Field Techniques Manual:
GIS, GPS and Remote Sensing

- Section D: Planning & Practicalities

Chapter 16: GISci Applications

16 GISci Applications

16.1 Archaeology

One of the earliest applications of remote sensing was in the use of aerial photography to map buried archaeological features, which can often be detected because of variations in the growth of overlying vegetation: infra-red aerial photography and imagery from multispectral scanners is therefore particularly useful (e.g. Anon. 2001). The regional overview provided by satellite remote sensing is useful for mapping large features, such as ancient city walls or road systems, a famous example being the re-discovery of the 'lost city of Ubar' in the desert of southern Oman. Multi-spectral and radar remote sensing have been used on various projects trying to detect lost cities in the jungles of Central and South America. McCauley *et al.* (1982) used free Space Shuttle radar imagery to map buried valleys and geoarchaeological features in the Sahara. More recently, both GIS and remote sensing have been used to model and visualise ancient landscapes. The Internet *Archaeology Journal* provides a good source of contemporary applications.

16.2 Ecology

Check recent editions of the *Journal of Landscape Ecology*: this frequently has papers summarising projects that have used GIS-based analyses for map-based ecological research – summaries of the papers can be downloaded from the journal's website. Jorgensen and Nohr (1996) used satellite images and GIS to map landscape and biodiversity in the Sahel, whilst Gillman and Teeuw (1996) used satellite radar and GIS to examine rainforest biodiversity, using associated ground-based surveys of butterflies, the selected biodiversity indicator species. On a regional scale, AVHRR weather satellite images have been used to map habitat types across the whole of the Mkomazi National Park, Tanzania (Coe *et al* 1999): the habitat zones were then compared with the locations of animal species, using field observations and locations derived from a Land Rover-mounted GPS receiver.

16.2.1 Land cover and land use

Maps showing land cover types are essential for effective environmental management. Landsat TM imagery has been used to create a digital land cover map of Britain, using imagery from summer and winter months (Fuller *et al.* 1994). The USA, with such a large surface area to map, has used GIS to derive 'ecological resource' maps from Landsat TM images (Cain *et al.* 1997). Adinarayana *et al* (1994) used GIS and remote sensing to map land use patterns. Since the 30th anniversary of the Landsat family of multi-spectral satellites in 2002, there have been many studies of land cover changes based on 10-year observation intervals – these are too numerous to cite here, but examples can be found via an internet search under the key words 'Landsat' 'land cover' and 'change analysis'.

16.2.2 Species mapping

Satellite-derived land-cover maps and GIS have been used on many projects that have mapped habitat types and indirectly assess species distributions, a classic example of which is summarised in a paper by Loffler & Margulis (1980): Wombats detected from space. Avery & Haines-Young (1990) used GIS and Landsat TM images to map dunlin

(*Caliadris alpina*) habitats in the remote and boggy 'flow country' of northern Scotland: GIS was then used to estimate the breeding population. Lauver & Whistler (1993) and Lauver (1997) used a similar approach to map species diversity patterns in Kansas grasslands. A useful summery of new advances in species distribution modelling is given by Vaughan & Ormerod (2005), who also cite several recent case studies. Some studies have attempted to monitor key biodiversity indicator species, such as certain butterflies or birds, using trap-record-and-release methods, with a GIS used to plot and monitor their distribution. This approach was extended by Gillman & Teeuw (1996) who used satellite radar to map rainforest habitat types, particularly forest canopy gaps.

16.2.3 Pollution

Jensen *et al* (1995) used Landsat MSS images from 1973, 1976 and 1982 to quantify changes in the distribution of Sawgrass (C*ladium samaicense)* and Caltail (*Typha samaicense*) in the Florida Everglades: further GIS analysis, involving water quality data, showed that community changes were related to high phosphorous concentrations.

16.3 Geology

16.3.1 General geological mapping

A good introductory text to geological fieldwork methods, including the use of airphotos is given by Moseley (1981). Lawrance *et al* (1993) clearly illustrate the use of remote sensing in terrain mapping. There are numerous textbooks that focus on geological remote sensing, notably Drury (1987, 2001), Beaumont & Foster (1992), Vincent (1997) and Berger (1996). Some 'classic' papers that may give you ideas on how to carry out geological mapping using remote sensing are: Baker & Baldwin (1981), mapping gossan duricrusts in Chile; Crosta & Moore (1989), mapping hydrothermally altered volcanic terrain; Loughlin (1990), using thermal scanning to detect buried features in Nevada; Rowan *et al*. (2003) assessing the mineral mapping potential of ASTER imagery; and finally, De Souza Filho & Drury (1998) and Derion *et al.* (1998), who have assessed the effectiveness of satellite radar and multispectral sensors for mapping in desert regions. There is also a Special Interest Group of the Geological Society of London and the UK Remote Sensing & Photogrammetric Society: the Geological Remote Sensing Group (GRSG) - for details of their activities (and bargain student membership rates) see *www.grsg.org*.

16.3.2 Groundwater

Lattman and Parizek (1964) used airphotos to map water-bearing rock fractures. Some excellent examples of satellite data and GIS used as tools for groundwater exploration in semi-arid regions have been produced by Gustafsson (1993) and Sander (1996). Teeuw (1995) used Landsat and airphotos, fieldwork and a low cost GIS in a groundwater exploration project in Ghana. A useful example of methodologies used to evaluate water resources in Jordan, using Landsat TM and SPOT imagery to map hydrogeomorphological and hydrogeological features, is given by Allison (2001).

16.3.3 Hazards

Van Western (1992) and co-workers at the ITC (Netherlands) have produced some excellent tutorials on the use of remote sensing and GIS in mapping slope instability features and associated hazard assessments. Further examples, involving the mapping of hazardous terrain for civil engineering projects, are given in Griffiths (2001).

16.4 Geomorphology

16.4.1 Landform mapping

A summary of landscape geomorphology with remote sensing examples is given in Drury (1987, 2002) and Foster & Beaumont (1992). Reviews of geomorphological sampling and mapping techniques are given in Goudie (1990), Brunsden *et al* (1975), Verstappen & van Zuidam (1975) and Lawrance *et al* (1993) detail the use of airphoto interpretation and geomorphological mapping for rapid surveys of terrain. Further examples with a civil engineering and hazard mapping emphasis are given in Cooke & Doornkamp (1990), Fookes *et al.* (1991) and Griffiths (2001). Carroll *et al.* (1976) review the use of airphotos for soil mapping. In recent years, a whole new field of 'geomorphometric' research has developed out of the integration of multispectral satellite images, Digital Elevation Models and GIS-based analyses. A good example of this is the project of Hung *et al*. (2002), who showed how Landsat-based mapping can be integrated with ground-based GIS analyses to predict the occurrence of limestone karst cave systems in Vietnam.

16.4.2 Glaciers and mountains

Cornelius *et al.* (1994) and Carver *et al* (1995) used remote sensing, fieldwork and GIS to carry out a baseline environmental survey for a proposed national park in the glaciated landscape of central Asia's Altai Mountains: A survey of the snowline and snow patches was carried out, based on Landsat imagery and GPS-aided fieldwork. A recent survey of glacier retreat, utilizing archive CORONA photos, Landsat ETM and GPS-aided fieldwork is given by Martin Whiteside in the Case Studies section of this manual (Chapter 17). For a useful summary of glacier mapping methods using Landsat TM imagery see Paul (2000). For those of you aiming to climb high altitude peaks, Mount and Rumsbachs (2002) have ingeniously used GIS to model climbing conditions for mountaineers (headline: 'Everest climbed by computer nerds') – this is written up in Chapter 17.

16.4.3 Rivers and wetlands

Mertes *et al.* (1995) and Mertes 2002, focusing on the Amazon, have produced a useful review of remote sensing for mapping patterns of hydrology, geomorphology and vegetation. Jensen *et al* (1995) – mapped changes in the Florida Everglades using change analysis on normalized Landsat TM images. Middelkoop (2000) ingeniously sampled suspended sediment loads in the Rhine during major floods and was then able to calibrate Landsat TM images of those flood events, allowing better estimations of suspended sediment loads, as well as zones of deposition, along major Dutch rivers. Mount *et al* (2000, 2003) used archive aerial photography to quantify upland river erosion and assessed the effectiveness of the ERDAS Imagine GIS against a low-cost approach based on the Paintshop Pro graphics software.

16.4.4 Marine and coastal environments

Blue, green and red light will penetrate clear water to depths of approximately 15 m, 10 m and 5 m respectively, allowing bathymetric maps to be produced from multi-spectral scanners data (Lyzenga 1981; Van Hengel & Spitzer 1991). This has been useful for mapping and monitoring tidal habitats (e.g. Khan *et al* 1992), particularly coral reefs (e.g. Michalek *et al* 1993). By contrast, Schweizer *et al.* (2005) attempted to remove the effects of variable depth when mapping the shallow-water habitats and biomass in a marine park off the coast of Venezuela. Suspended sediment is detectable by Landsat's infra-red bands: in the UK this has been used to illustrate tidal sediment fluxes during environmental impact studies for proposed barrages on the Mersey and Severn estuaries. Phinn *et al.* (2000) give examples of remote sensing used in the mapping, monitoring, modelling and management of coastal wetlands, using Californian and Australian examples. The uses of GIS in mapping coral reefs and as a tool for integrated coastal zone mapping have been summarised by Mumby *et al* (1995). Further offshore, Wright (1996) described the various uses of GIS in an expedition mapping ocean floor features.

16.4.5 Desert and semi-arid environments

The remote sensing textbooks of Sabins (1987) and Drury (2001) have considerable coverage of geological and geomorphological applications in desert and semi-arid regions. The 1940s saw the development of airphoto-based geomorphological mapping, focused on the suitability of terrain for troop movements and tank trafficability in the deserts of north Africa (Mitchell 1991). In Australia those techniques evolved into the Land Systems approach for mapping land suitability for agriculture (e.g. Christian & Stewart 1952; see also the summaries of Lawrence *et al*. 1993). By the 1970s, geomorphological surveys were developed to map hazardous terrain and potential construction materials for civil engineering projects, primarily in the desert environments of rapidly-developing petroleum-rich countries (see summaries in Brunsden *et al*. 1975; Cooke & Doornkamp 1990, Griffiths 2001).

16.5 Natural resource management

16.5.1 Forestry

The use of conventional aerial photographs to produce 'photo-maps' for community forestry has been reviewed by Mather *et al.* (1998). Hewitt (1990) used Landsat to map riverine forests. Satellite radar has been particularly useful in mapping rainforest regions, though discrimination between tree species can be complex, involving multi-temporal composite images or composite images produced from the use of different filters (Kuntz 1995).

16.5.2 Soils / land degradation

Aerial photography has been the basis of many surveys of soil types and soil erosion, from detailed site mapping through to national surveys, though since the 1980s many regional or national surveys have used multi-spectral satellite imagery and GIS (Clarke 1986; Landon 1991). Landsat images have been used to map UK peat bogs and areas of associated erosion using Principal Components Analysis (e.g. Reid *et al* 1993) and more recently using Artificial Neural Networks. The McArthur Project based at Cambridge University, used regional weather satellite images, census data and GIS to map vegetation cover and grazing pressures in Mongolia. Teeuw (1990) reviews a soil conservation expedition that used Landsat, airphotos and field surveys in Zambia's Luangwa Valley.

16.5.3 Flood defence and catchment management

Radar's ability to both operate at night and to 'see' through cloud makes it particularly useful for mapping and monitoring major floods. Agencies involved in flood defence have benefited from satellite radar imagery, for instance in Mozambique and China plus along the Mississippi and Rhine. Satellite radar allows a GIS-based assessment of antecedent soil moisture contents, river level variations, flooded areas, flood-water volumes and the probable rate at which the flood pulse moves down-river, enabling early warnings to be given to vulnerable sites (e.g. Goodrich *et al.* 1994; Koblinsky *et al.* 1993; McKim *et al.* 1993, Schultz 1993). Townsend & Walsh (1998) used GIS to integrate radar and optical remote sensing to map and model flooding. Hamilton *et al.* (1996) and Kasischke *et al.* (1997) have used microwave remote sensing to map wetland habitats. Clark *et al* (1991) reviewed the uses of GIS for river management, examining both catchment and channel-specific applications.

16.5.4 Vegetation changes

With sufficient records over many years, GIS allows changes in distribution over time to be assessed. AVHRR weather satellite images have enabled us to monitor deforestation in Amazonia, using the Normalised Difference Vegetation Index (NDVI) discussed in Section 2.4 (Myers 1988; Sader *et al.* 1990; Smith *et al.* 1990). AVHRR imagery has also been used to map and monitor desert vegetation changes as part of an early-warning system for locust activity (by Tucker *et al.* 1985). Along the coastal plain of Venezuela, Sebastini *et al.* (1989) used past Landsat imagery for a GIS-based assessment of wetland loss. Munyati (2000) used a multi-temporal set of Landsat images to classify and monitor wetland vegetation in Zambia's Kafue Flats.

16.6 Wildlife

An interesting case study is provided by Scotland's Dee Catchment Management Planning GIS, which assessed the optimum conditions for salmon, using hydrological, geomorphological, geological, land cover and water quality data (see *www.nmw.ac.uk/ite/banc/deecamp.html*).

16.6.1 Nature conservation

The US Nature Conservancy have used aerial photography and video filming and Landsat images for rapid recce surveys designed to guide conservation planning and fieldwork (Muchoney *et al.* 1991). Furley *et al* (1994) used Landsat images, aerial photography, field surveys and GIS to devise management guidelines for a nature reserve on Maraca Island in Amazonia.

16.7 Socio-economic applications

16.7.1 Health and epidemiology

Maps indicating malaria risk along the Pacific coastal plain of Mexico were generated by Pope *et al* (1994): the optimum habitat types of *Anopheles albimanus* mosquito larvae were determined from fieldwork and were then mapped across the whole region, using GIS, with Landsat TM images from the winter (wet) and summer (dry) seasons. Monitoring of mosquito occurrences at villages in the study region confirmed the GIS predictions. GISci analysis of environmental factors and population statistics helped Simon Brooker advice on delivery of a national *helminth* (parasitic worm) control programme in Chad (Brooker *et al* 2002). Satellite data was used to determine ecological zones, epidemiological information was used to identify eco-zones where *helminth* transmission was active, and this information was used to develop a national control strategy for the country, targeting resources where they were most needed.

16.7.2 Emergency mapping in disasters

The trends that allow small expeditions to make increasing use of GIS – accessible software, hardware and data – are now being used to help humanitarian aid agencies in the aftermath of disasters. A UK charity - MapAction (*www.mapaction.org*), sent a mapping team to Sri Lanka within two days of the Tsunami that struck on 26 December 2004. Basic infrastructure maps were the first need, showing roads, railways, ports and airfields; this helped assessment teams to access affected areas. The presence of a field teams with GPS and GIS allowed information to be incorporated in 'real time'; collapsed bridges and impassable roads were shown on the initial maps, and as the infrastructure was repaired, these maps were updated and re-issued. At this stage, Landsat imagery, available free for almost all parts of the world, was also helpful in providing an overview of terrain and land use. More detailed mapping resulted from further GPS fieldwork, showing the locations of affected populations, with their number and needs, and showing the resources at the disposal of local authorities and aid agencies in the response effort. Missions such as these can readily create close links with local mapping agencies and NGOs, providing an opportunity for collaboration and training.

16.7.3 Urbanisation

GIS can model the potential environmental impacts of proposed new developments. Pereira and Moura (1999) used GIS and SPOT multi-spectral imagery to model the impact of a new bridge over the Tagus estuary in Portugal, with particular reference to wading birds. Field observations of sediment types and vegetation covers were used to classify the SPOT imagery via a supervised classification and a Maximum Likelihood algorithm. The impact of the bridge on wading bird populations was assessed at 200 m, 400 m and 600 m intervals from the bridge axis, using probability analysis.

16.7.4 Land claims, participatory mapping and institution-building

Leake (1995 and *www.herts.ac.uk/natsci/Env/Research/Leake/resource_use.htm*), working in Paraguay (see Figure 16-1) and the Tumucumaque Mapping Project in north east Brazil (*www.ethnobotany.org/actnew/BrazilTumucumaqueMapping.html*), have shown how training in GI techniques can provide an effective tool for indigenous communities to map their lands, defend land claims, plan resource use and strengthen their own skills and institutions. In Zimbabwe, participatory mapping using GIS has been effective in investigating deforestation and highlighting the differing perceptions of local farmers and the forest authorities (Mapedza *et al.* 2003).

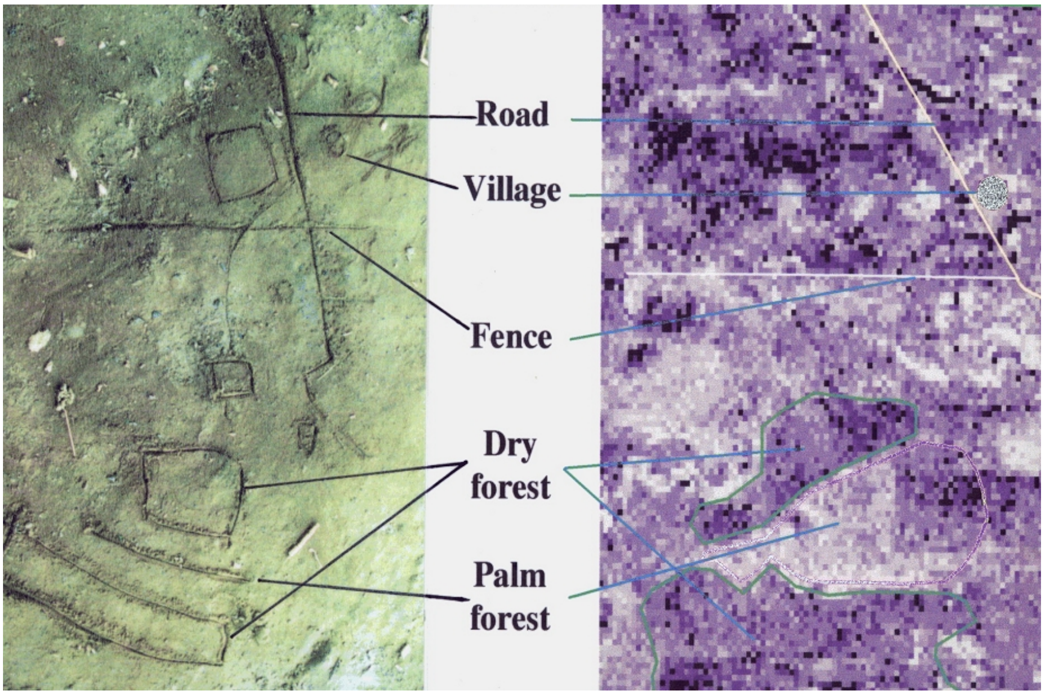

Figure 16-1 Linking indigenous people's knowledge with remotely sensed images, GPS locations and GIS analyses: on the left, a sketch map of hunting grounds scratched on the ground by Amerindians in the Gran Chaco of Paraguay; on the right, the same features plotted on a Landsat MSS image (photos courtesy of Andrew Leake).