3 AERIAL PHOTOGRAPHIC METHODS

P.H. Biggs, C.J. Pearce, M.A. Green, R.D. Spencer and P.J. Bowen

3.1 Design of photographic system

A twin-camera fixed-base design was selected after considering the advantages and limitations of single-camera and fixed-base systems in conjunction with the following, equally weighted, considerations:

- time requirements to implement the system,
- availability of a suitable altimeter,
- potential accuracies,
- costs.

The system could be implemented at reasonable cost using available expertise and equipment (Biggs and Spencer 1990). Transverse orientation of the air-base relative to the direction of flight was selected because of its lower requirements for precise camera synchronization, resulting in greater latitude in the selection of cameras (Spencer 1979).

This was especially important if Vinten reconnaissance cameras were to be used as they have focal plane shutters that are very difficult to synchronize.

The restricted choice of flying heights associated with a fixed air-base system was not considered to be a serious limitation for the project because the stereoscopic parallax would be adequate at the scales required and the project was large enough to justify building a dedicated system. On the other hand, it was recognized that implementing the altimeter and tip/tilt recorder required for timed-interval photography would be expensive and difficult because of a lack of experience with such systems in Western Australia.

The booms (Fig. 8) were designed in Perth by Aeronautical Engineers Australia and built by Aircraft and General Welding. They have a braced tripod construction similar to designs used for agricultural sprays in order to minimize flexing during flight which, if present, reduces the accuracy of scale calculations from photo-measurements.

They are mounted on three hard points on each side of a Bell 206 B Jetranger helicopter and are braced to a fourth hard point toward the tail boom. Vibration tests conducted during certification for the Department of Aviation showed that the booms are rigid enough for sharp photography. No major modifications were required to the helicopter apart from strengthening of the upper hard point.

Figure 8

Helicopter-mounted equipment. Transverse boom of 7.5 m mounted on a Bell 206B Jetranger supporting aerodynamic pods housing synchronized computer-controlled cameras.

Camera separation on the booms (i.e. air-base) is 7.5 m, with each of the cameras being housed in a Mylar-glass pod for protection from the weather, dust and minor impacts (Fig. 9). The tail-cone of each pod is secured by a quick release nut so that it can be removed quickly to gain access to the cameras for changing film magazines. An electrically driven hatch is installed in the bottom of each pod to protect the camera lenses from dust during take-off and landing. The hatch is opened by remote control during flight. Two types of cameras were used during the course of the inventory, Vinten 492 reconnaissance cameras during years one and three, and modified Hasselblad 500 EL/M cameras during year two.

Mounts for Vinten cameras were designed so that each camera can be bolted directly onto the ends of the booms. This is possible because the booms were designed to have parallel and vertical end plates that are aligned correctly for the cameras (Fig. 10). Once these cameras are installed, they remain in place for the entire photography season, so that their relative orientation remains constant for the whole season. This simplifies the calculation of scales and is less prone to errors.

Mounts for Hasselblad cameras (Fig. 11) were designed so that the cameras can be levelled after installation. This is done by placing bubble levels on the reseau plates and then bolting the cameras into their correct positions. These cameras are removed from the helicopter each day for security and for maintenance. Therefore, the camera angles vary slightly from day to day. In order to check camera orientation in flight, calibration targets are photographed at the beginning and end of each flight. This is satisfactory under perfect circumstances but is subject to error if the targets are missed by the cameras, if the calibration run is forgotten, or if the cameras are adjusted during the day without another set of calibration photographs being taken. The better solution is to leave the cameras in a fixed position for as long as possible.

The aircraft power supply is used to power the cameras, removing the need for batteries in the cameras. The aperture and film numbering of the Vinten cameras was also controlled from inside the helicopter.

3.2 Camera selection

Reconnaissance and semi-metric 70 mm cameras were considered for use in the photography (Table 1). Various 35 mm cameras were also considered but the disadvantages of smaller format size outweighed the potential savings in cost. The maximum film capacity of the 35 mm cameras investigated was 250 frames but no data backs were available

Figure 9
Camera pod with rear housing removed.

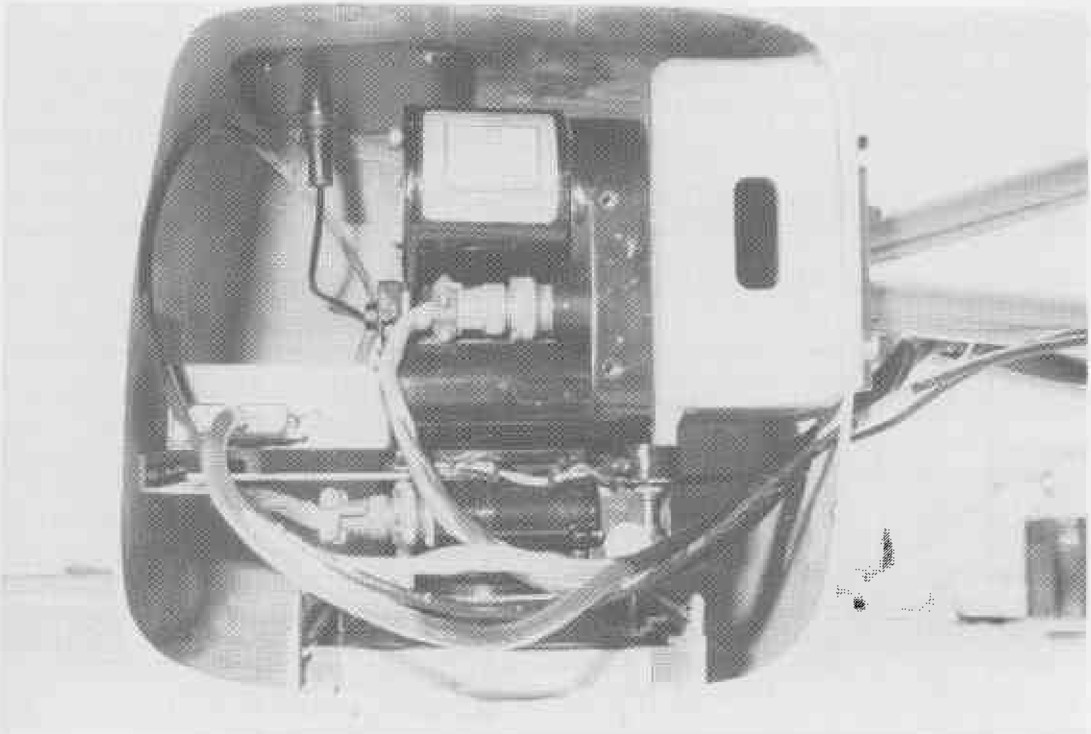


Figure 10
Mount for Vinten camera.

Figure 11
Mount for Hasselblad camera.

Table 1

Camera selection considerations

Camera	Shutter type	Shutter speed	Reseau plate	Aperture Control	Data Back	Magazine Capacity	Film Flattening	Approx Cost ($)
70 mm PHOTOGRAMMETRIC CAMERAS								
AMI /Bronica SQ/Am.	Leaf	1/500	Yes	Automatic	No	24	Yes	15 000
Hasselblad MK70	Leaf	1/500	Yes	Manual	Yes No	100/200 500	Pressure Plate and reseau	30 000
Hasselblad 500EL/M	Leaf	1/500	No (Custom Installed)	Manual	Yes No	100/200 500	No (Yes if reseau installed)	10 000
Rollieflex 6006 Metric	Leaf	1/500	Yes	Automatic	No	170	Vacuum back	15 000
70 mm RECONNAISSANCE CAMERAS [a]								
Vinten 492	Focal Plane	1/1000	No	Remote	Yes	500-1000	No	30 000

(a) Modern reconnaissance cameras were investigated by the Forests Department in 1984 for application in dieback photography. It was found that most were designed to be hand-held for marine surveillance, or were designed for jet fighter aircraft. Older cameras such as the Hulcher have been used for forestry photography and would be an alternative to the Vinten.

for such magazines. Bulk 35 mm transparency film would have cost as much or more per square mm of image to purchase and process as 70 mm transparency film.

Reconnaissance cameras, such as the Vinten, were designed for military surveillance and are characterized by their robust construction, large film capacity, remote operation and fast shutter speeds. Their lenses, however, are not generally of metric quality, although they can be exchanged for lenses of better quality, and they have focal plane shutters that cause distortions in images taken from a moving platform.

Semi-metric 70 mm cameras, on the other hand, have high quality lenses and intra-lens shutters to minimize image-distortion and provide for accurate photomeasurements. They also have reseau plates that provide fiducial marks for precise referencing purposes and flatten the film during exposures. These cameras have evolved from standard 70 mm studio cameras and are therefore usually of light construction and have a small film capacity.

The choice between the available cameras took account of shutter speed, potential for accurate measurements, film capacity, aperture control mechanism, availability of film numbering/data back, robustness and cost.

None of the available cameras met all of the requirements for the project, but the Hasselblad MK70 camera was considered to be the best technical option. It has a high photogrammetric standard, plus film numbering and a moderate film capacity with the DM 100/200 magazine which gives 200 frames. The cost of purchasing two cameras plus a number of magazines (minimum of six) and two lenses was, however, beyond the budget for the project. Furthermore, its limitation of 200 frames per magazine would have required more time for reloading, resulting in greater flying costs.

Vinten 492 reconnaissance cameras with 500 frames per magazine, 100 mm focal length lenses and a film numbering facility were already owned by the Department and had previously been used successfully to acquire large-scale aerial photographs for detecting jarrah dieback disease (*Phytophthora cinnamomi*) over large areas (Bradshaw and Chandler 1978). Although it was recognized that their photo-measurement quality is diminished because of distortions owing to their focal plane shutter and reconnaissance lens, reports from various Canadian users have shown that they can still be used to obtain satisfactory tree measurements (Sayn-Wittgenstein and Aldred 1967; Aldred and Lowe 1978; Titus and Morgan 1985). Therefore, it was decided to use the Vinten cameras, initially at least, until a better solution could be found.

Subsequently, large capacity magazines were acquired for the Hasselblad 500 EL/M cameras, which allowed for trials with these semi-metric cameras and gave the opportunity for more precise and detailed measurements using an analytical plotter. In cooperation with Mr Bruce Montgommery at Curtin University of Technology, reseau plates were installed in the Hasselblad cameras (Fig. 12) to provide fiducial marks for analytical photogrammetry. This was done by fabricating an aluminium frame which fitted into each camera body. A flat glass plate with crosses etched onto its surface (a calibration plate from the Adam MPS-2 analytical plotter) was bonded into the aluminium frame, bringing the surface of the glass plate into contact with the film plane in the camera magazine. Film was pulled through the modified camera, with a spring balance and the magazine in place, to ensure that the film did not bind on the glass plate, yet with the plate sufficiently close to the focal plane to focus correctly and to help flatten the film.

The cameras were calibrated by photographing target arrays (Fig. 13) and using software at Curtin University of Technology (Fraser 1980).

The cameras are electronically actuated in flight at the required spacings using a laptop computer coupled to a sophisticated navigation and flight recording system (Biggs *et al.* 1989).

3.3 Flight planning and photography

3.3.1 Flight planning

The first step in planning the photography was to identify the areas to be included in the inventory. Initially this was done on 1:500 000 computer plots that were generated from digital mapping information on multiple use and conservation forest areas. The multiple use areas were then divided into 29 *cells*, each of 150 000-200 000 ha, which were identified on the Department's 1:50 000 map series and later digitized into the GIS. These cells are a manageable size for planning and executing the photography as each cell takes about a week to photograph.

The next step was to use the GIS to create a flight plan, drawing upon the computer file of reference points, called way-points (Fig. 14). Most flight lines were orientated east-west at 1.0 km spacings, with stereopairs of

Figure 12
Hasselblad 500 EL/M with reseau plate installed.

Figure 13
Target array at Curtin University of Technology used for lens calibration.

photographs planned for 0.5 km intervals along each line. The east-west flight direction transects the major topographic relief, hence the main gradient of forest quality, and gave the longest (and most efficient) flight lines for most cells. Some cells, however, were flown north-south. Use of a grid locking system ensures that flight paths commence and end on even 500 m values. Interactive editing of the parallel flight lines is undertaken to remove unwanted areas and to check that all way-points were entered correctly.

The coordinates of each start and end point of each flight line are then extracted using application software and stored in a computer file for later entry as way-points to a GPS in the aircraft. Initially, a manual technique was used to determine the flight paths owing to timing constraints, but the method is now semi-automated using the GIS.

Completed flight maps are useful for planning other aspects of the program. For example, the GIS can provide flight lengths and the number of photo points, thereby permitting the calculation of film requirements and hence the need for landing areas to change film, as well as flying times and fuel requirements for planning appropriate fuel dumps in addition to the main bases.

Prior to flying missions, the owners of adjacent private properties are notified by mail to seek approval to fly over their land at low altitude. Initially, this task was undertaken by exhaustive searching of Local Government records, but it is now being automated by generating a distance buffer around each cell and using this as a spatial window into the State's Land Information System. At a cost of $0.10 per land parcel, data depicting owner details and address are then extracted as a computer file, which is used to generate mailing lists.

3.3.2 Photography

During flight, the navigator sets a course along each flight line using the Trimble 1OX GPS control unit while checking the course on flight-line maps (Fig. 14). The GPS receiver then provides continuous displays that enable the pilot to navigate along each flight line (Fig. 15). As each flight line is being flown, the laptop computer reads the aircraft's position from the GPS every second, from which it calculates the distance travelled and fires the cameras at 500 m intervals via an interface built by Protek Electronics Pty Ltd. It then records the geographic coordinates for each stereopair on its disk, along with the status of the satellite constellation, the aircraft's altitude as approximately

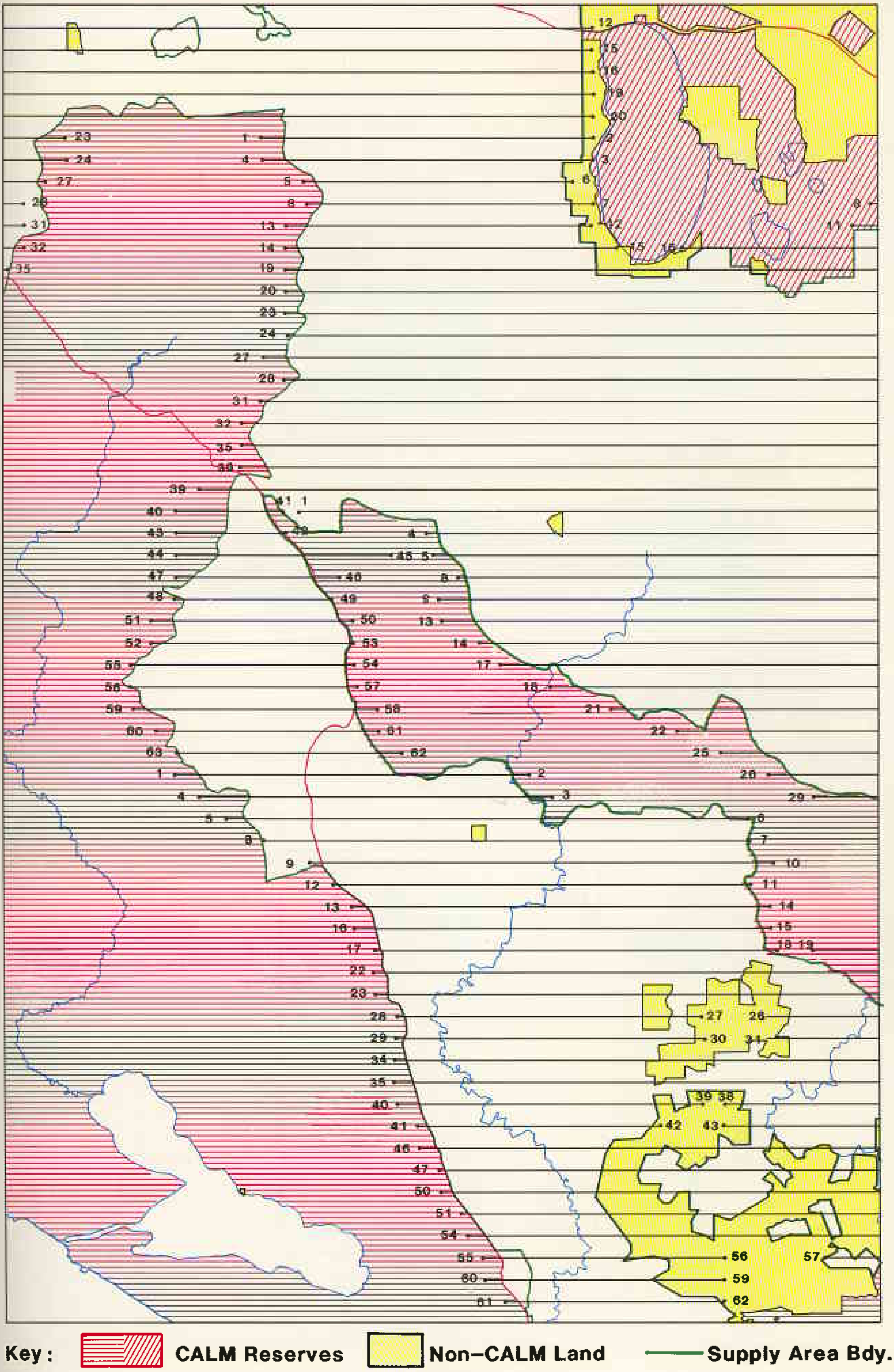
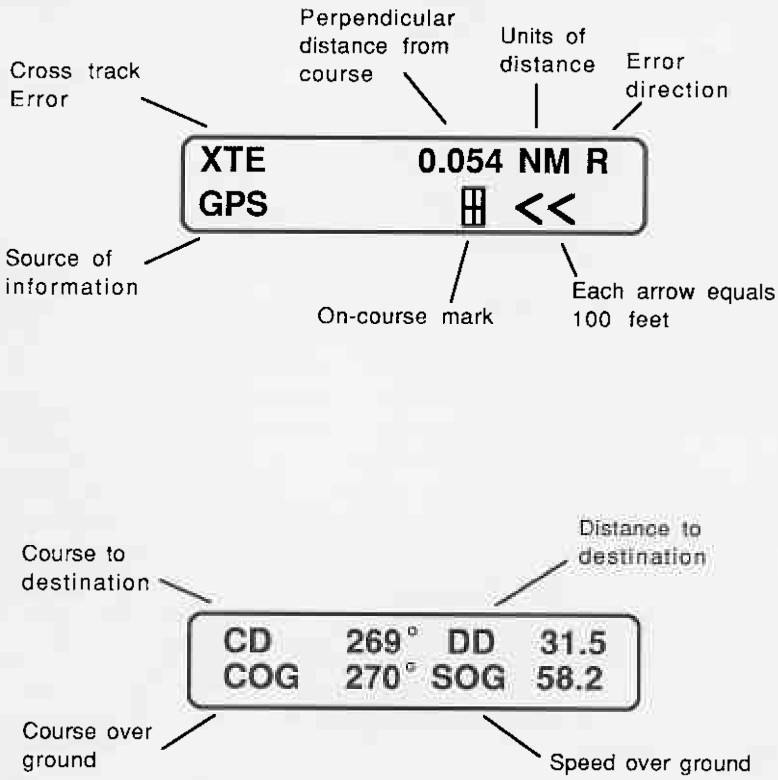


Figure 14
Example of flight line maps.

(a)



(b)

Figure 15
Example of Global Positioning System (GPS) receiver displays.
(a) shows the position of the GPS panel in the cabin and (b) displays data registered on the panel.

determined by a radar altimeter, and the frame number (Table 2).

As a cross-check, the camera operator records the numbers of each completed flight line in a log book, together with the number of the frames on each line. The name of the computer file in which the location data are stored is also recorded.

The inter-relationships between major components of the navigational and camera-control systems are illustrated in Figure 16; Figure 17 shows their layout in the aircraft and Figure 18 displays each unit.

The inflight positional data are subsequently transferred via a floppy disk to the Department's GIS, which is used to plot the photo-locations onto maps of suitable scale for administration (1:250 000 and 1:50 000) (Figure 19) and for relocation of selected photo-plots in the field for ground measurements (1:25 000) (see Figure 23). Photo and ground sample data are later attached to the positional data in a database that enable processing for the determination of sample volume estimates for any areas defined within the GIS. An example of a stereopair used for photo-measurement is given in Figure 20.

Photographs are acquired during summer under high overcast (i.e. shadowless) or full sunlit conditions. Hotspot was not found to be a problem on these photographs, so photography was able to continue through the middle of the day. Estar base Kodak Aerochrome MS 2448 colour transparency film was used, or Kodak Ektachrome if this was unavailable. These films give high resolution for measurements and good colour rendition for species interpretation. They are also cost-effective owing to their single-stage processing. Timing of photography is also affected by visibility of the satellites forming part of the GPS (Fig. 21). This varied throughout the project as more satellites entered the constellation.

Exposures are determined from a Sekonic lightmeter with a remote readout inside the cabin. The meter is attached below the aircraft in a cylindrical mount designed to restrict its angle of field to the coverage obtained with the 100 mm focal length lenses. All exposures are at 1/500 seconds, resulting in image motion of approximately 60 microns at a ground speed of 60 knots (30 m per second). Although a shutter speed of 1/1000 second is available on the Vinten cameras (but not the Hasselblads), which would reduce image motion to 30 microns, the slower shutter speed is used to give more choice of apertures so that photography can be continued under cloud. A flying height of 100 m ± 20 m above the tree tops is used, resulting in contact scales of around 1:1000 - 1:1500.

Films are processed in 30 m rolls by Irvin Datacolor of Perth. Roll pairs from the two cameras are processed together to eliminate colour differences owing to differences in processing conditions. The films are then

Table 2

Example of output from the navigation system. Each line is a separate record showing " Cross track position" (GGXP) and satellite status (GSS) from the GPS reciever, altitude from the radar altimeter and frame number from the computer

	Time	Latitude	Longitude	Satellite Status	Altitude	Frame No.
GGXP,	012217,	3344.827,S,	11529.534,E,	GSS,A,3,11,12,06,13,004.8	334	87001
GGXP,	012417,	3345.235,S,	11529.270,E,	GSS,A,3,11,12,06,13,004.8	274	86003
GGXP,	012433,	3345.212,S,	11528.940,E,	GSS,A,3,11,12,06,13,004.7	289	86004
GGXP,	012449,	3345.201,S,	11528.618,E,	GSS,A,3,11,12,06,13,004.7	348	86005
GGXP,	012503,	3345.217,S,	11528.303,E,	GSS,A,3,11,12,06,13,004.7	337	86006
GGXP,	012518,	3345.219,S,	11527.984,E,	GSS,A,3,11,12,06,13,004.7	363	86007
GGXP,	012531,	3345.213,S,	11527.664,E,	GSS,A,3,11,12,06,13,004.7	368	86008
GGXP,	012646,	3345.837,S,	11527.223,E,	GSS,A,3,11,12,06,13,004.7	213	84010
GGXP,	012705,	3345.811,S,	11527.507,E,	GSS,A,3,11,12,06,13,004.7	266	84011
GGXP,	012724,	3345.771,S,	11527.811,E,	GSS,A,3,11,12,06,13,004.7	304	84012
GGXP,	013707,	3348.363,S,	11527.757,E,	GSS,A,3,11,12,06,13,004.4	314	4014
GGXP,	013722,	3348.340,S,	11527.439,E,	GSS,A,3,11,12,06,13,004.4	344	4015
GGXP,	013737,	3348.349,S,	11527.120,E,	GSS,A,3,11,12,06,13,004.4	357	4016
GGXP,	013752,	3348.357,S,	11526.803,E,	GSS,A,3,11,12,06,13,004.4	392	4017
GGXP,	013808,	3348.361,S,	11526.480,E,	GSS,A,3,11,12,06,13,004.3	356	4018
GGXP,	013824,	3348.367,S,	11526.157,E,	GSS,A,3,11,12,06,13,004.3	338	4019
GGXP,	013934,	3348.877,S,	11525.428,E,	GSS,A,3,11,12,06,13,004.3	355	6021

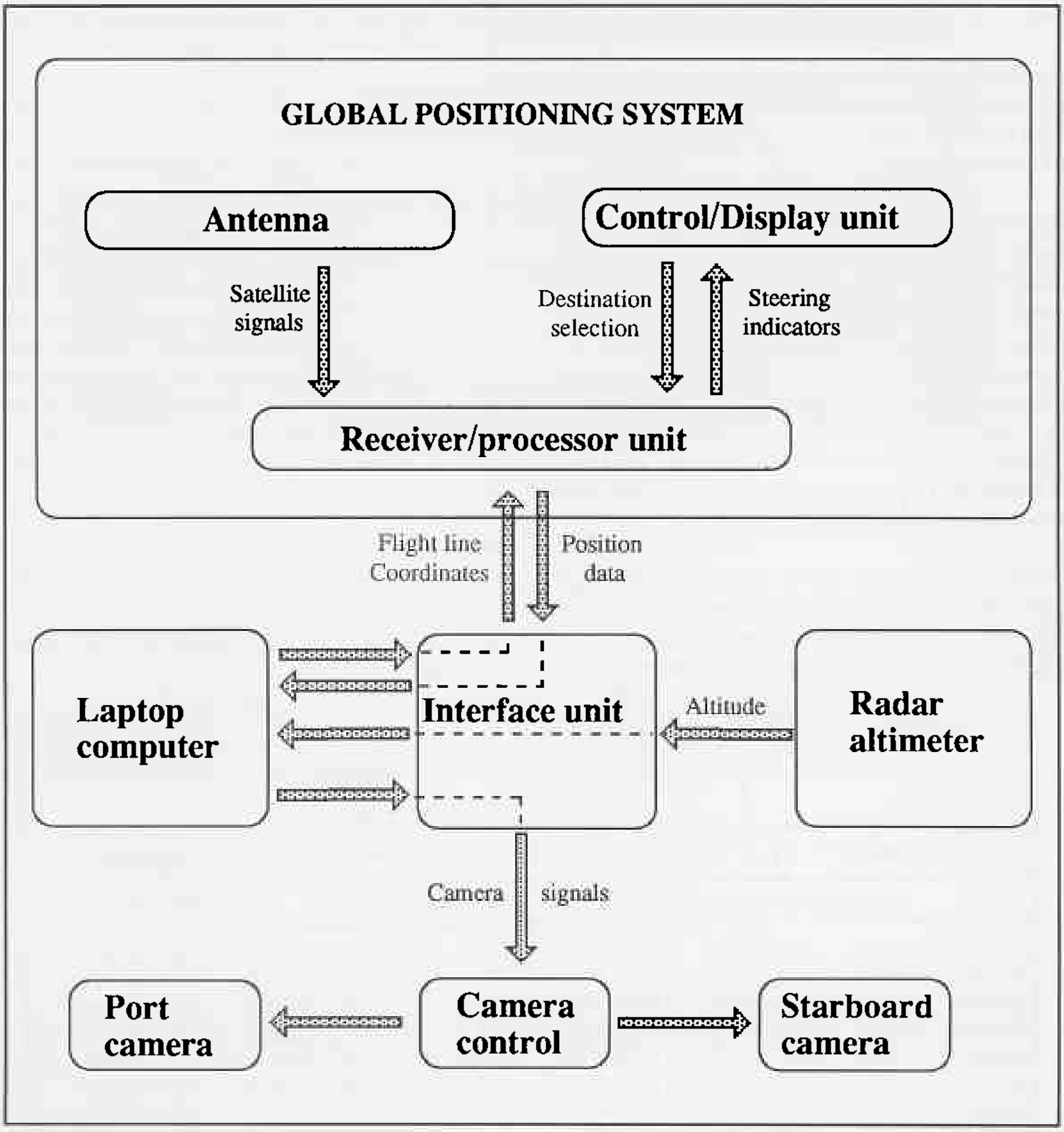


Figure 16
Components of integrated navigation, camera-control, and flight recording system.

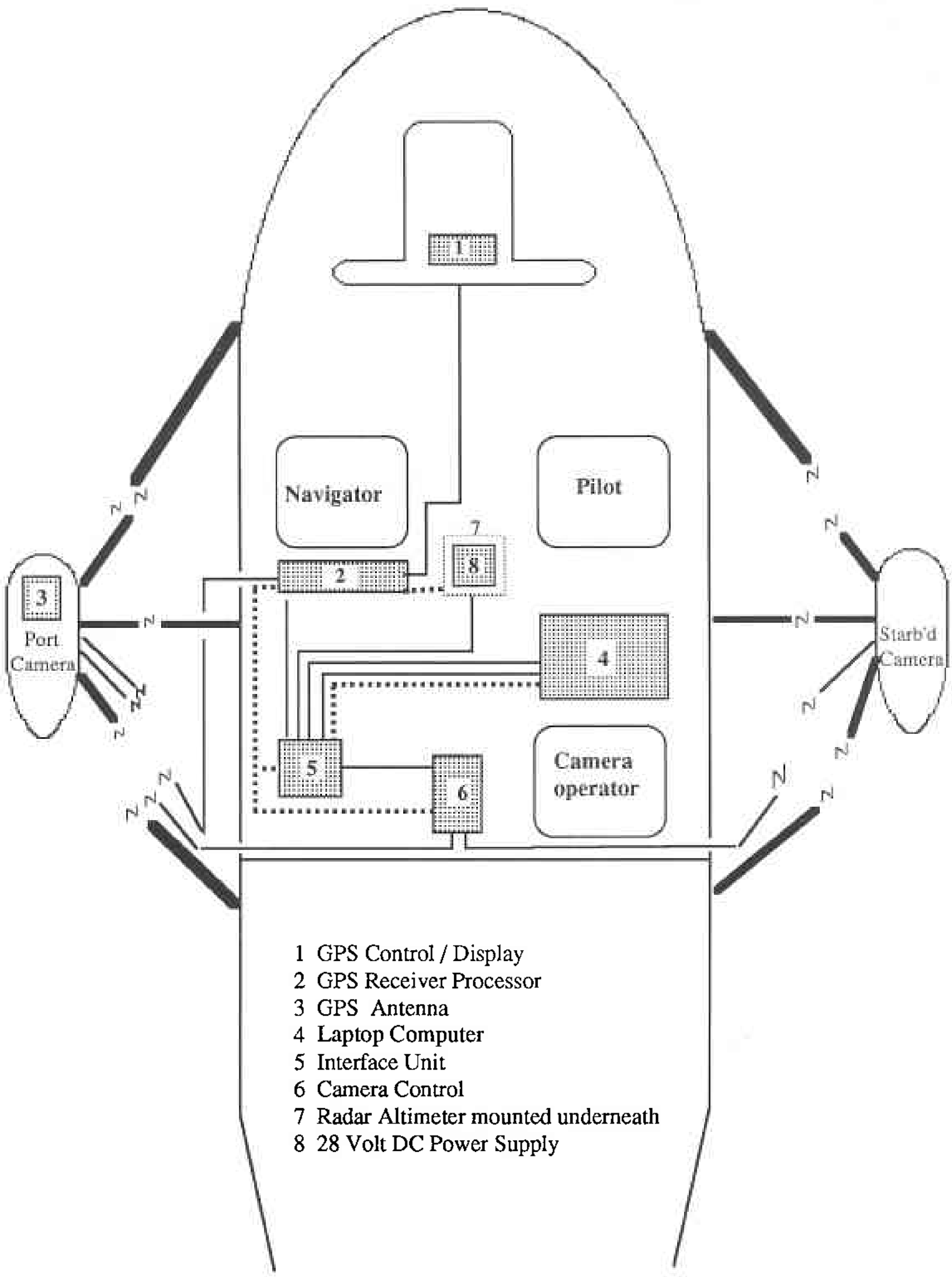


Figure 17
Layout of navigation system components.

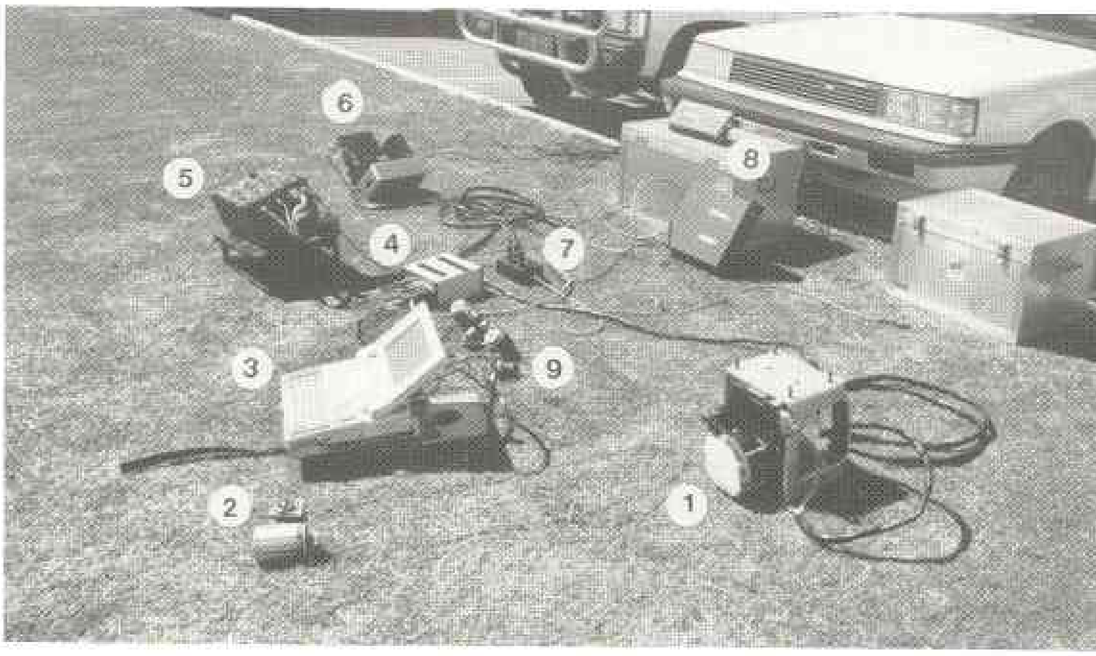


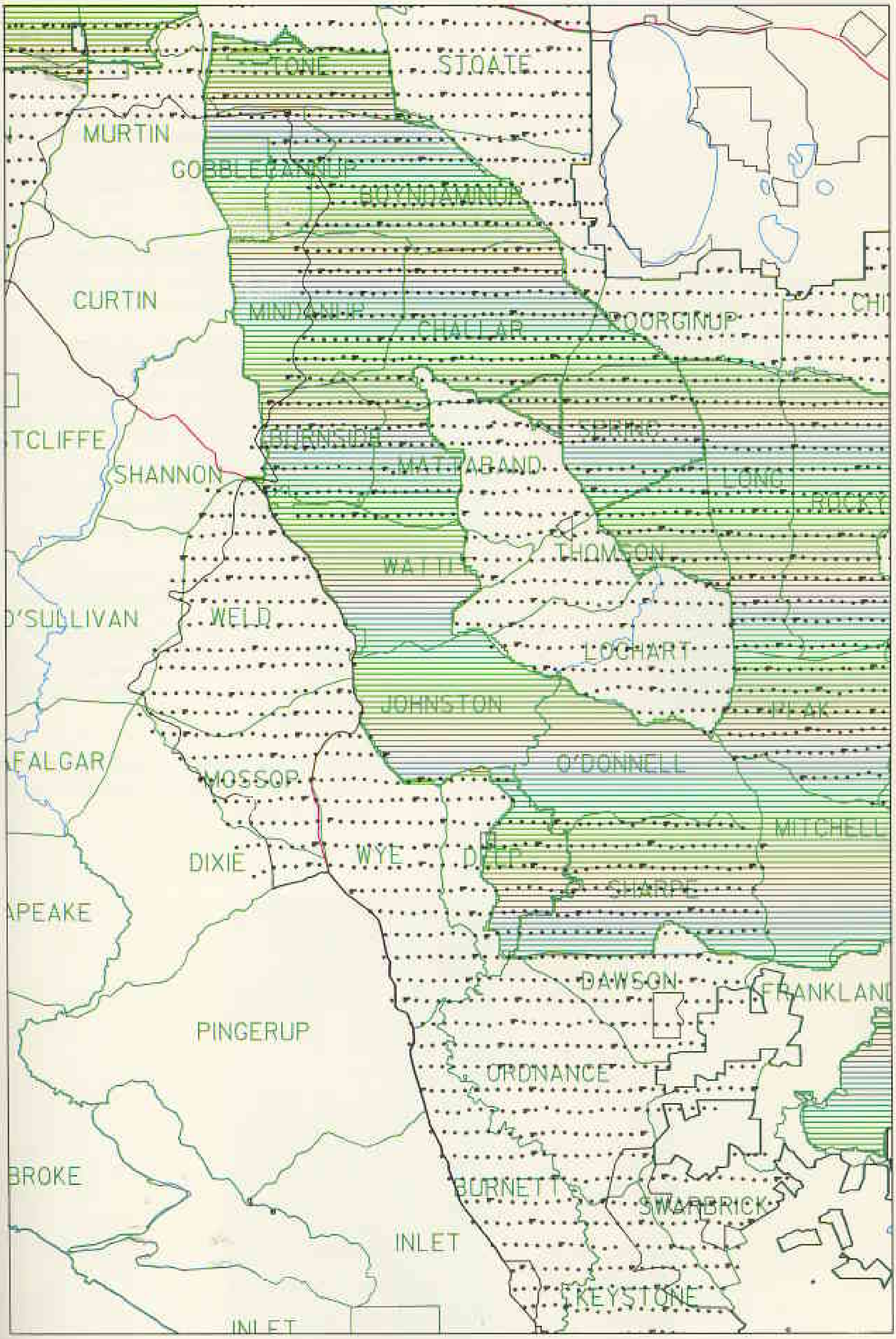
Figure 18

Major components of the navigational and camera systems.

1. Starboard camera
2. Light meter
3. Laptop computer
4. Interface unit
5. Camera control
6. Port camera
7. Power distribution board
8. GPS receiver (below) and control-display unit (above)
9. Tracking camera

Figure 20

Sample pair of stereoscopic photographs.



Key: •••••• Photolocations   Disease Risk Area

Figure 19

Example of photo-location map from ARC/INFO Geographic Information System based on positional data from the Global Positioning System as recorded by the on-board computer.

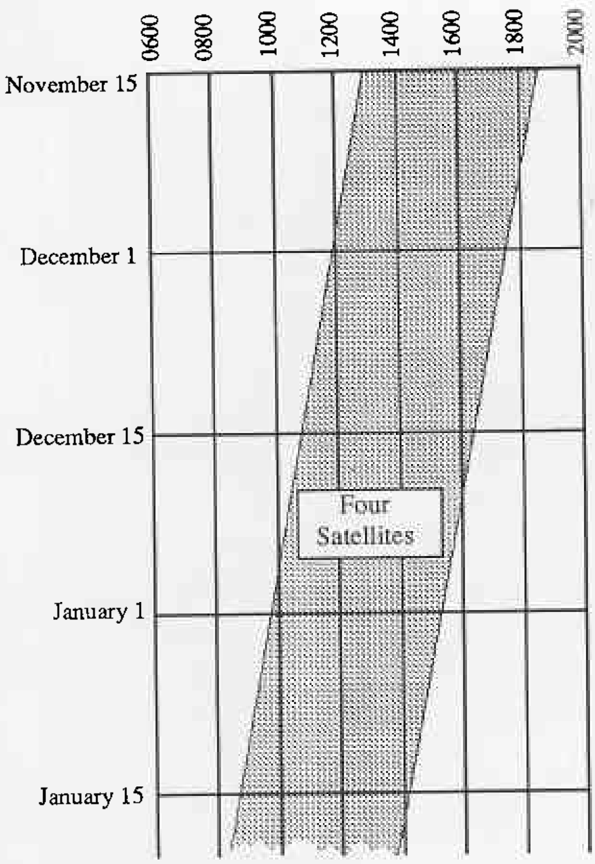


Figure 21

Global Positioning System. Time of the day when four satellites were available for accurate positioning - November 1988 to January 1989.

annotated by reference to the log book and location maps before individual frames are cut from each roll for storage as stereopairs in plastic vertical file pockets ready for interpretation. For security they are stored in a fireproof safe (Fig. 22).

3.4 Flight-line mapping and plot location

The locations of each photo-point are recorded as co-ordinates on the laptop computer. These data are later transferred to the Department's VAX mainframe computer system where they are processed into the GIS. By displaying photo-location data with the planned flight path data, it is possible to make a visual assessment of the success of the photographic coverage. In the display, graphic symbols define each photo-location, with frame numbers being displayed against every tenth location (Fig. 19).

Photo locational maps are then prepared for ground navigation and administration purposes, as follows :

(i) where 1:25 000 digital mapping coverage is available, computer plots are generated consisting of specified base themes together with photo point information;

(ii) a plot on clear film is generated together with a 1:25 000 map sheet layout (graticule) and map number for referencing.

Figure 22

Photo security involving storage in vertical file in a fire-proof safe.

Using an ammonia-based dyeline process, this overlay is positioned on the Department's appropriate 1:25 000 Australian Map Grid map sheet and a diazo film copy is produced. Owing to the roller process of this method, a linear stretch between the medium is evident and is compensated by allowing over registration at the beginning equivalent to half the calculated total stretch. An alternative method is to use a flat vacuum frame technique, with arc lights, to eliminate stretching.

Plot locational maps are also produced at 1:50 000 and 1:250 000 scale with land tenure information depicting the production and conservation areas, freehold lands and other non-Department lands for administration and planning use.

The reliability of the mapped photo locations depends on the accuracy of the GPS receiver (± 25 m), errors in the base map (± 25 m at 1: 25 000) and the registration of the two by paper overlay (up to 50 m errors). A further source of error can result from photographic tip and tilt.

Plots are located in the field by simple survey using a hip-chain and compass. The distances and bearings to plot locations are scaled off the 1:25 000 location maps (Fig. 23) using identifiable features such as track intersections, and reference tree as reference points. This introduces another source of error of uncertain magnitude. Plots are usually less than 1000 m from a track, although some plots are several kilometres from an access road, especially in areas of restricted access because of disease risk regulations. Such surveys are therefore prone to errors of variable magnitude but are probably within 25 m. As a result, very few of the photo plots are found exactly where expected.

Experience shows that half of the plots are found within 50 m of the expected position, with 90 per cent being within 100 m (Fig. 24). This is sufficient to find the general vicinity of each plot, with the exact plot centres being located from tree to tree navigation on the large-scale photos (Fig. 25). The remaining 10 per cent of plots can be up to 300 m out of position and difficult to find. Many of these problems are caused by errors in the GPS, resulting from photographs being taken during periods of the day when the satellite constellation is incomplete. These times should be avoided.

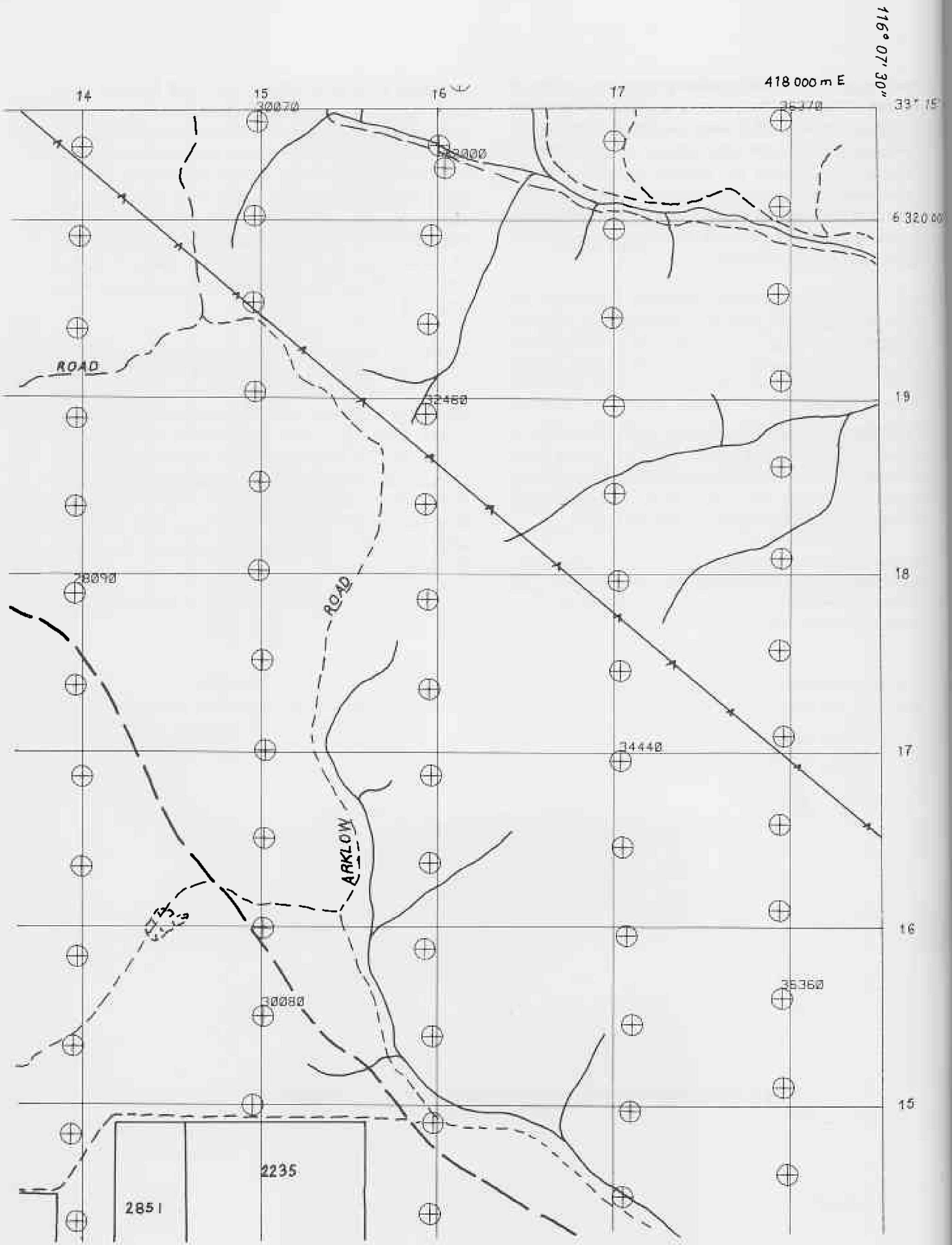


Figure 23
Sample Geographic Information System output of photo-locations at 1:25 000 scale as used for field navigation to ground plots.

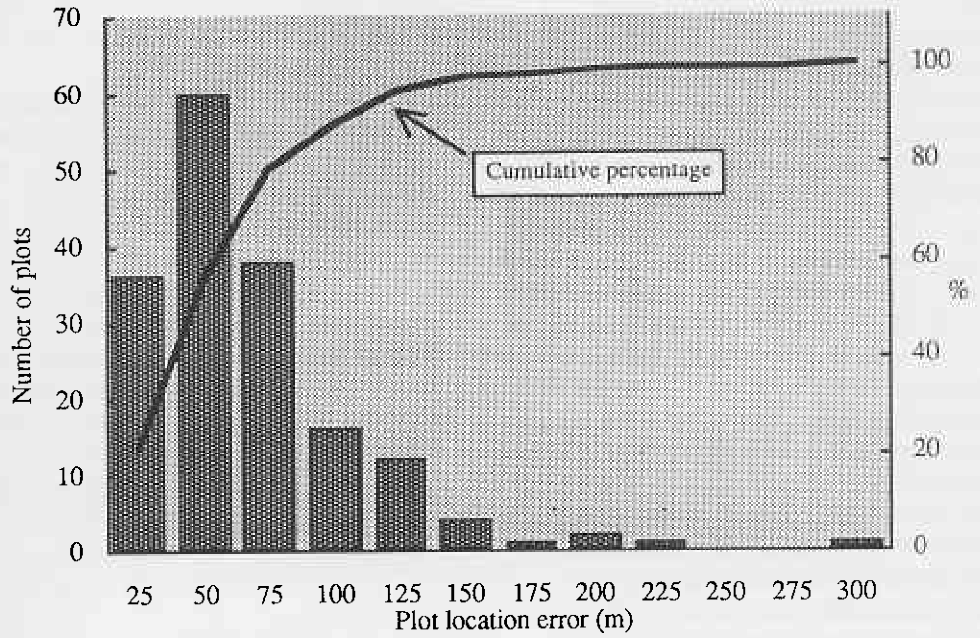


Figure 24

Ground plot location error. Frequency distribution and cumulative frequency percentage of plot location errors (m) for a sample of plots.

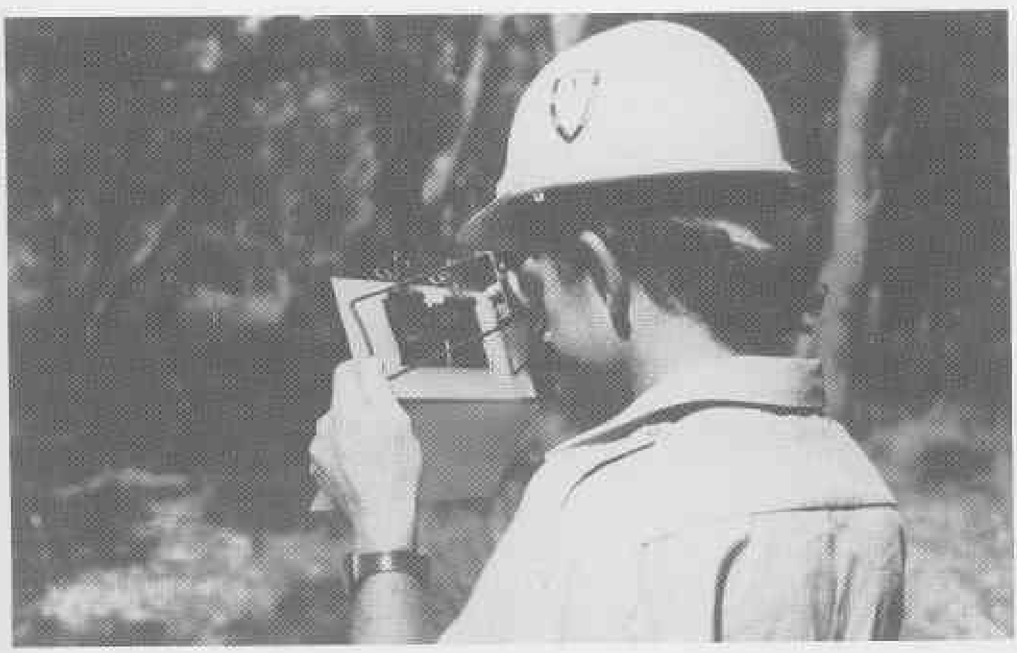


Figure 25

Ground plot location. Ground plots were located using the photos viewed on a portable light board, to identify features and navigate to the plot centres.