is a vital part in determining the effectiveness of a scenario to deliver benefits over an extended time period. Determining the environmental ramifications of a land use scenario is carried out using a catchment model. While many catchment models are complicated and require long processing periods to accurately determine the consequences of a scenario, simplified alternatives exist. While integrating a catchment model into the system for scenario analysis is outside the scope of this research, the creation of an appropriate file from the generated scenarios is outlined.

In the case of the regional-scale interface (section 6.4.2.2.2.1), the spatial representation of the scenario would be created by overlaying previously processed spatial layers using a rule-based approach. The pre-processed layers would reside in the spatial database (refer to 5.3.3), with other contextual data. A database function would be written to query the various spatial layers and apply acknowledged and documented rules to create a land use layer that best represents the users intended scenario.

Catchment models typically utilise grids (raster data sets) as they can be quickly and efficiently processed. While the spatial database (refer to 5.3.3) is not capable of handling raster data natively, it is possible to mimic the functionality using a vector layer containing equally spaced points representing the centre of a grid (raster) cell. This vector layer would be generated during the original scenario development (problem scenario 1 in Table 6.5) to ensure correct alignment with other layers in the catchment model. Each of the points would be attributed with the land use through an overlay operation and the resulting query output as a CSV file for input into the catchment model. Subsequently, the resultant point layer would be automatically submitted to the simplified catchment model to determine the positive and negative environmental impacts.

As part of any comprehensive catchment modelling process, a detailed hydrological model of the catchment needs to be created. Such models take substantial amounts of time to run, making them inappropriate to implement within a remote AR system. The mean annual water balance model (Zhang, Dawes & Walker, 2001) (also referred to as Zhang curves represented in Figure 6.5) is a simplistic catchment model which can provide a first-cut approximation of groundwater dynamics (Beverly et al., 2005). The curves represent a simple relationship between mean annual evapotranspiration and mean annual rainfall for a particular land use (land cover). These curves, in association with soil recharge data, can be used to determine the positive or negative hydrological consequences of altering the land use, providing a rudimentary comparison (almost) instantly. Naturally there are many more model options some of which are available from the Catchment Modelling Toolkit web site (eWater Limited, 2007). This web site is recognised and supported by the eWater Cooperative Research Centre (CRC) (eWater Limited, 2007).

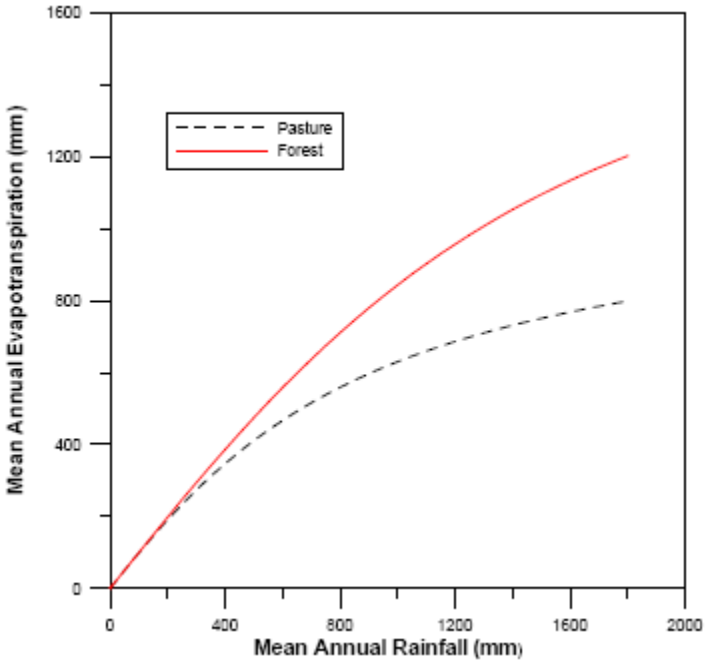

Figure 6.5 - The mean annual evapotranspiration for pasture and trees with respect to long-term mean annual rainfall defined by (Zhang, Dawes & Walker, 2001).

The process of generating a representative spatial layer, submitting it to the simplified catchment model, processing the scenario and ultimately returning to the results to the user should take less than a minute. While the user is waiting for the results they will be able to visualize the physical aspects of proposed landscape (such as the location of proposed vegetation), both on the PDA and through the HMD will be provided. Visualizing the results from the catchment model would be possible once the processing is complete.

Each developed scenario will be automatically saved, allowing catchment managers and modellers to later examine the land use scenarios to determine commonalities between them. In addition, each of the stored land use scenarios could be subsequently processed by the full catchment model to determine their positive and negative impacts in more detail. Storing basic metadata with each scenario, specifically the time and date the scenario was created along with information about the scenario author will allow catchment managers to see the changing trends and perceptions of the landscape and compare them with a range of other factors including climatic factors, information or education programs.

6.4.2.2.4 Scenario visualization

Visualizing the outputs, from either a simplified or detailed catchment model, is the core functionality of the AR system. Attempting to render realistic land use scenarios is not the strength of the proposed AR system. The ability to render individual landscape elements (such as vegetation, crops and fences) is limited by the computational ability of the system and the visual fidelity provided by the HMD. The true strength of the proposed system is to assist users understand the (positive and negative) impacts associated with particular ameliorations within the context of the surrounding environment. Appropriate methods of visualizing model outputs are therefore necessary to ensure users derive meaning and understanding from the land use scenarios that could not otherwise be gained from the current static methods of disseminating output.

Visualizing abstract model outputs in clear and meaningful ways needs careful consideration to ensure the results are accurately interpreted. Two methods of scenario visualization would be provided in the proposed AR system. The first would utilise a map metaphor implemented on the PDA while the second would utilise the HMD for visualizing the landscape augmented with various representations of the model outputs. While the outputs are displayed differently both methods would utilise the same data stored in the spatial database (refer to 5.3.3).

Visualizing the results of the simple analysis (6.4.2.2.3) in the HMD (and on the PDA) would highlight the beneficial, detrimental and neutral land use changes (in regards to hydrology). There are a variety of methods that could be used to display the model outputs. Firstly, the location of the various land uses could be represented as extruded polygons through the HMD. Alternatively, the impact of the land use could be represented with the height of extruded polygon representing the scale of the impact with a separate colour used to highlight positive and negative impacts (Figure B.4) .

The mapping interface on the PDA will allow users to visualize and query the land use scenario in a familiar context. Users would query individual polygons (representing the various land uses) using the PDA mapping interface to determine its impact, as compared to the current situation. Querying a particular land use polygon would also return a range of additional modelled attributes including the productivity implications of the proposed land use (simplified cost/benefit analysis), water yield and salinity benefits to name a few. The amount of information available to the user is only limited to the number of models available. Incorporating additional models such as carbon sequestration, water flow and biodiversity models would provide users with a wide spectrum of issues to explore and compare. The ability to aggregate the modelled data by property (or sub-catchment) would allow the user to determine the net positive or negative impact of the suggested land use scenario across a given area.

To assist with interpreting the models, relevant annotations will be displayed when visualizing outputs through the HMD. The user will be able to control which annotations are visible. The annotations will remain user orientated ensuring they are readable at all times.

6.4.2.2.5 On and off-site collaboration

Providing a collaborative environment that allows multiple users to not only see the visualizations associated with various land use scenarios but also interact with the system is extremely important. Collaboration is typically achieved using speech however, in augmented environments this is not as effective as each user may be visualizing different layers or have a completely different visual perspective on the topic being discussed. The Tourist Guide (Reitmayr & Schmalstieg, 2004) (section 3.4.7) adopts a simplistic approach to collaboration, allowing users to place virtual coloured icons on physical features which can be seen by subsequent users. Reitmayr & Schmalstieg's (2004) approach does not allow users to associate text or audio with the icons (due to the lack of a suitable input device) and therefore only a minimal amount of meaning can be derived from the various coloured icons. An ideal mobile outdoor AR system would allow users to collaborate by individually highlighting features using icons (as per Reitmayr & Schmalstieg (2004)) with the additional option of associating text (entered through the PDA) or other multimedia (ie voice recording) with the icon (as per Renevier & Nigay (2001)).

In addition to the interfaces provided on the PDA for users to interact with the spatial data sets, an application showing each users position and field-of-view will also be available allowing remote people to view (refer to Figure B.5). Each user could be selected and a live image of what they were seeing would be shown. The application could be implemented on the laptop (server) for assessing how the system is being used or alternatively made available via the Internet, allowing for remote assessment and collaboration.

This application could serve several purposes. Firstly, it could be used by off-site experts to provide real-time information and context to what users are viewing, either verbal or textual messages. Secondly, it could be used for evaluating users movements and interests in the given landscape (as per Suomela & Lehikoinen (2000)). Thirdly, it could be used in an interactive manner, allowing a 'facilitator' to create a dynamic environment in which users are 'directed' to particular areas of interest for discussion. Finally, it could be used by remote experts to explain the implications of in-field discussions for example “I'd like to see more trees planted on that hill”.

Renevier & Nigay (2001) adopt some of these approaches in the MAGIC system (section 3.4.4), allowing users to determine the location of other users and communicate with them through a virtual chat room. Off-site experts can also be communicated with to ensure an appropriate archaeological assessment is made.

6.4.2.2.6 Additional requirements

In almost every application, a map by itself is of little use (Plewe, 1997). Systems must provide the ability to interrogate analyse and display the data represented by the map in varying formats. Displaying model output spatially is one facet of informing users about the implications of their chosen land use scenario. Other contextual information including model assumptions, inputs and associated metadata will also need to be accessible enabling each scenario to be correctly interpreted.

As this additional information is predominantly text-based, using the PDA may be cumbersome and deter people from accessing it. A more intuitive method is the 'wearable communication space' described by Billinghurst et al. (1998). This approach uses a body-stabilised information display which provides quick access to textual information that users can explore using the HMD. Billinghurst et al. (1998) method reduces the need to move between the virtual and real worlds unnecessarily. Users would still be required to interact with the PDA to initially access the documentation for subsequent display, as an opaque layer, in the HMD. Controlling the display of the documentation would be done using the PDA or user position. The documentation would remain visible in the HMD while the user remained stationary. If the user moved (greater than a threshold distance indicating them moving to a different location) the documentation would be removed from the HMD, allowing them to see where they are going and avoid any obstacles.

6.4.3 Prototyping

Prototyping is the pen-ultimate stage of the SBD methodology and an important component of any Human-Computer Interaction (HCI) process and is an integral part of iterative design (McCurdy et al., 2006; Preece et al., 1994). A prototype formulates abstract ideas into a concrete, viewable, workable and testable object (Lim et al., 2006; M. Walker, Takayama & Landay, 2002). Prototypes can be developed for an entire system or for one aspect of a system (such as the user interface) allowing designers, clients and user to provide feedback about content, aesthetics and interaction techniques to aid design alteration or removal of unwanted or unnecessary features (Rosson & Carroll, 2002; M. Walker, Takayama & Landay, 2002). Prototyping is an essential part of evaluating a design, however there is no consensus about validating the evaluation results from the prototypes. Evaluation is even more “complicated and unpredictable” when the system being evaluated relies on mobile or ubiquitous computing elements (Lim et al., 2006).

There are a variety of approaches for developing prototypes however they fall into two categories that represent the extremes of a continuum (Bailey, Konstan & Carlis, 2001; Bailey, 2005; Lim et al., 2006; McCurdy et al., 2006; de Sa & Carrico, 2006; M. Walker, Takayama & Landay, 2002).

- Low-fidelity – these are low-cost, easy to build, simple to use and typically implemented using white board or paper-based sketches (or computer-based graphics that are printed out). They are purposely vague and imprecise and do not allow realistic user interaction; and,

- High-fidelity – these are highly-developed, interactive computer-based programs that allow realistic user interactions using input devices (such as mouse, keyboard, touch-pad etc) and are typically similar to the final product.

Fidelity is a composite of four dimensions (Snyder, 2003): breadth relates to the amount of the functionality represented in the prototype; depth refers to the amount of detail and the manner in which it has been implemented, for instance the data being displayed on a web page may be sourced from a database or may be static values; look refers to how well the prototype visually represents the final product, including fonts, colours, dimensions and graphics; and, interaction specify how well the prototype mimics the intended input device(s) (such as a mouse, keyboard, touch screen or haptic glove) of the final product.

While an entire prototype may be categorised as low or high-fidelity, it is quite possible that it is comprised of different fidelities (such as a low-fidelity paper prototype that has various print outs from a Photoshop® design which have a high-fidelity 'look'). The fidelity of each dimension determines the questions that can be answered by the prototype (Snyder, 2003).

As Bailey (2005) states, high-fidelity prototypes are generally “assumed” to be better at demonstrating proposed system functionality and collecting performance or evaluation data while low-fidelity prototypes are good for early visualization of alternate design ideas and predicting major usability problems for minimal cost (McCurdy et al., 2006; Preece et al., 1994; de Sa & Carrico, 2006). A prototype, regardless of its fidelity, should be quick and inexpensive to produce and be disposed of after an evaluation. The purpose of a prototype is vastly different from that of the final deployed system, specifically in regards to their “size, reliability, robustness, completeness and construction” (Preece et al., 1994, p 538).

Stone et al. (2005) suggests using paper-based mock-ups during the early phases of design because of their low cost and ability to derive a large volume of feedback from potential users. However, in an empirical study between computer and paper-based low-fidelity prototypes undertaken by Sefelin, Tscheligi & Giller (2003), it was found that users exposed to computer-based mock ups were more inclined to comment on the graphical details of the design whereas those shown paper-based mock ups wanted to draw suggested improvements.

Low-fidelity prototypes are claimed to be insufficient for ubiquitous computing applications (Lim et al., 2006) but, as Lim et al. (2006) highlight, a working high-fidelity prototype is impractical in most cases because they are based on rapidly emerging technologies. The choice of prototyping technique is therefore a trade-off between the cost, effort and time available to build it and the potentially misleading results that may derived (Lim et al., 2006; Rosson & Carroll, 2002; de Sa & Carrico, 2006). In a commercial context, low-fidelity prototypes may be viewed as unprofessional (M. Walker, Takayama & Landay, 2002).

While they do not reject the importance of paper-based prototyping, Sefelin, Tscheligi & Giller (2003) suggest that designers should always use a computer-based prototype to maximise the comfort of the subjects as the majority of subjects prefer computer-based prototypes as they provide more freedom to explore and fell less observed by the facilitator. According to Li, Hong & J. Landay (2004), computer-based prototyping tools have three significant benefits over paper-based and high-fidelity computer-based prototyping. They allow everyone to take part in application development, they speed up the iterative design process through ease of manipulation of the design and interactions and finally they provide a cheap and easy method of getting user feedback.

Lim et al. (2006) conducted a study comparing the effectiveness of three prototyping methods (paper-based low-fidelity, computer-based low-fidelity and high-fidelity). They concluded that major usability issues with the prototype were discovered by all three methods, a finding that Liu & Khooshabeh (2003) and M. Walker, Takayama & J. Landay (2002) have confirmed. Using the computer-based high-fidelity and low-fidelity prototypes, users were able to identify performance-related, physical handling and operation issues that the paper-based prototype could not. Lim et al. (2006) found the major limiting factors for the paper-based prototype was the abstractness of the graphics and the lag time between the user 'input' and the subsequent graphic being 'displayed' by the facilitator. Low-fidelity prototypes are therefore difficult to evaluate for timed tasks, interactivity and application scale (number of screens) (McCurdy et al., 2006).

Interactivity and scale issues can be improved by appropriate representation of interface elements (such as different colours defining whether an element is clickable, selectable or just a label) in paper-based prototypes Lim et al. (2006). Lim et al. (2006) conclude by saying that low-fidelity prototypes are only effective at identifying unclear label meanings, representational issues with icons, locating interface elements and, mental model mismatches. This is a view supported by de Sa & Carrico (2006) who state that low-fidelity prototypes are generally effective for designing desktop applications and go on to say that mobile ubiquitous applications require special attention to ensure that user interface elements which restrict usage in real world are represented appropriately.

A variety of options exist for creating low-fidelity prototypes including simple art supplies including pens, paper and Post-It® notes. Higher fidelity, static prototypes can be created using general purpose graphics software such as Photoshop®, PowerPoint® or HyperText Markup Language (HTML). Purpose built prototyping software including Anecdote (Harada et al., 1996), DENIM (University of Washington, 2008), DEMAIS (a derivative of DENIM targeted at rapid multimedia prototyping) (Bailey, Konstan & Carlis, 2001), MaggLite (Huot et al., 2004), Patchwork (van de Kant et al., 1998), SILK (Landay, 1996; Lin, 1999) and Topiary (Li, Hong & J. Landay, 2004; University of California, 2004) are capable of generating interactive, low-fidelity prototypes. Prototypes can also be developed using any application development framework, in which case the prototype may eventually evolve into the final system, referred to as evolutionary prototyping, however this often results in minimal exploration of alternative design solutions (Preece et al., 1994).

As suggested in section 6.4.2, in an actual system the user interfaces would be deployed on a PDA using the in-built web-browser. This not only allows other web-enabled hardware devices to be used for developing land use scenarios but also provides a familiar interface for users. However, for the purpose of this research the interfaces were deployed on a laptop computer.

Hundhausen et al. (2007) state that while the existing low-fidelity (paper-based) techniques adequately service rapid prototyping, the complementary activity of 'wizard of oz' testing (where a human 'wizard' simulates the computer by changing the 'screen' as the user interacts with the prototype) is not accommodated. In addition, making universal design changes is cumbersome and running 'wizard of oz' tests using paper prototypes is time consuming. Hundhausen et al. (2007) offer their Wizard of OZ Prototyper (WOZ Pro) (Hundhausen, 2008) software as a solution to these common problems, however it is specifically designed to run on Tablet PC's limiting its broader application.

Topiary's strengths over other rapid prototyping software included its capability to handle location contexts and its ability to evaluate applications remotely using Wi-Fi enabled devices and a 'wizard of oz' techniques. The Topiary application differs from other GUI prototyping applications in three distinct ways. Firstly, it allows the designer to model location contexts which, in real-world applications, are derived from various sensors such as GPS. Secondly, it integrates explicit (pressing a button, selecting from a menu) and implicit (display some information when the user arrives at a certain location) interaction methods. Finally, it allows designers to test and evaluate the design using mobile users (Li, Hong & J. Landay, 2004). This provides flexibility when creating a location aware, computer-based, low-fidelity prototype as the evaluation can take place after the user has used the interface. As a result, Topiary (University of California, 2004) was shortlisted for developing the prototype interfaces with its focus on rapid prototyping location enhanced services for ubiquitous computing. However, after a rudimentary evaluation of Topiary's functionality the Axure RP Pro software was selected to develop the interfaces for this research. While open source products were a preference, their capabilities and robustness were well below that of commercially available products. The Axure software was provided free of charge under the Good Student Program.

The reason for selecting a computer-based, low-fidelity system that utilised realistic graphics for developing and evaluating the user interfaces was three-fold. Firstly, the Axure software required no knowledge of any programming language. Secondly, the interfaces could be rapidly prototyped with the in-built interactions providing a realistic prototype and thirdly, the prototype could be deployed without the need for special software.

In order to accommodate the diverse requirements of interacting with and visualizing land use scenarios within an AR system, three distinct user interfaces are proposed. One provides the relevant tools for interacting at a regional level (ie sub-catchment scale) while another allows the manipulation of spatial data to create a land use scenario for the immediate area around the user (ie paddock/farm scale). While both interfaces utilise the same data and models, the context in which they are applied is different. The third interface allows users to explore landscapes by immersing themselves in a augmented narrative.

A prototype encompassing the three user interfaces outlined in 6.4.2.2 was created (Refer to the CD-ROM located in Appendix H). The subsequent sections describe the development of the proposed user interfaces which incorporate the requirements described in section 6.4.2 (specifically section 6.4.2.2). Within each section, the individual interfaces are discussed in the context of their intended implementation and supplemented with illustrations demonstrating the main elements to be visible on the prototype. The storyboard depicting the routes through the interface is depicted in Appendix A. Appendix B contains hand-drawn mockups of the interfaces and how they are envisaged to be used.

6.4.3.1 Narrative learning interface

As described in section 6.4.2.2.1, this user interface relies on a single user (the supervisor) having a PDA to select, start, pause and stop augmented narratives. To maximise the AR systems usefulness it should be applicable to various geographic locations and accommodate a variety of narratives. Each narrative would only be applicable at a single location (although generic portions of multimedia may be used at many locations) and this must be accommodated by the user interface using their spatial location.

The spatial relevance of a narrative could be determined in several ways. Firstly, the narrative title could include a reference to the location for which it is applicable such as “Burkes Flat salinity discharge”. All narratives could therefore be listed, regardless of their relevance to the specific location of the users, however this could result in a long list of potential narratives and potentially cause confusion if the name of the local area is not known or represented by a local name.

The other alternative is to utilise the location of the supervisor, determined by the GPS, to select the relevant narrative(s) within a given distance (such as a 200 metre radius of the current location). This method would simplify the narrative list to a manageable number of entries and require no additional effort because each 'narrative hot-spot' is tied to a geographic location and grouped into a narrative thereby providing its location and extent.

Aside from the supervisors PDA, all other users rely solely on the HMD as an interface and progress through the narrative by changing their location which ultimately determines what is displayed in the HMD. Appropriate visual cues within the HMD are therefore of utmost importance to navigate the user through the narrative.

As outlined in section 6.4.2.2.1, a combination of visual navigation aids and a 'world-in-miniature' map would be used to assist users navigate the narrative. The 'world-in-miniature' map would be displayed in the HMD when the user tilts their head below a certain angle (looking down), mimicking the task of reading a paper map (when walking through an unfamiliar environment). The map would be orientated to the user, allowing them to orientate themselves quicker. Information depicted on the map would include; major physical features relevant to the narrative (such as erosion gullies or salinity discharge), large physical features useful for orientation (such as roads and topographic features), present location of the user and icons representing narrative hot-spots coded according to whether they had been visited or not.

Showing the location of narrative hot-spots in the HMD may not be of assistance to the user if the hot-spot is occluded by another physical object or hidden by a topographic feature. A method of guiding users sequentially through the narrative is therefore required. Reitmayr & Schmalstieg (2004) have utilised the concept of virtual waypoints connected by arrows to depict the shortest route to an object of interest. In Reitmayr & Schmalstieg's 2004) system, the visual path is supplemented with simple directional information to assist the user orientate themselves to the correct direction, however this could be improved by a graphic arrow shown in the HMD to assist the user orientate themselves appropriately (Figure 6.6).

Figure 6.6 - Panoramic image depicting a rural landscape with area visible through the HMD highlighted. The arrow would be displayed in the HMD to indicate the location of a point of interest (represented by the virtual marker to the right of centre).

The orientation arrow would also be used once the user has entered a hot-spot assisting them to orientate themselves appropriately, maximising the benefit of the visual and multimedia (and potentially audio) narratives. The orientation arrow would only be displayed when the users orientation is greater than 20 degrees from the target. This value is determined by the horizontal field-of-view of the suggested HMD (5.2.1).

6.4.3.2 Scenario exploration interfaces

The scenario exploration interface is significantly more complicated than the narrative learning interface. The complexity of modelling landscape interactions make it necessary to look at the environment at different scales, depending on the focus of the end user and as a result there are two unique methods of generating individual scenarios. Firstly, a regional-scale methodology allows users to alter major landscape factors using an interactive radar chart to create a desired landscape. Secondly, a context-scale (or local-scale) method allows users to manipulate individual polygons representing land uses to create a desired interface. Summary results from either interface can be viewed on the PDA, while the spatial representation from either method can be viewed on the PDA through the mapping interface or through the HMD as an augmented visualization. While both interfaces are unique they share common elements such as the mapping interface and viewing the results as augmented graphics. The two interfaces are described in further detail below.

6.4.3.2.1 Regional-scale interface

The purpose of the regional-scale interface is to provide users with a quick and intuitive method of designing a land use scenario without the need to alter individual polygons representing those land uses. As discussed in 6.4.2.2.2.1 this interface will be implemented using a radar chart (Figure 6.7) which the user can manipulate to create a scenario.

Access to this interface would be granted through a series of screens as represented in the storyboard in Appendix 8.4. These screens, similar to a work-flow, guide the user through the process of creating a new scenario. After reading an instruction page outlining the process the user moves to the next screen where they are prompted to record some simple details (if they choose) enabling their scenario(s) to be saved for landscape modellers and scientists to review.

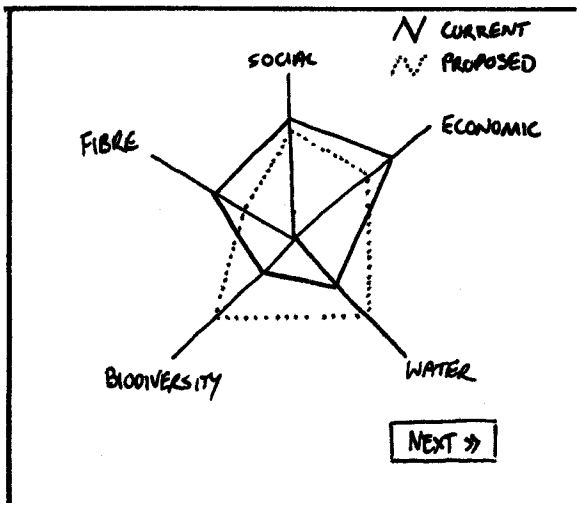

Figure 6.7 - Mock-up of regional-scale user interface for manipulating a land use scenario.

Altering the 'current' (or base) land use scenario is the next screen. By selecting each axis of the current scenario and dragging it to the desired position, the user creates a scenario. As mentioned in 6.4.2.2.2.1, moving one axis may result in other axes moving to ensure a realistic landscape is created. Once the user is happy with their scenario they move to the next step.

Continuing through the work-flow, the graphical depiction of the users desired landscape would be interpreted into a spatial representation. Each scenario would be generated from a variety of pre-defined spatial layers to speed up processing time and would provide a close approximation of the users desired landscape. The spatial representation of the scenario would then be displayed on the PDA within the mapping application (with similar tools to those displayed in Figure 6.8) where the user can further interrogate it. In addition to interrogating the scenarios on the PDA screen, the user will be able to control and display various spatial layers through the HMD. The location and orientation of the user would also be represented on the PDA assisting with orientating themselves.

The ability to iteratively develop a scenario would be provided by simplified “breadcrumbs”. Each screen in the work-flow would be represented by an icon, allowing the user to jump back to a specific process. If any changes are made at a particular point the user would have to redo each of the later steps. At all stages of the process the users actions and scenarios would be logged with either the details they provided or anonymously if they so desired. The logs would serve two purposes; recording issues or errors with the system and allowing modellers, policy makers and the like with the ability to interrogate the developed scenarios to derive common elements which may indicate over-arching stakeholder preferences.

6.4.3.2.2 Context-scale interface

The context-scale interface is a further iteration on the regional-scale interface described above, building on the mapping interface to allow users to change individual land uses for a specified location. This interface can be accessed by one of two ways, either on the completion of developing a scenario using the regional-scale interface or through a separate work-flow as represented in Appendix 8.4. This essentially integrates the two interfaces allowing users to create land use scenarios according to their ability or time.

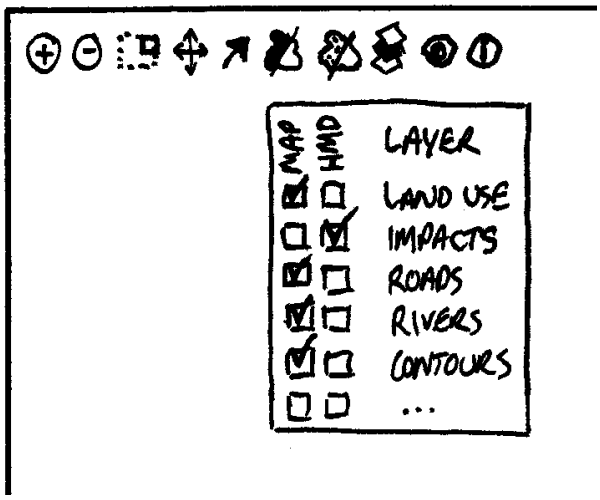

Figure 6.8 - Land use scenario mapping application. Tools provided include zoom in, zoom out, zoom to region, pan, select, split a polygon, alter a polygons land use, layer control (with the associated dialogue), view in HMD and information (or identify).

The reason for implementing the user interfaces on the PDA is highlighted by this interface. While the ability to select an existing polygon representing a land use and alter its land use would be possible in the HMD using haptic devices, the ability to select a polygon and split it into two or more polygons method would severely limit. The functionality provided by the mapping application in combination with the stylus to draw the dividing line(s) greatly increases the speed and efficiency.

6.4.3.3 Mapping interface

The amount of spatial information represented on a map must be limited to the essentials (Kraak & Ormeling, 1996) . With this in mind, the ability for users to control which layers are visible both on the PDA and through the HMD was added. It is possible for the user to be viewing two entirely different maps between the HMD and PDA which may assist the user in better interpreting the information being presented.

The identify tool provided in the mapping interface would return information about all layers at the location it is applied. While this may result in a longer list of features and attributes, the user does not have to manually specify which layer to identify. It is anticipated that, due to the small screen on the PDA and outdoor lighting conditions, the number of layers being viewed at any one time would be minimal, reducing the list to a manageable size on the PDA screen.

6.4.3.4 Generic interface requirements

An important aspect of any user interface is the availability of suitable help should the user require it. Every user interface should provide thorough and timely guidance and assistance (Galitz, 2007). There are various ways of providing user with help including generic dialog boxes and "intelligent" agents (such as the Microsoft® paperclip), however the content of the help system is most important. While the development of a comprehensive help system is outside the scope of this research it is important to note the specific requirements for an AR system.

Within an AR environment users may want access to help relating to the various user interfaces or they may want some generic information about landscape processes to assist them in creating an alternate land use scenario. Both aspects should be incorporated into a single system providing users seamless and integrated access about landscape processes and how to use the interface to explore the options.

6.5 Need for usability evaluation

The purpose of evaluation is to identify the issues affecting the usability of a product or system by assessing the user interface against various usability dimensions to identify problems and areas of improvement (Stone et al., 2005). Evaluation is the gathering of data about a product or interface by a specified group of users, for a specific activity within a specific context. Evaluation informs design and should be an on-going activity over the life cycle of the particular product. A variety of evaluation techniques are needed to support and validate the different stages of interface design (Stone et al., 2005).

Quality and usability standards need to maintained regardless of the device or the paradigms imposed by the device (de Sa & Carrico, 2006). Comprehensive usability evaluations in association with robust technology results in usable, performance-enhancing AR systems (Wang & Dunston, 2006). The evaluation of the user interfaces presented in this chapter occurs in the following chapter.

6.6 Chapter summary

At the beginning of this chapter, various usability engineering design methodologies were discussed. The Scenario-Based Design approach described by Carroll (2000) was selected as it provided the means of developing possible use scenarios for a theoretical augmented reality system. The SBD approach allowed the author to develop the scenarios and incorporate hands-on experience and knowledge from working with natural resource data and ICMs to make them as realistic as possible.

Six problem scenarios were developed encompassing the current process of developing a land use scenario. The inherent issues with the current methodology were analysed to form the basis of the activity scenarios. The activity scenarios were vastly different from the problem scenarios highlighting the quantum difference between the current and proposed systems. Rather than focus on new and innovative interaction methods, the interfaces developed as part of this research adopt existing metaphors. This has been a conscious decision to ensure the targeted audiences of landowners, catchment managers and natural resource scientists are exposed to familiar tools and paradigms.

The user interface requirements for two distinct interfaces were derived from the activity scenarios. The narrative interface was focused on educating potential users about landscape process and the impact of our actions. Users would be guided through the landscape by visual cues from the AR system and be shown a variety of multimedia relating to a specific NRM concepts.

The second role was targeted at developing land use scenarios while in the landscape. Two separate yet integrated methods were defined to accomplish this. The first utilised a radar chart with each axis representing a landscape factor. By moving each axis a land use scenario would be generated for viewing on the PDA and through the HMD. The second interface adopted an Internet mapping approach whereby users could alter individual land use polygons to develop an alternate landscape. In both cases, the user could explore the generated scenarios on both the PDA and through augmented graphics. The impacts, derived from a simple water balance model, could also be displayed, assisting the user determine the trade-offs between various actions and landscape implementations. Having discussed the need to evaluated UI in the last section of this chapter, an evaluation strategy is developed and undertaken in the following chapter.

Chapter 7

Usability evaluation

7.0 Chapter overview

After an introduction to usability evaluation a generic overview of evaluation processes is given. The dimensions of usability are discussed with reference to this research. Qualitative and quantitative evaluation methods are outlined prior to the development of an evaluation strategy for evaluating the prototype user interface developed in the previous chapter.

Tasks are developed to evaluate the effectiveness of the prototype user interfaces. Six users were observed undertaking tasks with the prototype. The use of human participants to evaluate the user interfaces was undertaken in accordance with the RMIT University Human Research Ethics Committee (HREC) procedures (http://www.rmit.edu.au/browse;ID=6sqqx7sd0wkp;STATUS=A?QRY=hrec&STYPE=ENTIRE). The evaluation of the user interface prototypes was assessed by the Human Research Ethics Sub-Committee Science, Engineering and Technology (SET) Portfolio to be risk level 2. In accordance with the approval to undertake usability assessments, all participants involved agreed with and signed the Informed Consent (Interviews or Questionnaires) form (Appendix D) prior to undertaking the evaluation.

The results from the evaluations are documented, analysed and discussed in the context of the recognised shortcomings of the prototype. Suggestions are offered on how the interfaces could be improved prior to concluding with a summary.

7.1 Introduction

The process of usability evaluation determines whether a particular system works as intended. Evaluation is an iterative process and should be used at all stages of the design process to inform and ultimately improve the system being developed (Stone et al., 2005;Wang & Dunston, 2006).

The evolution of software design from its origins saw a dramatic shift during the 1970s. The introduction of personal computers resulted in the diversification of users from traditional computing professionals developing and maintaining applications for an organisation to more diverse and less technical user base able to install (and manage) their own software. This shift resulted in the development of techniques for comparing and evaluating software (and system) usability (Rosson & Carroll, 2002).

Brooke (1996) states that it is impossible to define the usability of a system without first defining the intended user(s), the tasks they perform and the characteristics of the environment in which it will be used. The modern view of usability is comprised of three complementary perspectives: human performance; learning and cognition; and collaborative activity (Khan, 2005; Rosson & Carroll, 2002).

Usability has been defined by (Rosson & Carroll, 2002, p 9) as "...the quality of a system with respect to ease of learning, ease of use and user satisfaction."

The international standard Ergonomic requirements for office work with Visual Display Terminals (VDTs) - Part 11: Guidance on usability (ISO 9241-11:1998) (cited in Stone et al., 2005, p 6) extends this definition stating usability is "...the extent to which a product can be used by specified users to achieve goals with effectiveness, efficiency and satisfaction in a specified context of use."

Both definitions highlight three core aspects of usability: effectiveness; efficiency; and satisfaction (or engaging). The ISO definition specifically narrows usability down to a specific user group and context of use. Quesenbury (2003) incorporated two additional aspects (error tolerant and easy to learn) which better assist in defining a user experience. The combination of usability aspects has resulted in the "five E's" of usability. In a perfect system, each aspect would be equally considered when designing a UI (Stone et al., 2005).

While evaluations of complex interactive systems are essential, usability assessments of ubiquitous computing and AR systems have lagged behind those of typical computing and Virtual Reality (VR) systems (Liu & Khooshabeh, 2003; Wang & Dunston, 2006). Usability assessments are a necessity that must be adopted to ensure such systems are developed according to the requirements of the intended users (Wang & Dunston, 2006).

7.2 Usability evaluation

An evaluation technique is a systematic way of conducting a usability inspection. Usability inspection refers to a set of methods that rely on evaluators inspecting a (prototype) user interface (Nielsen, 2005a). Preece et al. (1994) p 602 has defined usability evaluation as being "...concerned with gathering data about the usability of a design or product by a specific group of users for a particular activity within a specified environment or work context."

There are a variety of inspection methods but no foolproof way of detecting all usability flaws (Molich et al., 2004). User interfaces can be evaluated as the system is being developed, known as formative evaluation or alternatively summative evaluation is carried out at the end of the development process. Formative evaluation is an empirical, observational assessment used in all phases of user interface development, to improve the user interface through iterative and quantifiable assessments (Wang & Dunston, 2006).

Nielsen & Mack (1994) outline eight methods, two of which require evaluators to inspect and discuss the user interfaces as a group. According to Stone et al. (2005), all methods are general variations of user observation and heuristic inspection. User observation involves an evaluator documenting comments and opinions regarding the systems user interface and usability as prospective (or representative) users undertake defined tasks, with Stone et al. (2005) describing it as the single most valuable evaluation technique. Heuristic inspection is carried out by a domain or usability expert evaluating the user interface for compliance against a set of documented design guidelines, design principles or usability standards.

Prototypes can be evaluated using qualitative and/or quantitative methods. Depending on the method used, data including user mistakes, time taken to complete a specific task and users comments are collected while observing users performing defined tasks (Walker, Takayama & J. Landay, 2002). Usability inspections typically require evaluators to undertake specific tasks with the user interface and where possible (and relevant), the evaluation should also consider the (actual or simulated) environment in which the system will be used. Evaluations can also be undertaken near the end of the design process to assess the overall usability and inform subsequent releases of a system (Stone et al., 2005). While regular users can serve as evaluators better results are typically achieved by using usability experts (Nielsen, 2005a).

Expert heuristic evaluation is an analytic evaluation of a user interface undertaken by a user interaction expert. The expert assesses the user interface according to defined usability guidelines to determine the shortcomings of the interface and subsequently recommends changes to improve the design (Wang & Dunston, 2006). Such rigorous, formal approaches are expensive in terms of money and expertise which results in usability evaluation being an intimidating proposition for many (Nielsen, 1994).

Nielsen has been referred to as an expert of web usability (Marks, 2001; Richtel, 1998) and has simplified the formal usability heuristics to create a quick and simple method of evaluating a user interfaces. His method utilises 10 rule-of-thumb heuristics that should be observed in any interface to ensure good usability. The 10 heuristics are (Nielsen, 1994):

- visibility of system status;
- match between the system and real world;
- user control and freedom;
- consistency and standards;
- error prevention;
- recognition rather than recall;
- flexibility and efficiency of use;
- aesthetic and minimalist design;
- help users recognise, diagnose and recover from errors; and,
- help and documentation.

Nielsen (2005a) states that heuristic evaluation is a popular method of usability inspection that is easy to learn and apply. The approach uses three techniques; scenarios, simplified thinking aloud, and heuristic evaluation. Nielsen's (1994) approach is no different to typical formative evaluations comprising the development of user task scenarios, allowing participants to undertake tasks so qualitative usability data can be collected to assist defining improvements for future designs. This method is undertaken by a small group of evaluators using the user interface and judging its compliance with recognised usability principles or heuristics. Nielsen (1994) utilises this method to overcome the often intimidating usability evaluations in something he refers to as a "discount usability engineering" method. The method described by Nielsen (1994) is a "bare bones" usability approach, and while acknowledging that it is not necessarily the most thorough usability evaluation method, says it is far better than no usability analysis at all.

Highly interactive, visual environments lack established paradigms for conducting usability research due to the use of various interaction techniques in a wide range of contexts for a wide range of users (MacEachren & Kraak, 2001). Evaluation methods applied in desktop environments are not generally applicable to evaluating wearable computer applications. Monitoring user actions in real time is core to any evaluation framework, however, the personal nature of wearable computers makes this difficult (Suomela & Lehikoinen, 2000). While formal usability guidelines do not exist for AR interfaces, informal standards have been developed by Gabbard & Hix (1997) and Wang & Dunston (2006) during the evaluation of their systems.

During the evaluation of working wearable systems, Suomela & Lehikoinen (2000) suggests that all user interactions be stored in log files allowing a summative evaluation to take place post user testing. Wang & Dunston (2006) utilise a formative heuristic usability evaluation method for assessing their indoor AR application.

7.2.1 Quantitative evaluation

Quantitative evaluation collects explicit usability metrics such as time taken to complete a task, the rate of errors or the number of times a participant refers to the help, the type of user (or participant) is also a consideration in the analysis (Stone et al., 2005). In order to record quantitative data the tasks need to be clearly specified and repeatable, something that is not always possible in interactive and exploratory applications (G. Andrienko et al., 2006; Slocum et al., 2001).

7.2.2 Qualitative evaluation

Qualitative evaluation is subjective and difficult to measure and quantify. Qualitative evaluations focus on what the participant is doing and how they are doing it, providing an insight into the cause of a usability problem while getting suggestions on how to resolve the problems. It is possible to convert some qualitative data into quantitative data, for instance, at least 3 of the 5 participants rated the system "easy to use".

Qualitative information is typically collected using the "think-aloud, task based testing" (Walker, Takayama & J. Landay, 2002, p 2). This method relies on evaluators verbally describing their actions and thoughts as they undertake a broadly stated task (G. Andrienko et al., 2006; Stone et al., 2005). It also allows the facilitator to assist the evaluator if they become lost or disorientated by asking open questions such as "Is that what you expected?" or "What just happened?" (Stone et al., 2005) to gain an insight into the cognitive processes that occurred (G. Andrienko et al., 2006).

While the think-aloud method is somewhat unnatural and distracting for the person doing the evaluation it provides rich and immediate feedback to the evaluator. The think-aloud protocol (or cognitive walkthrough) is particularly suited to qualitative assessments of low-fidelity prototypes (Stone et al., 2005).

The predominant purpose of evaluating the user interfaces in this research is to test the logic, structure and navigational aspects. The scenarios developed with the Scenario-Based Design (SBD) method (section 6.4) provide a sound platform for applying a cognitive walkthrough evaluation. According to Stone et al. (2005, p 71), a cognitive walkthrough "...evaluates the steps required to perform a task and attempts to uncover mismatches between how the users think about a task and how the UI designer think about the task."

A cognitive walk-through requires each task to be documented in a way which describes an end-point but not the specific manner in which to achieve it. Each participant then attempts to undertake the documented task by exploring the prototype, selecting an action they believe to be correct and interpreting the response from that action to assess whether it was correct. During this process and for each step in the task, the evaluator attempts to answer each of the following questions by watching and listening to the participants verbal feedback (Stone et al., 2005):

- How does the user know what to do next?
- Is the action evident from the interface or does the user recall what to do from memory?
- Does the user connect the correct action with what they are doing?

- Does the user realise if they have made a mistake?

Answering each of these questions assists the evaluator determine whether the user interface is intuitive, allows the user with the options they require to complete the task and provides sufficient feedback.

7.3 Evaluation processes

In order to evaluate a system a process needs to be developed and followed. Naturally the usability requirements of the system need to be defined prior to an evaluation strategy being developed. The strategy provides the structure for creating an evaluation plan. From the strategy an evaluation plan detailing how, when and who will attend the evaluation sessions is created. Once the evaluation sessions have been conducted the data is collated and analysed to determine whether the usability requirements have been met. The (probable) cause of the problems are documented in association with recommended resolutions. The analysis and interpretation phases are complimentary and undertaken simultaneously. Pending the outcome, the system may need to be altered to incorporate the suggested improvements or a whole new strategy may need to be developed to better test the interfaces. The whole cycle is worked through iteratively until the system meets the defined requirements. This process is shown in Figure 7.1.

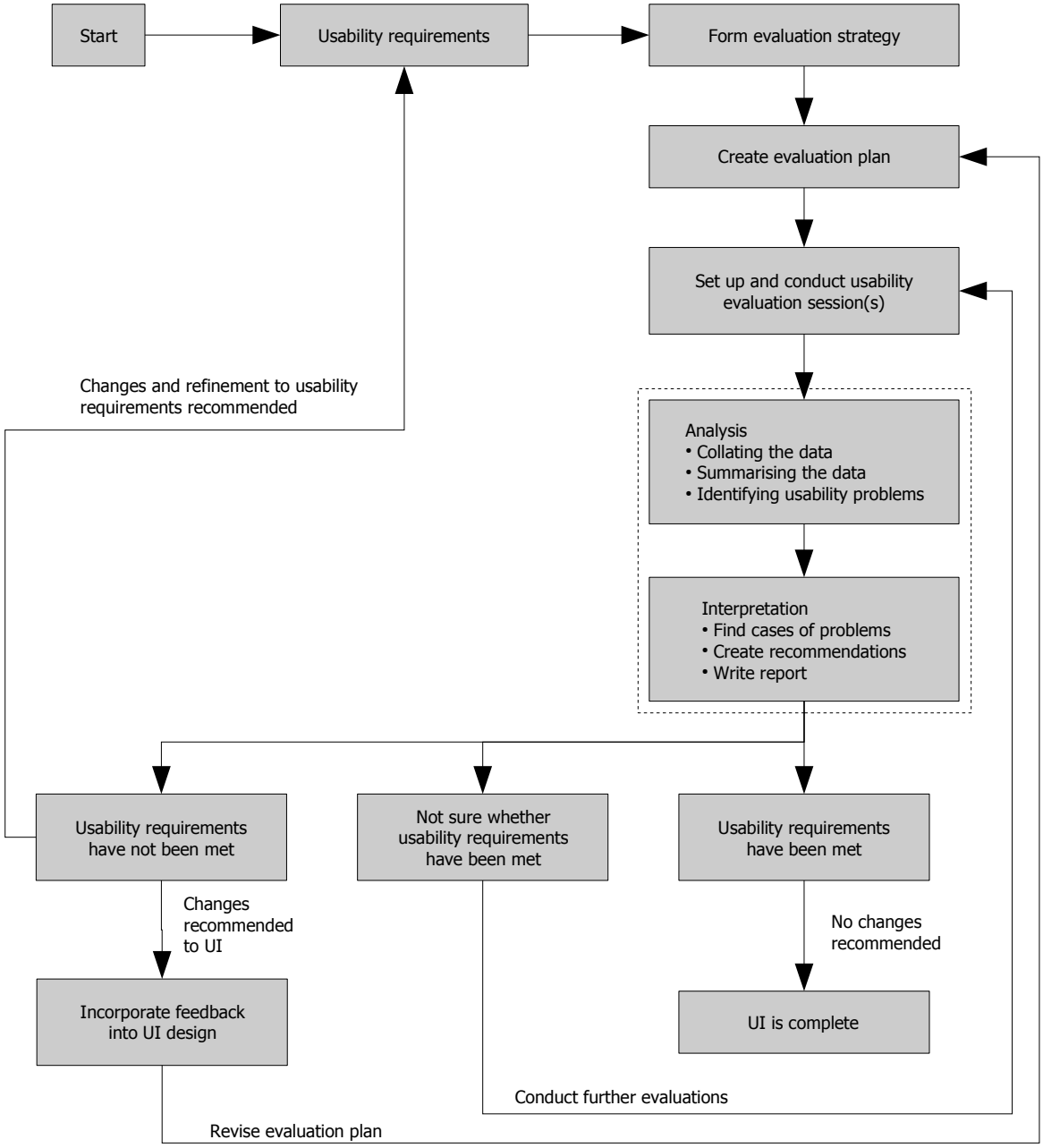

Figure 7.1 - Usability evaluation process, adapted from Stone et al. (2005, p 433)

Stone et al. (2005) suggests the usability requirements and concerns of a particular system be prioritised by assigning a weighting to Quesenbury (2003) “five E's”. Different weightings may be applied to different parts of the system, depending on its particular goal. For the purpose of this research each of the interfaces (narrative and scenario exploration) have been treated as one. Figure 7.2 (b) shows the desired weightings for the user interface being developed. The greatest weightings have been given to the efficient, ease to learn and the error tolerant dimensions as a result of the diversity of users at which the system is targeted. While the system must be effective at allowing users develop and interrogate land use scenarios it has been given a weighting equal to engaging as users must be able to effectively engage with the application to explore and understand the processes being represented. Error tolerance has the largest weighting to ensure errors are handled in a manner that minimises confusion without compromising the effectiveness of the user interfaces.

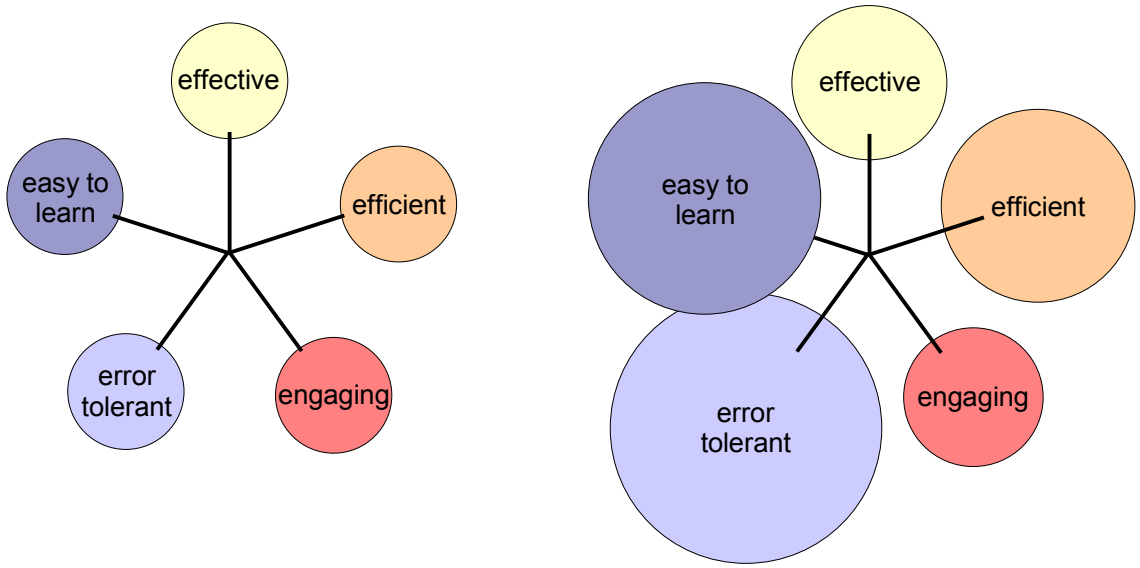

Figure 7.2 - The five dimensions of usability as defined by Quesenbury (2003) (a) with equal weightings and, (b) the weightings applied for the User Interfaces (UI) on the Personal Digital Assistant (PDA). Adapted from Stone et al. (2005, p 443).

7.4 Evaluation design

Designing and documenting the tasks that users will undertake during the evaluation is one of the most important aspects of usability testing, although it is also one of the more difficult. According to Snyder (2003) tasks have the following characteristics (the first two being critical):

- Specific to a goal that users would normally undertake. (Goals must be important, including those undertaken frequently and infrequently);

- Include specific and broad questions that are important to the success of the final product. (Specific questions are easier to answer however the broad questions contribute more to the success of the product. The questions form the basis of the tasks);
- Has an appropriate scope that isn't too broad nor too specific. (Although screens are designed one at a time, broader usability issues can not be uncovered without a user attempting to accomplish a task that involves multiple screens);
- Has a finite and predictable set of solutions. (This is especially important when a prototype only represents a portion of the envisaged system. Constraining tasks to ensure a result is obtained is the best way of accommodating a limited prototype);
- Has a clear and recognisable end point making facilitation easier. (Ultimately the users must decide when they have completed a specific task); and,
- Elicits both action and opinion. (The majority of the time users should be interacting with the prototype rather than speaking about it. As a result, opinion-based questions should be left to the end of the evaluation, and only be included if the prototype is a close replica of the final system).

Well designed tasks ensure "the user covers the areas of the interface that you have questions about while on their way to accomplishing something that they care about" (Snyder, 2003, p. 124). Usability tasks for low-fidelity prototypes are developed through a seven stage process Snyder (2003) and focus on developing tasks that reside in the overlap between the designers questions and the goals of the user, as illustrated in Figure 7.3. Rather than detailing each of the seven stages explicitly, several stages have been combined (where appropriate) and discussed in the sections below. A background to each step is provided followed by specific details relating to this research. Each task developed through the process below is fully documented in Appendix E utilising the template from Stone (2005, p. 73).

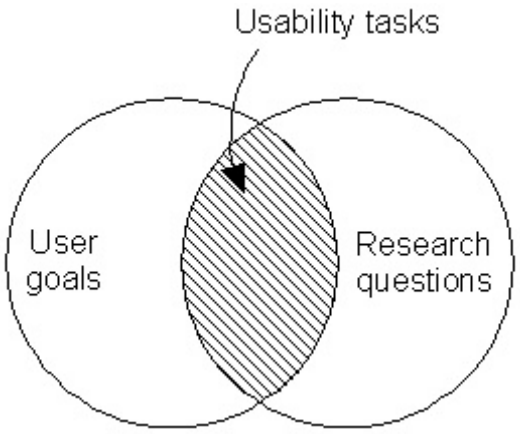

Figure 7.3 - Usability tasks are derived from the area of overlap, after Snyder (2003, p.124)

7.4.1 Evaluation strategy

Nielsen & Landauer (1993) determined that five to eight users is sufficient to evaluate a user interface to determine major usability issues with additional participants simply re-stating issues. Nielsen (1994), Stone et al. (2005) and Snyder (2003) agree that a small number of participants (between four and six) are sufficient at uncovering major usability issues of a user interface.

Stone et al. (2005) state that the selected participants should reflect the different skills, domain knowledge and experience level of the eventual system users. Snyder (2003) disagrees, suggesting that testing should involve a specific user group to ensure the results can be unequivocally interpreted. This does not undervalue the importance of evaluating against a broad range of (potential) users but makes interpreting and responding to issues simpler. Narrowing the participants down to a specific group is accomplished through the creation of a user profile which typically specifies such things as the users desired education, work responsibility, familiarity with technology or any number of other traits.

The stakeholders (6.4.1.1) and hypothetical stakeholders (6.4.1.3.1) developed for the scenarios document the anticipated users of the AR system. For the purpose of this research, the natural resource scientist and policy stakeholders have been targeted to evaluate the user interface prototypes. Both groups have high computer literacy, domain knowledge about landscape processes and their impacts on the environment. These factors ultimately contribute to the evaluation of the user interface by ensuring each participant is focused on accomplishing the defined tasks using the user interface rather than wanting to understand the reason (or purpose) behind undertaking a task. Once again, the importance of alternative stakeholders (landholders for example) would not be neglected in the development of a fully developed system as they are sure to highlight different issues.

Of the six participants chosen to undertake the evaluation two were directly involved with policy making either through allocating and managing funding of scientific research programs or through the dissemination of existing research to develop suitable policies relating to land use management. The other four participants were natural resource scientists with backgrounds in Geographic Information Systems (GIS), geology, soils or biodiversity. At least one of the participants had been directly involved with the development of land use scenarios.

7.4.2 List of participant goals

This step involves listing the goals that users are to achieve using the interface, the factors of the interface that are important to them and the reasons why the interface makes their life easier. Attention needs to be paid to the tasks that users undertake often as well as those tasks that are done infrequently but are essential (Snyder, 2003).

For the purpose of this research both the problem scenarios (Table 6.5) and activity scenarios (Table 6.7) provide the basis for determining the goals that users would undertake. To summarise, the goals that are to be achieved through user interface include:

- Select and publish a narrative for participants to view;
- View the location of participants within the landscape and determine their progress through the narrative;
- Follow a narrative at a single 'narrative hotspot' as a participant;
- Load various pre-defined land use scenarios at a regional scale to determine their comparative impacts by exploring the scenarios on the PDA and through the HMD;
- Alter an existing land use scenarios and compare the preliminary results against the existing scenarios; and,
- Alter an individual land use polygon and compare (both visually and numerically) the implications against the proposed land use scenario.

Each of these goals forms the basis of a specific task formulated to answer specific questions about the effectiveness of the prototype user interface. These questions are listed and prioritised, according to the desired usability dimensions (refer to Figure 7.2b) in the following section.

7.4.2.1 Listing and prioritising questions

This step involves listing all the specific questions and concerns regarding the design of the user interfaces. The questions may be derived from previous user feedback or underlying doubts and can be very specific or vague. Snyder (2003) suggests documenting 20 or more questions for most projects.

While specific questions are easier to answer, the answers to the broad questions are more important to the success of the product. It may not be possible to answer all questions due to a range of constraints however, prioritising the questions ensures tasks which assist in answering multiple questions are undertaken as a priority. Many broader questions will not be answered by the completion of a single task and, as a result, certain tasks may need to overlap to ensure such questions can be answered (Snyder, 2003). The list of generic questions developed by Snyder (2003) has been adapted in Table 7.1 for the purpose of this research. Questions that were not relevant to low-fidelity prototypes were removed and additional questions, specific to the developed interfaces were added.

Question category	Question	Priority
Concepts and terminology	1. Does the user understand the terms used in the user interface?	High
	2. Are there concepts they gloss over or misconstrue?	High
Navigation, work flow and task flow	3. Are users able to navigate the interface?	High
	4. Does the work flow of creating a land use scenario match the users expectation?	High
	5. Does the user have access to all the required information when developing land use scenarios?	High
	6. Are data entry fields ordered correctly?	Moderate
Content	7. Is the application useful?	Low
	8. Is there functionality that is not needed or annoying?	Low
Documentation, help	9. What assistance does the user need to successfully complete the tasks?	Moderate
	10. What is the best way to provide that information?	Moderate
Requirements, functionality	11. Does the interface do the right set of things for the target audience?	Moderate
	12. Do users have additional needs that aren't being met?	Low
	13. Is there anything which could be done to make the users life easier?	Moderate
	14. Is the application really needed?	Low

Screen layout	15. Is the amount of information on each screen overwhelming, not enough or about right?	Moderate
	16. Do users miss seeing something that is important?	High
	17. Are there elements that need to be highlighted or subdued?	Moderate
Colours, fonts and graphic elements	18. Can users see and read everything well enough?	Moderate
	19. Do the most important elements stand out?	Moderate
	20. Is the interface aesthetically pleasing?	Low
	21. Do the users understand what the icons mean?	Moderate
Real-world use	22. How does this tool fit in with the users day-to-day tasks?	Low
	23. What things will annoy power users after continual use?	Moderate
	24. Which of the functions are people really going to use?	Moderate
	25. What happens when the user is interrupted mid-task?	Moderate

Table 7.1 - User interface questions (adapted from Snyder (2003, p268)) which are to be answered by observing participants undertake the tasks (Appendix E).

The high, moderate and low indicates the priority of determining the answer during the evaluation sessions. Those questions that are high priority are essential to answer. The low priority questions can not be explicitly answered by the prototype user interfaces, but require the users to offer their opinion. The tasks to answer the listed questions are developed in the following section.

7.4.2.2 Task creation and ordering

This step is the culmination of understanding the goals of the user (with respect to the purpose of the software) and the usability questions as detailed in Table 7.1. Specific, physical examples of the goals and questions are required to develop a task. The number of tasks created is determined by project time constraints, complexity and scope of the system and number of participants being evaluated. Snyder (2003) suggests a minimum of 1-2 hours should be set aside for evaluating each user while (Stone et al. (2005) suggests 30 to 90 minutes is sufficient. These time periods ensure participants have sufficient time to familiarise themselves with the user interface concepts.

Each participant should be evaluated in a fixed time period with sufficient tasks developed to ensure the evaluation period is filled. Additional tasks should be developed to accommodate those users who complete the specified tasks earlier (Snyder, 2003). For the purpose of this research, six tasks were developed reflecting the goals that potential users may want to accomplish when analysing, visualizing and interpreting land use scenarios.

Table 7.2 lists the tasks developed for this research. The questions (listed in Table 7.1 above) to be answered by the task are also listed. All tasks contribute to answering multiple questions, with the specific questions listed in the right hand column.

Three tasks (1, 2 & 3) were dedicated to the narrative aspects of the user interface, with two tasks undertaken as the narrative leader and one as a participant in a narrative. The remaining tasks (4, 5, & 6) where focused on scenario exploration and development at both the context and regional scales.

Task	Task description	Target questions
1.	Choose and publish a narrative	All but 5 & 6
2.	Monitor narrative participants	All but 5 & 6
3.	Participate in a narrative	All but 5 & 6
4.	View land use scenarios	All but 5 & 6
5.	Create an alternate land use scenario	All
6.	Alter specific land uses of an existing scenario	All

Table 7.2. - List of evaluation tasks and questions that may be answered.

The extent of the prototype user interfaces developed for this research restricted the number of tasks that could be developed. The time taken for users to complete a task is determined by the time an 'expert' takes to complete the same task. Snyder (2003) suggests that the 'expert' time should be multiplied by a factor of 3 to 5 times for web-based applications. No task should take less than 5 minutes to compete. As the developer of the prototype, and therefore the 'expert', the author took approximately 25 minutes to complete the tasks. As a result it was estimated that the participants would complete the six tasks in approximately an hour.

Users do not need to complete the tasks in the same order when utilising a low-fidelity prototype as specific quantitative metrics (such as time taken to complete a task and error rates) were not being evaluated in this research. This allows flexibility to change or re-arrange the task order as the evaluations progress to ensure the designated time is met (Snyder, 2003). For the purpose of this research the task order was kept the same. The written instructions for the participants are described in the next section.

7.4.3 Instructions for the users

Each evaluation session was comprised of a 5-10 minute introduction (refer to Appendix C) and brief explanation of augmented reality. The introduction re-iterated the conditions (specified in the Informed Consent form Appendix D) under which they were taking part in the evaluation session and gave each participant some contextual information relating to the basis of the prototype system, including an explanation of the prototype implementation and how the augmented reality portions of the evaluation were simulated.

After the introduction each participant was provided with a set of written instructions describing a particular situation, asking them to perform a task and, in some cases, answer questions. Written instructions allowed the participant to refer to and annotate them as required. Each task was presented on a separate page as suggested by Snyder (2003) and Stone et al. (2005) allowing participants to work at their own pace and not feel pressured by having to complete the tasks in a specific time. The instructions for the participants avoided terms that were explicitly referred to in the interface (such as menu or button names) preventing the participants being lead through the task.

Stone et al. (2005) suggests giving each participant the same initial task, then shuffling the remaining tasks to maximise the chance of different usability issues being found by each participant. For the purpose of this research, the tasks were delivered to the participants in a common order as the prototype user interface provided a work-flow metaphor (step-by-step). This metaphor extended throughout the user interface and as a consequence, most tasks formed the foundation of a subsequent task, for instance, task 2 (Monitor narrative participants) relied on task 1 (Choose and publish a narrative) being completed.

7.4.4 Cognitive walk-through

A cognitive walk-through approach was chosen for the evaluations. Cognitive walk-throughs are a technique of exploring participants mental processes while they undertaking a particular task. They provide a method for collecting usability information by examining whether the appropriate actions (as intended by the system designer(s)) were taken to complete the task. The technique relies on participants informing the evaluator of their (intended) actions and the results of those actions. The 'talk-out-loud' technique can be unusual for participants, having to concurrently speak and concentrate on an unfamiliar interface, a large amount of information pertaining to the systems usability can be gained that would not otherwise be apparent if only physical actions were documented (Stone et al., 2005).

During the course of the evaluation the participants were reminded to explain their thoughts and describe what they were trying to do. This was achieved by asking the participants what they were trying to do or what they thought the next step in the process was and why. Only incorrect comments were documented to assess (potentially common) issues experienced by the participants.

7.4.5 Post-evaluation questionnaire

It is difficult to determine a systems usability when evaluating outside its intended context of use. In some cases it is not possible to evaluate a system in its intended context, however an evaluation will still yield important feedback for the developers. Post-evaluation questionnaires can also assist in determining high-level usability. A variety of questionnaires (refer to UsabilityNet (2006) and Perlman (n.d.)) have been developed to assess usability aspects of user interfaces from a higher, more subjective view point.

The reliability of several questionnaires (for evaluating web sites) were tested in a study undertaken by Tullis & Stetson (2004). All questionnaires evaluated were publicly available. Commercial or proprietary questionnaires such as the Website Analysis and MeasureMent Inventory (WAMMI, 1995) and the Software Usability Measurement Inventory (SUMI, 1991) were not included in their study. Over 120 participants undertook tasks on two web sites and their responses recorded on a randomly selected questionnaire from the five evaluated. While the study explicitly compared the usability of two sites it did conclude that the System Usability Scale (SUS) questionnaire was the most reliable (Tullis & Stetson, 2004).

The SUS (Appendix F) is a simple questionnaire consisting of 10 generic statements relating to usability. The questionnaire provides a subjective assessment of a systems usability and was completed by each participant at the end of their evaluation session, but prior to any discussion or debriefing. The SUS is a Likert scale, providing respondents with five choices in responding to each of the ten statements, ranging from strongly disagree (1) to strongly agree (5). A composite score in the range of 0-100 is derived from the responses. For odd numbered questions the score contribution is determined by subtracting 1 from the scale position (if a participant answered 4 for question 1 the score would be 4-1 or 3) and for the even numbered questions it is determined as 5 minus the scale position (if a participant answered 3 for question 2 the score would be 5-3 or 2). The sum of all scores are then multiplied by 2.5 to obtain the overall rating (from 0-100) for the systems usability (Brooke, 1996).

7.5 Analysis of results

This phase of the evaluation determines whether the user interface has met the usability requirements specified when designing the evaluation tasks (as described in 7.4.2 and its sub-sections). All the comments and issues documented during the evaluation sessions have been compiled in the following sections.

7.5.1 Known limitations

Most software applications have limitations that are documented and known by the application developers. The implementation of the prototype interface developed for this research had a series of limitations. Some were imposed by limitations with the software used to develop the prototype while others related to how the evaluations were conducted. Each of these limitations are discussed below.

There were several issues with the software used to develop the prototype user interfaces. Axure RP Pro (http://www.axure.com/) provides a drag-and-drop interface for creating prototype desktop and Internet applications (Figure 7.4). While it does provide the functionality to create low to medium fidelity prototypes it does have several shortcomings when attempting to develop highly interactive applications. In the case of developing the prototype application for this research a large number of layers were required to simulate the mapping interface and the HMD. Each of these layers required several images that needed to be developed using graphic applications.

Another issue was the inability of the software to generate screens larger than the defined area and provide a scroll bar when rendering (as occurs in any web page if the content exceeds the viewable area). While this ensures no page content exceeds the viewing area, it is more than restrictive with small screen sizes.

Axure RP Pro can handle conditional statements (if, then, else) and check the logic of a limited number of variables (maximum of 10). This resulted in variables having to be re-used (causing some confusion during development) limiting the ability to create an unrestricted, dynamic interface (both PDA and HMD) that provided multiple options was not possible. Other issues including the lack of a timer function, ability to dynamically enable and disable interface elements (such as buttons and drop-down lists) meant the implementation was restricted.

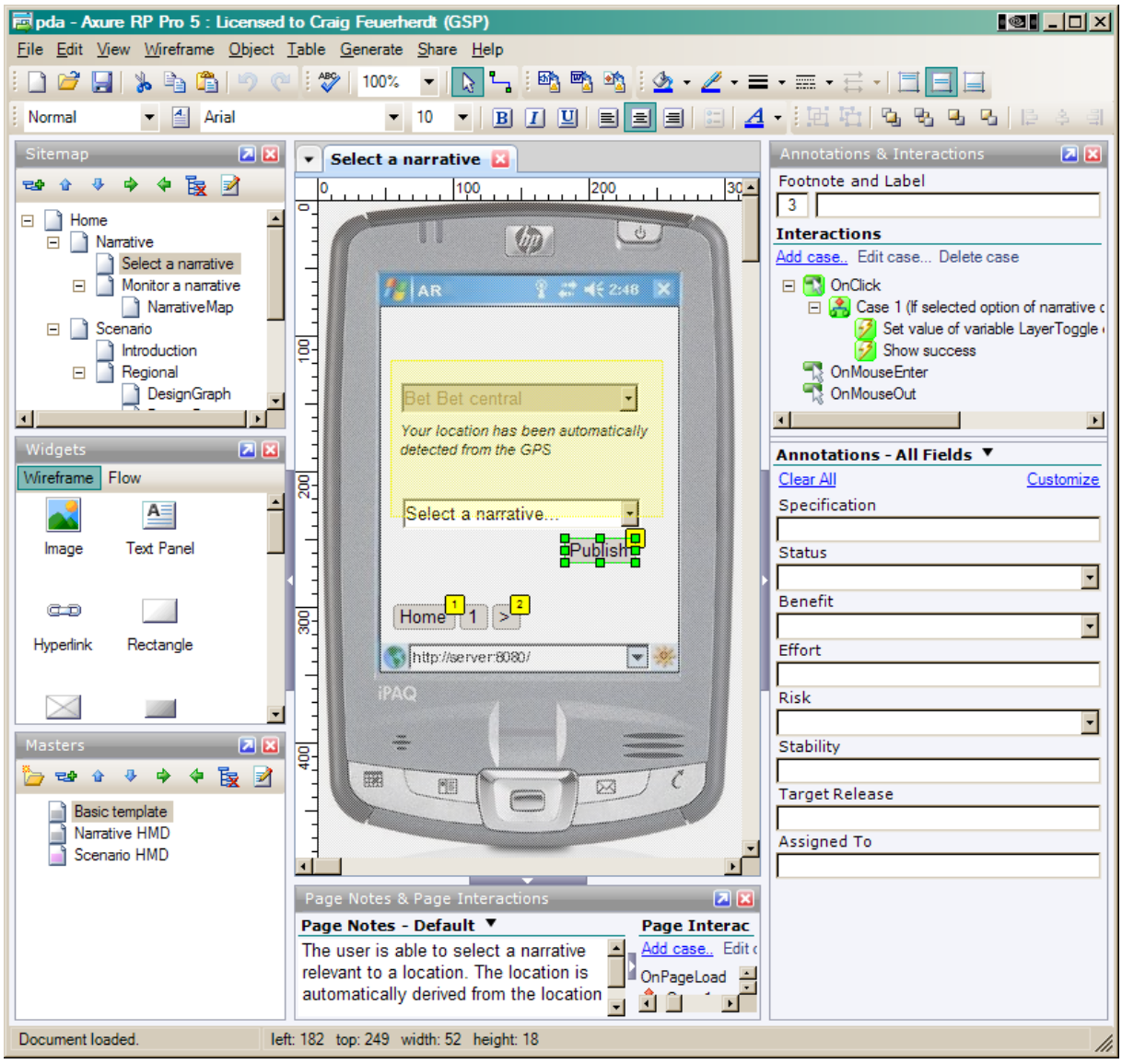

Figure 7.4 – Axure RP Pro interface showing the interactions (top left) associated with the selected button (centre).

The Axure RP Pro software generates HyperText Markup Language (HTML) pages with embedded Javascript (refer to the attached CD-ROM). For the purpose of the evaluation a graphic representing a PDA was used as the basis for the user interfaces. This allowed the user interfaces to be represented at a realistic scale. These pages were rendered in version 2 of the Mozilla Firefox web browser (http://www.mozilla.com/en-US/firefox/) for evaluation by the participants. All the tool bars, address bar and status bar of the browser were hidden during the evaluation to minimse distractions to the participants. By default the prototype interface was rendered in the top left of the browser window. This made the interface appear cramped rather than open as would be the case when holding a PDA in the hand.

The author did not have access to a PDA and therefore a laptop computer was used. Evaluating the prototype PDA interface on a laptop reduced the authenticity of the application. While it could be argued that a mouse is less accurate than a stylus and touch screen (given good hand-eye coordination) access to a keyboard definitely simplified the text input tasks for the participants.

Attempting to replicate a HMD on the laptop screen was also difficult. Several issues including; the screen resolution and size, depth perception, peripheral context (2.4.2), method of interacting (rotating) with the display, stability of the augmented graphics, the weight and sensation of the HMD, and switching focus between the PDA and the HMD where difficult to replicate. Each of these will be discussed in further detail.

The resolution of the laptop screen was far greater than that of any commercial HMD. The image representing the landscape and augmented graphics as seen through the HMD was physically larger so participants could recognise the features and to replicate the real-world situation where the HMD is within several centimetres of the eye thereby producing a perceivably larger image.

Depth (or distance) was difficult to perceive viewing the images on the laptop screen due to it being a 2 dimensional (2D) image versus being physically located in the landscape. The lack of landscape features (trees, buildings) in the image also added to the issue. Lack of peripheral context was an associated issue, although commercial HMD typically have a narrow Field-Of-View (FOV) the user is still aware of their physical position in the landscape by sensing the location of physical objects within the landscape, something impossible to replicate in a computer-based environment. Rotating was replicated in the prototype by providing small arrows for the users to select.

The images representing the HMD graphics were generated using the GIMP (http://www.gimp.org/) graphics package with the augmented graphics “painted” onto the landscape image. Naturally this resulted in augmented graphics that were perfectly aligned with the landscape regardless of the users movements. This created an artificial sense that augmented reality is “as good as” virtual reality in regards to the graphics. There was no way of replicating the naturally jerky movements of the augmented graphics as viewed through a HMD.

With a wholly computer-based prototype it was impossible to replicate the sensation of wearing a HMD and interacting with a PDA. The participants could choose to look away from the laptop screen at any time during the evaluation, something that is not possible while wearing a HMD (unless it was removed). Switching context between the PDA and HMD was replicated with a small icon that hid one or the other. This was an overly simple method and did not recognise that the HMD would still be worn while interacting with the interfaces on the PDA.

The tasks (and associated questions) were predominantly focused on the user interfaces displayed on the PDA as the purpose of the HMD in this research was about the dissemination of information rather than providing an environment in which users would interact with augmented objects. As a result of the documented limitations and issues restricting a more realistic prototype the findings from this research may have been different. The following section discusses the findings, in the context of these limitations, as documented in the previous section.

7.5.2 Results

This section outlines the results of each task from the evaluation of the prototype. As the prototype was delivered via a web browser (Mozilla Firefox), all menu, status and tool bars were hidden before going to full screen mode to minimise distraction to the participants. The frames of the prototype were also hidden, as a result only two tabs were displayed to the participants. The purpose of each task will be outlined followed by a summary of the participants movement through the interface. The issues highlighted by the participants are collected under each task and these will be further discussed in the subsequent section along with proposed solutions to rectify them.

7.5.2.1 Task 1 – Choose and publish a narrative

This was a very simple task designed to introduce the basic concepts to the participants, including the Personal Digital Assistant (PDA). Aside from people not reading the task description provided to them all participants completed the task within the suggested time.

7.5.2.1.1 Performance

Two participants sought clarification on the task prior to interacting with the prototype interface specifically asking what a "narrative" was. Both participants were provided with a brief description of a narrative. After reading the question one participant asked whether the keyboard had to be used. The background information supplied in the evaluation script (Appendix C) was re-iterated to this participant. The remaining participants assumed that because it was the first task it was the first (top-most) button on the screen.

There was some hesitation from all participants on the narrative introduction page, with several attempting to select the listed options. Participants then noticed the buttons on the bottom of the screen and proceeded to the following page using the forward (>) button. One participant tried selecting the top drop-down box to change the location but then noticed the small message and realised it was unchangeable.

All participants selected one of the listed narratives, not necessarily the one specified in the task. After making a selection, three of the six participants questioned whether they had to explicitly click the publish button with one of the participants returning to the home page before retracing their steps to determine whether the narrative had been published. All three participants tried selecting the forward button (with no result) prior to selecting the publish button and reading the resulting dialogue. All but two of the participants had to be told that the task had been completed.

7.5.2.1.2 Issues

- Publish dialogue – The predominant confusion when attempting to complete this task was realising that the narrative had been published and there was another stage in the process. This could be achieved by taking the user to an additional page (rather than dialogue) stating that the narrative had been published;
- Table labelling – The lack of labels and clarity around the meaning on the column headings resulted in confusion amongst participants. The lack of an overall table title was also highlighted as an issue;
- Table content and access – Most participants were wanting to derive answers to the question from the table indicating the need for additional information to be presented. If the table was made available from the mapping interface (such as in task 3, 4 and 5) users may realise the connectivity between narrative sites and users;

- Improved map symbology and labelling– This covers a wide range of issues including appropriate labelling of narrative sites and active participants. This small alteration may have improved the participants interpretation of the Estimated Time of Arrival (ETA) figure. Improving the map symbology to better distinguish between sites, moving and stationary users may have improved the map interpretation. The lack of a map legend (either on-screen or on a pop-up dialogue) inhibited the participants.
- Map tool status – It was apparent that some participants found it difficult to distinguish which map tool they had selected. Altering the cursor icon (not possible in prototyping software used) may alleviate this issue. This alteration would be augmented by making the information tool the default tool upon entering the mapping interface and providing feedback in a status bar as to which tool had been selected.

7.5.2.2 Task 2 – Monitor narrative participants

This task was the logical consequence of the first task, building on the concepts and user interface elements to monitor those participating in an augmented narrative. There was some general confusion amongst participants on this task due to unclear terminology, the information table being inappropriately labelled and unclear map symbology. Specific issues are described below.

7.5.2.2.1 Performance

There was one participant who didn't see the linkage between this task and the previous, as a result they went to the home screen and re-read the task before realising their error. All but one participant had difficulties interpreting the table displayed, specifically the meaning of 'S1', S2' etc. All participants were quizzed as to what they thought it meant with responses ranging from site, section, stages and scenarios. All participants wanted to know how to determine the title meaning with some clicking on respective titles, others using the forward button to progress to the next screen with one participant stepping back through the sequence to re-publish the narrative to see if they had missed a vital piece of information.

Two participants were looking for times to be displayed in the table in order to answer the questions before realising they could progress forward using the buttons. A single participant required assistance to progress to the mapping interface. Participants familiar with Internet-mapping applications were clearly distinguishable from their reaction and desire to explore the options provided to them. Three participants spent the time understanding the map tools by rolling over each one to read the tool-tip prior to clicking the button. The remaining three participants tried clicking the map symbols. When there was no response they selected the information tool and tried again.

Two participants had difficulty interpreting the meaning of ETA displayed in the information panel for each user (in the context of the application) resulting in four of the six participants answering question 1 correctly. One of the successful participants did question which location the ETA referenced. The remaining two participants interpreted ETA as the time taken by the narrative participant to get to their current location and subsequently got the question incorrect. Question 2 was a little easier although some ambiguity existed as the narrative sites were not labelled. Two participants answered site 2 and 5 while the remaining four participants answered site 2.

Several users explored the other functionality provided in the mapping interface, although it was outside the scope of the task, indicating a level of comfort and familiarity. Those participants who spent the time exploring commented on the need for a legend and some form of labelling to distinguish narrative sites from users.

All but one participant successfully closed the mapping interface using the map icon on the mapping interface and terminated the narrative session appropriately. The other participant was happy exploring the user interface.

7.5.2.2.2 Issues

- Terminology – Several participants sought clarification on the meaning of the terminology, especially the concept of a narrative. Clarification was given to ensure it didn't bias the task outcome;
- Participants not reading the task properly – Several participants were very keen to get the evaluation session over and done with in the shortest amount of time possible, possibly due to work commitments. All but one participant settled into the subsequent tasks and became more relaxed;

- Publishing not intuitive – Apart from seeking clarification on the terminology the process of publishing the narrative was not intuitive. Rather than the confirmation appear as a dialogue it may have been better to take the user to another screen to remove the ambiguity; and,
- Lack of reporting – In the case where the evaluation participants navigated away from the publish page they had to re-publish the narrative on their return. The interface should report if a narrative is published (and active) if users wish to leave the 'publish a narrative' page (when the narrative session was terminated). If there was valid reason to navigate away from the page (perhaps the narrative manager wishes to explore other aspects of the interface while a narrative is active), a message could be presented to the user reminding them that there are users currently participating in the narrative.

7.5.2.3 Task 3 – Participate in a narrative

This task was implemented in a separate browser window to highlight that it would be a different interface in the full implementation. The task assumed that the participant had already joined a narrative and were viewing the landscape through the Head-Mounted Display (HMD). Each participant was given a brief introduction to the elements on the prototype interface specifically the on-screen icons that replicated re-world physical actions such as rotate left, rotate right and view the Personal Digital Assistant (PDA).

7.5.2.3.1 Performance

After reading the task, all participants switched to the PDA view. Half of the participants read the information on the PDA and clicked into each of the narratives but never went back to the HMD view to see the animations making it impossible for them to answer the first question. After reading both narratives on the PDA the participants selected the continue button, read the message and went to the HMD view as instructed. All three participants were confused about the meaning of the large green arrows and assumed they were highlighting the areas of runoff and discharge as mentioned on the PDA's. One of the three participants realised that the arrows were directing them to the next site and acknowledged that they had missed the animations.

The other three participants read the narrative text and noticed the instruction “return to the HMD”. All three participants became used to switching between the PDA and HMD. They also understood that the arrows were directing them to change their orientation. All three participants got question 1 and 2 correct.

7.5.2.3.2 Issues

- Clearer symbology – Altering the colour of the arrows depending on whether they are directing the user to a new site versus an element in the narrative may be beneficial.
- Improved terminology – The continue button was a little ambiguous with half the participants selecting it prior to viewing the narrative animations. Changing the button label to “next site” (and potentially “previous site”) may have reduced this error occurring.
- No going back – Pressing the continue button forced the participant away from the narrative site and didn't allow them to return. A method of canceling the request for directions to the next (or previous) site is required.
- Distinction between PDA and HMD – This was difficult to prototype and the reason that all participants were given a brief introduction to the interface. Users of a physical augmented reality system with a PDA and HMD would be more inclined to switch between the landscape and PDA to ensure they are seeing all the information being provided to them.

7.5.2.4 Task 4 – View land use scenarios

This task introduced participants to visualizing existing land use scenarios on the PDA and through the HMD. The prototype interface was reset to the home screen prior to the participants beginning the task.

7.5.2.4.1 Performance

Five out of the six participants selected the scenario option on the home screen. The other participant thought that a narrative needed to be published prior to viewing the scenarios. After going to the narrative page and viewing the options in the drop-down list they realised that none of the narratives matched the scenarios provided in the task. They returned to the home screen and selected the scenario option.

Four out of the six participants decided to record their personal information. All of them intuitively used the computers keyboard rather than looking for the functionality on the PDA (even though it wasn't provided). This highlighted that the participants weren't used to using PDA devices and didn't fully recognise that the interface was a mock-up of such device.

There was some ambiguity in selecting the appropriate scenario scale (regional or contextual) with one participant selecting context and beginning to manipulate individual land uses before being prompted that they were in the incorrect location to undertake the particular task. Several other participants took a guess that it was the top option (regional) and commented that the information displayed when rolling over the buttons made no mention of "viewing" scenarios as described in the task. All participants selected "visualize scenarios" and proceeded to the map interface.

All participants explored the map tools icons by rolling over them and reading the tool tip and in some instances clicking them. One participant was trying to determine how to load the scenarios as insinuated in the task. This participant was instructed that, for the purpose of this exercise, the scenarios had already been loaded. All participants opened the map layers and turned on some of the land use scenario layers. All but one participant noticed the small icon allowing them to switch to the HMD. Two participants spent time exploring each of the scenarios (and combinations of scenarios) on the HMD even though it was of no relevance to the task and associated questions.

All six participants found the table icon and realised they provided the answers to the task questions. Two participants were informed that there were two tables after which they noticed the numbers at the bottom of the window. All participants correctly answered the first question. Four of the six answered the question correctly while the other two associated biodiversity with re-vegetation and utilised the table on the second tab rather than the first. Admittedly, the question was a little ambiguous.

One of the participants, when attempting to close the tables dialogue accidentally clicked the close map icon rather than the close dialogue icon. The participant realised what had occurred and immediately returned to the mapping interface. The same participant suggested that the map display should be displaying the current land use scenario when first entering the interface.

7.5.2.4.2 Issues

- Terminology – Some of the terminology used in the intermediary screens was a little ambiguous requiring participants to re-read and occasionally seek clarification. In a real system the words and terminology would be written and vetted by several natural resource practitioners to ensure clarity.
- Navigation buttons – The home button provided on the bottom of the regional scenario page goes right back to the application home, rather than the scenario scale selection page.

- Simplified information access – The availability of multiple screens on the table dialogue was not obvious, especially positioned at the bottom of the screen. The use of tabs at the top of dialogues would assist users realise there was additional data available.
- Loading scenarios – There is no method of loading scenarios generated by third parties. While this is outside the scope of the research it is an important functionality which needs to be considered.
- Layer control – The layer control functionality needs additional intelligence. This would ensure that multiple land use scenarios aren't switched on simultaneously resulting in layers being obscured. It would also ensure that the same layer is being displayed on both the PDA and HMD.

7.5.2.5 Task 5 – Create an alternate land use scenario

This task introduced the participants to an alternate method of creating land use scenarios. All participants were familiar with creating land use scenarios using models that alter land uses according to rules and/or targets. The method tested in this task allowed participants to generate an alternate scenario at a macro scale using landscape factors comprised of many related land uses.

7.5.2.5.1 Performance

Having read the task all but one participant realised they had to return to the previous screen where there was an alternate option. The other participant was reminded of their route to their current position in the interface prior to realising they had to return to the previous screen and closing the map would probably take them there. Upon closing the map, one of the participants went right back to the home screen and retraced their steps back to the options at the regional scale before selecting the design scenarios option and moving forward.

All participants were surprised with the interface being displayed. Two of them had seen such representations of landscapes in the literature before but the others required some clarification on how to interpret it. Two participants tried clicking on the blank graph to generate a scenario but noticed that nothing occurred. They (and the other participants) selected an existing scenario from the drop-down list and noticed the graph changed. Four of the participants then tried to go to the next screen using the forward button but noticed that nothing occurred. They were prompted to re-read the task before realising they had to edit an existing scenario (plantation). The other two participants had been more patient and noticed the tool-tip (click axis to edit) associated with the graph. One participant attempted to click and drag the axes of an existing scenario but were informed that, in this prototype, it was necessary to click to edit the axes.

All the participants were surprised that, upon clicking a particular axis on the graph, a whole new scenario had been generated. The limitations of the software used to generate the prototype were explained to the participants. All participants agreed it was a novel method of generating land use scenarios with several wanting to know how it would be practically implemented. After creating the new scenario all participants proceeded to the next screen using the forward button. They all waited until the model was processed, having been informed that it was not an actual model running, and clicked the forward button to arrive at the mapping interface.

Once again, several participants suggested that a land use scenario should have been displayed on the map by default. All participants went straight to the layers icon to alter the layers being displayed, with two participants noticing the comparison layer shown only in the HMD. All the participants understood the first question and immediately opened the tabular results. One participant provided a partially correct answer (naming only one of the two scenarios that impact on water yield when compared to the current scenario) while the remaining five answered with both scenarios.

A single participant answered the second question correctly. One of the remaining participants incorrectly interpreted the graphs depicted in the HMD, while the other four participants failed to realise that it was impossible to answer the question based on the information provided in the tables. Both participants who used the graphs stated they were difficult to interpret as there were both positives (biodiversity, water yield) and negatives (erosion and recharge) displayed together. Does a taller negative mean it is worse than or better than the scenario with which it is being compared? One user interpreted them correctly (higher graph equates to better) while the other participant thought the opposite.

7.5.2.5.2 Issues

- Graph editing – The software used to create the prototype had no ability for dynamic editing functionality which made the graph interface less realistic, reducing the overall impact and portrayal of it being a valuable method of generating land use scenarios.
- Comparing scenarios – The availability of the tables in this task confused users into thinking they contained all the necessary information to answer the questions. The information depicted in the graphs (shown on the PDA) should also be represented in tabular format to cater for all users.
- Comparison graphs – Rather than depicting the graphs as vertical columns they could be shown as a horizontal bars with beneficial factors being represented as positives (bars to the right) and detrimental factors represented as negatives (bars to the left). These would be further highlighted with colouring to accentuate the affect.
- Interface inconsistencies – The functionality provided in the interface used for this task should have been the same as task 4. The inconsistencies resulted in participants making assumptions regarding the location of information to answer the questions. The differences were predominantly in the layer control dialogue with the addition of the comparison layer visible only in the HMD.

7.5.2.6 Task 6 – Alter specific land uses of an existing scenario

Task 6 provided a familiar working environment for the majority of users to alter an existing land use scenario at a context (local) scale based on defined units (paddocks). This task also allowed users to compare their altered land use scenario with the proposed scenario in regards to monetary terms and landscape features, something which all participants agreed was often overlooked in current landscape planning projects.

7.5.2.6.1 Performance

All six participants closed the mapping interface from the previous task and selected the home option on the bottom of the graph. One participant did hesitate at the graph screen, pondering what to do next prior to going to the home screen. All participants selected context from the scenarios option and went straight to the mapping interface.

Once again, several participants commented that the land use scenario should have been initially displayed on the map. All participants, now familiar with the mapping interface, noticed a new icon. Five of the six participants, after reading the tool tip, selected the edit land use button. This resulted in a dialogue instructing them to turn on the planned land use layer. The other participant wanted to edit the land use scenario by altering the values in the tables. Once they realised that was not possible they noticed the edit land use icon. All participants opened the layer control dialogue and turned on one of the planned land use layers.

All the participants selected the edit land use icon and clicked on the map. Two participants noticed that some of the land use polygons could not be clicked on (altered). They were informed that these were polygons that could not be altered in the scenario and continued to change the land use of other polygons. All participants then opened the table dialogue. The one participant who had previously opened the table dialogue immediately noticed that some of the numbers had changed and were displayed in different colours. Three other participants also noticed that some of the numbers in the tables were a different colour. All four participants were looking for a legend to describe the meaning of the colours. Two hypothesised that the colouring matched that used in financial practices (red negative, blue positive) before noticing that the numbers wouldn't add up if that was the case.

None of the participants noticed the switch tables icon located under the tab icons on the table dialogue. Because it was an essential element in the prototype interface all participants were informed of its presence. Once they understood they could change between the planned (or proposed) land use scenario and their user defined scenario they were able to see the difference in the tabular figures. After analysing the data all participants correctly answered the question by saying that the costs for implementing the user defined land use scenario were lower while the cashflow (income) was more evenly spread over the 10 year period.

7.5.2.6.2 Issues

- Ambiguous naming – The naming used for the land use scenario layers did confuse several participants. Planned was used in the layers dialogue while proposed was used in the tabular results dialogue.
- Select new land use dialogue – The option provided in the dialogue was the same as previously selected. Participants agreed that the current land use should be selected (and highlighted) to assist in making a decision.

- Table colour coding – A legend explaining the colours is required. The colours should be different to those used in financial practices as red generally indicates a negative number.
- Comparison data – Displaying the tabular data in separate tables made it difficult to compare the figures. Pending screen real estate, the data could be combined into a single table allowing better comparison and analysis.
- Explanatory text – Several participants wanted explanations of the terminology used on the tables, suggesting the table titles provide an explanation when clicked. This had been implemented in the tables on the regional interface but not noticed by any of the participants.

7.5.3 System Usability Scale (SUS) questionnaire

Table 7.3 summarises the results from the System Usability Scale (SUS) questionnaire completed by each participant at the end of their evaluation session. The highest score of 72.5 was recorded by participant 4 while the lowest score of 45 was recorded by participant 6 (the only one below 50). The mean score recorded by all participants was just over 58 indicating that the participants were generally positive about the user interfaces.

When looking at the individual questions in the SUS questionnaire, questions 1, 4 and 8 had the largest deviation in answers (1 or greater). Question 1 asked whether the participant would like to use the interfaces frequently. Question 8 asked whether the participants found the user interfaces cumbersome to use while question 4 asked whether they would require the support of a technical person to use the interfaces. The variation in the remaining questions was less than 1 and generally around half a point.

The large deviation in question 1 is attributed to participant 2 responding with a score of 1, the remaining participants responded with a score of 4 or 5. Score deviation in question 4 can be attributed to the confidence of the participants during the evaluation although four of the six participants indicated that the interfaces were cumbersome to use. This somewhat contradicted the responses from question 4 with only one participant indicating they would require technical assistance to operate the user interfaces with the remaining participants responding with a score of 3 or less.

It was anticipated that participants would respond with similar scores to both questions, the assumption being that if they found the interfaces cumbersome they would require technical support in using them and visa versa. Four participants (1, 2, 4 and 5) met this assumption by either responding with the same score or within 1 point of each other. The responses of the other two participant (3 and 6) were separated by 2 points between both questions. It is interesting to note that several participants commented that they would require technical support initially, but once they were shown the interfaces they would feel comfortable using them without the support.

Looking at the even numbered questions, the mean score of the questions ranged between 2.33 and 3.17, indicating a slight disagreement with the statement. Conversely, the scores for the odd numbered questions ranged from 2.83 to 3.83 indicating that participants slightly agreed with the statement. Overall this indicates that the participants had a slightly negative view of the user interfaces, but generally "sat on the fence". Only four responses were at the scale extremes (1 and 5).

		SUS question										
		Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Score
Participant	1	5	2	2	4	4	3	4	4	2	3	52.5
	2	2	2	4	1	3	3	4	2	4	4	62.5
	3	4	2	2	4	3	2	3	2	3	2	57.5
	4	4	2	3	1	3	2	4	1	3	2	72.5
	5	4	3	4	4	4	3	4	3	3	2	60
	6	4	3	3	5	3	2	2	3	2	3	45
MEAN		3.83	2.33	3	3.17	3.33	2.5	3.5	2.5	2.83	2.67	58.33
STANDARD DEV		0.9	0.47	0.82	1.57	0.47	0.5	0.76	0.96	0.69	0.75	8.5

Table 7.3. - Summary of responses from the System Usability Scale (SUS) questionnaire

7.5.4 Discussion

The results, as documented in 7.5.2 and Table 7.3, confirm the general consensus that 5 to 7 participants is sufficient to evaluate a low-fidelity prototype. Very few issues were highlighted by a single participant and after completing the evaluation of the forth participant the same issues were being highlighted. The issues highlighted by the participants, having been outlined in 7.5.2, are discussed in more detail below.

Altering the order of tasks provided to the participants would have had little effect on the outcome of the evaluation. Although Snyder (2003) suggests altering the order of tasks, a workflow metaphor had been adopted with subsequent tasks building on the previous, making it difficult to do so. It may have been possible to rearrange groups of tasks (narrative publishing, narrative participation and scenario creation) to reduce people making assumptions from the interface. This was highlighted in Task 1 where all participants assumed that, because it was the first task, the top button must be the correct option.

All but one of the participants were in a rush to complete the tasks. Only one participant took the time to thoroughly read each task and highlight the pertinent information prior to touching the computer. Given that all participants were told they should allow 90 minutes for the evaluation session, each participant knew the evaluator, they were told they weren't being timed and all sessions were held in meeting rooms, away from the office environment the anxiety can be attributed to their work deadlines. If the participants had contributed to the development of the prototype they may have been more focused on the content of the tasks rather than completing the tasks in the shortest time available.

Stone et al. (2005). mentions that annotated screen shots are a good method of reporting issues found during an evaluation session. This is obviously more applicable to high-fidelity user interfaces although it can be applied to low-fidelity user interfaces to highlight major shortcomings of the interface. The interface issues discussed below are supplemented with screen captures depicting the implementation in the prototype (shown on the left) and a mock-up of the suggested alterations (shown on the right) (refer to figures 7.5 through 7.14).

One of the first problems to be noticed were the issues associated with participants using the numbered buttons to move through each sequence (workflow). Due to the limitations with the prototyping software (discussed in 7.5.1) it was not easily possible to alter the colour of the buttons to assist users interpret what was clickable (Figure 7.5). In a production system, the alternative would be to display an icon for each step (or page) in the workflow, with the current step being highlighted. A next button would be provided at the bottom of each page, allowing the user to move through the workflow. The user could also jump back to a previously completed step to make alterations. Sufficient room would be available along the bottom of the screen to suit the total number of tasks within any workflow. Where a large number of screens were necessary, the icons could be overlapped. The overlapping icons would still be accessible to the user (Figure 7.6).

Associated with the workflow buttons, the home button caused some confusion during the evaluation sessions. In all cases, the home button took the participant back to the front screen of the application. Some participants highlighted there was no way of returning to the start of the particular workflow they were working through. Given the previous suggestion, step 1 would represent the start (introduction) of the particular workflow. A home button would still be required, however it should be differentiated from the other buttons through a combination of colour, style and/or position (Figure 7.6). Both alterations would significantly improve users navigating through the user interface.

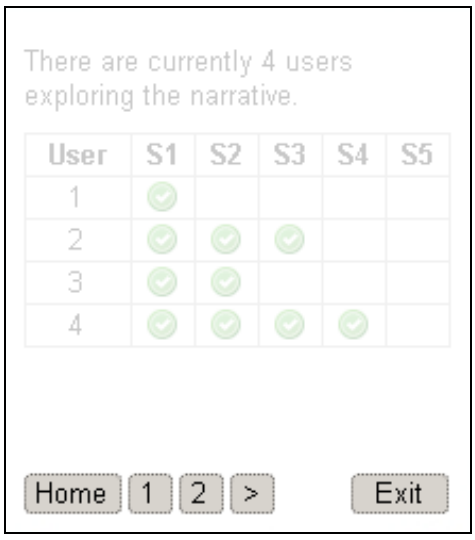

Figure 7.5. - Navigation (workflow) buttons as represented in the prototype with all buttons represented in the same manner.

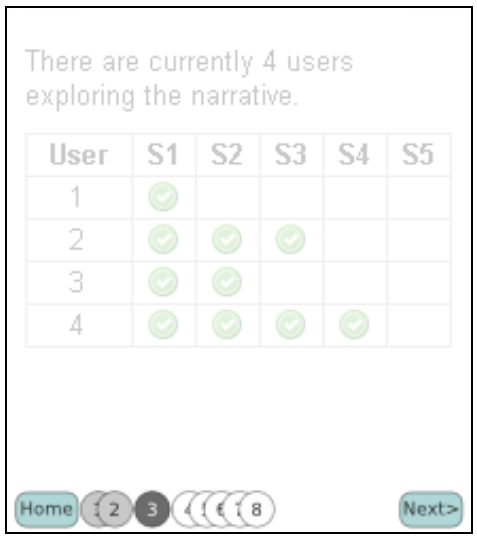

Figure 7.6. - Suggested changes to navigation (workflow) buttons showing different colours for various buttons and representation of overlapping icons where a large number of pages exist.

None of the participants sought to find the on-screen keyboard for text input reducing the authenticity of the prototype. While this is difficult to overcome when presenting the interface on a device with a keyboard, it is a potentially important usability aspect within a production system. Any text input needs to be carefully considered on a PDA due to the restrictive methods provided by such devices. In the prototype there was a single screen that required participants to enter text, however in an ideal AR system (as described in Chapter 5), users may be interacting with remote experts using written communication. Users familiar with PDA devices and their text input methods may have no issues, however new or inexperienced users may be restricted by the time taken to write a message using the on-screen keyboard, reducing the timeliness of responses and potentially undermining the value of the interaction. As a result, incorporating a method of interacting with remote experts verbally would be a necessity in a production system.

For the purpose of the prototype the number of land use options provided to the participants when creating an alternative land use scenario (at the context scale) was limited to three. In the latest version of the Australian Land Use and Management (ALUM) classification (Bureau of Rural Sciences, 2006a) there are over 130 categorised land uses. Naturally not all land uses are applicable at a particular location allowing the extensive list to be filtered, however there may still be too many options to practically display to the user using the method in the prototype (Figure 7.7). By utilising the hierarchical structure of the ALUM classification the selection could be achieved through a set of linked drop-down boxes (Figure 7.8). The drop-down boxes would display the selected land use of the chosen polygon assisting users interpret and alter the scenario.

In the prototype regional mapping interfaces there was a disabled icon representing the functionality to switch to the context mapping interface. While none of the participants commented on the need to switch from a regional to a contextual scale, the ability to do so should be seamlessly integrated into the user interface. At its simplest, creating a land use scenario is scale dependent and therefore switching between the regional interface and context interface should be related to the movement of the user through the map. By way of example, a user may want to generate a land use scenario using the regional tools, but then alter particular aspects of the resulting scenario. This could be achieved by setting a scale threshold, beyond which the user moves to contextual editing. Once the user has entered the context scale (and is provided with the tools to edit the land use scenario at that scale) the ability to return to regional scale would be removed (because of the qualitative manner in which scenarios are developed at a regional scale). As a result there would be a single mapping interface with icons being displayed and hidden depending on the scale.

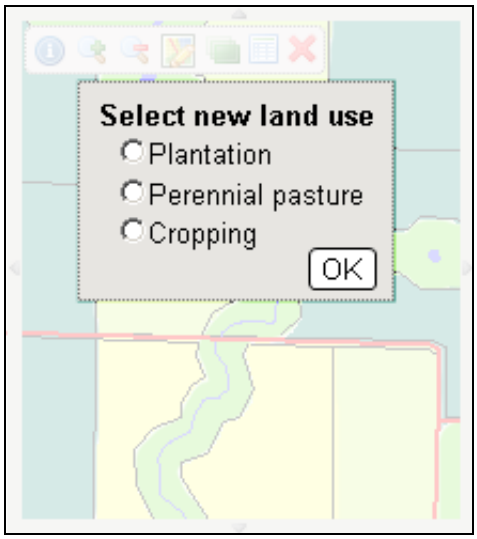

Figure 7.7. - Altering the land use of a polygon in the application prototype.

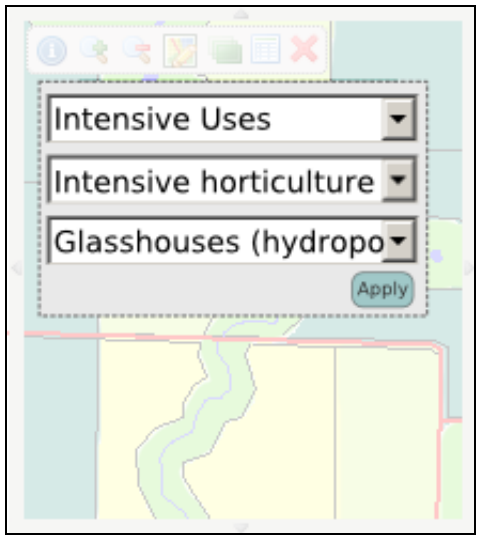

Figure 7.8. - Land use selection using a series of linked drop-down boxes which take advantage of the hierarchical ALUM codes (refer to Appendix G).

Several users commented on the selected mapping tool not being highlighted (Figure 7.9). This resulted in users selecting icons multiple times to ensure they had selected the necessary tool. Users therefore require feedback from the user interface. This could be implemented by way of a status bar along the bottom of the screen but would result in a smaller area for the map. The preferred option would be to highlight the selected icon on the toolbar. This functionality would be augmented with the use of different on-screen icons such as a cross-hair for editing or an arrow with an “i” for information. The combination of changes would provide users with instant visual feedback about the selected tool while not taking up any more screen area.

Appropriate editing tools are also required. For the purpose of the prototype editing of land uses was restricted to altering an existing paddock (or polygon). In a production system users may need to alter the existing landscape layout by splitting or merging existing paddocks. As a result, a suite of editing tools is required. These tools would be displayed to the user through a roll-over menu, saving screen real estate while ensuring the map has maximum exposure. This concept could also be applied to the zooming functionality (once again disabled in the prototype) with a slide bar implemented rather than zoom in and zoom out icons. Some the mapping interface alterations are represented in Figure 7.10.

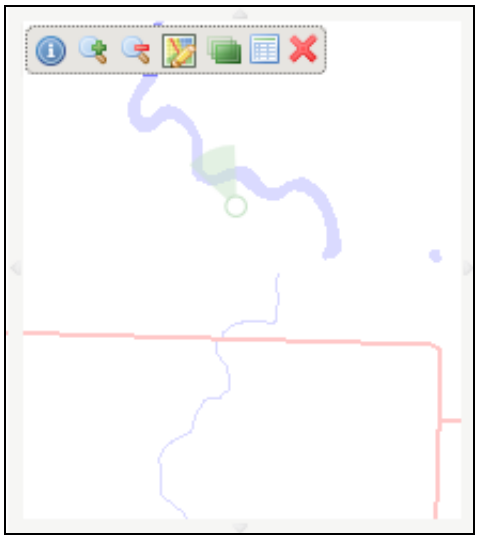

Figure 7.9. - Mapping tools as depicted on the Context-scale mapping interface.

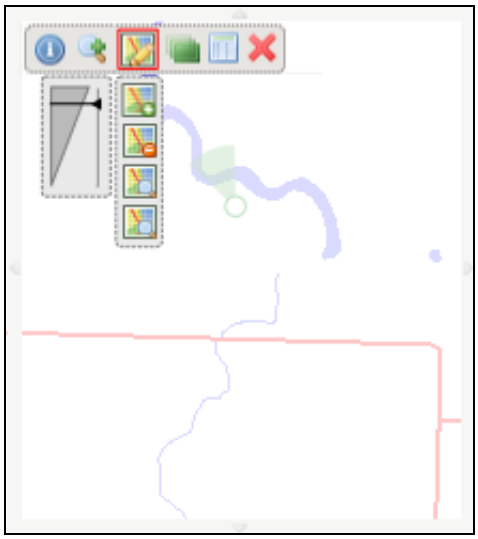

Figure 7.10. - Suggested alterations to mapping interface tools including; slider for scaling map scale, alternate tools for editing data and selected tool being highlighted.

While none of the participants made comment, appropriate error handling would be essential for making the production interface robust. Numerous situations can be envisaged where user friendly error reports are provided in conjunction with methods of rectifying the error. One such situation is where a narrative is published but the interface reports four participants are connected when in fact there are more participants. The system should be able to carry out some rudimentary analysis to determine whether the participants device is accessible and provide sufficient information to assist the user rectify the issue.

One of the recurring issues during the evaluations was the reluctance of the participants to utilise the HMD in an attempt to resolve tasks, even though the implementation in the prototype had been explained to them. This may have been due to several factors including; the difficulty in comprehending the concept of AR without seeing nor interacting with the physical components of an actual system, the lack of ancillary information displayed on the HMD, the cues about the existence of the HMD being too subtle, because the majority of the information required to complete the tasks was available on the PDA or the fact that the evaluation was conducted on a laptop within a different space of interaction. Trying to pin point the actual cause or combination of causes was not possible, however it was felt that several issues were to blame.

The first experience of participants with the HMD was during task 3 (refer to 7.5.2.3) where there was a direct connection between the actions carried out on the PDA and the animations being depicted on the HMD. While all participants glanced at the textual information on the PDA, only half the participants read the text thoroughly and switched to view the HMD with only one participant interpreting the meaning of the arrows being displayed. The necessity to view the HMD needs to be made more explicit (when simulating a HMD on a computer) to cement the linkage between the multimedia presented on the PDA and the animations on the HMD.

The lack of peripheral context in the prototype resulted in participants loosing track of their position in the HMD. This issue was exaggerated by the selected landscape image. Each section of the image contained similar landscape features and the images overlapped one another in an attempt to mimic the user rotating through the image. While a compass rose was present on the images it was subtle and most participants didn't recognise it until asked a specific question relating to direction. Improvements to the representation of the compass rose (such as making it less subtle or showing it across the bottom of the viewable area) may have improved participants perception of location.

The lack of descriptive information on the HMD may have been another limitation for the participants. The restrictive resolution ultimately determines the amount of ancillary information that can be comfortably displayed on the HMD without adversely impacting on the viewing area. Many prototype AR systems (outlined in section 3.4) display an extensive amount of data relating to the users position (including rotational parameters). However, such rudimentary data needs to be transformed into information that is meaningful to the user, assisting them locate and orientate themselves within the landscape.

In the case of the HMD for the narratives (Figure 7.11), useful ancillary information to display would include distance to next narrative hot-spot and time remaining, located along the bottom or in a corner of the screen. Distance is more important than direction as it may be necessary for the user to negotiate impassable landscape features (such as an erosion gully) in order to arrive at a narrative hot-spot. The arrows directing users are therefore an essential element however they could become more subtle once users were headed in the right direction or move to the edge of the HMDs viewable area, maximising the viewing area to negotiate obstacles (Figure 7.12). The arrow would be highlighted and return to the centre of the visible area for the purpose of informing the user of a direction change.

Figure 7.11. - Prototype HMD as shown during evaluation.

Figure 7.12. - Inclusion of additional information including distance to next hot-spot, remaining time and smaller direction arrow shown in a compass rose.

The display on the HMD in scenario mode needs to be keep as simple as possible to maximise the augmented viewing space. It must be remembered that the users location and orientation will be represented on the map displayed on the PDA and therefore the inclusion of specific locational information is superfluous. The HMD in scenario mode is purely about viewing the land use scenario (and its impacts) as augmented graphics to assist the user gain a greater understanding of the implications.

Display of the augmented graphics greatly affects the users ability to interpret what is being shown. During the course of the evaluations the majority of participants asked questions about the display of the HMD to ensure they were interpreting it correctly. Due to the manner in which the augmented display was generated for the prototype the graphics were not clearly represented. Some AR systems (such as Tinmith, section 3.4.6) represent augmented graphics with some level of realism, however they operate across a physically smaller area than the system proposed here. Computational processing limitations in mobile AR applications necessitate simple graphics (where appropriate) be used for representing features.

Utilising extruded polygons provides a simple method of representing land use scenarios. Extruded polygons are computationally easy to calculate given a polygon representing the extent of the land use and a Digital Elevation Model (DEM) of the landscape (which is essential for any AR system to calculate what is visible to the user). Another advantage that extruded polygons have over more realistic representations of landscape elements is they can be purposefully exaggerated (by a combination of dimension, colour or texture) without looking abnormal. This can be utilised for a number of purposes, including; highlighting particular landscape features or land uses and allowing distant or obscured land uses to be seen (by increasing the extrusion height with increased distance).

Depiction of information as a chart on the HMD raised several questions from the participants with the most significant one relating to the meaning of each element. It was acknowledged in the evaluation results from task 6 (refer to 7.5.2.6) that the chart was ambiguous, such as the case where there is a large bar for erosion, does it mean that when compared to the current land use scenario that erosion is better or worse (Figure 7.13)? Simplifying these charts would reduce the confusion and be clearer to read. Changing the chart from vertical to horizontal bars and moving the axis to the centre (bars to the left representing a negative impact and bars to the right a positive impact) in conjunction with simplified colouring would assist with interpretation (Figure 7.14).

Some confusion also existed around the location of the chart and whether it explicitly referred to the land use it was positioned over or to the scenario as a whole. The intention of the chart was to represent, in graphical form, the differences between the current scenario and the proposed land use. While the comparison chart was fixed regardless of the direction the user was facing, it was large enough for users to imply a direct association with individual land uses. A combination of making the chart smaller and moving it to one of the lower corners of the HMD may overcome these issues (Figure 7.14). These alterations would also allow multiple land use scenarios to be compared as charts on the HMD.

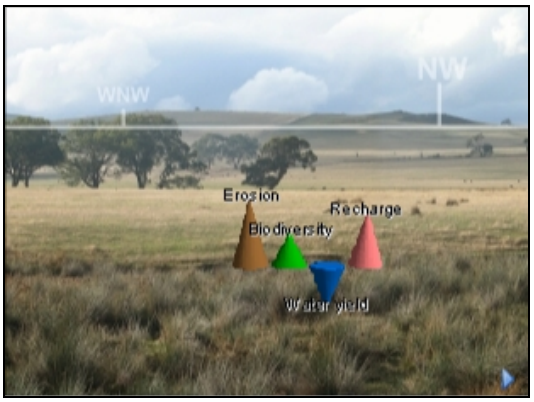

Figure 7.13. - Chart showing relative differences between two scenarios as depicted in the prototype.

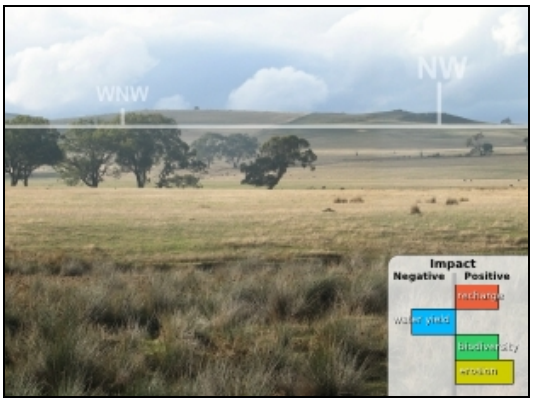

Figure 7.14. - Impact comparison changed to horizontal bar chart and displayed in lower-right of HMD.

Post evaluation and after completing the SUS questionnaire, several participants commented that the user interfaces would also be a good vehicle for the delivery of a web-based system that collects information about farming practices. Another participant mentioned the increasing number of web-based mapping applications which make it difficult to access and disseminate the disparate data and ultimately questioning the need for "yet another one". This is an important issue that must be addressed. Developers of such sites must recognise the capacity of users to create, display and interpret information (assuming the necessary metadata and contextual information is available) for their particular purpose. The ability to draw spatial data from a range of sources can be met by organisations publishing their data using Open GIS Consortium (OGC) standards, an underlying assumption in theoretical AR system described in Chapter 5.

7.6 Chapter summary

This chapter began with an introduction to the purpose of usability evaluation. The difference and application of qualitative and quantitative evaluation techniques were also outlined. A standard evaluation process was described, providing the context for developing and evaluating the user interfaces developed in the previous chapter. The envisaged weightings of the five dimensions of usability were discussed and depicted.

While the development of an evaluation process iterates through many steps, for the purpose of this research these steps were consolidated into five. The strategy for evaluating the user interface was developed, based on multiple authors suggesting that 5-8 participants are sufficient to evaluate a low-fidelity prototype. Six participants were chosen to evaluate the low-fidelity prototype covering a range of expertise relating to natural resource management.

The goals of the participants were documented, informed by the capabilities of the prototype and the necessities of developing a land use scenario. This phase included listing and prioritising the questions that were to be answered by the participants through their interaction with the prototype. These questions provided the framework on which the tasks were developed with each task attempting to assist in answering multiple questions. To ensure consistency across all participants, the introductory explanation of the evaluation and its purpose was documented along with the tasks.

The evaluations were held over the space of a week with no more than two participants being evaluated on any one day. Each participant was asked (and constantly reminded) to verbalise their thoughts to assist documenting all the (potential) issues, a process known as a cognitive walk-through. While participants initially found this process difficult, they became progressively more comfortable with each successive task. Upon completion of the evaluation, each participant completed a qualitative questionnaire.

The results from the evaluation sessions were then analysed in light of the known limitations (prototyping software and prototype extent). The performance against each task was documented with the unique issues being listed and potential solutions offered. The results of the questionnaire were also analysed with the conclusion drawn that participants were generally neutral about the interfaces, as presented in the prototype.

The chapter concluded with a discussion of the issues highlighted by the participants. Alternative options for implementing various aspects of the interfaces were discussed, with some of the alternative options illustrated. The following chapter will summarise the learnings regarding the use of augmented reality for the purpose of visualizing and interacting with land use scenarios and outline recommendations for implementation.

Chapter 8

Conclusions and recommendations

8.0 Thesis overview

Chapter 1 outlined the research problem, aims and methodology for determining the hypothesis with explicit reference to the inclusions and exclusions. Chapter 2 described the the paradigms for viewing and interacting with scientific visualization outputs. Various interaction techniques used in augmented environments were described before outlining the linkages to ubiquitous (or wearable) computing infrastructure.

Chapter 3 outlined the five necessary components required to implement a mobile outdoor augmented reality system. The importance of data management for delivering effective AR applications was highlighted before outlining a variety of existing (research) AR systems. Some software libraries for integrating the various AR components were outlined along with applications available for authoring AR applications. Chapter 4 framed catchment modelling to provide context for the development of a hypothetical mobile outdoor AR system focussed on land use scenario development and dissemination.

Chapter 5 integrated the information from the previous chapter to develop a theoretical mobile outdoor AR system suitable for landscape visualization. Chapter 6 progressed through the Scenario-Based Design (SBD) methodology to develop a low-fidelity, computer-based prototype of user interfaces for the intended application. Chapter 7 described the methodology and results from evaluating a small group of target users undertaking specific tasks with the prototype. This chapter synthesises the research findings, highlights further research opportunities and concludes the thesis.

8.1 Summary of research findings

The aim of the research was to develop a variety of user interfaces to enable users to develop, query and interact with land use scenarios within a mobile AR system. To achieve this, the user interfaces requirements were derived using the Scenario-Based Design (SBD) methodology and implemented as a low-fidelity prototype using a commercial software application (refer to section 6.4.3 and Figure 7.4). The prototype incorporated a visualization component that simulated the view through a HMD.

The conclusions derived during the development of the prototype user interface include:

- The separation of the landscape (regional-scale) planning (refer to 6.4.3.2.1) and local (context-scale) area alteration (refer to 6.4.3.2.2) roles into two distinct interfaces was necessary due to the inherent differences in how land use scenarios are developed. It also clearly distinguished the roles to the participants, although the nomenclature used (regional and context) needs further thought to ensure clarity.;
- Using a workflow metaphor to guide users through the process of creating and editing land use scenarios allowed the process to be broken into discrete tasks, allowing the creation of screens which were succinct and clear;
- Displaying a mapping interface on a small-format screen is difficult given the tools (buttons) that need to be displayed; and,
- Visualization of data through a HMD is unrealistic at a regional scale. The ability to see a reasonable portion of a regional landscape would be limited by the users position in the landscape.

Conclusions drawn from the evaluation of the low-fidelity prototype include:

- Further dividing each workflow into a greater number of pages would better suit the small screen and allow the application to better guide the users through the (sometimes) complicated process;
- The requirements of the users need to be better incorporated into the mapping interface. Considerations such as the number; visibility and location of the tools (buttons), the scale dependencies of the layers being displayed and symbology of the layers to ensure they are visible in outdoor environments; and,
- The functionality offered may be viable as a PDA only system. Comments from several participants suggested the system would be useful for undertaking rudimentary analysis of land use scenarios in the field and assist in on-ground scenario implementation.

8.2 Key learnings

While the extent of this research was quite narrow and specifically excluded implementation of working user interfaces on a PDA within a mobile AR system, several key learnings regarding the implementation of an actual AR system for the creation and dissemination of land use scenarios are outlined below.

- The integration of individual hardware components into an integrated, functioning AR system would require a substantial amount of expertise and time;
- Implementing appropriate interfaces that provide the logic and intelligence for users to access and manipulate land use scenario data in a mobile environment would require further research;
- It was difficult to assess users reactions to AR using the low-fidelity, computer-based prototype. In the end the users were most likely evaluating a mapping application rather than an AR application; and,
- Utilising a hand-held device (such as a PDA) as the sole interaction device may make it easy for users however may introduce a barrier between the visualization and user interface in a real, working system.

8.3 Further Research

The following areas of research are suggested to further progress the development of user interfaces on PDA devices for use as the primary interface of outdoor mobile AR applications:

- Can wireless networks be used to improve the usability of AR systems by providing a means of centralising computational power on a remote server and minimise system weight? Development of an AR system that utilises wireless networking technology to facilitate remote data processing and collaboration amongst users may expand the application of AR;
- Do hand-held devices provide users with the best interaction method or does interaction within the augmented space produce better results? Exploration of methods of interaction within augmented spaces, especially in large outdoor environments, is required to determine what is most appropriate for various user groups;
- Can users readily swap between viewing a hand-held device and augmented space without becoming disorientated or confused? Providing the ability to switch between the PDA and augmented space for interacting with features would allow the strengths of each paradigm to be leveraged, however the impacts on the users need to be explored;

- What are the best techniques for displaying complex NRM data in augmented spaces? There has been no comprehensive analysis to determine the merits of realistic versus simplified AR graphics. Are there specific reasons that one should be used over the other? What are the trade-offs with processing power versus interpretation?; and,
- What is the most appropriate data management method for landscape-scale AR applications? Data management is a continuing area of research in the field of AR and especially in outdoor environments where a large extent of data is required. Methods of data management which maximise data availability, access and use across the whole scenario modelling spectrum needs further exploration to ensure data is stored appropriately for all purposes.

8.4 Chapter summary

This chapter highlighted the conclusions drawn from developing and prototyping user interfaces for the creation and dissemination of land use scenarios. The research question posed in the introduction of this thesis asked if suitable user interfaces for small, hand-held devices could be developed for creating, examining and disseminating land use scenarios within a mobile augmented reality environment. Through the development and evaluation of a prototype user interface the answer is yes, although significant improvements would be necessary if implementing a fully functional system.

A list of further research goals which would further improve the prototype user interfaces and potential implementation of such a system was provided. Many of them related to the implementation and testing of the interfaces in a realistic technical and physical environment to determine the practicality of such a system. In addition, some broader research questions relating to data management and wireless networks for augmented reality were posed.

Appendix A - Storyboard

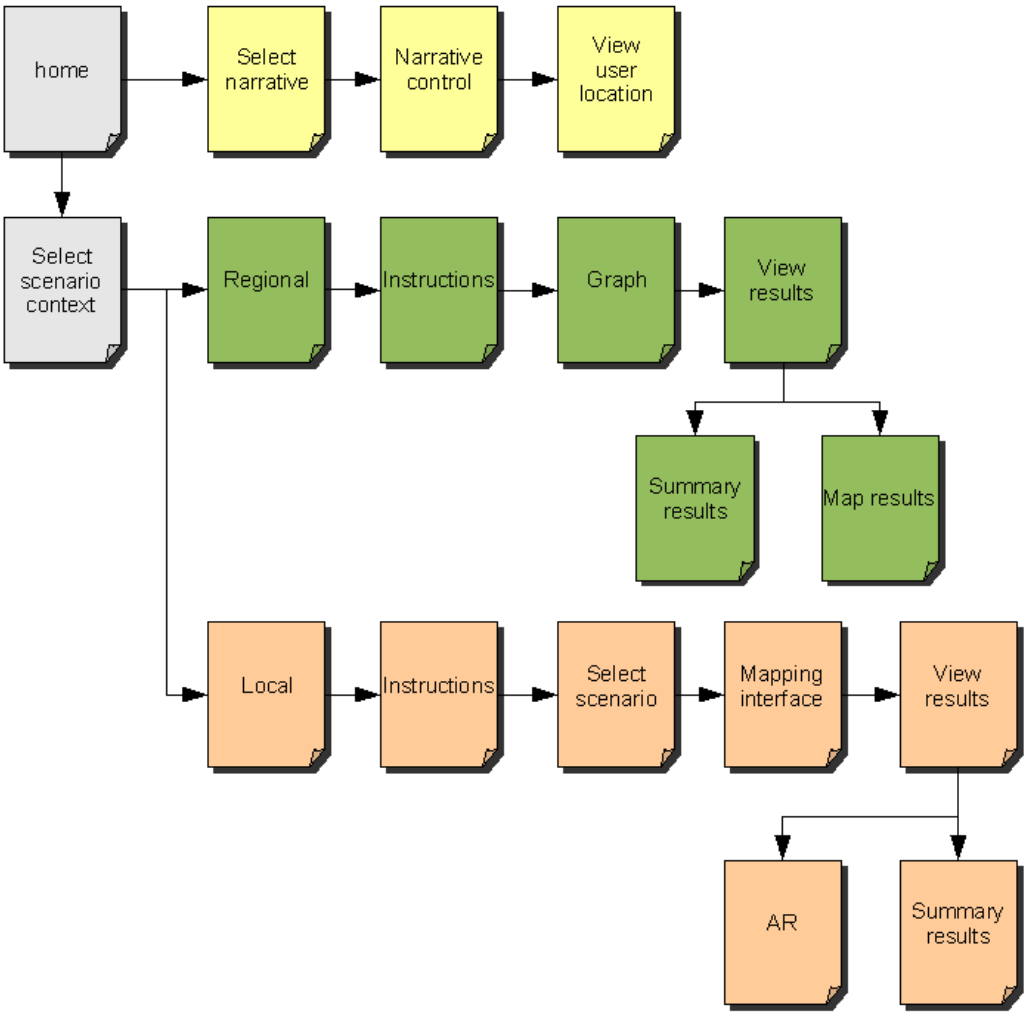

Figure A.1 - Storyboard depicting three main user interfaces 1) Narrative (yellow) 2) Regional scenario (green) and 3) Local scenario (orange).

Appendix B - Interface mockups

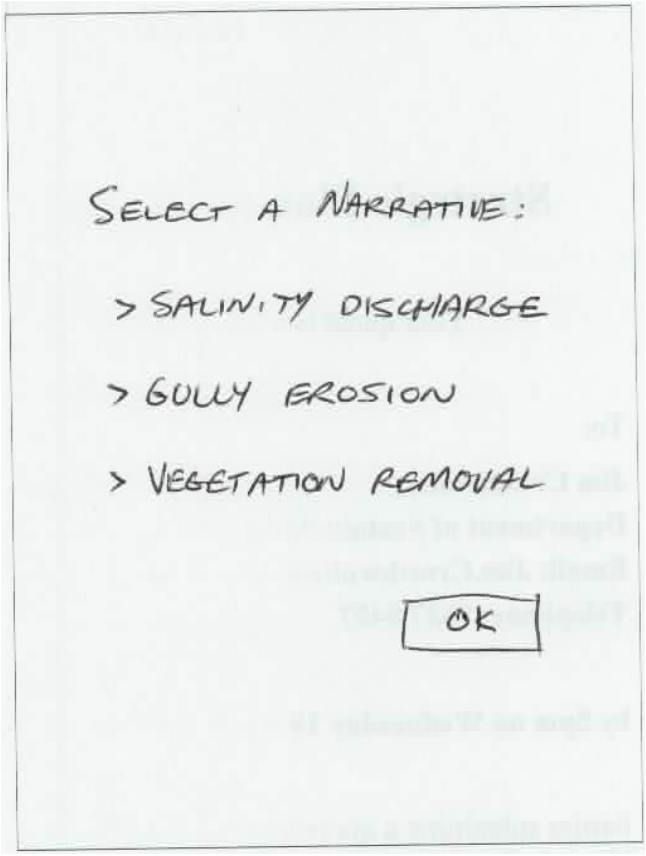

Figure B.1a – PDA interface showing choice of narrative.

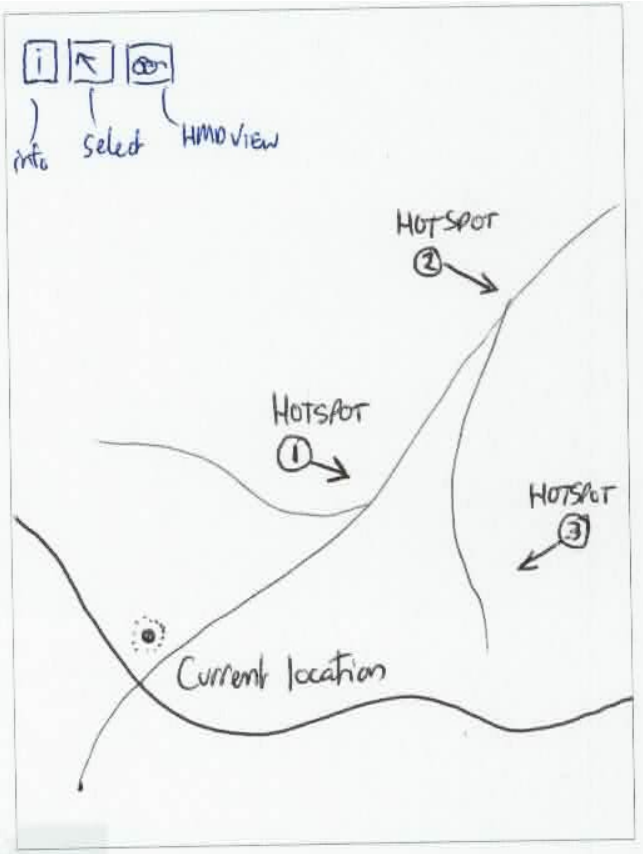

Figure B.1b – PDA map showing location of narrative hotspots. This could also be shown as a 'world-in-miniature' map through the HMD.

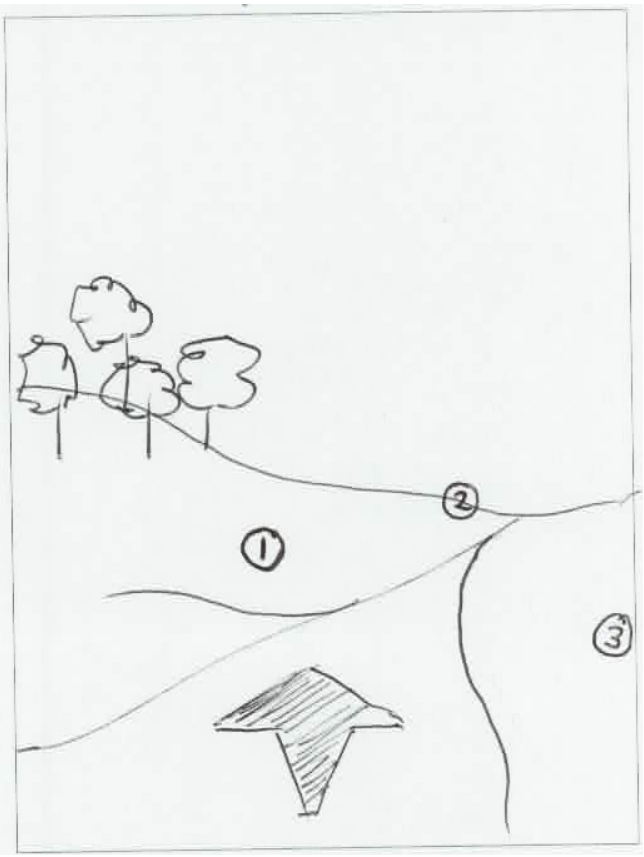

Figure B.1c – Display of HMD assisting the user to navigate to a narrative hotspot using a direction arrow.

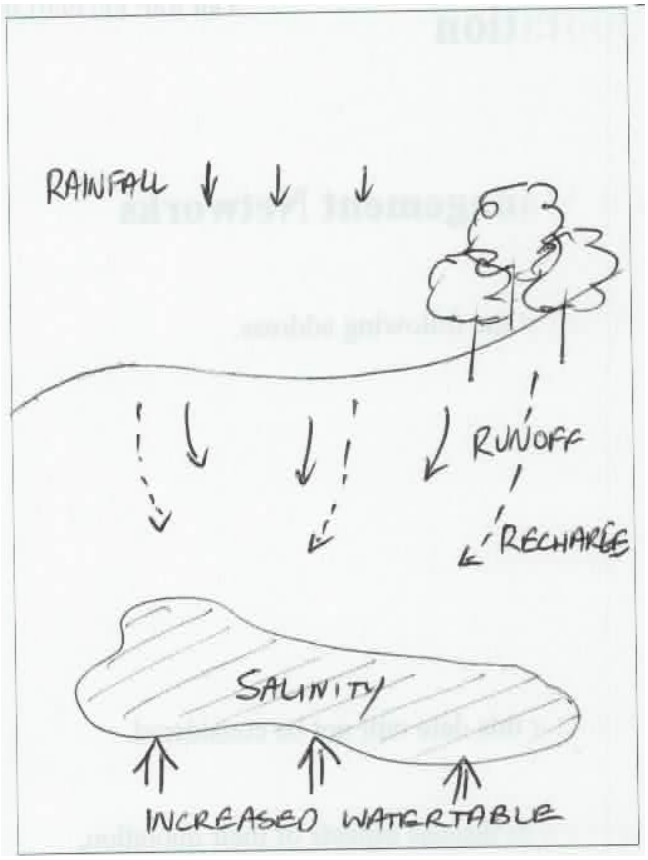

Figure B.1d – Depiction of a narrative animation representing the cause of salinity discharge as displayed in the HMD.

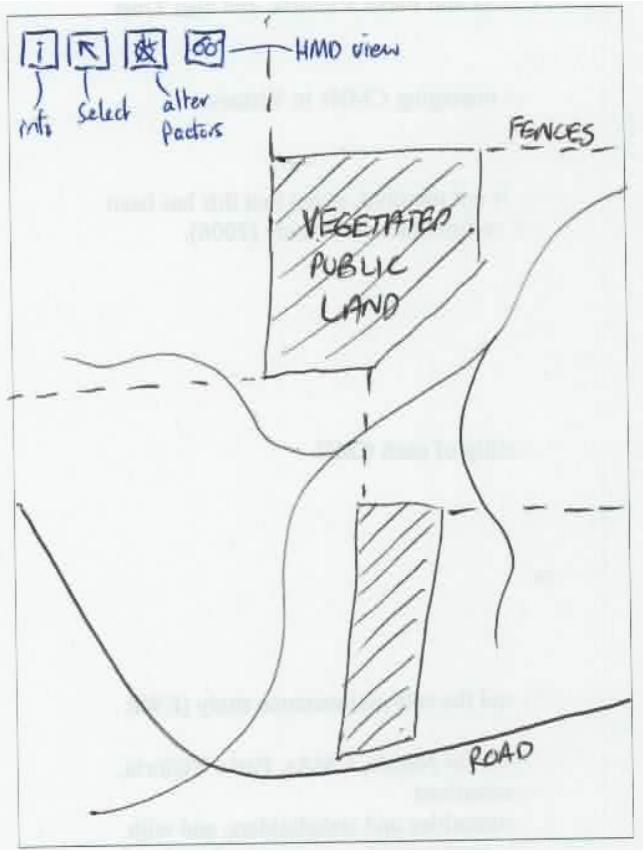

Figure B.2a – Current landscape as depicted on PDA. Tools for regional-scale editing are shown.

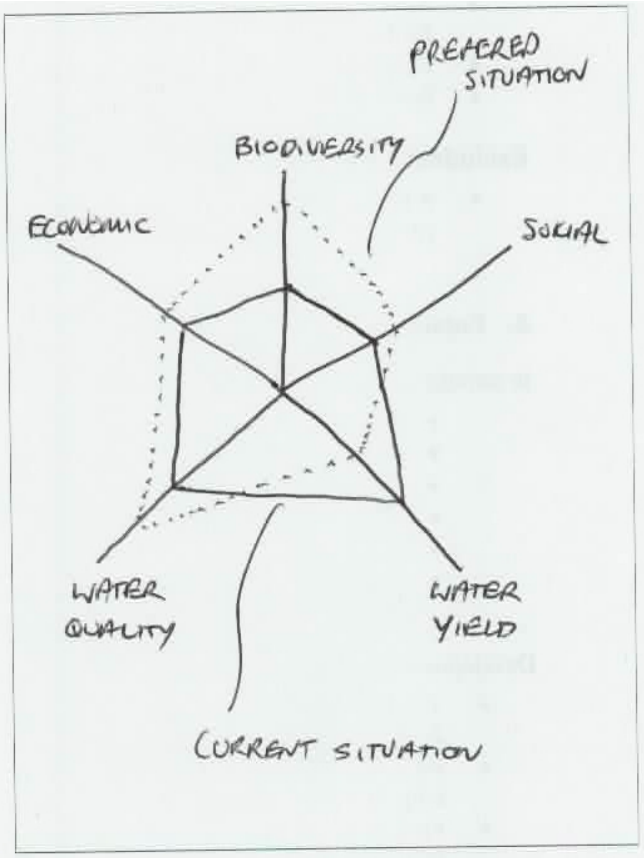

Figure B.2b – Use of a radar chart to simplify the creation of alternative landscapes by altering landscape factors.

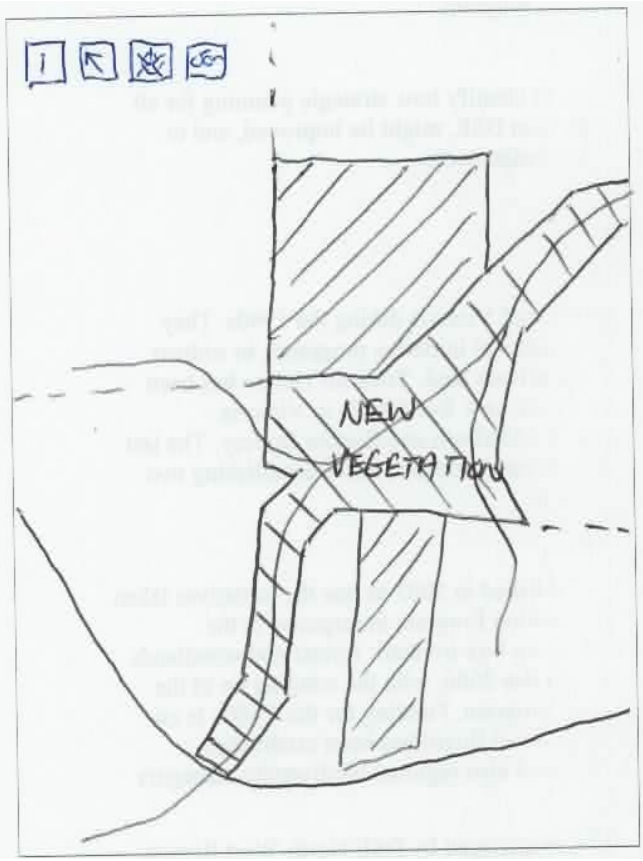

Figure B.2c – Alternative land use scenario generated from altering the landscape factors using (Figure B.2b) and depicted on the PDA.

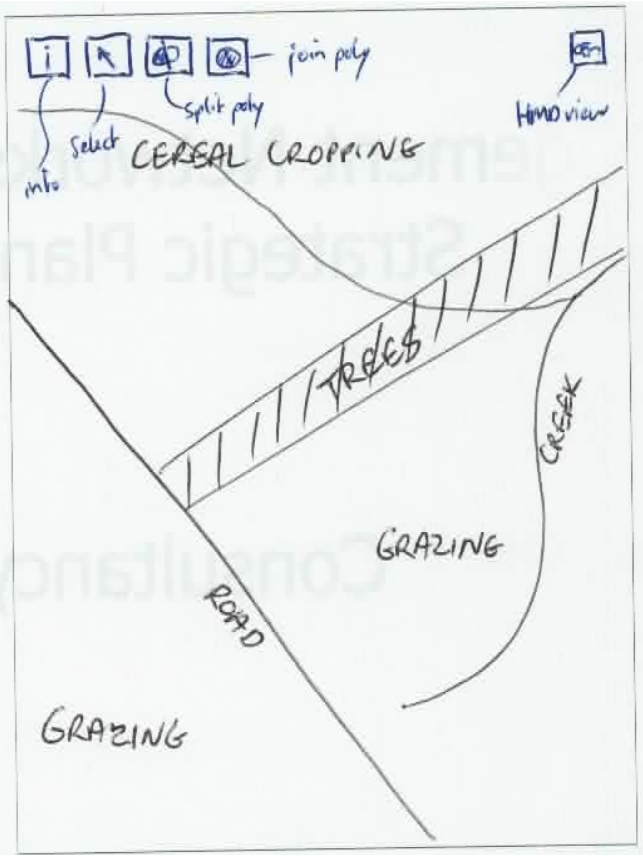

Figure B.3a – PDA interface for context-scale land use manipulation showing map and editing tools.

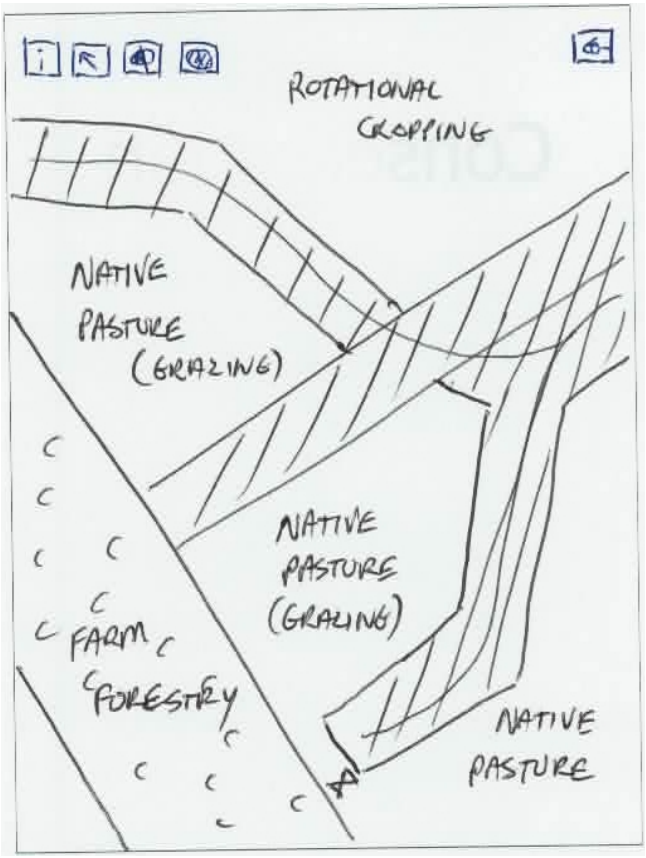

Figure B.3b – Context-scale PDA interface showing edited land uses.

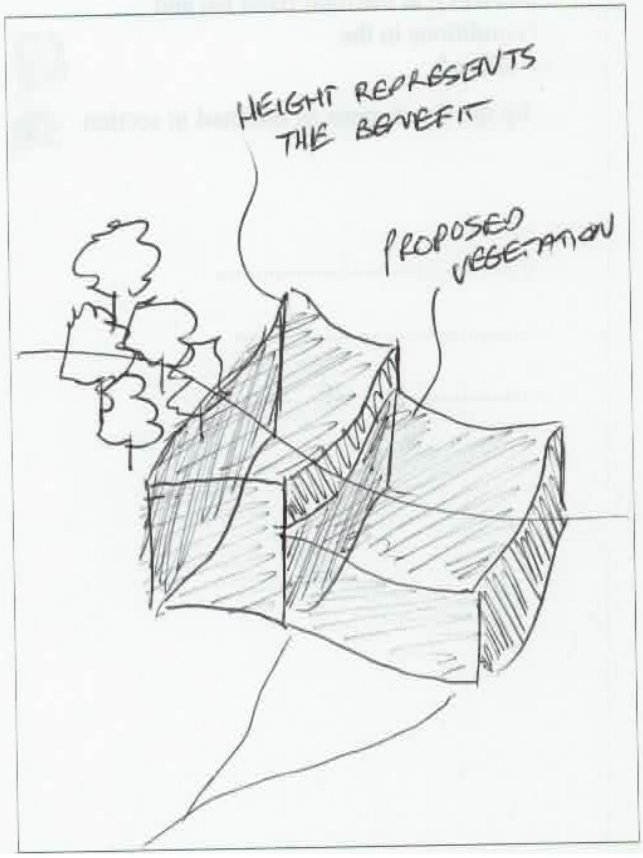

Figure B.4 – The use of extruded polygons to either depict different land uses or to show the relative benefit of a particular land use.

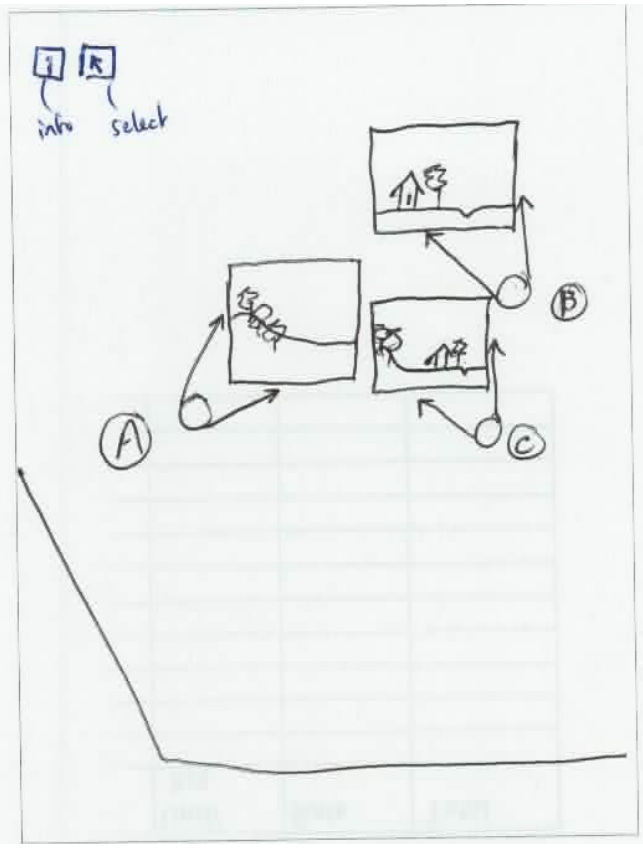

Figure B.5 - PDA interface for viewing user location within landscape. The users FOV could be displayed on screen to assist in problem solving or explaining a topic.

Appendix C - Evaluation script

Firstly, thank you for coming here today. I have a script here that I'll read to you. While this may seem formal it ensures that each participant receives the same information. If you have any questions please don't hesitate to ask.

The purpose of today's activity is to test a user interface that has been developed for creating and interacting with land use scenarios in an Augmented Reality (AR) system. I want to determine whether the interface is intuitive by asking you to complete some tasks and provide me with feedback. It is important to emphasise that I am not testing your abilities in any way. We will be finished in about an hour.

During the course of the evaluation I will be taking notes and recording you with the video. Any information I collect is confidential. Your name will not be stored with the information and it will be securely stored during the course of my research and for a term of five years after my research.

You were provided with a plain language statement explaining the purpose of this evaluation. Prior to commencing the formal part of the evaluation can you please read and sign the consent form if you agree. If you have any questions please don't hesitate to ask me.

Before we start, could you please complete this brief questionnaire about yourself. Let me re-iterate that your name will not be stored with this information.

We will now move onto the tasks. For each task I will give you a card with instructions written on it. I would appreciate if you can give me a running commentary on what you are doing and thinking as I am unable to see the screen very clearly from where I am sitting. You may find that the user interface makes it difficult to do a task or the next step is not clearly evident. If you get stuck because of this, thats fine. Just let me know and we will skip that task and move on. If you want to take a break at any stage please let me know.

Are you ready to begin?

That completes the tasks. It has been really helpful to know that some of the tasks have been difficult. Your comments will assist me to make improvements to the user interface.

I would now like you to complete a short questionnaire. Please answer each of the 10 questions by placing a tick in box that best describes your opinion.

That completes the session. Thank you for giving your time today, it has been appreciated.

Appendix D - Informed Consent

HREC Form No 2b

RMIT HUMAN RESEARCH ETHICS COMMITTEE

Prescribed Consent Form for Persons Participating In Research Projects Involving Interviews, Questionnaires or Disclosure of Personal Information

PORTFOLIO OF	Science, Engineering & Technology		
SCHOOL OF	Mathematical & Geospatial Science		
Name of participant:			
Project Title:	Exploring future landscapes using virtual environments		
Name(s) of investigators: (1)	Craig Feuerherdt	Phone:	(03) 5442 3104
(2)	Professor William Cartwright	Phone:	(03) 9925 2423

1. I have received a statement explaining the interview/questionnaire involved in this project.
2. I consent to participate in the above project, the particulars of which - including details of the interviews or questionnaires - have been explained to me.
3. I authorise the investigator or his or her assistant to interview me or administer a questionnaire.
4. I acknowledge that:
   - (a) Having read Plain Language Statement, I agree to the general purpose, methods and demands of the study.
   - (b) I have been informed that I am free to withdraw from the project at any time and to withdraw any unprocessed data previously supplied.
   - (c) The project is for the purpose of research and/or teaching. It may not be of direct benefit to me.
   - (d) The privacy of the personal information I provide will be safeguarded and only disclosed where I have consented to the disclosure or as required by law.
   - (e) The security of the research data is assured during and after completion of the study. The data collected during the study may be published, and a report of the project outcomes will be provided to those who are interested. Any information which will identify me will not be used.

Participant's Consent

Name:		**Date:**	
	(Participant)		
Name:		**Date:**	
	(Witness to signature)		

Any complaints about your participation in this project may be directed to the Secretary, RMIT Human Research Ethics Committee, University Secretariat, RMIT, GPO Box 2476V, Melbourne, 3001. The telephone number is (03) 9925 1745. Details of the complaints procedure are available from the above address.

Appendix E - Evaluation tasks

Task 1:	**Choose and publish a narrative (Narrative)**
Goal/output:	To select and publish a narrative for participants to view
Inputs/Assumptions:	• Prototype is initialised and displaying the 'Home' page
Steps:	1. Select 'Narrative' 2. Select 'Begin' 3. Select 'Recharge and salinity' from the drop-down menu 4. Select 'Publish'
Time for expert:	2 minutes
Instructions for user:	A new system has been made available to you as a catchment management officer that allows people to explore the natural processes that contribute to negative (and positive) impacts on the landscape. You have decided to utilise the new resource to supplement a field trip of the Bet Bet catchment involving delegates from the local council and respected landowners. You have arrived at the site and want the delegates to gain an understanding of the physical processes contributing to the degradation at the site. Select the narrative that explains the occurrence of dryland salinity and provide all members of the delegation access to partake in the narrative.
Notes:	• None

Task 2:	**Monitor narrative participants (Narrative)**
Goal/output:	View the location of participants within the landscape and determine their progress through the narrative.
Inputs/Assumptions:	• The user has completed Task 1a, and • The prototype is displaying the 'Publish a narrative' page
Steps:	1. Click 'Monitor' 2. Click 'View map' 3. Select 'Information' icon 4. Click each user to display information 5. Click 'Close map' 6. Click 'End narrative" 7. Click 'Yes'
Time for expert:	5 minutes
Instructions for user:	The delegates have been viewing the narrative for about 15 minutes. A total of 30 minutes was allocated for this part of the field trip. View the progress of the users to determine the estimated amount of time for all participants to complete the narrative. If the time taken to complete the narrative is greater than 15 minutes, terminate the session. Q1: *How many users will take longer than 15 minutes to complete the narrative?* Q2: *Which site(s) did User 4 not complete?*
Notes:	• Answers: Q1 – 2, Q2 - 2

Task 3:	**Participate in a narrative (Narrative)**
Goal/output:	To follow the narrative at a single 'narrative hotspot' as a participant.
Inputs/Assumptions:	• The prototype is displaying the 'Narrative HMD interface' page • The screen is displaying the HMD view
Steps:	1. Click the 'Switch view' icon 2. Select 'Surface runoff' or 'Groundwater recharge' 2.1. Read notes 2.2. Click 'Switch view' icon 2.2.1. Navigate to the view with the animation 2.3. Click 'Switch view' icon 2.4. Click OK button 2.5. Repeat for other option(s) 3. Click 'Continue' button 3.1. Click 'Switch view' icon 3.2. Navigate to view with arrow pointing up (forward)
Time for expert:	5 minutes
Instructions for user:	You are one of the delegates on the field trip through the Bet Bet catchment. At the first stop on the tour the organiser provides you and the other delegates with a set of goggles (know as a Head-Mounted Display) and a Personal Digital Assistant (PDA). Having been provided with a brief oral explanation of how the system works the organiser publishes a narrative for you to follow. With the HMD on, you are guided to the first site by arrows displayed on the screens. You are informed by the system when you arrive at the first site. Utilising the PDA, view the various multimedia and answer the following questions. Q1: *In which general direction are the narrative animations shown?* Q2: *Once you have viewed the narratives, in which general direction do you need to proceed to the next narrative site?*
Notes:	• The HMD is a mockup and users can only view a certain portion of the landscape by using the arrow(s) depicted on image. Displayed text is minimal due to inability of software to insert images into the text area field. • Answers: Q1 – North, Q2 – North West

Task 4:	View land use scenarios (Regional scenario)
Goal/output:	To load various pre-defined land use scenarios at a regional scale to determine their comparative impacts through exploring the scenarios on the PDA and through the HMD.
Inputs/Assumptions:	• The prototype is displaying the 'Home' page
Steps:	1. Click 'Scenarios' 2. Select 'Yes' or 'No' 2.1.If 'Yes', enter personal details and click 'Continue' 2.2.If 'No', click 'Continue' 3. Click 'Regional' 4. Select 'Visualize scenarios' and click the '>' button 4.1.Alter visible layers as necessary 4.2.Query the layers as necessary 4.3.Click 'View in HMD' icon on view the map through the HMD
Time for expert:	10 minutes
Instructions for user:	Having been impressed by the trial of the new system on the field trip a few weeks ago, you decide to test some of the additional functionality provided by the system. You have been sent the latest documents and associated data files from the landscape planning project that is taking place across the Bet Bet catchment. The project has developed and modelled the impacts of three scenarios: current (or 'as is'); plantation; and, water yield. After reading the documents and loading the data files onto the computer you drive to a location which provides a good vantage point for part of the catchment. View each of the land use scenarios using the PDA and the HMD. Q1: *Which scenario provides the best social outcomes for the region?* Q2: *Which scenario maximises revegetation for biodiversity outcomes?*
Notes:	• The maps aren't necessarily represented correctly in the HMD • Answers: Q1 – Current, Q2 – Water yield

Task 5:	Create an alternate land use scenario (Regional scenario)
Goal/output:	Alter one of the existing land use scenarios and compare the preliminary results against the existing scenario.
Inputs/Assumptions:	• User has completed Task 2a, and • Viewing the scenario mapping interface or the HMD.
Steps:	1. Click 'close map' icon 2. Select 'Design scenarios' and click the '>' button 3. Select a scenario from the drop-down list 3.1. The graph will update showing the proportion of each landscape factor 4. Click on graph (this will display an alternative scenario) 5. Wait until model processing is completed then Click '>' 6. Alter layer visibility 6.1. Explore scenario on PDA and through HMD
Time for expert:	10 minutes
Instructions for user:	Having some knowledge of the issues facing the catchment, you want to explore your ideas through a scenario. The 'Plantation' scenario is predominantly focused on commercial tree plantings in an attempt to reduce erosion and dryland salinity discharge. One of the implications of the plantation scenario is a negative impact on the current social aspects of the region. With the suggested increase in the area covered by vegetation, the land will become uneconomical to farm and result in a net loss of population. You want to explore an alternative with a greater focus on maintaining (or even increasing) the current population while still tackling the environmental degradation issues facing the region. Create an alternative land use scenario using landscape factors and compare it against the existing scenario to determine whether your aspirations are possible. Q1: *Compared to the current situation, which scenario(s) results in a negative impact on water yield?* Q2: *What is the greatest benefit of the water yield scenario compared to current?*
Notes:	• Creating an alternate scenario is not dynamic (one pre-defined option is provided) • The HMD graphics are indicative, not an actual representation of the PDA map. • Answers: Q1 – Plantation, Q2 – Erosion

Task 6:	Alter specific land uses of an existing scenario (Context scenario)
Goal/output:	To alter an individual land use polygon and compare (both visually and numerically) the implications against the current land use.
Inputs/Assumptions:	• User is on the 'Home' page
Steps:	1. Click 'Scenarios' 2. Select 'Yes' or 'No' 2.1. If 'Yes', enter personal details and click 'Continue' 2.2. If 'No', click 'Continue' 3. Click 'Context' and Click 'Begin' 4. View land use results using "View tabular results' button 5. Alter layers to display 'Planned land use' 6. Click 'Edit land use' button 6.1. Select polygon (paddock) on map 6.2. Select the new land use and Click 'OK' 7. Click 'View tabular results' button 7.1. Compare edited scenario with proposed scenario
Time for expert:	10 minutes
Instructions for user:	You are working to implement the land use scenario that provides the most equitable outcome for the region. While the broad guidelines of the scenario have been determined, flexibility exists to make local changes to better accommodate the needs of individual landholders. To this extent, you are working with a local landholder whose livelihood would be adversely affected if the selected land use scenario was to be implemented on her farm. You as the regional catchment manager have been charged with the ability to alter proposed land uses, provided the impacts result in a net positive outcome. Using your knowledge of landscape processes, alter some of the land use areas to provide the landholders with a more productive landscape. Q1: *What are the benefits of altering the land use with respect to costs and cashflow?*
Notes:	• Tables will not reflect individual land use changes • Answers: Q1 – Reduced costs and more even income

Appendix F - System Usability Scale questionnaire

	Strongly disagree				Strongly agree
1. I think that I would like to use this system frequently	1	2	3	4	5
2. I found the system unnecessarily complex	1	2	3	4	5
3. I thought the system was easy to use	1	2	3	4	5
4. I think that I would need the support of a technical person to be able to use this system	1	2	3	4	5
5. I found the various functions in this system were well integrated	1	2	3	4	5
6. I thought there was too much inconsistency in this system	1	2	3	4	5
7. I would imagine that most people would learn to use this system very quickly	1	2	3	4	5
8. I found the system very cumbersome to use	1	2	3	4	5
9. I felt very confident using the system	1	2	3	4	5
10. I needed to learn a lot of things before I could get going with this system	1	2	3	4	5

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Appendix G - Australian Land Use Mapping codes

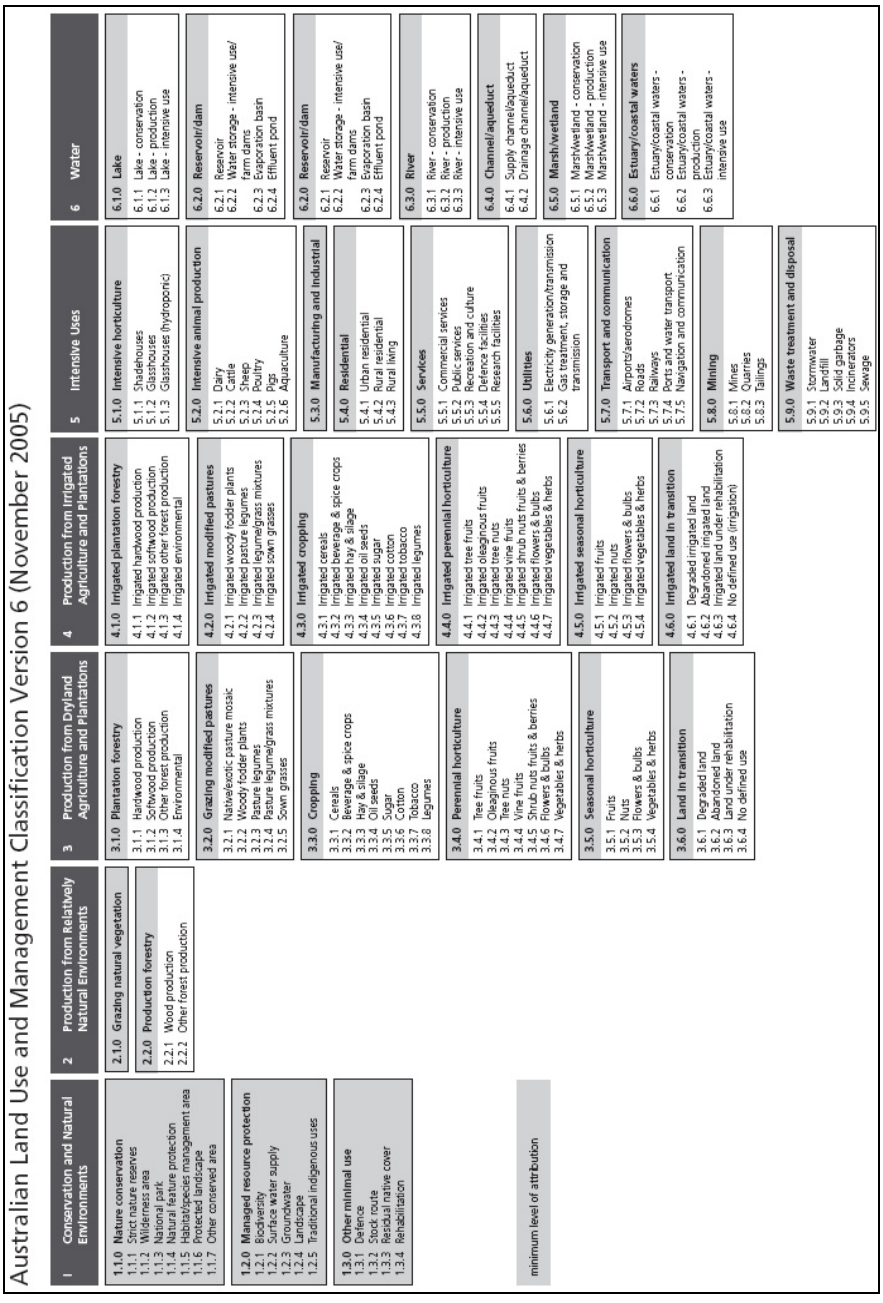

Figure G.1 - ALUM codes (source: Bureau of Rural Sciences, 2006b).

Appendix H - Prototype as evaluated

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