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An Evaluation of Low-cost Digital Photogrammetry and GIS in a Landfill Site Selection Process

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DECLARATION

I hereby declare that this thesis represents my own work and that where the work of others has been used it has been duly accredited.

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June 1998

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ABSTRACT

Many earlier solid waste management studies and environmental studies carried out in Malaysia have indicated the need for better management of solid waste, especially in terms of locating new waste disposal sites. As a consequence of improper site selection in the past, most of the existing waste disposal sites within the region are unsuitably located, causing considerable environmental and social problems. Some previous studies have proposed a stage-by-stage procedure for site selection. The main problems of implementing such proposals are the diversity of data required and the lack of existing data to make effective decision making.

This study investigates the role of spatial data collection technologies such as digital photogrammetry, satellite remote sensing and Geographic Information System (GIS) technology in the management of solid waste in Malaysia with particular emphasis on locating new waste disposal sites. The study emphasises on the use of low cost spatial data collection methods to update digital data needed in the waste disposal site selection process. The proposed low cost method of data acquisition includes the use of cheap A4 format desktop publishing scanners (DTP) and the Desktop Mapping System (DMS) version 3.1, which is a PC-based digital photogrammetric system (DPS). DTP scanners are used to convert hardcopy aerial photographs into the digital format required in DPS. Satellite remote sensing imagery has been used as a backdrop for on-screen digitising to update maps for large geographical areas. The ARC/INFO version 6.1 GIS software has been employed as the data capture, data integration, data visualisation and data analysis tool.

A series of tests have been carried out to assess the geometric accuracy of four different types of DTP scanners and the geometric accuracy of digital photogrammetric products, that is, automatically generated digital elevation models (DEM) and ortho-images. Results from accuracy assessment of DTP scanners have indicated that, while the distortion errors introduced by scanner imperfection are significant, they can be minimised using proper calibration procedures. Results for

accuracy assessment have further indicated that high quality DEMs and ortho-images can be produced with a low cost DPS provided high quality aerial photo images and ground control points are available.

The Petaling District in the Klang Valley Region has been used as the study area to demonstrate the role of digital photogrammetry, satellite remote sensing and GIS in the stage-by-stage site selection process for solid waste in Malaysia.

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ABBREVIATIONS AND ACRONYMS

ABC	=	Action Plan for a Beautiful and Clean Malaysia
CCDs	=	Charge Couple Diodes
CEC	=	Cation Exchange Capacity
DEM	=	Digital Elevation Model
DIB	=	Device-Independent Bitmap format
DMS	=	Desktop Mapping System
DoE	=	Department of Environment
DOS	=	Disk Operation System
DPS	=	Digital Photogrammetric System
DPW	=	Digital Photogrammetric Workstation
DTP	=	Desktop Publishing
DVP	=	Digital Video Plotter
EPD	=	Environment Protection Department
EIA	=	Environmental Impact Assessment
EIA	=	Environmental Impact Analysis
EIS	=	Environmental Impact Statement
EMSD	=	Electrical and Mechanical Services Department
EPA	=	Environmental Protection Agency
EPS	=	Encapsulated Postscript file format
EC	=	European Community
GCPs	=	Ground Control Points
GIS	=	Geographical Information System
GPS	=	Global Positioning System
HP	=	Hewlett-Packard
JICA	=	Japanese International Co-operation Agency
KVEIP	=	Klang Valley Environmental Improvement Project
MACRES	=	Malaysian Centre for Remote Sensing
MRSO	=	Malayan Rectified Skew Orthomorphic projection
MRT	=	Malaysian Revised Triangulation
MSL	=	Mean Sea Level
NGO	=	Non-governmental organisation
PC	=	Personal Computer
RAW	=	Raw file format
RDBI	=	Relational Database Interface
SEDC	=	State Economic Development Co-operation
SEPU	=	State Economic Planning Unit
SWM	=	Solid Waste Management
TIFF	=	Tagged Interchange File Format
TIN	=	Triangulated Irregular Network
TM	=	Thematic Mapper
UK	=	United Kingdom
USA	=	United States of America

CHAPTER 1

INTRODUCTION: THE CASE FOR USING LOW-COST DIGITAL DATA ACQUISITION TECHNOLOGIES AND GEOGRAPHICAL INFORMATION SYSTEM

1.1 Overall aim of the research

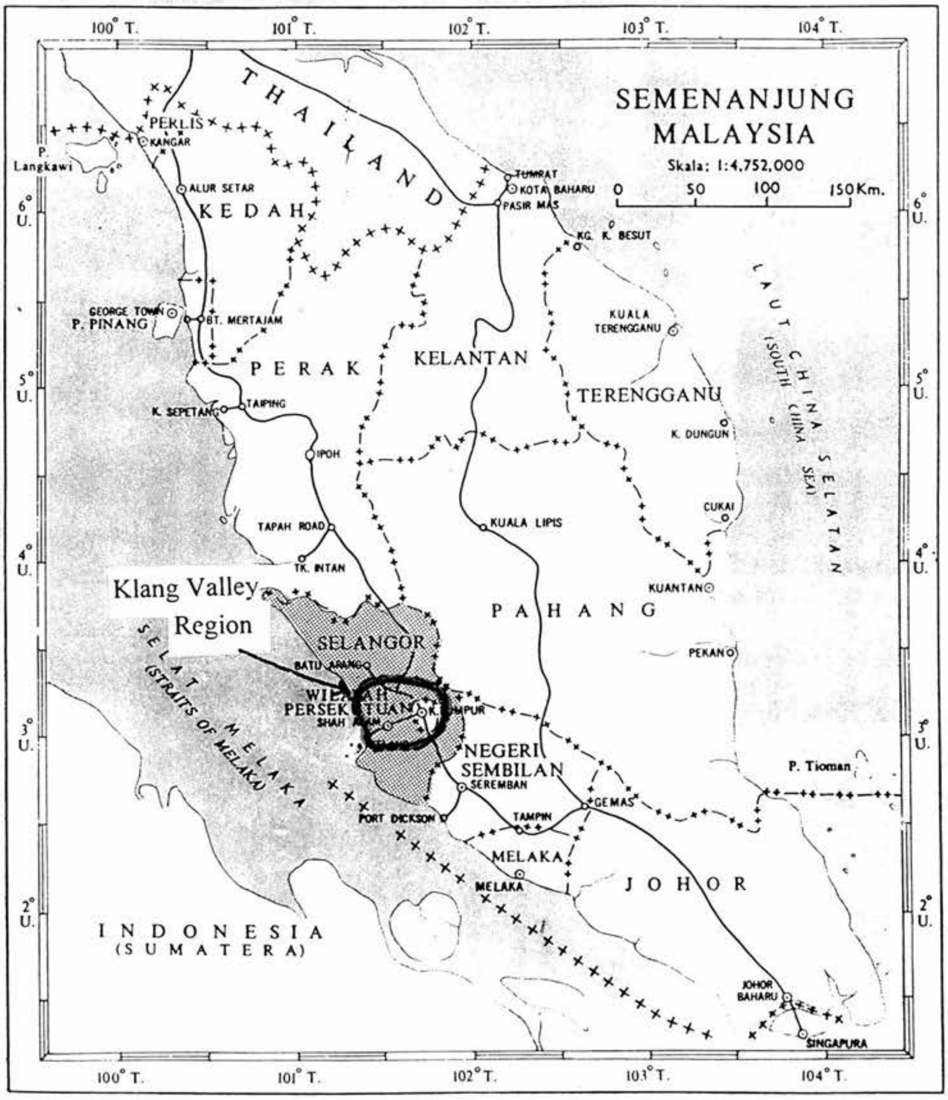
This study concerns the use of particular technologies and of Geographical Information System (GIS) as tools to aid effective planning and decision making in the context of a Developing Country such as Malaysia. As in other Developing Countries, the main problems of using GIS within small organisations such as local authorities and planning authorities in Malaysia are associated with the availability of data, the availability of skilled personnel and the constraints of budgets. Low-cost digital data acquisition methods, which include the use of low-cost scanners and a low-cost digital photogrammetric workstation (DPW), are proposed for generating some of the necessary data. Before such methods can be utilised, it is necessary to confirm that they are suitable for generating the required digital data accurately, quickly and without the need for highly skilled personnel. The process of locating new landfill sites within the Petaling District in the Klang Valley Region, Malaysia, was used to demonstrate the role of these technologies. The overall aim is to analyse and demonstrate the feasibility of using low-cost data acquisition technologies, such as desktop scanners and digital photogrammetric systems as well as GIS, to aid effective planning and decision making particularly in locating new landfill sites.

1.2 Background

In the last decades of the twentieth century, Malaysia has experienced unprecedented economic development, which has involved a large population increase, industrial growth, intensification of pressure on land uses and the development of communication and other service infrastructures. This economic growth has been accompanied by technological development but also by serious environmental problems including the management of waste materials, as regional and local structure plans have proved inadequate to deal with changing circumstances. In Malaysia, environmental problems have been most severe in the Klang Valley Region. Figure 1.1 shows the location of the Klang Valley Region in the context of Peninsular Malaysia.

Earlier environmental studies (Engineering Science Inc., SEATEC International and the Department of Environment, 1987; Ministry of Housing and Local Government, 1988) and waste management studies (Engineering and Environmental Consultant Ltd., 1991; Japan International Corporation Agency, 1989a) carried out in Malaysia both by internal Malaysian departments and by overseas consultants over many years have identified that one of the most serious environmental problems, needing immediate attention, concerns the disposal of solid waste, either industrial or municipal waste, some of which must inevitably be disposed of by landfilling. Whereas solid waste may be disposed of by other methods including incineration and composting, as is the case also in many economically developed countries, much solid waste must evidently be disposed of into landfill sites. The selection of these sites is of great consequence. The wide-ranging recommendations made in the studies listed above to improve the current problems of solid waste disposal include: i) a different approach involving the use of a regional site or sites rather than a local site or sites, and ii) the use of a stage-by-stage approach for locating new sites.

It was also generally felt that the local approach for locating new landfill sites can no longer be considered as a viable solution because of the decreasing land areas available within developed local authorities and therefore that a regional approach was necessary. The stage-by-stage approach using suitable siting criteria for locating new landfill sites can help decision makers and planners in the region to eliminate unsuitable areas systematically and later select the best possible alternative site or sites for further consideration. The only attempt to implement the regional and stage-by-stage approaches in Malaysia so far has been made by the Pulau Pinang and Seberang Perai Municipality.



(Source: 1:4,752,000 scale map of Peninsular Malaysia, 1984)

Figure 1.1 Location of the Klang Valley Region in the context of Peninsular Malaysia.

As outlined in the Solid Waste Management Study for the Pulau Pinang and Seberang Perai Municipality carried out by the Japanese International Corporation (JICA, 1989a), a manual method of overlaying different types of maps was used to locate new landfill sites. This method can be time consuming and to certain extent can be considered as an impossible task due to the diversity of data required and to the different theme maps required for analysis at different scales. If a proper procedure for locating new landfill sites is to be introduced in Malaysia, alternative methods to integrate and analyse data effectively from maps at various scales and from different data sources have to be explored.

One approach particularly well suited to the management of diverse data sets is the use of a Geographical Information System (GIS). GIS has been widely recognised as a tool which can store, manage, manipulate and present data effectively as well as analyse the spatial and non-spatial data required in the site selection process. With its inherent capability to store, manage, manipulate and present spatial data, GIS technology is increasingly preferred in many applications such as street network applications, natural resource applications, facility management and land parcel applications. Many authors have commented on the nature and the role of GIS, of which only one is quoted here: according to Seetharam (1992a) the role of GIS can be classified into five categories: i) GIS as an intelligent database, integrating maps and tabular records containing information on each feature on the map, ii) GIS as a powerful spatial analysis tool, capable of performing polygon overlays, proximity analysis such as point-in-polygon analysis and network analysis such as shortest path estimation, iii) GIS as a powerful tool for modelling spatial information, iv) GIS as a visualisation tool and v) GIS as a system integration tool.

Petts and Eduljee (1994) and Green (1996) have suggested that GIS has great potential as a tool to aid the management of waste disposal and treatment sites, starting with site selection and continuing through to the monitoring of sites and land in the vicinity. Many earlier studies (Lane and McDonald, 1983; Smith and Robinson, 1983; Jensen and Christiensan, 1986; Zee and Lee, 1989; Richason and Johnson, 1990; Bagheri and Dios, 1990; Weber and Ware, 1990; Siderelis, 1991; Carver, 1991;

Carver and Openshaw, 1992) have demonstrated the potential use of GIS in the site selection process. Green (1996) has suggested that GIS can be used in waste management starting from the site investigation stage of a landfill site, through the site development and filling and then during its post closure.

The availability of computer hardware and software is not in itself an obstacle for the use of GIS as an analysis tool to assist decision making in Malaysia. According to Samik (1985), the first GIS was installed in Malaysia in 1984 in the Department of Agriculture which is located in Kuala Lumpur. Since then many other government organisations such as the Department of Environment, the Klang Valley Planning Unit, the Malaysian Centre of Remote Sensing (MACRES), the Forestry Department, the Geology Department, the Agriculture Department, the Shah Alam Municipality, the Petaling Jaya Municipality and the Kuala Lumpur City Council have installed GISs. As reported in Ramly (1995), there were more than 100 GIS installation sites in Peninsular Malaysia. Although GIS has been widely accepted in many government organisations, their current applications are mainly limited to automated mapping and inventory tasks which should strictly be considered as component parts of GIS, rather than the complete system.

However an obstacle to the use of GIS as an analysis tool in Malaysia either for mapping or a complete analysis is the lack of appropriate digital map data, unlike the situation in more developed countries such as the UK and the USA. According to Yaakup (1991), the main problems of implementing a GIS project in Malaysia were the lack of appropriate map data, obsolescence of map information, secrecy of information and poor maintenance of record keeping. Although steps are being taken by the Department of Survey and Mapping, Malaysia through the implementation of three digital mapping programmes (i.e. Computer Assisted Mapping System-CAMS, Computer Assisted Land Survey System-CALS, Fast Mapping System-FMS) to produce maps in digital format, the area coverage is still very limited. In Malaysia, vector line digitising of existing maps or plans has been widely accepted as the main method of acquiring digital data for a GIS. Only in large government organisations such as the Department of Agriculture, the Department of Environment and the Forestry Department is digital image processing of satellite data utilised.

In all land management and planning applications numerous spatial and non-spatial data sets of different themes and scales are required. For locating new landfill sites, maps at different map scales are required, including: i) small to medium scale maps (ranging from 1:250,000 to 1:50,000) for general site selection (at regional level) ii) medium to large scale maps (ranging from 1:10,000 to 1:5,000) to evaluate the suitability of alternative sites based on social, economic and environmental points of view, and iii) plans at the largest possible scale usually 1:1,000 scale for detailed site evaluation and site management (engineering applications). Since the national mapping programme conducted by the Department of Survey and Mapping, Malaysia, concentrates on producing topographic maps at three major scales only, that is, 1:50,000, 1:25,000 and 1:10,000 scale for town areas, the only short-term solutions for local authorities or planning authorities are to update existing maps or generate new maps in-house.

It follows that, if GIS is to be used, alternative cheap and easy methods of data acquisition have to be explored to enable local authorities or planning authorities to produce their own maps or update existing maps. One such technology which allows rapid acquisition of up-to-date map information is photogrammetry. Photogrammetry has been recognised as an important method of map updating especially for medium to large-scale mapping. The main problems with manual photogrammetric methods are the need for skilled photogrammetrists and large capital investment. Recent developments in computers and sensor/scanner technology have increased the capabilities and reduced the cost of digital components. These developments have significantly transformed photogrammetry from a purely analogue to an analytical and later to a fully digital method. Digital photogrammetry and satellite remote sensing technologies have provided new possibilities of acquiring data quickly, easily, cheaply, effectively and without the need of skilled personnel. An important criterion to differentiate digital photogrammetry from analogue or analytical photogrammetry is that the input to the system is in digital format.

DPW is an integral part of a complete Digital Photogrammetric System (DPS). DPW has been widely accepted as capable of speeding-up important photogrammetric tasks and generating new products. Currently there are many types of DPWs available in the market, with different functions, capabilities and prices. High-end DPWs such as the Helava 750/770, Intergraph IMD and Zeiss PHODIS ST mostly run on UNIX operating system and are very expensive. The more affordable DPWs such as the Digital Video Plotter (DVP) and Desktop Mapping System (DMS) are based on PCs and run on DOS and/or Windows operating systems.

Automatically or semi-automatically generated Digital Elevation Model (DEM) and orthoimage are the two main products of DPW. The integration of these digital photogrammetric products in GIS provide great advantages in comparison to their analogue counterparts, especially with respect to flexibility, production of derived products and combination with other data sets (Baltsavias, 1994c). Many authors (Trope, 1989; Dall, 1990; Skalet *et al.*, 1992; Steiner, 1992; Han, 1993; Manzer, 1993a; Dams and Larsson, 1993; Baltsavias, 1994c; Tanner, 1994; Dams and Larsson, 1993; Nale, 1995; Baltsavias, 1996) have identified the potential of orthoimages as a powerful tool for extracting spatial and non-spatial information. In the context of landfill studies high-resolution DEMs taken at different dates can be used to monitor volume change due to subsidence and/or additional filling at an existing landfill (Vincent, 1994). Besides that, a DEM can also be used as an input to a surface run-off model. Other potential applications are: i) to combine a DEM and orthoimage mosaic in perspective views of the potential landfill site, and ii) to use a DEM as input to estimate the capacity of the potential sites. Perspective views could be useful to planners or decision-makers to visualise the true appearance of a proposed waste disposal site.

A DPW requires data in digital format. Scanned aerial images, stereo SPOT satellite imagery, digital camera images and imagery from new high resolution satellites (e.g. EarlyBird, QuickBird and OrbView) can be used as input to DPW from which digital photogrammetric products such as Digital Elevation Models (DEMs) and orthoimages or orthoimage mosaics can be automatically or semi-automatically generated.

Although there have been enormous developments in the technology relating to direct digital acquisition, such as digital aerial cameras, small-format digital cameras and video cameras, they are not expected to replace the film-based systems technology for aerial photogrammetry in the near future due to the inferior spatial resolution of these cameras. For this reason high quality scanners are still required to convert hardcopy aerial photographs to digital format. Currently there are many types of scanners available in the market that could be used to scan aerial photographs. Although photogrammetric scanners are purposely built for photogrammetric applications, which are characterised by high geometric and radiometric accuracy, their price is quite high. On the other hand, Desktop Publishing (DTP) scanners are cheap general-purpose scanners for converting hardcopy drawings or photographs into digital format. These types of scanners can either be in A3 or A4 format size.

With proper geometric and radiometric calibration procedures some of the available A3 format DTP scanners can be used for photogrammetric applications (Gagnon and Agnard, 1992; Sarjakoski, 1992; Finch and Miller, 1994; Baltsavias, 1994b). Although some of these scanners have the potential to be used to scan aerial photographs the price of acquiring A3 scanners is still high for small government organisations. A4 format scanners are the cheapest, and seem to be a feasible alternative to these organisations. The price of a typical A4 format DTP scanner with an optical resolution of 600 dots per inch (dpi) is less than £1000.

Carstensen and Campbell (1991) have argued that, although these scanners are not designed for photogrammetric applications, they have greater potential than their manufacturers suggest. These scanners have excellent spatial resolution and a relatively low, though adequate and improving, radiometric resolution. According to Baltsavias (1994a), some of their components like sensor, electronics, computer platform, software and characteristics like radiometric performance and speed are equivalent or better than those of expensive photogrammetric scanners. The main problem with DTP scanners as identified in R-Wel Inc., (1992), Baltsavias (1994b) and Baltsavias (1996) is not resolution, but the insufficient geometric accuracy caused by the mechanical instabilities, large lens distortions or imperfection of other mechanical parts such as mirrors and filters.

Many earlier studies on the accuracy of scanners concentrate only on photogrammetric scanners (e.g. Bethel, 1993 and Bethel, 1994) or A3 format DTP scanners (e.g. Baltsavias, 1994b, Baltsavias, 1996). Although there are a few earlier studies on A4 format scanners (e.g. Bosma *et al.*, 1989 and Carstensen and Campbell, 1992) most have dealt only with the suitability of using A4 format DTP scanners for scanning line maps rather than for photogrammetric application. Since the introduction of digital photogrammetry, studies on scanners have begun to assess the suitability of flatbed scanners to scan aerial photographs. All previous studies on scanners investigated the radiometric and geometric accuracy of photogrammetric or A3 format DTP scanners not A4 scanners.

1.3 Definition of research problem

If a regional stage-by-stage approach of locating new landfill sites is to be implemented, better tools are needed to manage the diverse data sets effectively. As most of the up-to-date data required for effective decision making is not available, new data sets have to be generated. For local authorities or planning authorities, which are not responsible for any mapping or map making task, this is not an easy solution as map-making requires high capital investment in terms of the hardware/software and skilled manpower which is not readily available in the local authorities or planning authorities.

It is proposed that low-cost A4 format DTP scanners can be used to convert hardcopy aerial photographs into digital format as required in a DPW. Outputs from a low-cost digital photogrammetric system may be used to provide some of the necessary up-to-date data required in the process of locating new landfill sites. It was also felt that GIS technology can effectively be used as tools to integrate diverse data sets from different sources to aid decision making. As there were no earlier comprehensive studies on the geometric accuracy of low-cost scanners and low-cost DPW a detailed assessment of these technologies is required.

Assessment of A4 format DTP scanners would allow potential users to address the following questions:

- What are the pattern and magnitude of distortion of images scanned in A4 format DTP scanners?
- Can image distortions be minimised, and if they can, in what way?
- Can mathematical formulae be used to model and rectify distortions of images scanned in A4 format DTP scanners?
- What are the optimum number and arrangement of the image control points (points used to transform image coordinates to correct for image distortion) required to rectify image distortions?
- How repeatable are scanner measurements over time?

Assessment of digital photogrammetric products generated for a low-cost DPW using low-cost scanners would further address the following questions:

- What are the effect of scanning resolution and the effect of ground control point (GCP) accuracy on the digital photogrammetric stereomodel set-up?
- What is the planimetric accuracy of measurement from stereoimages?
- What is the accuracy of automatically generated height points?
- What is the accuracy of an automatically generated orthoimage?

Simply stated, the specific research problem is:

Can the use of low-cost scanning and low-cost digital photogrammetric technologies help in the production of the high-accuracy spatial digital data required for a GIS and can their integration with GIS be a practical possibility to aid planning and decision making, particularly in the specific context of locating new landfill sites in the Klang Valley Region, Malaysia?

1.4 Hypotheses

1. Desktop scanners can be used as a substitute for photogrammetric scanners.
2. Low-cost scanning and digital photogrammetric technology can be used to produce high quality digital output such as the DEMs and orthoimages required in the site selection process.
3. GIS can be used effectively to integrate, manage and analyse data from various sources including digital photogrammetry needed in the landfill site selection process.
4. The use of GIS can improve the quality of decision making particularly in locating new landfill sites.

1.5 Objectives of the research

Based on the above problem statement and hypotheses, the principal research objectives may be detailed as follows:

1. to review the existing practices and problems of solid waste management particularly related to landfill site selection, data (requirements and availability) and the current use of modern data acquisition techniques and GIS in Malaysia as a framework for evaluating the roles of digital photogrammetry and GIS as tools to aid effective planning and decision making;
2. to evaluate the suitability of using low-cost A4 format DTP scanners as a substitute for expensive photogrammetric scanners to scan aerial photographs;
3. to evaluate the suitability of using a low-cost PC-based digital photogrammetric system to generate digital photogrammetric products such as digital elevation models (DEMs) and orthoimages;
4. to develop a methodology for integrating digitised vector data, remote sensing data and digital photogrammetric data with GIS and hence demonstrate how this integration can help in the process of locating new landfill sites.

1.6 General methodology

This section is intended to give a brief outline of the methodology adopted for this study. A more detailed methodology for each of the objectives is given in other chapters.

To achieve research objective 1 a field study was carried out. The field study involved three major tasks, i) collecting and evaluating previous reports such as environmental studies, environmental guidelines and solid waste management studies; ii) informal discussion with officers from various organisations who were directly or indirectly involved in the management of solid waste and data collection; and iii) visiting existing waste disposal sites. In addition, various data sets such as maps, aerial photographs and satellite digital data of the study area were acquired. Informal discussion with officers from various government organisations regarding the use of GIS and other mapping technologies was also carried out in Malaysia during leave of absence from September to November 1994.

As this study proposed the use of low-cost scanning technology, an assessment of only low-cost A4 format DTP scanners was carried out. The choice of scanners to be tested was based strictly on their availability within the University of Edinburgh. Assessment of these scanners was not only intended to assess their geometric accuracy but also to test the suitability of the proposed image calibration method.

In the suitability assessment of digital photogrammetric products, a low-cost PC-based DPW was used. Aerial images were scanned in different scanners including the photogrammetric scanner and DTP scanners. Measurements from two different test sites were used to assess the geometric accuracy of digital photogrammetric products. One test site was located in Edinburgh, Scotland, while the other was located in the Petaling District, Malaysia. Accuracy assessments of digital photogrammetric products were made by comparing results obtained from the DPW and the AP190 analytical plotter. The measurements from the AP190 analytical plotter were assumed to be error-free and were considered as the standard for assessing the accuracy of the generated digital products.

The process of locating new landfill sites within the Petaling District, Klang Valley Region, Malaysia, was used to demonstrate how GIS and digital photogrammetry could be used conjointly as tools to aid effective planning and decision making especially in the context of a Developing Country. Several steps were followed, starting with the formulation of the site selection criteria followed by the identification of the required and available data sets, the construction of spatial and non-spatial databases and finally the evaluation of potential landfill areas. The ARC/INFO version 6.1 software was used to integrate, analyse and present the final results. The methodology presented in this thesis is not intended to be an exact model to be applied in all landfill site selection but rather as an indication how low-cost digital photogrammetry and GIS could typically be used by local authorities in Malaysia to assist a variety of land management problems.

1.7 Organisation of thesis

The thesis is presented in eight chapters.

Chapter 1 sets out the background and the rationale for the research project, develops a statement of the problem, and later identifies the hypotheses and research objectives. The general methodology adopted in this study is given in the following section. In the final section a brief outline of the organisation of the thesis is given.

Chapter 2 starts by outlining the status and problems associated with solid waste management in Malaysia. Specific discussion on the problems associated with waste management in the Klang Valley Region is given emphasis. The later section describes the methods of landfill site selection and the criteria used to determine suitable landfill sites used in different countries and in Malaysia. Discussion on the issues related to data and technology will also be given.

Chapter 3 reviews in the basics of digital photogrammetric technology, image scanner technology, and GIS. A review on previous studies on the accuracy of digital photogrammetric products and image scanners is also given.

Chapter 4 starts by discussing the current and potential applications of data acquisition technologies such as photogrammetry, satellite remote sensing and GIS in the management of waste. The following sections describe the proposed strategy of data collection and data analysis for locating new landfill sites in Malaysia and the proposed GIS and low-cost digital photogrammetric software to be used in this study.

Chapter 5 describes the methodology for geometric accuracy assessment of various A4 format DTP scanners. Results of various tests carried out to assess the suitability of four different types of DTP scanners, that is, HP Scanjet IIc, HP Scanjet 4c, Epson GT-9000 and Apple Colour One scanners, are also presented.

Chapter 6 discusses a series of tests carried out to determine the accuracy of digital products generated from a PC-based digital photogrammetric system, that is, the Desktop Mapping System (DMS). The results obtained from two different test sites are given.

Chapter 7 describes and demonstrates the methodology for integrating GIS and digital photogrammetry in the landfill site selection process. The chapter starts by describing the study area, that is, the Petaling District, and later the steps involved in the landfill site selection process. The following sections describe the site selection criteria and the available data sets to be used. Steps involved in the database construction are also given. The detailed steps involved and results obtained in the preliminary and further site-specific evaluation are given in the following sections. A summary and conclusions are given in the final section.

Chapter 8 summarises the main findings and conclusions of the study and identifies areas for further improvement. This thesis ends with a general discussion of the potential of the methodology for application in Malaysia.

CHAPTER 2

LANDFILL SITE SELECTION: CURRENT PRACTICE AND ISSUES RELATED TO THE USE OF SPATIAL DATA ACQUISITION AND DATA ANALYSIS TECHNOLOGIES IN MALAYSIA

2.1 Introduction

One of the land management issues that need immediate attention in Malaysia is the issue of locating new landfill sites. The selection of appropriate technology to be used (especially in the context of a Developing Country) to locate and manage landfills requires an understanding on the current practice of solid waste management, data requirement and the current level of usage of the appropriate technologies.

This chapter reviews and discusses the issues that provide the context for this study. The discussion concentrates on five main issues, that is, issues related to solid waste management in Malaysia with particular emphasis on the Klang Valley Region, issues related to the landfill site selection process, issues related to the criteria for locating new landfill sites, issues related to the data required for the landfill site selection process and issues related to the use of modern mapping and spatial data analysis technologies in Malaysia. Although this research is not directly related to the management of solid waste, discussion on the status of solid waste management in Malaysia especially within the context of Klang Valley Region will assist the reader to a better understanding on the extent of the problem related to the topic.

2.2 Issues related to the solid waste management in Malaysia and the Klang Valley Region

This section gives a brief account of the status of solid waste management in Malaysia and the Klang Valley Region. A profile of Malaysia will be given first.

2.2.1 Profile of Malaysia

Malaysia is situated in the heart of Southeast Asia, just north of the equator. Its territory of 330,434 square kilometres is divided into two main region: i) Peninsular Malaysia (West Malaysia) and ii) East Malaysia (consisting of the state of Sabah and Sarawak). Peninsular Malaysia extends for 740 km from Perlis in the north to the straits of Johor in the south. It has an area of about 131,500 square kilometres and consists of the states of Johor, Kedah, Kelantan, Melaka, Negeri Sembilan, Pahang, Perlis, Perak, Terengganu, Pulau Pinang and the Federal Territory of Kuala Lumpur. Malaysia has an equatorial climate, which is characterised by high temperatures ranging from 21^{o} C to 32^{o} C and heavy rainfall, with an average yearly rainfall of 2,000 mm to 2,500 mm. The population of Malaysia is slightly over 17 million, with 14 million living in the Peninsular Malaysia and 3 million in East Malaysia.

2.2.2 Status of solid waste mangement

Ideally the management of solid waste in Peninsular Malaysia should involve various government agencies (federal, state and local level), non-governmental organisations and also the private sector. As mentioned in the Action Plan for a Beautiful and Clean Malaysia Report (1988), there is no proper coordination among solid waste management related agencies, and this causes considerable management related problems. At the federal level the management of waste should involve the following agencies: the Prime Minister's Department (Economic Planning Unit and Klang Valley Planning Secretariat), the Ministry of Finance, the Ministry of Housing and Local Government (Local Government Division), the Department of Town and

Country Planning, the Ministry of Health (Engineering Services Division), the Ministry of Science, Technology and Environment (Department of Environment) and the Ministry of Works (Public Works Department). At state level the agencies involved are the State Economic Planning Unit, the State Economic Development Corporation, the State Division of Local Government, the State Medical and Health Services Department and the State Town and Country Planning (refer to Appendix A). According to the Local Government Act (Act 171), 1976, the responsibility for managing solid waste at local level is assigned to the local authorities (that is, city hall, municipal councils and district councils).

The waste management service can be considered as the most expensive service in many local authorities in Peninsular Malaysia, consuming between twenty and eighty per cent of their total budgets (both operational and development budgets). This is a severe financial burden on the budget of the local authorities. Although this service constitutes the major portion of the local authority budget, it has been delivered with little planning from either the local authority or the Federal Government. As indicated in the Action Plan for the Beautiful and Clean Malaysia (ABC), the main problems faced by the local authority in implementing efficient solid waste management are related to lack of national policies, lack of basic law related to waste management, insufficient assistance from the State Government and no consideration given to solid waste problems in the preparation of structure plans.

Unlike the situation in many Developed Countries like the USA and Japan, there is no basic law for the management of solid waste in Malaysia. In the USA, solid waste management is governed by the Resource Conservation and Recovery Act, 1976, while in Japan by the Waste Disposal and Public Cleansing Law, 1970. Although there is no basic law which deals specifically with the management of solid waste, provisions in the following existing laws and regulation [the Land Conservation Act (Act No. 3) 1960, the National Land Code, 1965, the Street, Drainage and Building Act (Act 127) 1974, the Local Government Act (Act 171) 1976, the Town and

Country Planning Act (Act 172) 1976 and the Environmental Quality Act 1974] can be utilised by the Local Authorities. Most of these laws concern with the control of waste disposal rather than the landfill site selection.

The Environmental Quality Act was enacted in 1974 for the prevention, abatement and control of environmental pollution and to enhance the quality of the environment. The Environmental Quality (Prescribed Activities) (Environmental Impact Assessment) Order 1987 came into force on the 1st April 1988 and after that date it was mandatory for all local authorities to carry out an Environmental Impact Analysis (EIA) for the following activities: land development for agriculture, airport, drainage and irrigation, coastal reclamation, fisheries, forestry, housing, industry, infrastructure, port, mining, petroleum, power generation and transmission, quarries, railways, transport, resort and recreational development, water supply, and waste treatment and disposal. The waste treatment and disposal activities are divided into three categories i) toxic and hazardous waste; ii) municipal solid waste; and iii) municipal sewage. Under category ii) the construction of incineration plant, composting plant, recovery/recycle plant and landfill is effected by this order.

Effective planning of waste management, especially to estimate the landfill capacity requires reliable information on the quantity and the composition of waste being generated. In Malaysia, this information is not readily available. According to the report in the ABC carried out by Technical Section, Local Government Division, Ministry of Housing and Local Government, 1988, only one authority, the Pulai Pinang and Seberang Perai Municipality, keeps continuous records of the above information. According to the Solid Waste Management Study for Pulai Pinang and Seberang Perai Municipality carried out by JICA, the amount of waste generated within the Pulau Pinang and Seberang Perai is 0.711 kg/person/day. Other estimates of waste generated in other municipal councils are given in Table 2.1.

Table 2.1 Estimated waste generation rate of selected municipal councils

Municipal Council	Population	Amount collected (ton/month)	Waste generation (kg/person/day)
Ipoh	404,000	6,000	0.495
Kota Bharu	157,000	2,400	0.510
Kota Setar	178,000	4,200	0.787
Kuala Terengganu	117,000	2,100	0.598
Melaka	220,000	5,000	0.758
Petaling Jaya	300,000	7,590	0.843

(Source : Action Plan for a Beautiful and Clean Malaysia, 1988)

Before the introduction of the Guideline on the Storage, Collection, Transport and Disposal of Solid Waste in Malaysia by the Technical Section, Local Government Division in 1984, the situation of on-site storage was not satisfactory. Since the introduction of this guideline, the situation has improved remarkably. In areas outside the control of the local authorities, various types of communal bins such as metal bins, stationary concrete bins and big bins for tilt frame vehicles are used for storage. The use of communal concrete bins is very unsatisfactory because in many cases the bins become mini dumping sites.

In residential areas, the most common methods of waste collections are door-to-door kerbside and door-to-door back-lane collection (not in high-rise building areas). In rural areas, villages, small settlements and squatter areas which are inaccessible to collection vehicles, collection is done from communal bins. In high rise building areas, refuse chute systems are widely used. In commercial areas both the door-to-door collection and the communal bin systems are used. Because of the hot and humid climate and high content of organic wastes, the minimum collection frequency is once in 2 to 3 days. Due to the government privatisation policy, the use of private contractors in waste collection is on the increase.

Current practice of site selection is based on ad-hoc methods. Usually any available vacant land or abandoned mining pond is selected without proper consideration of the impact on the environment. No long term planning in terms of locating new disposal sites is carried out. This practice has meant that many inappropriate sites have been used. Many of the existing sites were located near residential areas and in areas where extensive pollution to the water supply can be caused by leaching. Scavenging of animals for food, illegal collection of recycled materials and open burning are also widely practised, causing environmental pollution and nuisance to nearby residents.

As of 1987 most municipal solid waste is disposed on land where open dumping and burning is a common phenomenon. According to the 1987 report by the Local Government Division, Ministry of Housing and Local Government, there are 230 legal municipal waste disposal sites in Peninsular Malaysia. Municipal Councils have an average of 1.8 dumping sites while the District Councils have an average of 2.7 disposal sites. Utusan Malaysia newspaper dated the 7th of January 1998 has reported that the number of illegal sites in Malaysia could be three times the number of legal sites. The sites are usually small in size, making the use of conventional sanitary landfilling method technically and economically difficult. In most sites crude open dumping is practised, creating environmental problems such as air pollution and water pollution. Most of the existing disposal sites are not managed or fenced and hence are hazards to the public in surrounding areas.

Most of the disposal sites are located in the vicinity of the collection sites and no transfer operations of any kind have been practised. Misconceptions regarding the landfill and higher cost of acquiring land has made the process of finding suitable land for landfilling more difficult. Typical existing landfill sites are riverbanks, abandoned tin mining areas, forest areas, swamps and flat ground.

Some local authorities (the Kuantan Municipality, Petaling Jaya Municipality, Shah Alam Municipality, Pulau Pinang and Seberang Perai Municipality) have tried to improve the overall management of solid waste especially the final disposal problem. They have started planning for landfill sites that will be designed and managed properly. Although sanitary landfilling is hardly practised in the strictest manner, however, many local authorities are now attempting at least to cover the solid waste with suitable cover material and then spray it with chemicals to prevent breeding of vectors and rodents.

2.2.3 Solid waste management practice in the Klang Valley Region

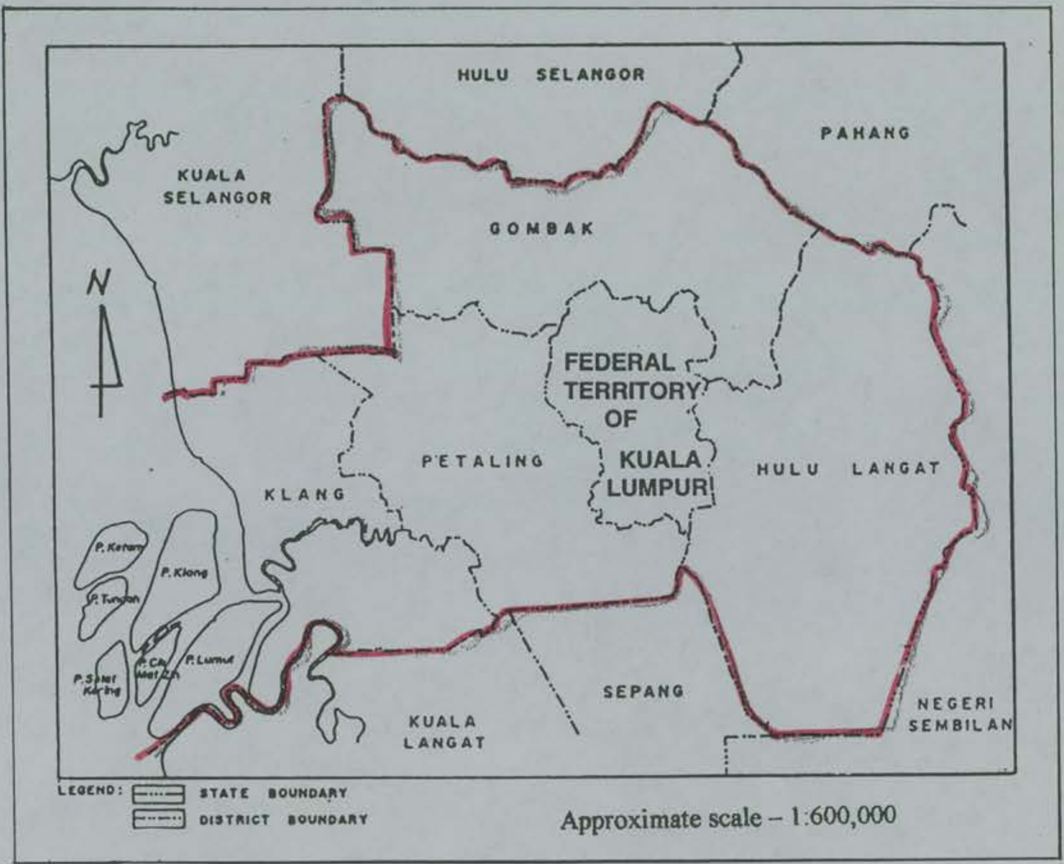
The Klang Valley Region is an administrative area consisting of the Federal Territory of Kuala Lumpur and the four major districts of Selangor, namely Petaling, Gombak, Hulu Langat and Klang (refer to Figure 2.1). Although this region covers an area of only 284,346 hectares and accounts for only 2.1 per cent of the total area of Peninsular Malaysia, it is the country's fastest developing region and is expected to remain so.

In 1970, the population of the Klang Valley Region was approximately 1,266,500, which represented 76.3 per cent of the population of Selangor and the Federal Territory of Kuala Lumpur and 14.4 per cent of that of Malaysia. By 1980, the population had increased to 2,019,800, that is, an average increase of 4.8 per cent per year in all the districts. By 1985, the population of the Klang Valley Region had increased to 2,475,100, that is, an increase of 22.5 per cent. This figure accounts for 81 per cent of the total population of Federal Territory and Selangor and 15.5 per cent of Malaysia. The population growth rate within the Klang Valley Region has been higher than the national rate for 1970-1980, that is, 4.8 per cent compared to 2.8 per cent respectively. According to the Klang Valley Perspective Plan studies carried out in 1988, the population was expected to increase further to 3.1 million in 1990 and 3.7 million in 1995.

This region represents the major centre of industry, commerce, finance, and administration in Malaysia. Most of the region's activities concentrate in the Federal

Territory of Kuala Lumpur. Most of the industrial activities are located between Kuala Lumpur and Klang in the west, and between Kuala Lumpur and Bangi in the South.

The quantities of solid waste generated in 1985 and the estimated quantities for five-year interval from the year 1990 to 2005 according the four classes within this region are given in Table 2.2. The amount of waste generated is expected to increase, the industrial sector being expected to generate the highest quantity of waste followed by the domestic sector. This is because of the rapid urbanisation and industrialisation of the Klang Valley Region.



(Source: Adopted from Department of Town and Rural Planning of Malaysia and Klang Valley Planning Secretariat, 1988)

Figure 2.1 Administrative boundaries of the Klang Valley Region

Table 2.2 Categories and quantity of wastes collected and estimated for the whole of Klang Valley Region

Type of Waste	1985 (tonnes/day)	1990 (tonnes/day)	1995 (tonnes/day)	2000 (tonnes/day)	2005 (tonnes/day)
Domestic Wastes	964	1,321	1,747	2,311	2,862
Commercial Wastes	482	648	858	1,156	1,431
Market Wastes	289	324	381	438	477
Industrial Wastes	1,643	1,985	2,297	2,638	3,049

(Source: Draft Structure Plan for the District of Petaling and Part of Klang 1988-2010, 1994)

According to the Klang Valley Environmental Improvement Project Study (1987), the estimated daily waste not collected from the rural areas is about 400 tonnes. This contributes more than 10 per cent of the total waste generated in the Klang Valley Region. In these areas the refuse is generally burned, buried or composted. In contrast, the squatter areas do not follow any of these desirable practices and indiscriminate littering is more common, causing considerable environmental problems.

As is the case for the rest of Peninsular Malaysia, the practice at most of the disposal sites in the Klang Valley Region before early 1990's is of open dumping, and many of the sites are not properly managed. Also, during the setting up of the waste disposal sites, very little consideration was given to longer-term issues. Most of these sites are located near residential or commercial areas, creating environmental and social problems. Only one site (i.e. the Air Hitam landfill site) which was built in 1996, gave some consideration to the environmental and social issues. At other sites no consideration was given to the impact on the local environment. In most local council areas, site selection was based solely on the availability of any unused land or any government land allocated by the Selangor Land Office. Another consideration is the proximity of the new site to the waste collection centres.

As of 1986 there were 18 landfill sites in the Klang Valley Region provided by the local authorities (refer to Table 2.3). Since 1986, dumping sites in the Klang Valley Region have increased by 7, that is, Sungai Besi in the Federal Territory of Kuala Lumpur, Kampung Pinang and Sungai Buloh for Petaling District, Padang Jawa in

Klang District, Kuang in Gombak District and Semenyih and Balakong in Hulu Langat District. At the time of the author's visit to Malaysia in September to December 1994, most of these sites were still in operation (except for the dumping sites in Padang Jawa, Shah Alam, and Bt. 14, Puchong) although most had exceeded their capacity limits.

As of 1997 all sites within the Shah Alam Municipality, Petaling District Council (currently known as Subang Jaya Municipality) and Petaling Jaya Municipality have been closed. Since its closure, all waste from these municipalities are sent to the Air Hitam landfill site which is located approximately 30 km from Shah Alam. Within the Federal Territory of Kuala Lumpur there is only one legal landfill site left. The number of illegal sites is about 78 (informal discussion with Alam Flora, waste management company). There is only one legal site left within the Klang Municipality. This site has already exceeded its limit and will be closed soon. The number of illegal sites is not known. Officers from various local authorities have expressed their concerns about future landfill sites. Among their concerns are: i) the difficulty of finding new sites due to rapid urbanisation and ii) appropriate methods that can be used to locate new sites which fulfil various environmental, social and economic criteria.

Table 2.3 Waste Disposal Sites in the Klang Valley Region in 1986 and 1997

Local Authority	Sites	Area (acres)	Disposal Methods	Start Operation	Expected End Operation	New Site/s – 1997
Shah Alam	Bukit Kemuming	10	Control	1988	1995	Air Hitam
Municipility			tipping			
Petaling	Jalan Balakong	14.9	Open	1981	1997	Air Hitam
District	Sg. Buloh	4.5	dumping	-		
Council	Bt. 12, Puchong	-	Open	1991	-	
(currently			dumping			
known as			Open			
Subang Jaya			dumping			
Municipality)						
Majlis	Batu Arang	3	Control	1950	1990	Kundang
Daerah			tipping	1950	1990	(extension
Gombak	Kuang	0.5	Open	1950	1990	of old
(currently			dumping	1950	1990	site)
known as	Kundang	0.5	"	1982	1995	
Selayang						
Municipality)	Rawang	5	"			
			Control			
	Batu Caves	15	tipping			
Federal	Sri Petaling	8	Control	1975	1990	
Territory of		4	tipping	1970	1982	
Kuala	Jinjang		-			
Lumpur						
Petaling Jaya	Kg. Pinang		Control	-	-	Air Hitam
Municipility			tipping			
	Kelana Jaya		"			
Klang	Pandamaran	22	Control	1986	1994	Telok
Municipility			tipping			Gong
Hulu Langat	Sg. Chua	43	Open	-		Not
District	Semenyih	5	dumping	-		available
Council	Balakong	6	"	-		
	Ampang	20	"	-		
			"			

(Source: Klang Valley Environmental Improvement Project, (1987), author's visit in November 1994 and recent visit in 1997)

2.2.4 Studies on solid waste management

Although there is no national policy for the management of solid waste, there are a number of national, regional and local level studies that are directly related to the management of solid waste, the aim is to improve current situation. A list of these studies is given in Table 2.4.

Table 2.4 Studies related to municipal solid waste management

Study	Year	Prepared by:
Klang Valley Environmental Improvement Project (KVEIP)	1987	Engineering Science Inc., SEATEC International and Department of Environment of Malaysia
Action Plan for a Beautiful and Clean Malaysia (ABC)	1988	Technical Section, Local Government Division, Ministry of Housing and Local Government
Klang Valley Perspective Plan	1988	Department of Town and Rural Planning and Klang Valley Planning Secretariat.
Solid Waste Management Study for Pulau Pinang and Seberang Perai Municipalities	1989	Japan International Corporation Agency (JICA)
Proposed Masterplan on Solid Waste Management for Petaling Jaya Municipality	1991	Engineering and Environmental Consultant Ltd.

The Klang Valley Environmental Improvement Project is a comprehensive study on the current state of the environment of the whole of Klang Valley Region. This study was undertaken by the Engineering Science Incorporation, SEATEC International in conjunction with the Department of Environment of Malaysia, and the report from this study was published in 1987. Among the topics emphasised are those related to water resources/quality, air quality, watershed management and solid waste management. The study on solid waste management aimed to achieve the following: i) to update existing data on solid waste characteristics, ii) to assess the adequacy of the existing systems, and iii) to make recommendation for improving the existing waste collection and waste disposal system.

The Action Plan for a Beautiful and Clean Malaysia (ABC) report was produced by the Technical Section of the Local Government Division, Ministry of Housing and Local Government of Malaysia in 1988. The first part of this three-part report examines the existing municipal solid waste management system in Malaysia. The second part presents a proposal for a National Policy on Municipal Solid Waste Management. The final part of this report deals specifically with the actions to be taken to implement the national policy suggested in the second part.

The main objectives of the Klang Valley Perspective Plan are to formulate and plan future strategies for population growth, land use, public utilities and environment for the whole of Klang Valley Region. This perspective plan was jointly prepared by the Department of Town and Rural Planning and the Klang Valley Planning Secretariat and the report was published in 1988. The problem of solid waste and toxic disposal has been identified as one of the major environmental issues that need immediate attention.

The Solid Waste Management Study for Pulau Pinang and Seberang Perai Municipality was carried out by the Japanese International Corporation Agency (JICA) in 1989. The Proposed Masterplan on Solid Waste Management for Petaling Jaya Municipality was carried out by the Engineering and Environmental Consultant Limited. The final report was published in 1991. Both of these studies have highlighted the status and make suggestions for future improvement of solid waste management within the related municipalities.

Among the wide-ranging recommendations made in the studies listed above to improve the current problems of solid waste disposal include:

- the use of incinerators to burn waste (Department of Town and Rural Planning and Klang Valley Planning Secretariat, 1988),
- the use of sanitary landfill methods to dispose municipal solid waste (Engineering and Environmental Consultant Ltd., 1991),
- the use of large scale regional disposal site/s (Engineering Science Inc., SEATEC International and Department of Environment of Malaysia, 1987 and Department of Town and Rural Planning and Klang Valley Planning Unit, 1988),
- the use of a more systematic stage-by-stage approach using suitable siting criteria to select new waste disposal sites (JICA, 1989a), and
- the use of transfer station rather than direct haul to the disposal site (Engineering and Environmental Consultant Ltd., 1991).

As indicated in the 1987 project report by Engineering Science Inc., SEATEC International and the Department of Environment, the use of incinerators to dispose of solid waste is not a feasible solution for the Klang Valley Region due to its geographical location, the wet Malaysian climate and high capital equipment and maintenance costs of using an incinerator. It was also generally felt that the local approach for locating new landfill sites can no longer be considered as a viable solution because of the decreasing land area available within developed local authorities such as the Kuala Lumpur City Hall, the Petaling Jaya Municipality and the Shah Alam Municipality, and therefore that a regional approach was necessary. The stage-by-stage approach using suitable siting criteria for locating new landfill sites can help decision makers and planners in the region to eliminate unsuitable areas systematically and later select the best possible alternative site or sites for further consideration.

The only attempt to implement such an approach in Malaysia was made by the Pulau Pinang and Seberang Perai Municipality. As outlined in the Solid Waste Management

Study for Pulau Pinang and Seberang Perai Municipality (JICA, 1989a) the following work procedures were followed:

- The study area is defined according the specified hauling distance from the centroid of the potential service area. Only areas within this specified radius are considered
- The areas to be excluded from further considerations such as areas unsuitable from the economic and environmental point of view, and areas incompatible with any regional plan, are traced and shaded onto transparent paper.
- The shaded transparent papers of the unsuitable areas are overlaid on the study area map. The unshaded areas are considered as suitable areas for waste disposal sites.

2.3 Issues related to the methods of landfill site selection

Basically there are two distinct approaches to site selection: i) the two stage approach as used in the UK and ii) the stage-by-stage approach as followed by other countries such as the USA and Canada. Although the approaches might differ, the selection processes are aimed to achieve the same ends: i) to minimise the impact on the environment, ii) to maximise the public acceptability of the proposed site and iii) to minimise the development cost of the site.

Since Malaysia is adopting the UK land use planning system, the process of site selection is supposed to follow the two stage approach. In the UK, the site selection process follows two distinct stages, which are the identification of a potential site by the developer followed by a detailed assessment of the likely impact of the proposed facility at the preferred location. The identification of potential sites has to consider planning criteria which include various siting constraints such as physical characteristics, safety measures, environmental issues, social factors, economic factors, technical and political issues. There are no national siting criteria for the new waste disposal facilities. In most cases in the UK, the identification of the site is the responsibility of the developer. Relevant siting objectives and criteria according to the proposed project and to any local land use and waste disposal plan must be determined by the developer. The Environmental Impact Assessment is only carried out (if necessary) after the site has been selected.

Countries like the USA and Canada have adopted a stage-by-stage approach towards landfill site selection. This approach reduces the size of study area at each stage using a set of predetermined criteria until the final few alternative sites are selected for a more detailed analysis. The best possible site is later selected from this detailed analysis.

Typical examples of the application of the stage-by-stage method of site selection can be found in Weber and Ware (1990), Jensen and Christensen (1986), and Converse/TenEch (1981). Weber and Ware (1990) described the stages followed by Loudoun County, Virginia. The planners followed a county-wide systematic screening process and specific site selection evaluation process. Twenty four exclusionary criteria were used for county-wide screening. After the initial screening process areas of the county were rated using four criteria ranges: i) exclusion (not suitable); ii) poorly suited, iii) marginally suited and iv) suited. Further detailed site specific screening of only the suited and marginally suited areas were later carried out to identify the candidate sites. Three of the most suited sites were selected for further evaluation by on-site geo-technical investigation and public input.

The methods used by the Sussex County in the USA, as described in Converse TenEch (1981), were as follows: i) applying initial screening using broad exclusionary criteria, ii) further screening using geo-technical/hydro-geological criteria, iii) rank sites based on environmental criteria, iv) rank further based on economic and socio-economic criteria, and v) detailed site investigation of sites which passed the first four screening processes.

Site selection in Ontario, Canada, as described in Ontario Waste Management Corporation (1985) also adopts the stage-by-stage approach as used in the USA. The stages involved were as follows:

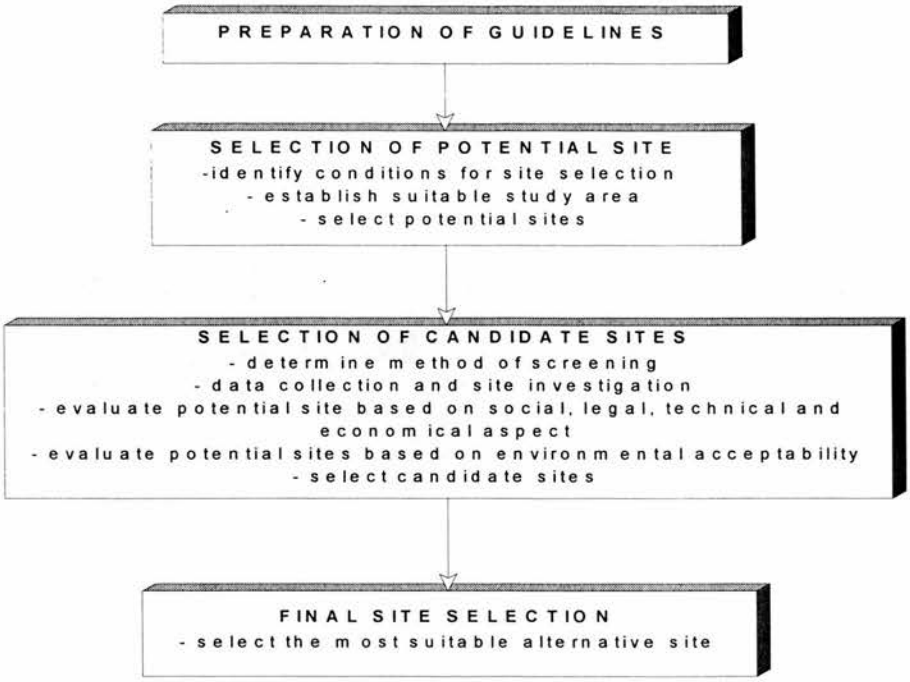
- Stage 1 Narrow the search area to a single geographic area in Ontario.
- Stage 2 Identify the candidate areas within this region.
- Stage 3 Identify the candidate sites within the candidate areas.
- Stage 4 Compare the candidate sites and identify preferred sites.
- Stage 5 Carry out test of preferred sites.

In Malaysia the process of identifying potential sites based on planning criteria as adopted in the UK has never been practised due to lack of guidelines related to the development of new landfill sites. As described earlier, any vacant land or ex-mining areas were considered suitable for waste disposal. Only after the introduction of the Environmental Quality (Prescribed Premises) (Scheduled Waste Treatment and Disposal Facilities) Regulations in 1989, some environmental considerations were included in the site selection process. An Environmental Impact Assessment (EIA) on any proposed landfill site has to be carried out. Ideally the incorporation of EIA in the process of landfill site selection will help to minimise the adverse effect to the environment. In most cases, this does not happen because the state land approval committee is always under pressure to approve a site proposed by the local authority or the land office, even if the site construction could cause considerable adverse impact on the environment, as well as social and economic implications to the surrounding area.

Since land matters are under the control of the state not the federal government, the State or District Land Office is responsible for land applications for various different developments including the allocation of land for landfill sites. Within their jurisdiction area, the local authority can propose to the Land Office that any land be used as a landfill site. The State or District Land Office as the coordinating agency will usually consult other related agencies such as Geology Department, Public Works Department, Planning Department, Water Works Department, Agriculture Department, Civil Aviation Department for the suitability of the proposed site. In developed local authorities like the Kuala Lumpur City Council, the Shah Alam and the Petaling Jaya Municipality where there is no more land available for waste disposal sites, the local authority has to apply for state land which lies outside its jurisdiction area. The task of identifying potential sites is normally carried out only by the junior officers at the State or District Land Office. As mentioned earlier, the single most important criterion used to identify a potential site is its availability as vacant land. Another important consideration is haul distance.

As mentioned earlier a few local studies have suggested the use of a multi-criteria stage-by-stage approach as adopted in the USA and Canada to select the most suitable landfill sites in Malaysia. The methods proposed in only two of these studies, that is, the Solid Waste Management Study for the Pulau Pinang and Seberang Perai Municapility and the Proposed Masterplan on Solid Waste Management for Petaling Jaya Municpality, will be given here.

The Solid Waste Management Study for the Pulau Pinang and Seberang Perai Municipility proposed that the site selection process for major waste disposal facilities (landfill, incinerator and transfer station) should be carried out in four different stages, that is, i) preparation of guidelines on the selection of potential sites, ii) selection of potential sites (identification of potential sites), iii) selection of candidate sites and iv) final site selection (selection of the most favourable alternative site or sites). Figure 2.2 shows the flowchart for the proposed site selection process for Pulau Pinang and Seberang Perai Municipality.



(Source: Adapted from JICA, 1989a)

Figure 2.2 Proposed site selection process for the Pulau Pinang and Seberang Prai Municipality

It was also agreed that the committee for the preparation of potential site guidelines should include state government departments (Town and Country Planning Department, Land and Mines Department, and Northern Regional Office of the Department of Environment), local government department (Health Department, Engineering Department under Public Works Department, and Town Planning Department) and others non-governmental organisations. Factors to be considered in designing the site selection criteria should include the following:

- possibility of land acquisition
- possibility of getting neighbouring consensus
- compatibility with regional development plan (i.e. Structure Plan, present and future land use and other major development plans)
- economic feasibility
- environmental acceptability

Before the actual identification of potential sites, the site selection committee is requested to consider all the five factors above. Maps showing regulatory constraints on land use (that is, environmentally sensitive areas map, land use policy plan, national resource reserve maps) and land classification maps, showing the extent of federal, state and local government lands, are required to determine the possibility of land acquisition. The committee has to consult the public and special interest groups to get feedback. A study on the economic feasibility (that is, land price, present system of solid waste management), environmental acceptability and compatibility with all existing development plans has to be carried out.

Based on the established suitable study area, the site selection committee will select the candidate sites. The same five factors as mentioned earlier are to be considered. A detailed description of the criteria used in each factor is given later. Initial site evaluation should be based on social, legal, political, technical and economic aspects followed by evaluation based on environmental acceptability. Finally, the most favourable site is selected.

The Proposed Solid Waste Management Masterplan for the Petaling Jaya Municipality also outlined four basic stages in the site selection process. The stages are as follows:

1. Preliminary evaluation and screening process
2. Land Ownership evaluation
3. Field investigation of sites
4. Identification of the most suitable sites

In the first stage, preliminary evaluation and screening process based on broad criteria are applied to a large geographic area to locate potential sites. The next stage involves the assessment of land ownership of potential sites. This is to determine whether the sites are state government land, local government land or privately owned land. This will be the basis for calculating the cost for land acquisition. In the following stage a detailed site investigation on the selected sites has to be carried out.

2.4 Issues related to the landfill site selection criteria

A review of earlier studies (Converse TenEch, 1981; Melbourne and Metropolitan Board of Works, 1985; Roger *et al.,* 1985; DOE-Malaysia, 1986; Engineering Science Inc., SEATEC International and Department of Environment of Malaysia, 1986; JICA, 1989; United States Environmental Protection Agency-USEPA, 1990, Engineering and Environmental Consultant Ltd., 1991; Environmental Protection Compendium of the British Colombia Ministry of Environment, Lands and Parks of Canada, 1993 and Miaoli Perfecture, 1996) has indicated the differences in criteria used to locate new landfill sites. The differences in criteria used are largely governed by each country's political system, economic system, social structure, legislation related to waste management and the current state of the environment (Oweis and Khera, 1990). General exclusionary criteria are used in most of these studies to locate potential areas within a large geographical area before applying further detailed restrictive criteria to select the most suitable site. In some of the studies mentioned above (for example Converse/TenEch, 1981; Roger *et al.*, 1985; Engineering and Environmental Consultant Limited, 1991) different criteria weightingswere attached to indicate its importance. A higher criteria weighting is assigned to the more important criteria. As different studies adopt different sets of criteria, a critical account on various site selection criteria will not be given. The following sub-sections will only review some of the landfill site selection criteria used in overseas countries and also in Malaysia.

2.4.1 Site selection criteria used in overseas countries

In Australia, the Melbourne and Metropolitan Board of Works for waste disposal facilities criteria was developed from the State of Victoria Environmental Protection Agency's general approach (Melbourne and Metropolitan Board of Works, 1985). Exclusionary criteria were classified into six main categories, that is, topography, surface soils, atmospheric conditions, recreational value, population density and water supply. All these criteria are relevant to locate landfills, incinerators and transfer stations siting. Further detailed site assessment is carried out using criteria such as soil permeability and evaporation/rainfall ratios. An explanation on detailed preference and exclusionary criteria is given in Table Appendix C1.

The process of screening used in Sussex County, USA (Converse/TenEch, 1981) starts by applying broad exclusionary criteria such as distance from water supply wells, wetland, agricultural preservation area, flood plains, archaeological and historic sites, dedicated lands, habitats for threaten or endangered species, and developed land. Further screening using the geo-technical and hydro-geological exclusionary criteria (e.g. suitable geology, suitable soil and ground water protection) is later applied. The groundwater criterion is considered as the most important, followed by soil and geology criteria.

Factors to be considered in groundwater criteria are yield from groundwater wells, use of acquifer for water supply, the quality of groundwater, direction groundwater flow and seasonal groundwater level within the selected site. Site with high acquifer capabilities, high groundwater level, high groundwater quality and groundwater flow is towards the site must be avoided. A knowledge of soil characteristics, that is, soil permeability, soil acidity (pH), soil cation exchange capacity (CEC) and characteristic of surficial soils, is most important in understanding leachate flow at the proposed site. Lower subsoil and surficial soil permeability, higher pH and higher CEC are preferred. As with many other types of engineering constructions, landfill sites require stable geological areas. Geological stability relates to bedrock and outcropping, continuity and mass permeability and existence of faults. Carbonate rocks and fractured rocks are not suitable as they area soluble and hence facilitate pollution migration. The choice of site with suitable geology will help to minimise pollution migration.

Slope erodibility and run-on and run-off factors must be considered in the topography criteria. Site prone to soil erosion and run-on of leachate and rainwater from upland must be excluded. Steep slope (greater than 22%) is considered too steep for the development and operation of the sites. Areas near streams, lakes, production wells, and within flood-prone areas should be excluded.

Application of these hydrogeological and environmental criteria leads to exclusion of many sites for further consideration. Further ranking of the selected sites is based on economic and socio-economic criteria.

The Hunterdon County siting study (Roger *et al.,* 1985) rated the site based on the environmental, economic and social-economic criteria. The groundwater protection criterion was given the highest priority, followed by the floodplain criterion and finally the pedestrian right-of-way criterion. These criteria are only applied after applying exclusionary criteria, which include distance from airport of 5,000-10,000 feet, sites with wetlands and head of stream within 500 feet and sites with glacial outwash, limestone and pre-Cambrian material.

Under the Federal Register on Solid Waste Disposal Facility Criteria (Final Rule) prepared by the United States Environmental Protection Agency (USEPA) location restrictions applied to existing landfill units are distance from airport, floodplain areas and unstable areas. For new landfill units and lateral expansions, three more restrictions are added, that is, wetlands, seismic impact zones and fault areas. Detailed descriptions of the siting limitations are given in Table 2.5.

In the Miaoli Perfecture, Taiwan, landfill siting rules are categorised into four, that is, essential rules, secondary rules, recommended rules and particular rule. Essential rules are regulations with which a proposed landfill must comply (Miaoli Perfecture, 1995.. Secondary rules are mostly regulations which are not clearly defined or not directly proposed for landfill siting while Recommended Rules are conditional or heuristic rules suggested by some researchers or experts but not yet considered as formal regulations. Particular Rules only applies to a specific site or are derived from previous case study experience. Essential rules include the environmental and social/cultural factors. A detailed description on the criteria in the essential rules is given in Appendix C2.

Table 2.5 Siting limitations contained in Subtitle D of the Resource Conservation and Recovery Act.

Location	Siting Limitation
Airport Safety	Siting limitation is 10,000 ft or 3,048 meters from airport used by turbojet aircraft; 5,000 ft or 1,524 meters from airport used by piston-type aircraft. Any new and existing MSWLFs and lateral expansions closer will have to demonstrate that it does not pose a bird hazard to aircraft.
Flood plains	The flood plain provision applies to new and existing MSWLFs and lateral expansions units located on 100 years flood plains. Any landfill units on this flood plain will have to be designed so as not to restrict the flow of the 100 years flood, reduce the temporary storage capacity of the flood plain, or result in washout of solid waste so as to pose a hazard to human health and the environment.
Unstable areas	New and existing MSWLFs and lateral expansions located in an unstable area must demonstrate that the design ensures stability of structural components. The unstable areas include those that are landslide prone, those that are in karst geology suspectability to sinkhole formation, and those that are undermined by subsurface mines. Existing facilities that cannot demonstrate the stability of the structural components will be required to close within five years of the regulation's effective date.
Wetlands	New MSWLFs and lateral expansions will not be able to locate in wetlands unless the following conditions have been demonstrated: 1) No practical alternative with less environment risk exists 2) Violations of other state and local laws will not occur. 3) The unit would not cause or contribute to significant degradation of the wetland. 4) Appropriate and practicable steps have been taken to minimise potential adverse impacts. 5) Sufficient information to make determination is available.
Seismic impact zone	The rule bans the location of new MSWLFs units and lateral expansions in seismic impact zones. Units located within the impact zone will have to demonstrate that all contaminant structures (liners, leachate collection systems, and surface water control structure) are design to resist the maximum horizontal acceleration in lithified materials (liquid or loose materials consolidated into solid rock) for the site. For the purpose of this requirement, seismic impact zones are defined as areas having a 10 percent or greater probability that the maximum expected horizontal acceleration in hard rock, expresses the percentage of the earth's gravity pull (g), will exceed 0.10g in 250 years.
Fault areas	The rule bans the location of new MSWLFs units and lateral expansions within 200 ft (60 meters) of a fault line that has had displacement in Holocene time (past 10,000 years)

(Source : Federal Register Part 11 - on solid waste disposal facility criteria by EPA, 1991)

The Environmental Protection Compendium of the British Colombia, Ministry of Environment, Lands and Parks of Canada, requires a detailed site location investigation which address the issues of location (refer to Table 2.6) as well as water contamination, air pollution, wild life conflicts, transportation, social and economics issues.

Table 2.6 Landfill site selection criteria used by the Environmental Protection Compendium of the British Colombia, Ministry of Environment, Lands and Parks of Canada

Criteria	Explanation
Property boundary	• The buffer zone between the discharge municipal solid waste (MSW) and the property boundary should be at least 50 metres of which the 15 metres closest to the property boundary must be reserved for natural landscaped screening. Depending on adjacent land use and environmental factors, buffer zones of less than 50 metres but not less than 15 metres may be approved by the Manager
Other Facilities	• The distance between the discharge municipal solid waste (MSW) and the nearest residence, water supply well, water supply intake, hotel, restaurant, food processing facility, school, church pr public park is to be a minimum of 300 metres. Greater or lesser separation distances may be approved where justified.
Airport	• The distance between an airport utilised by commercial aircraft and a landfill containing food wastes which may attract birds is to be a minimum of 8 km, unless bird control measures acceptable to Transport Canada and approved by the Manager are instituted or the potential for birds causing hazard to aircraft is minimal.
Surface water	• The distance between the discharge MSW and the nearest surface water is to be a minimum of 100 metres.
Floodplain	• Landfills proposed for locations within the 200 years floodplain and the associated floodway are not to be sited without adequate protection to prevent washouts.
Unstable area	• Landfills are not to be located within 100 metres of an unstable area.
Other excluded area	• Landfills are not to be located within boundaries of the following areas: • National, provincial, regional or municipal parks • Wildlife management area • Critical wildlife area or wildlife sanctuary • Ecological reserve • bird sanctuary • wildlife area designated under the Canada Wildlife Act (Canada)

(Source: Environmental Protection Compendium of the British Colombia Ministry of Environment, Lands and Parks, Canada, 1993)

Landfill site selection criteria as suggested by the World Bank (Cointreau-Lavine, 1996) emphasise three main factors: economic, socio-economic and environmental. The economic factors include adequate land area for landfilling, travel time of less than 30 minutes from the collection centres to the proposed landfill, accessible distance from public roads and the availability of on-site cover material. The environmental factors are intended to protect surface water and ground water from contamination. Environmentally sensitive areas such as wetland and endangered species areas should be avoided. Other factors considered are distance from airports, culturally sensitive areas, residential areas and streams. Refer to Appendix C3 for a more detailed description of the criteria.

2.4.2 Existing recommended siting criteria in Malaysia

In this section a review of five different sets of criteria from different studies or guidelines will be given. Results obtained from informal discussions with officers involved in the management of solid waste will also be presented. The Recommended Code of Practice for the Disposal of Solid Waste (DoE of Malaysia, 1985) was intended to give a general guideline to be followed by all organisations involved in solid waste management in Malaysia. The criteria given in the Klang Valley Environmental Improvement Project (Environmental Science Inc., SEATEC International and DoE of Malaysia, 1987) were intended to be used in the Klang Valley Region. Three other sets of criteria were proposed in three different local waste management studies. These studies are as follows:

- Solid Waste Management Study for the Pulau Pinang and Seberang Perai Municipality
- Proposed Solid Waste Management Masterplan for Petaling Jaya Municipality
- Proposed Solid Waste Management Masterplan of Ipoh for the year 2010.

Only two sets of criteria as given in the Proposed Solid Waste Management Masterplan for Petaling Jaya Municipality and the Proposed Solid Waste Management Masterplan of Ipoh for the year 2010 include both the exclusionary and restrictive criteria. Other studies or guidelines do not differentiate between exclusionary and restrictive criteria. Criteria with different weighting as described in Converse/TenEch, (1981) and Roger et al., (1985) were only given in the Proposed Solid Waste Management Masterplan for Petaling Jaya Municipality.

The Recommended Code of Practice for the Selection of Disposal of Solid Waste on Land was prepared by the DoE of Malaysia in 1985. This code outlines the general criteria for site selection, information required in selecting waste disposal site, code of practice for landfill development and management and methods of landfill construction. The criteria proposed in these guidelines concentrate not only on the environmental issues but also on social and economical issues. Some of the criteria outlined in this code contradict with the aim of protecting the environment, for example, criterion 1 (land characteristic suitable for waste disposal), where disposing of waste into water bodies will also cause serious odour problems and direct seeping of leachate into groundwater. Other criteria considered are geological and hydro-geological issues, availability of cover material at the site, accessibility for major roads, proximity to airports, proximity to residential and industrial areas, ultimate use of the site after closure, effective life expectancy of the site and other criteria such as the direction of prevailing wind and topography. A brief explanation of the criteria is given in Appendix C4.

In the Klang Valley Environmental Improvement Project the recommended criteria to be used for site selection can be divided into three main types, that is i) environmental factors, ii) economic factors, and iii) social and political acceptability factors. The introduction of environmental factors allows the protection of surface and ground water supply, and proper screening of surrounding areas from flying debris, odour and noise. The economic factors can usually be resolved but the social and political problems are often difficult. The best possible locations that meet the recommended criteria are usually at foothills at the periphery of the Klang Valley Region. Such locations are generally away from usable groundwater, not subject to flooding and can be naturally isolated from any residential areas. A general outline of the proposed criteria is given in Appendix C5.

According to the Solid Waste Management Study for the Pulau Pinang and Seberang Perai Municipal, Malaysia, such factors as the possibility of land acquisition, the possibility of getting neighbouring consensus compatibility with the regional development plan, the economic feasibility, and environmental acceptability must all be considered for screening and siting of major solid waste disposal facilities. Land acquisition should not contradict with land use restrictions and must conform to any regional development plans (structure plan, current and future land use plan, other major development plan). In terms of economic feasibility, the site must be big enough to be operational for more than five years and should be located at an economical distance from the waste source. Other factors are a reasonable cost of acquiring land for the site (if not government land) and close proximity of the site to public services (electricity, water, telephone). In terms of environmental acceptability the selected site must be located at an acceptable distance from public facilities, water resources conservation area and densely populated area. Other considerations are that the site should not slope excessively or include areas of endangered species or of historical and archaeological importance. Refer to Table 2.7 for the proposed siting criteria for Pulau Pinang and Seberang Perai Municipality.

As in other proposed studies, the Proposed Solid Waste Management Masterplan for Petaling Jaya also considers technical/engineering factors, environmental factors, economic factors, social factors, political factors and compliance with applicable local, state and federal agencies guidelines. Initial screening should start by applying broad criteria to exclude all areas located within regulatory limitations such as distance from airports, distance from water sources and surface water resources and areas which have unsuitable soil, geology, topography and land use. The second stage is to screen land ownership of potential sites. This criterion is used to ascertain the availability of specific sites before more detailed criteria which consider social/political factors, physical factors and economic issues are applied to the selected potential sites to determine the best possible site.

Table 2.7 Proposed siting criteria for Pulau Pinang and Seberang Perai Municipality

Item	Screening criteria
Possibility of land acquisition	• Land use restrictions • Land ownership • Necessity of compensation
Possibility of getting neighbouring consensus	• necessity of neighbouring consensus • out of sight from public • isolation from noise, dust and odour

Compatibility with the regional development plan	• Conformity with regional development plans such as :
	  • Structure Plans
	  • Present land use plans
	  • Future land use plans
	  • Other major development plans

Economic feasibility	• Area of site – lifespan of site shall be more than 5 years • Location of site – economical distance from collection area, accessibility and availability of cover material at or site or its vacinity • Reasonable acquisition cost of land for site • Availability of public services (electricity, water, telephone)
Environmental acceptability	• Acceptable distance from airport, and other public facilities • Water resources conservation – should not pollute drinking water • Not within densely populated area • Not within area of unsuitable slope • Not within area of critical habitat of endangered species • Not within archaeological or historical significant area

(Source: JICA, 1989a)

As shown in Table 2.8, a different weight is attached to each of the criteria to indicate its importance. The highest possible weight assigned is 100. In the social/political criteria the adjacent land use criterion is considered as the most important, followed by haul route suitability, offsite suitability, down stream suitability and current zoning criteria. In the physical criteria the impact of waterbody and wetland criterion is considered as the most important, while the water supply proximity criterion is considered as the least important. Site development is considered as the most important criterion to be considered in the economic criteria. Other criteria to be considered are the availability of cover material, cost of haul route improvement, haul cost and cost of land acquisition.

The selected sites are ranked for suitability in three main categories, that is, not suitable, medium suitability and very suitable. The score given for the ranking is from 1 to 10; 1 for the most unsuitable site, 5 for medium suitability and 10 for the most suitable site (refer to Appendix C6). Appendix C7 shows a sample of site suitability assessment score based on the best possible site, worst possible site and hypothetical site. The maximum possible score for any selected site is 10,600 while the worst possible score is 1,060. Based on this table the score for each of the selected sites is calculated.

Table 2.8 Siting criteria and it's associated weights

Social/Political Criteria	**Weight**
Adjacent Land use	100
Haul Route Suitability	90
Offside Visibility	30
Downstream Sensitivity	20
Current Zoning	10
Physical Criteria	
Waterbody and Wetland impact	80
Subsurface Conditions	80
Acreage of Suitable Land	70
Configuration of Suitable Land	60
Existing Slope	50
Flood Zone Impact	40
Water Supply Proximity	30
Economic Criteria	
Site Development Cost	100
Cover Material Availability	90
Haul Route Improvement	80
Haul Cost	70
Land Cost	60

(Source: Engineering and Environmental Consultant Limited, 1991)

Two types of criteria were proposed in the Proposed Ipoh Solid Waste Management Masterplan for the year 2010, exclusive criteria and restrictive criteria. The exclusive criteria are those where the significance does not allow further consideration of the site. Factors to be considered in exclusive criteria are hydro-geology factors; geology factors; natural conservation factors; intramission protection factors and the air traffic security factor. Restrictive criteria are those where the suitability of the site has to be carefully balanced with other factors such as economic and socio-economic factors. Factors to be considered in the restrictive criteria are hydro-geological factors, natural conservation factor, intramission protection factor, waste management factor and other factors such as airport safety. A more detailed explanation of criteria in each factors in given in Table 2.9.

Table 2.9 Proposed siting criteria (Proposed Solid Waste Master Plan for Ipoh)

A. EXCLUSIVE CRITERIA

1. Hydrogeology factors
   The selected site should not located be within the following areas:
   - drinking water protected areas
   - medicinal spring protected areas
   - flood areas
   - karst areas
2. Geology factors
   The selected site should not located be within the following areas:
   - earthquake areas
   - area of extreme terrain profile
   - synchne (dolines) area
   - raw material resource areas
3. Natural conservation
   The selected site should not located be within the following areas:
   - natural parks
   - existing and planned nature conservation area
   - forest reserve
4. Intramission protection
   The proposed site must be at least 200 metres from the nearest settlement.
5. Air traffic safety factors
   The recommended safe distance is 3,048 meters from airport used by turbojet aircraft and 1,524 Meters from airport used by piston-type aircraft (similar to that used in USA)

RESTRICTIVE CRITERIA

1. Hydrogeology
   Ground water of regurial significance for drinking water production.
   Area with insufficient geological barrier. These areas are only acceptable if no Hydrologic reservation exist
2. Nature conservation factor
   The area includes the following areas:
   - landscape protected areas
   - buffer zones to national parks
   - recreation areas

(Source: Kielbrer Burger and Perunding Sdn. Bhd., 1990)

Informal discussions with officers from a private company (Alam Flora – a waste management company responsible for the waste collection in Kuala Lumpur) and government organisations (Subang Jaya Municipality, Shah Alam Municipality, Petaling Jaya Municipality, Ampang Jaya Municipality, Municipality,Selangor State Town and Rural Planning, Selangor State Land Office, Selangor State Economic Planning Unit, Department of Environment, Department of Agriculture, Department of Geology and Technical Section of the Ministry Housing and Local Government) have suggested nine main types of criteria to be considered in locating new landfill sites.A list of the suggested criteria is given in Table 2.10

Table 2.10 Suggested criteria based on informal discussion with various organisation

Criteria	Description
Safety	Must be located at certain distance from existing airports and existing waste disposal sites.
Surface water	Areas near to the surface water such as reservoir, lakes, rivers, water intake point and flood plain should be avoided.
Ecology	Areas with poor, harvested, distributed or damaged forest are considered suitable. Areas with excellent quality forest, mountain forests and mangrove forests areas should be avoided.
Land use	Ex-mining area, agriculture areas, forest reserve are considered suitable by many organisations. Recreational, cultural, residential and commercial areas should be avoided. The selected area must not contradict with any future regional or local development plans.
Land ownership	Preferred land areas are government lands or HICOM owned lands (land allocated for industrial use). In areas where there are no more government owned land privately owned land can also be used.
Geology	Site must not be within limestone or karst areas. Areas with granite and allied rocks forming rugged terrain, steep slopes and high relief are also not suitable. Preferred areas are schists, phyllite, slate, shale with minor occurrence of limestone and sandstone of undulating topography
Transportation	Should be near to existing highways and main roads.
Economic	Site capacity must be more than five years, some organisation more than 10 years. For it to be economic the size of site must me more than 50 acres. To avoid extra cost for building new roads, the selected sites should not be at certain specified distance from existing roads. Areas with slope more than 10 per cent should be avoided.
Social	The selected areas should not be visible from any residential, commercial or recreational areas.

2.5 Issues related to the data for landfill site selection

2.5.1 Data requirements for landfill site selection

Discussions on the site selection methods and site selection criteria used in various countries have indicated that numerous information of different scales, sources and themes are needed for selecting new landfill sites. The information for landfill site selection includes published and unpublished statutory, local restrictions or guidelines, material on current waste management practices, data related to the amounts of waste collected and projected, various types of maps, aerial photographs at different scales, detailed site reports and others. For ease of discussion, data requirements are classified into two main categories: i) the data required for large geographical area, which aim to locate potential sites, and ii) the data required for specific site evaluation or investigation.

The initial data required to determine candidate sites (for large geographical areas) follow the predetermined exclusionary criteria for the siting purpose. As indicated earlier there are no standard exclusionary criteria that can suit all countries or even all states. In most cases different criteria are required, addressing the following issues: i) regulation issues, that is, issues that do not contradict any national or local guidelines regarding land use or waste disposal; ii) public safety issues; iii) protection of environmentally sensitive areas issues; and iv) protection of surface water and groundwater issues. Data sources required for this purpose are mainly small scale maps such as geological maps, hydro-geological maps, soil maps, topographic maps, land use (current and future) maps, zoning maps, and other maps.

For a detailed site assessment, larger scale maps or plans are required. Examples of such maps or plans include cadastral plans and large-scale engineering plans to show planimetric details and height at the selected candidate sites. Cadastral plans are essential to determine ownership (whether privately owned land or government land) of the affected land and hence estimate the cost of land acquisition. Not all data required for the detailed site assessment can be obtained from maps. Detailed site investigations and site surveys data based on geological suitability, soil suitability, groundwater suitability, slope suitability and surface and groundwater hydrology criteria are always essential at this stage of the evaluation.

Ideal spatial data sets required for the landfill site selection should include data related to topography, soil, geology, surface and groundwater hydrology, existing land use, potential land use, road infrastructure and land ownership. Data for this purpose can come from different sources such as maps (topographic maps and various thematic maps), aerial survey and satellite remote sensing. A list of the data sets and their probable data sources and their justifications is given in Table 2.11.

Table 2.11 Ideal data sets required for the landfill site selection

Data set	Data source	Justification
1. Topography	• Topographic map • Aerial photography • Satellite remote Sensing	• to generate slope map from which areas with suitable or unsuitable slope can be determined • to determine areas visible from potential sites • to model surface run-on and run-off at the potential site • to estimate the capacity of potential sites
2. Soil	• Soil map • Aerial photography • Satellite remote Sensing	• to determine soil type - from which information on soil suitability in terms of its permeability of subsoil and surficial soil, acidity and cation exchange capacity (CEC) can be derived • to determine whether soil is suitable for cover material
3. Geology	• Geology map • Aerial photography • Satellite remote sensing	• to determine the existing geological condition such as bedrock and outcropping, continuity and mass permeability, and location of faults.
4. Surface and groundwater hydrology	• Hydrology map • Topographic map • Aerial photography • Satellite remote sensing	• to determine location of unsuitable areas such as streams, lakes, potential or existing wells, flood-prone areas and recharge area (lands draining to existing or planned reservoirs). • to determine area of high aquifer, area with poor natural groundwater quality and direction of groundwater flow.
5. Existing land use	• Land use map • Topographic map • Aerial photography • Satellite remote sensing	• to determine existing land use of the area and later exclude unsuitable areas such as developed land (existing residential or commercial area), special reserve area, or water catchment areas
6. Potential land use	• Potential land use map • Aerial photography • Satellite remote sensing	• to determine area suitable for future land use such as agricultural, urban or natural environmental conservation
7. Road infrastructure	• Road map • Topographic map • Aerial photography • Satellite remote sensing	• to plan suitable route to transport waste • to estimate the cost of constructing new access road from existing road • to estimate the transportation cost (from waste collection to the potential sites)
8. Land ownership	• Cadastral map	• to determine ownership of affected land and hence estimate the cost of land acquisition and compensation

2.5.2 Availability of data for landfill site selection in Malaysia

In the specific context of a procedure for locating new landfill sites, data from different sources are required to enable effective and reliable decisions to be made. Unlike the situation in the Developed Countries such as the USA and the UK, not all data sets for effective land use planning in Malaysia (particularly for landfill siting) are readily available. As indicated in Yaakup (1991), the main problems of implementing GIS as a tool for spatial analysis in Malaysia are lack of appropriate data and obsolescence of data. Most of the maps available in Malaysia are out of date. In addition, much mapped information is not available between departments because of a secrecy of information code. In some cases where information can be obtained, it is difficult to retrieve mainly due to poor maintenance of the record keeping.

Particular acute problems occur in relation to land use data and the absence of large-scale maps (larger than 1:10,000 scale) for detailed assessment of the potential landfill sites. Detailed land use data are considered as classified information, and are not accessible to the public. Even other government organisations find it difficult to access these data. Although general land use maps produced by the Department of Town and Rural Planning and the Klang Valley Planning Secretariat are available to the public, they are not to scale or refer to any map projection. Although these general land use maps were initially traced onto the existing 1:50,000 or 1:63,360 scale topographic maps they were later reduced by photocopy methods without considering the scale of the final product. As these maps are not to scale they cannot be used as a reference layer in GIS.

The Federal Department of Survey and Mapping, Malaysia (DSMM) is the main organisation responsible for producing hardcopy maps (i.e. topographic maps and thematic maps) and supplying aerial photographs to users, while at state level it is responsible for producing cadastral plans. The national mapping programme conducted by the Department of Survey and Mapping, Malaysia, concentrates on producing topographic maps at three major scales only, that is, 1:50,000, 1:25,000 and 1:10,000 (for town areas) scales. Other maps produced by the Department of Survey and Mapping include state maps, report maps, physical maps, political maps and road maps. A list of the maps produced by the Department of Survey and Mapping is given in Table 2.12. Most of these maps were at least 10 years old or were derived from aerial photographs of more than 10 years old and in some cases more than 20 years old.

The Department of Survey and Mapping (both at federal and state levels) is also currently engaged in the digital mapping programmes, that is, Computer Assisted Mapping System (CAMS), Computer Assisted Land Survey System (CALS) and Fast Mapping System (FMS). The CAMS project was undertaken under the Fifth Malaysia Plan (1986-1990) budget and was fully operational in 1990. The objectives of the CAMS project are to expedite map production of the national topographic maps series (L7030 and T738), to contribute to the development of National Land Data Bank, to create and maintain up-to-date and accurate topographic database at 1:25,000 and cartographic databases at 1:25,000 and 1:50,000 scales, and to act as a national cartographic data clearing house. The CALS project was first introduced in 1986 and the aim is help in the construction of state cadastral database. The FMS programme is aimed to produce maps for military applications.

The introduction of these digital mapping programmes has not contributed significantly to the current shortage of digital data for many planning applications. Significant progress in the preparation of digital database (1:50,000 scale) has been made only in the States of Pahang and Johor where 50 and 80 per cent of the state have been mapped respectively. The mapped areas are mostly forests. In other states of the Peninsular Malaysia, less than 10 per cent have been mapped digitally. The digital database for the Klang Valley Region is still under construction. This database is prepared using photogrammetric methods (based on the 1:20,000 aerial photos of 1995 and 1996).

Table 2.12 Maps produced by the Department of Survey and Mapping, Malaysia

Series	Scale
Topographic Maps of Peninsular Malaysia	
• L808 (Kuala Lumpur and the surrounding areas)	• 1:10,000 (restricted)
• L905	• various scales (restricted)
• DNMM 5101	• 1:50,000
• DNMM 6101	• 1:10,000
• DNMM 6102	• 1:25,000
• L 7010	• 1:63,360 (restricted)
• L 7030	• 1:50,000 (restricted)
• L 8010	• 1:25,000 (restricted)
• L 8101	• various scales
Topographic Maps of Sabah and Sarawak	
• L 735	• 1:50,000 (restricted)
• L 738	• 1:50,000 (restricted)
• T 834	• 1:25,000
• T 931	• 1:50,000 (restricted)
• DNMM 5201	• 1:50,000
Other Maps	
• Miscellaneous Town Maps	• 1:25,000 to 1:15,000
• State Maps	• 1:250,000
• Report Maps	• 1:4.500,000 to 1:1,250,000
• Road Maps of States in Malaysia	• 1:1,700,000 to 1:150,000
• Physical Maps	• 1:760,000 to 1:500,000
• Political maps	• 1:2,000,000 to 1:25,000
• Non-restricted topographical maps of Malaysia	• 1:50,000
• Non-restricted town maps of Peninsular Malaysia (Series L 5101)	• 1:10,000 to 1:3,000 (very limited coverage)

Beside producing maps (both in hardcopy and digital format), the Department of Survey and Mapping is also responsible for supplying aerial photographs to the user. The whole of Malaysia is covered with 1:40,000 scale aerial photographs. Most town areas in the Peninsular Malaysia are covered with a larger scale aerial photographs, that is 1:20,000 scale. Within the Klang Valley Region, extensive aerial photo coverages of different scales were available. The photo scales range from 1:5,000 to 1:24,000. In areas where there are no recent aerial photo coverage, request for new aerial photos can always be made to the Department of Survey and Mapping.

Recently, private surveying companies such as Geomatic Data Services and Jurukur Teguh are also actively involve in supplying aerial photographs to the general public.

Beside the Department of Survey and Mapping there are other government organisations which are responsible for producing and updating different data sets. Among them are the Department of Town and Rural Planning, the Geology Department, the Agriculture Department and the Malaysian Centre for Remore Sensing (MACRES). Most of the maps produced by these department are out-of-date. Even within the Klang Valley Region, where map revision (for topographic or town maps) is frequently carried out, most of the maps were found to be more than 10 years old.

The State Department of Town and Rural Planning is responsible for updating detailed land use maps and zoning maps. These maps were manually traced onto the base map, which are initially prepared from the 1 inch to 8 chain cadastral plans. The Geology Department produces geology maps and hydro-geological maps. Both of these maps for the Klang Valley Region are more than 20 years old. The Agriculture Department is responsible for producing land use classification maps, agroclimatic maps, erosion risk maps and soil classification maps. According to Mansor (1994), soil maps are published at various scales, that is, 1:500,000 to 1:250,000 scale for reconnaissance soil survey, 1:63,360 to 1:25,000 scale for semi-detailed soil survey and 1:10,000 to 1:5,000 scale for detailed survey. As of 1994, there is only very limited soil map coverage at scales larger than 1:25,000.

Digital satellite remote sensing data for both LANDSAT Multispectral (MSS) and Thematic Mapper (TM), SPOT (panchromatic and multispectral) can be bought from the Malaysian Centre for Remote Sensing (MACRES) in the form of tapes or diskettes at minimal price. The centre has sufficient funds to acquire LANDSAT digital data for the whole of the country annually. Stereo-SPOT and SPOT panchromatic imagery for some areas (including small areas of the Klang Valley Region) in Malaysia can also be acquired from MACRES.

A summary of the responsible data related agencies, their map products and scales of various maps/photos produced is given in Table 2.13.

2.6 Issues related to the use of mapping and spatial analysis technology in Malaysia

Although the idea of having a system which relates spatial and non-spatial data was first recognised by the Federal Land Administration Department back in the early 1970s (Kamaruddin, 1974), the first GIS was only installed in Malaysia in 1984. Until recently, there have been very limited studies on the usage in Malaysia. Rusmani (1987) carried out the earliest comprehensive study to the various government departments directly involved in managing and handling of geographical information. Most of the organisations interviewed were aware of the importance of GIS to their organisations. Another comprehensive study was carried out by MARA Institute of Technology (Ahmad, 1991). One of the main findings of this study is that there were no proper organisational structures being laid out for the GIS section. Most of the GIS sections were either placed under planning or computer section. A similar trend was also observed during the author's visit to some of the government organisations listed in Appendix B2.

Since the introduction of GIS in the Department of Agriculture many other government organisations such as the Department of Environment, the Klang Valley Planning Secretariat, MACRES, the Forestry Department, the Geology Department, the Agriculture Department, the Shah Alam Municipality, the Petaling Jaya Municipality, the Klang Municipality and Kuala Lumpur City Council have installed GISs. As reported in Ramly (1995), there were more than 100 GIS installation sites in the Peninsular Malaysia. A brief survey carried out by the author has found that there are more than 20 GIS installationswithin the Klang Valley alone. List of organisations which have installed GIS are given in Table 2.14

Table 2.13 Major contributors of data in Malaysia.

Agency	Typical data	Map/photo scale
State Planning Department	• Detailed land use maps * • General land use and zoning map	• 1 inch to 8 chains or 1:6,336) • not to scale
Federal Department of Survey and Mapping	• Aerial photographs - Both monochrome and colour aerial photographs are available for the Klang Valley Region • Hardcopy Maps • Topographic maps • Thematic maps • Digital data	• 1:5,000 (special request for civil engineering projects); 1:8,000; 1:10,000; 1:20,000; 1:24,000 (this variable photo scale only applies to Klang Valley Region) Refer explanation in Table 2.12 • Digitised from existing topographic maps 1:50,000 (some areas in the Klang Valley Region, Pahang, Johor and other states of the Peninsular Malaysia • New digital database for The Klang Valley Region is still under construction
State Department of Survey and Mapping	• Cadastral maps	• 1 inch to 8 chains • digital data (spatial data only) of certain developed areas within the Klang Valley Region such as part of Petaling Jaya and Subang Jaya are also available
Geology Department	• Geological maps • Hydro-geological maps	• 1:63,360 • 1:250,000 • large scale geology maps of certain area are also available
Department of Agriculture	• Soil Map • Land use maps • Agroclimatic maps • Erosion risk maps	• 1:250,000 to 1:50,000 (reconnaissance) • 1:50,000 to 1:25,000 (semi-detailed) • 1:10,000 to 1:5,000 (detailed) • compiled at 1:50,000 but published at varying scale • 1:250,000, 1:500,000 and 1:750,000 • 1:1,000,000 •
Malaysian Centre for Remote Sensing	• LANDSAT and SPOT satellite digital data and imagery	• Digital data • extensive LANDSAT coverage for the whole country but very limited SPOT coverage (only cover some part of the Klang Valley Region)

Note: * not available to public or other government organisations

Table 2.14 List of some of the government organisations which have installed GIS

Federal level
Department of Agriculture
State Department of Survey and Mapping
Statistic Department
Department of Forestry
Geology Department
Town and Rural Planning
Department of Environment
Economic Planning Unit, Prime Ministers Department
Public Works Department
Regional level
Klang Valley Secretariat
State level
Selangor State Economic Planning Unit
Selangor State Town and Urban Planning
Municipal level
Petaling Jaya Municipality
Shah Alam Municipality
Klang Municipality
Kuala Lumpur City Council
Academic/research Institution
University of Malaya
National University of Malaysia
MARA Institute of Technology
University of Technology, Malaysia
University Putra Malaysia
Forest Research Institute
Malaysian Agriculture Research and Development Institute (MARDI)

Although GIS has been widely accepted in many government organisations, its current applications are restricted mainly to automated mapping and inventory tasks which is considered as a component task of GIS, rather than the complete system Only in organisations such as the Department of Agriculture, Department of Environment and Forestry Department the analysis capabilities of GIS were utilised. As mentioned earlier, the function of GIS within the Department of Agriculture is mainly to produce land use maps, soil maps, land use suitability maps, erosion risk maps and agroclimatic maps. The Department of Environment uses GIS as an Environmental Decision Support System.

Currently, the data acquisition method adopted by most government organisations using GIS is to digitise from existing maps. Only in some large organisations (not including academic institution and research institute), such as the Department of Environment, the Forestry Department and the Department of Agriculture, satellite remote sensing data were utilised. In Malaysia, digital photogrammetric techniques are only utilised within the Department of Survey and Mapping for rapid production of maps for military applications. In small organisations (local authorities), topographic maps and cadastral plans produced by the Department of Survey and Mapping are considered as the major data sources for the GIS. To most of the personnel involved in GIS, the concept of the digital photogrammetric workstation is a totally new technology to them, but most have expressed their interest in this new technology because of its capability to generate DEMs and orthoimages automatically.

Since local authorities or planning authorities are not responsible for any mapping or map making tasks, they have to rely heavily on maps produced by other government organisations although most of the maps are out-of-date. The data acquisition methods used in some organisations are summarised in Table 2.15. The main problems of adopting more modern data acquisition techniques such as remote sensing and photogrammetry are due to two main reasons, i.e. budget constraints and lack of skilled personnel. In most GIS set-ups, the only budget consideration given is on the cost of acquiring hardware and software. Most organisations do not have any mapping personnel. Most of the personnel involved in GIS are from planning and computing educational backgrounds.

Table 2.15 Method of data acquisition

Organisation	Digitising	Scanning	Remote Sensing	Ground Survey	Photo-grammetry	Others (digital data from DSMM)
Shah Alam Municipality	✓	-	-	-	-	✓
Klang Municipality	✓				-	✓
Petaling Jaya Municipality	✓				-	
Selangor State Town and Rural Planning	✓				-	
Selangor State Economic Planning Unit	✓				-	✓
Department of Environment	✓		✓		-	✓
Statistic Department	✓				-	
Geology Department	✓		✓		-	
Agriculture Department	✓		✓		-	
Forestry Department	✓		✓		-	

In terms of software used, smaller organisations such as the Shah Alam Municipality, Klang Municipality, Petaling Jaya Municipality used PC-base GIS software. Among the most popular software are Arc/Info and Mapinfo. In large organisations such the Department of Environment, Department of Agriculture, Geology Department and Forestry Department the more powerful UNIX-based software (i.e. Arc/Info for workstation) are utilised. In these organisations digital image processing software such as Erdas Imagine is also used to process satellite remote sensing and radar data. Refer to Table 2.16 for the list of hardware and software used in various organisations.

Table 2.16 GIS hardware, software and its applications within government organisations

Organisation	Hardware	Software	Other software	Applications
Shah Alam Municipality	PC Digitiser HP750 plotter	MapInfo Genamap (PC)	Oracle Dbase AutoCAD	Inventory
Klang Municipality	PC Scanner Plotter Printer	PC Arc/Info ArcView	-	Inventory (not fully operational)
Petaling Jaya Municipality	PC	REGIS	AutoCAD	Inventory (not fully operational)
Selangor State Town and Rural Planning	PC	TerraSoft		Mainly for producing planning maps
Selangor State Economic Planning Unit	PC	MapInfo	-	Producing maps and providing digital data related to planning to local authorities (initial stage of implementation)
Department of Environment	HP workstations	Arc/Info version 7(workstation) PC Arc/Info	-	Mapping and spatial analysis (Fully operational)
Geology Department	Workstation (HP9000) Digitiser Plotter	Arc/Info workstation PC Arc/Info ArcView Erdas Imagine	Oracle Dbase AutoCAD	Mapping and inventory

Continue next page.......

.......continued

Agriculture Department	HP workstation PC	Arc/Info PC Arc/Info ArcView (Unix and PC) Oracle 7 database Edras Imagine	Dbase Oracle	Mapping and spatial analysis (Fully operational)
Forestry Department	HP workstation PC	Arc/Info PC Arc/Info ArcView (Unix and PC) Edras Imagine	Oracle Dbase	Mapping and spatial analysis (mainly for forestry research)
Forestry Research Institute of Malaysia (FRIM)	PC Digitiser Scanner Plotter	PC Arc/Info IDRISI and TNT Mips digital image processing software	AutoCAD Dbase	Mapping and spatial analysis (mainly for forestry research)
Public Works Department	PC Plotter Digitiser	PC Arc/Info ArcView (Unix and PC) Oracle 7 database Edras Imagine	Oracle Dbase	Mapping and spatial analysis (mainly for forestry research)

2.7 Summary and conclusions

Although there are legislation and guidelines related to waste management in Malaysia, there is no national waste management policy which could tie together all this legislation and these guidelines. In many local authorities, waste disposal practices are still governed by the philosophy, 'out of sight, out of mind'. Most of the existing waste disposal sites within the Klang Valley Region are located in unsuitable areas and are operating beyond their capacity limits. With the amount of solid waste generated increasing yearly and the decreasing land areas suitable for landfilling, a better management, especially in terms of locating new waste disposal sites which are environmentally, socially and economically acceptable is urgently needed.

A number of studies carried out in Malaysia have recommended the use of a regional stage-by-stage approach using various siting criteria as practised in the USA and Canada for locating new landfill sites. The implementation of such an approach requires various data sets. GIS seems to be a suitable alternative as many government organisations including local authorities have been using GIS for other applications. The main problem of implementing this approach is the lack of appropriate data.

It is not easy to introduce remote sensing and photogrammetry in small government organisations because these organisations do not have skilled mapping personnel and operate within limited budgets. With the availability of extensive aerial photo coverage and satellite remote sensing data within the Klang Valley Region there is always a possibility of introducing new mapping techniques such as low-cost digital photogrammetric to small government organisations in Malaysia.

CHAPTER 3

AN OVERVIEW OF GIS AND DIGITAL PHOTOGRAMMETRIC TECHNOLOGY

3.1 Introduction

This chapter is intended to give an overview of GIS and digital photogrammetric technology. The first section starts by defining GIS, the development of GIS and its applications. Discussions on digital photogrammetry will concentrate on digital photogrammetric systems and a review of previous studies on the accuracy assessment of digital photogrammetric products. The following section describes image scanners, an important component of a complete digital photogrammetric system. A review of previous studies on the accuracy assessment of image scanners will also be given.

Detailed descriptions of the components and the capabilities of a specific GIS and DPW used in this study will be given in Chapter 4. Descriptions of image scanners used in this study will be given in the following chapter (i.e. Chapter 5).

3.2 Geographical Information System (GIS)

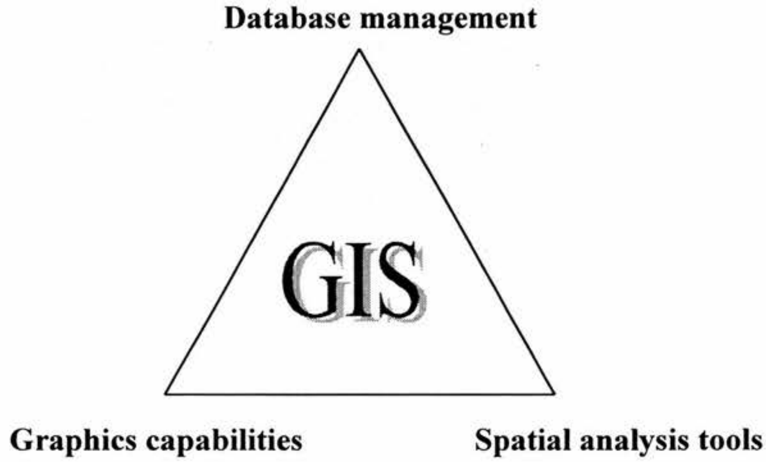
A review of the GIS literature has identified several different definitions of GIS. Among the definitions given by different authors are:

A powerful set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world for a particular set of purposes. (Burrough, 1988)

A system which comprise not only sophisticated computer software, but also contains the following major components: i) data input subsystem, ii) data storage and retrieval subsystem, iii) data manipulation and analysis subsystem and iv) data reporting subsystem. (Marble, 1990)

From the above two definitions, GIS can be considered as a computer system (hardware and software) which serve as tools to capture or collect, store, retrieve, integrate, manipulate, analyse and display spatial and non-spatial data. Other authors (ESRI, 1993; Dueker and Kjerne, 1989) expand the above definitions to include data, people and the organisational set-up. Based on diverse GIS definitions given in different literatures, Peuquet and Marble (1990) classified the definition of GIS into four main approaches: the process-oriented approach, the application approach, the toolbox approach and the database approach. The Australian Institute of Spatial Information System Technology (AISIST) also defines GIS into four main approaches: the system approach, transformation approach, integration approach and modelling approach (AISIST, 1993).

According to Peuquet and Marble (1990), GIS was first introduced in the middle of the 1960s by government agencies as a response to a new awareness and urgency in dealing with complex environmental and natural resource issues. Many early GIS developments failed due to poor computer system design and limited hardware capabilities to meet the users' needs. Substantial improvement in computer systems during the last three decades, especially in ten years has made it possible for large volumes of spatial data to be stored, manipulated and analysed. GIS rely on the integration of three main distinct aspects of computer technology: database management (spatial and non-spatial data): routines for manipulating, displaying and plotting graphics representations of the data; and algorithms and techniques that facilitate spatial analysis (Antenucci *et al.,* 1991). The three aspects of GIS are shown in Figure 3.1.



(Antenucci *et al.,* 1991).

Figure 3.1 Aspects of GIS

GIS has been widely recognised as a powerful tool for managing spatial data. With its inherent capability to store, manage, manipulate and present spatial data, GIS technology is increasingly preferred in many applications. As mentioned earlier, GIS can play the following role: as an intelligent database, as a tool for modelling spatial information, as a tool for spatial analysis, as a tool for visualisation and as a tool for system integration.

Generally software packages for GIS consists of four basic subsystems. These subsystems are: data input subsystem, data storage and retrieval subsystem, data manipulation and analysis subsystem and data reporting subsystem. A brief description of the subsystems are given below.

a. Data input subsystem

All GIS provide facilities to collect and/or process both spatial and non-spatial data derived from other data sources. These data can be entered into the system by any of the following methods:

- direct digitising from existing hardcopy maps
- buying commercially available digital data (e.g. United States Geological Survey and Ordnance Survey digital data)
- converting an ASCII-formatted file from other system (e.g. digital photogrammetric system)
- scanning existing maps/images
- scanning hardcopy document
- converting digital data (vector or raster) from other formats (e.g. DXF, SIF, LAN, TIFF or PCX)
- reading ground survey data (e.g. total station and Global Positioning System - GPS) from a data file

b. Data storage and retrieval subsystem

The data storage and retrieval subsystem organises the spatial data in suitable format for further manipulation and analysis. Data updating and editing of the spatial database can be carried out within this subsystem.

c. Data manipulation and analysis subsystem

The data manipulation and analysis subsystem allows a variety of operations such as converting the spatial data into different forms and performing spatial analysis. This subsystem allows user to query and obtain solution/s to particular questions. Spatial operations in a GIS involve adjacent maps merging, creating buffer zones and polygon overlays. In a more sophisticated GIS, surface (3D) analysis and network analysis can be carried out.

d. Data reporting system

The data reporting subsystem is capable of displaying all or part of the original databases as well as performing data manipulation. The output can either be displayed on screen, printed as tabular data, written to a graphics file or plotted as hardcopy maps.

Hanigan (1988) identifies the use of GIS into twelve main categories, that is business applications, real estate information management, renewable resources management, surveying and mapping, transportation and logistics, urban and regional planning, research and education, infrastructure development, election administration and redistricting, map and database publishing, public health and safety and oil, gas and mineral exploration. A practical approach as suggested by Cowen (1990) is to classify the applications of GIS into four main groups:

- street network applications (e.g. address matching, location analysis, development of evacuation plans, and bus routing and scheduling),
- natural resource applications (e.g. environmental impact analysis, groundwater modelling, facility siting and wildlife habitat analysis),
- facility management applications (e.g. locating underground cables and pipes, planning facility maintenance and tracking energy use),
- land parcel applications (e.g. maintenance of ownership records, land acquisition and subdivision plan review).

Although GIS can be used for a wide range of planning and decision making applications, the principle is the same: GIS is able to support planning and decision making with powerful inventory, analysis, modelling and presentation functions

(Juppenlatz and Tian, 1996). Examples of GIS applications can be found in numerous GIS literatures.

As of 1993 there are nearly 300 different kinds of "GIS" software packages and related service software commercially available in the world (GIS World, 1993). These GIS software run on various operating systems such as Unix, DOS/Windows, Macintoch, WindowsNT, OS 2 and VMS. A list of some of the software running under different operating systems is given in Table 3.1. An important criterion that differentiates simple GIS software from a sophisticated one is the type of questions it can answer. ESRI (1993) has outlined five generic questions a sophisticated GIS can answer. These questions are summarised in Table 3.2.

Table 3.1 List of GIS software

UNIX	Dos/Windows	Machintosh	WindowsNT	OS2	VMS
Arc/Info	PC Arc/Info	Grass	InfoCAD	MapInfo	Arc/Info
ArcView	Atlas-GIS	MacGIS	Intergraph MGI	SPANS	Laser-Scan
Erdas Imagine	Idrisi	MapInfo	SiCAD		
Genamap	Ilwis	MACMAP	SmallWorld		
Grass	ArcView	MAPGRAFIX	WinGIS		
InfoCAD	MapInfo				
Intergraph MGI	PC MOSS				
Laser-Scan	OpenGIS				
MapInfo	PMAP				
MOSS	PaMap				
OpenGIS	SPANS				
PaMAP					
Regis					
SiCAD					
SmallWorld					
SPANS					
System 9					

(Source: Valentine, 1996)

Table 3.2 Generic questions a sophisticated GIS can answer.

Location	What is at....? • What exists at a particular location. Location can be described in many ways e.g. place name, a post code or geographical reference, such as latitude or longitude.
Condition	Where is it? • Typical question - where is unforested section of land at least 2,000 sq. m in size within 100 m of a main road and with soil suitable for agriculture.
Trends	What has changed since.....? • The third question might involve both of the first two and seeks to find differences within an area over time.
Patterns	What spatial patterns exist? • This pattern is more sophisticated. You might ask this question to determine whether cancer is a major cause of death among residents near nuclear power station. Just as important, you might want to know how many anomalies there are that don't fit the pattern and where they are located.
Modelling	What if....? • "What if..." questions are posed to determine what happens, for example, is a new road is added to a network, or if a toxic substance seeps into the local groundwater supply. Answering this type of question requires geographic as well as other information.

(Source: ESRI, 1993)

3.3 Digital photogrammetry

Photogrammetry is the technique of obtaining precise three dimensional measurements from overlapping stereo imagery. Since its introduction, photogrammetry has undergone four main phases of development (i.e. analogue, numerical, analytical and digital). In analogue photogrammetry no automation in the modern sense is involved. Measurement and drafting are done manually by human operator (Madani, 1992). The second and third phases of the development (numerical and analytical) began in the early 1950s with the advent of computers. Analytical plotter was first introduced at the ISPRS Congress in

1976. Developments in computers and sensor/scanner technology have significantly transformed photogrammetry from a purely analogue to a fully digital method. Although digital photogrammetric workstations were only introduced in the late 1980s, the idea of digital photogrammetry began as early as the 1950s when Hobrough began experimenting with correlation (Schenk, 1988). Among important factors that have affected the development of digital photogrammetry are:

- the availability of powerful computer hardware that can speed up digital processing,
- the ever-increasing availability of digital data from satellite sensors, Charged Couple Diode (CCD) cameras and scanners (Madani,1992), and
- the lack of skilled photogrammetric operators and high-cost photogrammetric equipment (Madani, 1992).

The introduction of digital photogrammetry has brought many changes in terms of the characteristics of photogrammetry. In analogue photogrammetry, the input is hardcopy aerial photographs (diapositives), stereomodel set-up is done manually in the stereoplotter and the output is hardcopy maps. In numerical photogrammetry, the input is also hardcopy aerial photographs. Although computation for the stereomodel set-up is done numerically, the model set-up is still done manually. The output is either in hardcopy form or in digital format. Like analogue and numerical photogrammetry, the analytical methods also use hardcopy aerial photographs as the input to the stereoplotter. The stereomodel set-up is done with the assistance of digital computers. In digital photogrammetry all the three components (input, model and output) are in digital format. The digital (soft) characteristics of digital photogrammetry bring greater flexibility in terms of data input, data manipulation and data output. The change of the characteristics of photogrammetry (analogue, numerical, analytical, and digital) as described by Li *et al.* (1993) is summarised in Table 3.3. An important criterion to differentiate digital photogrammetry with analogue, numerical or analytical photogrammetry is the input to the system is in digital format (either from SPOT satellite data, CCD cameras or scanned aerial photographs) instead of hardcopy aerial photographs or diapositives. High-resolution imagery (image resolution of less than 3 metres) from new satellite such as EarlyBird, QuickBird, CRSS, OrbView and Resource-21 can also be potential data sources(refer to Table 3.4)

Table 3.3 The characteristics of photogrammetry at different stages of the development

Stage of development	Input component	Model component	Output component	Degree of "hardness"	Degree of flexibility
Analogue	Hard	Hard	Hard	3	0
Numerical	Hard	Hard	Soft	2	1
Analytical	Hard	Soft	Soft	1	2
Digital	Soft	Soft	Soft	0	3

(Source: Li *et al.,* 1993)

Table 3.4 Major new data source

Satellite	Owner/Operator	Launch date	Sensor/resolution
EarlyBird	EarlyWatch (US)	1997	Pan/MSS (3m/16m)
Clark	CTA/NASA (US)	1996	Pan/MSS (3m/15m)
QuickBird	EarthWatch (US)	1997	Pan/MSS (1m/4m)
CRSS	Space Imaging (US)	1997	Pan/MSS (1m/4m)
OrbView	OrbImage (US)	1997	Panchromatic(1m)
Resource-21	R-21/Boing (US)	1997	Pan/MSS (3m/10m)

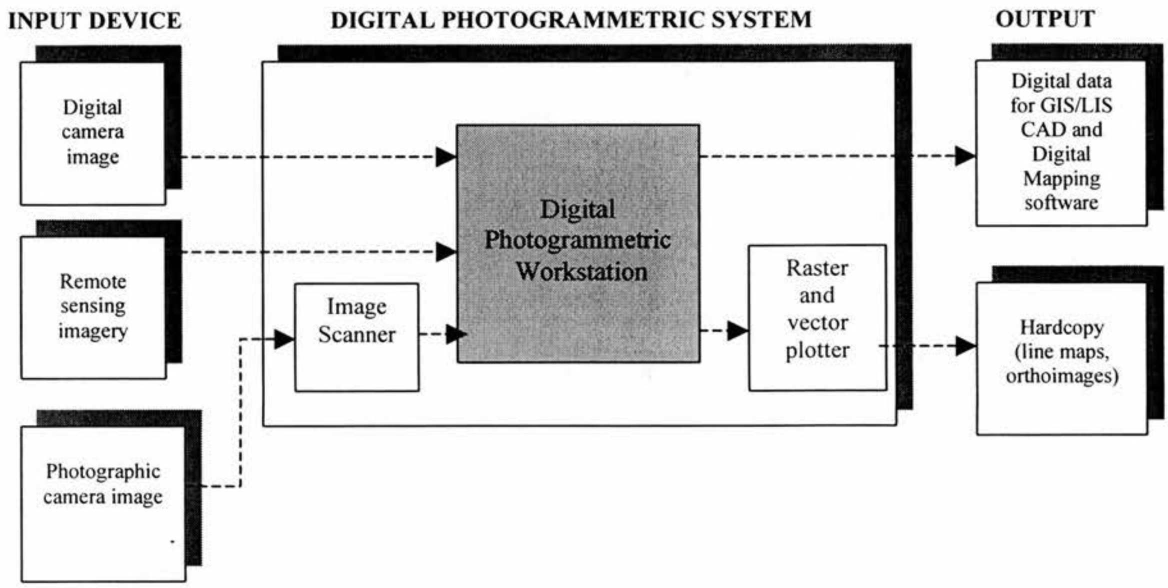
(Source: Adapted from Plangraphics, 1998)

3.3.1 Digital photogrammetric system

Digital photogrammetric system (DPS) is fully based on photogrammetric software and runs on standard computer hardware (with additional viewing system) and software. A complete DPS (refer to Figure 3.2) consists of the following subsystems:

- Digital Photogrammetric Workstation (DPW)
- Image scanner (analogue to digital converter)
- Hardcopy device e.g. printer and plotter (digital to analogue converter)

The following section will discuss the two earlier DPS subsystems, i.e. DPW and image scanner.



(Source: Adapted from Heipke, 1995 and Petrie, 1997)

Figure 3.2 Overall concept of the digital photogrammetric system

A. Digital Photogrammetric Workstation (DPW)

Digital Photogrammetric Workstation (DPW) is the main component of a complete DPS and consists of two components: hardware and software system to support all the photogrammetric operations. According to Welch (1992), a DPW is not only designed to perform the measurement functions of an analogue or analytical plotter but also to allow the operator to perform the following functions:

- to integrate image and map data in raster and vector formats,
- to edit data that has been collected,
- to implement image-processing functions such as contrast enhancement, edge sharpening, change detection, vector on raster overlay,
- to interface with GIS software for overlay analysis and modelling applications,
- to automatically generate DEMs and display data in perspective and plan view, and
- to produce orthoimages and orthoimage mosaics.

The main hardware components of a DPW include a computer with storage device, stereo-viewing system, pointing and measuring device. The two most commonly used computer platforms are workstations and PCs. As a DPW deals with large image data and functions as a measuring device, the graphics workstation needs to have a powerful processor and large memory, large data storage, additional processors (in some workstation) to accelerate heavy computation such as auto-correlation to automatically generate DEMs. Different DPWs adopt one of the following stereoviewing techniques:-

- twin monitor technique (e.g. Galileo/Sicam Stereodigit)
- split screen technique (e.g. GeoSystem Delta WS, Leica DVP and PRI^{2}SM)
- anaglyphic technique (e.g. R-WEL DMS and MicroImage TNT-MIPS)
- alternating shutter technique (e.g.Intergraph Image Station, AMSA DC, ISM DiAP, ERDAS Orthomax, VirtuoZo and Zeiss PHODIS)
- polarising filter technique (e.g. Helava 750/770 and Matra Traster)

With the rapidly increasing interest in GIS and the use of digital images, firms such as I^{2}S, Intergraph, Helava, Carl Zeiss, Leica, R-Wel and others are entering the DPW market. Most of the currently available DPWs were designed around RISC architecture computer workstations running under a variety of the UNIX operating system. Examples of these workstation-based DPWs are Imagestation of Intergraph, Helava and DPW of Leica, Matra Traster T10, VirtuoZo and Zeiss Phodis ST. With the advent of powerful PCs, a number of firms have introduced PC-based DPWs with somewhat lower measurement accuracy and slightly less speed at a much lower cost (Welch, 1992). Typical examples of such systems are Desktop Mapping System (DMS) from R-Wel and Digital Video Plotter (DVP) from Leica. Other digital photogrammetric workstations such as the ERDAS OrthoMAX and PCI EASI/PACE are based on the digital image processing system. A list of currently available DPWs in the market is given in Table 3.5.

Table 3.5 Digital Photogrammetric Workstation

Digital Photogrammetric Workstation based on UNIX OS			
Type	**PRI^{2}SM**	**Zeiss PHODIS ST**	**Helava 750/770**
Hardware Platform	SUN Workstation	Silicon Graphics	Sun Sparc
Stereoviewing system	Split Screen	Alternating shutters	Polarising filter
Measuring system	Info N/A	3-D cursor	Trackball
Type	Matra Traster T10	Intergraph IMD	VirtuoZo
Hardware Platform	Sun Sparc	Intergraph 6000	Silicon Graphics
Stereoviewing system	Polorising filters	Liquid crystal shutters	Alternating shutters
Measuring system	Trackball	3-D cursor	Mouse

Digital Photogrammetric Workstation based Digital Image Processing System			
Type	**PCI EASI/PACE**	**ERDAS Orthomax**	**MicroImage TNT-MIPS**
Hardware Platform	Sun/SGI/PC	Sun/SGI	PC
Stereoviewing system	None	Alternating shutters	Anaglyph
Measuring system	Mouse	Mouse	Mouse

Digital Photogrammetric Workstation based on PCs running on DOS and/or Windows				
Type	**AMSA DC**	**GeoSystem Delta WS**	**Intergraph Image Station**	**Galileo/Siscam Stereodigit**
Stereoviewing system	Alternating shutters	Split screen	Alternating shutter	Twin monitor
Measure	H/F wheels	H/F wheels	3D cursor	Mouse
Type	AMSA DC	GeoSystem Delta WS	Intergraph Image Station	Galileo/Siscam Stereodigit
Stereoviewing system	Alternating shutters	Split screen	Alternating shutter	Twin monitor
Measuring system	H/F wheels	H/F wheels	3-D cursor	Mouse

Type	**R-WEL DMS**	**ISM DiAP**	**Leica DVP**
Stereoviewing system	Anaglyph	Alternating shutters	Polarising filters
Measuring system	Mouse	3d cursor	3D cursor
Type	R-WEL DMS	ISM DiAP	Leica DVP
Stereoviewing system	Anaglyph	Alternating shutters	Split Screen
Measure system	Mouse	3-D cursor	3-D cursor

(Source: Adapted from Petrie, 1997)

Software is the heart of a DPW. To enable a DPW to function as a stereoplotter the basic software in a DPW must be able to reconstruct and orientate a stereomodel and view stereoscopically. Other basic functions include project and image management system, control of image and floating mark display and movement (zooming, windowing, scrolling and panning); stereoscopic superimposition of graphics on image and mensuration (Stefanovic, 1996). Other more powerful software available in a DPW are automatic DEM collection, orthoimage and orthoimage mosaic generation. Some powerful systems allow automatic aerial triangulation and model orientation to be performed.

B. Digital photogrammetric products and their accuracy

The flexibility of a DPW has opened the door to new products (e.g. high resolution DEM and orthoimages), which traditional methods not produce cost effectively in the past. The production of DEM and orthoimage in a DPW can either be carried out semi-automatically or automatically. The semi-automatic or automatic production of DEM and orthoimage has provide great advantages in comparison to their analogue counterpart especially in terms of their production speed and flexibility of output. Since these products are in digital format they can readily be input in a digital mapping software or GIS.

A DEM represents the shape of the earth's terrain in digital format. The DEM has proven to be a valuable part of the digital map database in a GIS especially for land management and planning applications. DEMs in GIS can be stored either as a grid of elevations or a triangulated irregular network (TIN). DPW produces DEM in a regular raster format. Since a DEM contain no structured information or topology it can be almost directly input into a GIS (Han, 1994). The automatically DEM generated in a DPW can be used to generate slope and aspect maps, perspective views, contour maps and perform modelling and surface analysis such as run-off modelling to trace the path of surface water, volumetric analysis and inter-visibility analysis.

A digital orthophoto or orthoimage is a scanned aerial photograph fully rectified to remove all the distortion which occurs in the original image such as the pitch and roll of the aircraft, camera distortion, and image displacement due to terrain height variation. The removal of these distortion elements results in the true scale representation on the ground (correct distance, area and azimuth). Beside this, orthoimages contain the images of an infinite number of ground objects which can be identified (Dall, 1990).

Orthoimages lay the foundations for new methods of data acquisition. This product can be used by the GIS user to create or update a digital topographic database (through on-screen monoscopic digitising) in his GIS environment, a task which is usually done by the specialised photogrammetrist. Other applications of orthoimages in GIS are for geometric or semantic quality control of vector or raster data (Baltsavias, 1996) and change detection applications (Dall, 1990).

The accuracy of automatically generated height points are influenced by a number of factors, such as scale of the photographs, the quality of photography, the geometric and radiometric quality of scanners, the scanning resolution, the accuracy and configuration of ground control points to orientate the stereoimage and the accuracy of algorithms to perform autocorrelation (to generate height points). The quality of DEMs depends on the height accuracy of individual points and the density of observation (Han, 1993). Since the density of observation can be easily set in a DPW, the production of high-density height observations is not a problem any more. According to Dall (1990), the accuracy of the orthoimage is influenced by three major factors, which are, the quality of ground control surveys, the density of DEM collected and the number of lines per inch at which the positive is scanned, that is, the scanning resolution.

A review of previous studies on the geometric accuracy assessment of digital photogrammetric products using aerial photographs as described by Gagnon *et al.* (1990), Boniface (1992), Nolette *et al.* (1992), Zhang and Wu (1993), Finch and Miller (1994), Miller (1995), Nale (1995), and Drummond *et al.* (1997) indicates that these papers concentrate on three major aspects, that is, planimetric and height accuracy of stereomodel measurements, geometric accuracy assessment of automatically generated DEMs and geometric accuracy assessment of automatically generated orthoimages. The results of some of the earlier studies using different DPWs are given below.

Gagnon *et al.,* (1990) reported on a test carried out on the Digital Video Plotter (DVP), a PC-based DPW. A pair of 1:6,000 scale aerial photographs taken with a 50 UAG objective Wild camera was used in this test. Aerial photographs were scanned using a HP Scanjet DTP scanner at 300 dpi resolution. A total of 19 well-distributed X, Y, Z ground points known to the nearest 1 cm and materialised 30 by 30 cm targets were used to analyse the planimetric and height accuracy. Of these 19 points, 9 were used as control points and 10 used as check points. The r.m.s.e. in terms of X, Y, Z for the control points were ± 0.23 m, ± 0.32 m and ± 0.08 m for control points while for the check points the r.m.s.e. were ± 0.25 m, ± 0.51m and ± 0.22 m.

Another test using DVP was carried out by Nolette *et al.* (1992). Five stereomodels at scales ranging from 1:5,000 to 1:40,000 were used. All the photographs used were scanned at 450 dpi resolution. The results, expressed in microns at photographic scale, are summarised in Table 3.6.

Table 3.6 Accuracy of the DVP, scanning at 450 dpi

		R.m.s.e. at the check points		
Model	Photographic Scale	Planimetric (μm)	Height (μm)	No. of check points
1	1 : 6,000	34	35	14
2	1 : 6,000	40	34	17
3	1 : 6,000	45	35	12
4	1 : 5,000	42	42	33
5	1 : 40,000	50	33	44
Mean		42	36	

(Source : Nolette *et al.* (1992)

Boniface (1992) reported the results of planimetric and height accuracy of stereomodel obtained from the PRI^{2}SM system using large-scale (1:3,000) aerial photographs. Three models were tested. Scanning was carried out using Optronics C4100 SP scanner (10 x 10 format) at 25 micron scanning resolution. Thirty seven check points were used. The planimetric accuracies (r.m.s.e.) obtained in terms of X and Y were ± 0.28 feet (0.08 m) and ± 0.39 feet (0.12 m) respectively. The heighting accuracy (r.m.s.e.) was ± 0.33 feet (0.10 m).

In Zheng (1993), automatically generated DEMs were compared against manual measurement of height points the Planicomp C100 analytical plotter. A pair of 1:10,000 scale photographs was used. A total of 900 height points were compared and a standard deviation of ± 0.207m was obtained.

Zhang and Wu (1993) reported the results of two tests carried out on the WuDAMS Version 3.0 DPS. The first test was carried out using four models of aerial photographs taken with Wild RC-8, with camera focal length of 210.23 mm and photo scale of 1:10,000. The aerial photographs were scanned at 50 microns resolution. In this test 45 check points were all measured by field surveying methods. The height accuracy of DEM

± 0.78 m or ± 0.37 m/1000 m flying height. The second test was carried out in the Loess Plateau, an area which is well known for its deep deposits and wide distribution of loess and which is considered as a very difficult region for mapping. Aerial photographs of 1:50,000 scale with camera focal length 152.77 mm were used. A total of 1225 manually observed and automatically generated height points were compared. The height accuracy of ± 3.7 m was obtained.

Finch and Miller (1994) reported the results obtained from a study carried out in the South-east Grampian region. The study area is a low lying area, relatively level agricultural land in the south and heather and peatland hill moorland in the north. The ERDAS digital ortho module was used. Accuracy assessment of images scanned in HP Scanjet Plus A3 format scanner at three different scanning resolutions, that is, 75, 150 and 300 dpi, was carried out. A pair of 1:24,000 scale panchromatic aerial photographs was used. The results obtained from this test are as follows (refer to Table 3.7).

Table 3.7 Planimetric and height accuracy of a stereomodel

Scanning resolution (dpi)	R.m.s.e. X coord (m)	R.m.s.e. Y coord (m)	R.m.s.e. Z coord (m)
75	8.17	3.10	5.42
150	7.74	6.98	3.08
300	7.24	6.92	2.08

(Source: Adapted from Finch and Miller, 1994)

The accuracy assessment of automatically generated DEM was made by comparing heights with those shown on a 1:10,000 Ordnance Survey (OS) map. Height accuracies of ± 5 m and ± 10 m were obtained from images scanned at 300 dpi and 150 dpi respectively. The planimetric accuracies of the generated orthoimages were found to be ± 3.3 m and ± 5.7 m using two different sets of control derived from 1:2,500 and 1:10,000 scale OS maps respectively.

Miller (1995) reported the results obtained from a test carried out to determine the planimetric and height accuracy of a stereomodel using 1:24,000 scale panchromatic aerial photographs on the ERDAS Orthomax DPS. The camera focal length was 152 mm. Scanning of aerial photographs was done using an AGFA A3 format DTP scanner at 1,200 dpi resolution. The control and check points used in this test were obtained from land survey methods using either theodolites and Electronic Distance Measurement (EDM) or Global Positioning System (GPS). The results obtained are summarised in Table 3.8.

Table 3.8 Planimetric and height accuracy using ERDAS Orthomax

Control method	R.m.s.e. X coord (m)	R.m.s.e. Y coord (m)	R.m.s.e. Z coord (m)
Land survey (theodolite + EDM	0.13	0.11	0.15
GPS (Trimble)	0.36	0.45	0.83

(Source : Adapted from Miller, 1995)

In Nale (1995), the positional accuracy assessment of an orthoimage was carried out by comparing coordinates of test points measured in the orthoimage with those observed with high-order GPS. The orthoimages used in this test were compiled for use at three different nominal scales of 1 inch to 20 feet (1:240) with a 6-inch pixel, 1 inch to 50 feet (1:600) with 1-foot pixel and 1 inch to 200 feet (1:2,400) with a 2-foot pixel. The planimetric accuracies of the first two orthoimages were found to exceed the allowable US National Mapping Agency standard. Only the accuracy of the last orthoimage was within the allowable standard.

3.3.2 Image scanners

Image scanners are used to convert hardcopy aerial photographs into digital format before being used in the digital photogrammetric systems. According to Baltsavias and Bill (1994) scanners can be classified into six main categories based on function. These are photogrammetric scanners, modified analytical plotters or monocomparators, scanners of large documents, microdensitometers, desktop publishing scanners and other scanners. Scanners can also be classified according to the following criteria: i) type of sensor used, that is, whether it employs point sensor, line sensor or area sensor; ii) scanning pattern/movement, that is, whether it is a flatbed scanner or rotating drum scanner; or iii) mode of operation, that is, whether transmissive or reflective mode. Transmissive scanners shine the light through the material to the sensor which is located on the other side while the reflective scanners have the light source on the same side of the material to be scanned. The transmissive scanners generally produce high quality images since there is less light scattering and therefore this type of scanner is widely used in digital photogrammetry.

Petrie (1997) has identified 4 main technologies (Figure 3.3) currently available for scanning images, that is:

i) a rotating drum scanner equipped with a scan head,
ii) a 2D flatbed scanner equipped with a photo head or Charge Couple Diode (CCD) linear array, which scans the photographs in raster pattern, giving a series of parallel swaths,
iii) a 1D scanning linear array of CCDs, which scans the photo in a single sweep, and
iv) a CCD areal array (often described as a CCD camera or staring array), which allows patch-by-patch scanning of photographic image with reassembly of the patches later into a single seamless image.

As the overall research concern is with the use of flatbed scanners in digital photogrammetry, only photogrammetric and DTP scanners will be discussed here.

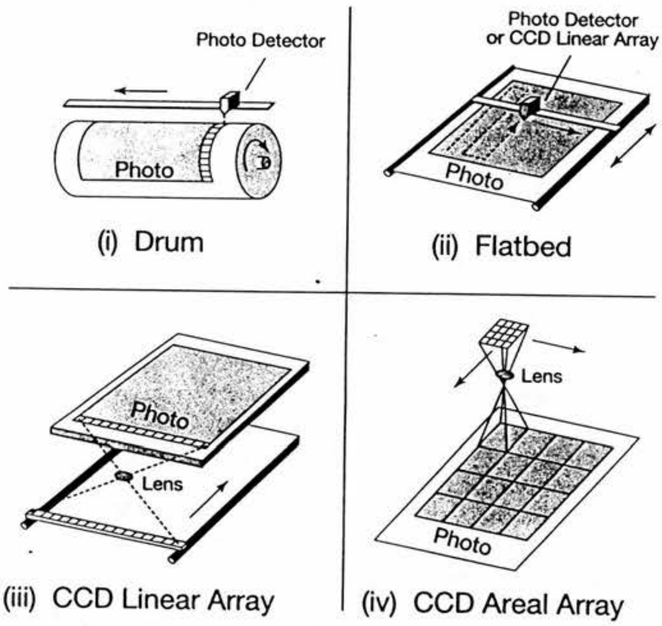


Figure 3.3 Principal scanner technologies
(Source: Petrie, 1997)

A. Photogrammetric and DTP image scanner

Photogrammetric scanners are purpose built for photogrammetric applications and usually form an integral part of an expensive digital photogrammetric system. Low-cost digital photogrammetric system do not include a photogrammetric scanner. These scanners employ either linear or area CCDs. Typical examples of such scanners are the Zeiss/Intergraph PhotoScan PS1 and the Leica/Helava DSW 100 and DSW 200. These scanners are used to scan aerial photographs but can only be operated in transmissive mode, that is they can only scan photographic diapositives and not paper prints. All these scanners are able to scan full size aerial diapositives (23 x 23 cm) and have a high scanning resolution (5-12.5 μm minimum pixel size) and high geometic accuracy (typically 2-5 μm). Baltisavias and Bill (1994) have divided these scanners into two groups based on price, that is, those priced higher than US$125,000 (e.g. the Zeiss/Intergraph PS1, Leica/Helava DSW 100 and DSW 200), and those in the price range of US$40,000 to US$75,000 (ISM's DiSC, Vexcel VX 3000, Wehrli's RM 1). Table 3.9 gives an overview of some of the photogrammetric scanners.

DTP scanners are the fastest growing segment in the scanner market. As mentioned earlier, although these scanners are not designed to be used for photogrammetric applications, they have great potential. This type of scanner can be either flatbed or rotating drum format. Although the rotating drum scanner can scan at a much higher resolution than flatbed scanners, it has no photogrammetric application potential because of low geometric accuracy. Flatbed scanners employ one or more linear CCDs and during scanning move in a perpendicular direction to the CCDs.

Table 3.9 Photogrammetric scanners

Brand/model	[A] Zeiss/Intergraph (PhotoScan 1	[B] Leica/Helava (DSW 200)	[C] Leica/Helava (DSW 100)
Mechanical movement	Flatbed, Moving stage *	Flatbed, Moving stage	flatbed, moving stage
Sensor type	Linear CCD, 2048 pels	Kodak Megaplus 2029 x 2044 CCD	2 standard area CCDs (high, resolution)
Scanning format (mm)	260 x 260	265 x 2 65	254 x 254 (270 x 270 option)
Geometric resolution (µm)	7.5 –120	5 - 15 (and any multiples of 2)	10 (high res.) 20 – 25 (low res) ##
Radiometric resolution (bits) (internal/output)	10/8	10/8	8
Illumination	halogen, 100W, fiber optic	Xenon,fiber optic, sphere diffusor	Quartz halogen, fiber optic, sphere diffusor
Colour passes	3	3	3
Density range		3D	
Geometric Accuracy	2	< 3	3
Radiometric accuracy (DN)	± 2		
Scanning throughput and/or speed	variable, 2 Mb/s (7.5µm) 0.5Mb/s (15µm)	1 Mb/s (12.5µm) (include. disk save) max 35 mm/s	67 Kb/s max 35 mm/s
Host computer/interface	Intergraph UNIX workstation	Sun Sparc 20	Unix -based PC/SCSI
Price	400,000 (Sfr.) or approx. (£194,175)	240,000 (Sfr.) or approx. (£116,505)	240,000 (Sfr.) or approx. (£116,505)
Brand/model	**[D] Int'l Systemap Corp. (DiSC)**	**[E] Vexcel Imaging Corp. (VX3000)**	**[F] Wehrli and Assoc. Inc. (RM-1)**
Mechanical movement	flatbed, moving stage	Vertical back-lit stage, moving sensor.optics	flatbed, moving stage
Sensor type	3-chip colour CCD, 8,000 pels	Standard area CCD	Linear CCD 2048 pels
Scanning format (mm)	320 x 320	254 x 508 #	260 x 260
Geometric resolution (µm)	10 – 40	8.5 - 160	12.5 – 100
Radiometric resolution (bits) (internal/output)	10/8	8	8
Illumination	halogen, fiber optic	Cold cathode, variable intensity	Fluorescent
Colour passes	1	3	3
Density range		0 - 2.6 D	0.2 - 2.4 D
Geometric Accuracy	5		3
Radiometric accuracy (DN)			
Scanning throughput and/or speed	0.25 - 2.5 Mpixel/s	Variable, 31 Kb/s ** (include. set-up and disk save)	0.2 Mb/s
Host computer/interface	PC-DOS/ SCSI-2	Unix-based PC and workstation required	PC-DOS/SCSI
Price	115,000 (Sfr.) or approx. (£55,825)	90,000 (Sfr.) or approx. (£43,690)	80,000 (Sfr.) or approx. (£38,835)

* stage refers to the stage holding the document
# Special option to scan 30 cm x 30 cm Russian satellite imagery
Typical value. Highest resolution is 7 µm. Through a software option any pixel size can be selected
** About twice this speed can be achieved with 3000+ model

(Source : Adapted from Baltsavias and Bill, 1994)

Most of the currently available flatbed DTP scanners on the market are A4 format and a few, such as Agfa Horizon Plus and Sharp JX-610, scan up to A3 format. In terms of price, the A3 format scanner is still considered expensive compared to the A4 format scanner. According to Baltsavias and Bill (1994), some of the A3 format DTP scanners can fulfil photogrammetric requirements. Examples of such scanners are given in Table 3.10. A typical price of an A4 format colour scanner such as HP Scanjet 4c is around £700 and of an A3 format such as Sharp JX -610 is around £7500 (educational price).

Table 3.10 The A3 format DTP scanners which fulfil the photogrammetric requirements

Brand/Model	**[A] Agfa (Horizon Plus)**	**[B] Sharp (JX-610)**	**[C] Scitex (Smart 340 L)**	**[D] Intergraph (AnaTech Eagle 1760)**
Mechanical Movement	Flatbed, Stationary stage	Flatbed, moving stage	Flatbed	Flatbed
Sensor type	3 linear CCDs 3 x 5,000 pels	Liner CCD, 7500 pels	Linear CCD	2 linear CCDs, 2 x 5,000 pels
Scanning Format (mm)	A3 (reflective) 240 x 340 (transparency)	305 x 432	A3	419 x 610
Geometric resolution (μm)	21.2 – 1270	21.2 (v) x 42.3 (h) *	21.2	42.3 – 25400
Radiometric resolution (bits) (internal/output)	12/10 or 8	12/8	8	8
Illumination	Halogen, 400W	3 RGB strobing fluorescents	-	Quartz halogen, fibre optic
Colour pass	3	1	-	-
Geometric accuracy (μm)	80 (without calibration)	-	-	460 (in x) 0.1% (in y)
Scanning throughput and/or speed	0.35 Mb/s (1200dpi) 5 – 100 mm/s	0.62 Mb/sec (A3, 600 dpi)	0.48 Mb/s (A4) 0.68 Mb/s(A3)	-
Host computer/ interface	Mac, PC, Unix Workstations/SCSI –2	Mac, PC, Unix workstations/GPI B, SCSI-2	Mac	PC, PS-2, Mac
Price (SFr.)	45,000 (£21,845)	22,000 (£10,680)	-	48,000 (£23,300)

(Source : Baltsavias and Bill, 1994)

As reported in Bosma *et al.* (1989), earlier versions of A4 format DTP scanners manufactured by Epson, Sharp, Apple, Canon and Hewlett-Packard (HP) have a maximum optical resolution of only 300 dpi. Exceptions are those manufactured by Agfa (model MacScan, S800GS, S600GS, S800 and S600) and Siemens (model ST-400 and ST-800). In the later versions of HP (Scanjet 4c) and Epson (GT-9000) DTP scanners, an optical resolution of 600 dpi (42.5 μm pixel size) is available. A more recent survey by Bethell (1996), has shown that some A4 format DTP scanners (e.g. Agfa DuoScan, Microtek Scanmaker 5 and Umax Powerlook III) have an optical resolution of more than 1000 dpi. With enhanced resolution, hardcopy aerial photographs or documents can be scanned up to 2400 dpi in most scanners. The characteristics of some of the A4 format scanners are given in Table 3.11 and Table 5.2.

B. Geometric accuracy of scanners

Baltsavias (1996) classifed errors in scanners according to different criteria, that is, geometric and radiometric errors, or slowly and frequently varying errors. Lens distortions, defect pixels, CCD misalignment errors, subsampling errors, smearing due to defocussing and high speed, and colour misregistration have been identified as the main factors that cause the slow varying errors. The frequently varying errors are mainly due to mechanical positioning, vibrations, stripes, illumination instabilities and electronic noise. The slowly varying errors are usually referred to as radiometry while the frequently varying geometric errors refer to mechanical positioning and vibrations.

Table 3.11. Desktop scanner features and specifications

Model	Optical Resolution	Bit Depth	Dyn Range	Scan Area	Connection Type	Street Price (US$)
Agfa SnapScan 600	600	30	2.55	8.5x11	SCSI	$399
Agfa StudioStar	600	30	2.75	8.5x14	SCSI	$749
Agfa Arcus II	600	36	3.0	8.5x14	SCSI	$1499
Agfa DuoScan	1000	36	3.3	8x14	SCSI	$3495
Agfa DuoScan T2000XL	667	36	3.3	12x18	SCSI	N/A
Epson Perfection 600	600	30	n/a	8.5x14	SCSI	N/A
Epson Expression 636	600	36	3.0	8.5x12	SCSI/Par	$899
Epson Expression 836XL	800	36	3.3	12x17	SCSI	$2499
Fujitsu Scan Partner 600	600	30	n/a	8.5x14	SCSI	N/A
HP ScanJet 5p	300	24	n/a	8.5x11	SCSI	$379
HP ScanJet Office	300	24	n/a	8.5x14	SCSI	N/A
HP ScanJet 6100C	600	30	n/a	8.5x14	SCSI	N/A
Microtek ScanMaker E6	600	30	3.0	8.5x13.5	SCSI	$349
Microtek ScanMaker V600	600	30	n/a	8.5X11	SCSI/Par	$249
Microtek ScanMaker 5	1000	36	n/a	8.5x14	SCSI	$2495
Microtek ScanMaker 9600XL	600	36	n/a	12x17	SCSI	$1499
Mustek Paragon 1200SP	600	30	3.0	8.5x14	SCSI	$379
Mustek Paragon 1200 IIIEP	600	36	n/a	8.5x11	Parallel	N/A
Mustek Paragon 1200 A3 Pro	600	36	n/a	11x17	SCSI	N/A
Nikon ScanTouch AX-210	600	24	n/a	8.5x11	SCSI	$599
PIE Scanace II	600	30	2.8	8.5x14	SCSI	$599
PIE Scanace III	600	36	3.1	8.5x11	SCSI	$899
Ricoh FS2	600	30	n/a	8.5x14	SCSI	$2245
Sharp JX-330	600	24	n/a	8.5x14	SCSI	$1449
Tamarack Artiscan 12000C	600	24	2.1	8.5x11	SCSI	$749
Tamarack Artiscan 8000C	400	24	2.1	8.5x11	SCSI	$599
Umax Astra 610	300	30	n/a	8.5x11	SCSI/Par	N/A
Umax Astra 1200/1210	600	30	n/a	8.5x11	SCSI/Par	$198
Umax PowerLook II	600	36	3.0	8.5x12	SCSI	$1295
Umax PowerLook III	1200	36	3.4	8.5x11	SCSI	$4195
Umax Mirage IISE	700	36	3.2	11x17	SCSI	N/A

(Source: Adapted from Bethell, 1996)
http://www.scanshop.com/pages/tables/tables_frames.html

Notes: 1. Resolution is the true optical resolution of the scanner.
2. Price in US dollar

One of the advantages of using a high precision photogrammetric scanner to scan an aerial photograph is its high geometric performance. Baltsavias (1994) has reported the geometric accuracy of less than 5 microns of six different photogrammetric scanners (i.e. Zeiss/Intergraph PhotoScan, Leica/Helava DSW 200, Leica/Helava DSW 100, DiSC, Vexcel VX 3000 and Wehrli RM-1). Other related studies on A3 format DTP scanners, as mentioned in Baltsavias (1994a), Baltsavias and Bill (1994) and Baltsavias (1996), outlined three main findings: i) the overall geometric accuracy is larger than the scanner resolution, ii) different scanners have different geometric accuracies and iii) the error in the x direction is always larger than in the y direction.

Earlier published results on geometric accuracy testing (Sarjakoski, 1992; Gagnon and Agnard, 1992; Finch and Miller, 1994; Baltsavias, 1994b; and Baltsavias, 1996) have shown that the measured errors in the A3 format DTP scanners after calibration are far less than the pixel dimension. Sarjakoski (1992) reported that an accuracy of ± 0.2 pixel can be achieved using a Sharp JX-600 after careful image calibration. Gagnon and Agnard (1992) reported an accuracy of less than the scanner resolution can be achieved on A3 format HP Scanjet and Xerox scanners. Finch and Miller (1994) reported an accuracy of ± 0.25 pixel is obtained using an A3 HP Scanjet Plus scanner when scanned at 300 dpi resolution. In another study by Baltsavias (1994b), an accuracy of less than 0.5 pixel (after calibration) was achieved using the Agfa A3 format DTP scanner. Results from these earlier studies also indicates that while distortions are significant, they could be minimised using proper calibration procedures. The most recent study by Baltsavias (1996) also indicated similar results. Until this thesis is published there is no comprehensive publication on the accuracy assessment of A4 format DTP scanners.

3.4 Summary

GIS is a powerful tool for managing spatial data in many planning applications. The success of any GIS project largely depends on efficient data acquisition methods. Photogrammetry has been considered as an important tool for acquiring digital data for a GIS. Recent developments in computers and computer-related technology such as sensor/scanner have totally revolutionised photogrammetry from an analogue to a fully digital method. This method has brought greater flexibility in terms of the digital photogrammetric input and output. The two main products i.e. automatically generated DEM and orthoimage can be input directly into a GIS. Many earlier tests carried out by different authors have shown that the accuracy of digital photogrammetric products such as point digitising and DEMs generated from a DPW is comparable to that of a low-order analytical plotter.

Data from a DPW can come from various sources such as stereo-SPOT satellite, digital cameras and image scanners. The selection of appropriate image scanners to be used to scan aerial photographs is crucial. Beside photogrammetric scanners, some A3 format scanners can be used to scan aerial photographs provided proper image calibration is carried out. A4 format DTP scanners, although cheap but is not normally used to scan aerial photographs because of its geometric properties.

CHAPTER 4

PROPOSED STRATEGY FOR INTEGRATING DIGITAL PHOTOGRAMMETRY AND GIS FOR LOCATING NEW LANDFILL SITES

4.1 Introduction

This chapter is intended to discuss the proposed strategy for integrating digital photogrammetry and GIS in order to implement the proposed stage-by-stage approach for locating new landfill sites. In the first section discussions on the current and potential use of GIS and digital photogrammetry in landfill studies will be given. The second section describes in detail the proposed strategy. The following section describes the two main tools (software) used in this study i.e. ARC/INFO GIS and Desktop Mapping System (DMS) a low-cost digital photogrammetric workstation.

4.2 Current and potential use of GIS and photogrammetry in landfill studies

In the context of landfill studies GIS can be used as i) a tool for siting new landfill (Zee and Lee, 1989; Jensen and Christiensen, 1990; Bagheri and Dios, 1990; Weber and Ware, 1990; Richason and Johnson, 1990; Siderelis, 1991; Carver and Openshaw, 1992), a tool for finding suitable routes for collecting and transporting waste (Murray and Church, 1995; Brainard *et al.,* 1996; Ghanem, 1997), and a tool for monitoring landfill sites and land in the vicinity (Estes *et al.,* 1987).

Some earlier studies have indicated the practical use of GIS for siting new landfill. Zee and Lee (1989) described the use of GIS to facilitate examination of the interaction between site-related factors. A PC-based STINGS GIS was used to cartographically model and identify potential landfill disposal sites for hazardous waste in Colorado. Jensen and Christiensen (1990) discussed the results of some initial work on the use of GIS for the selection of solid and hazardous waste disposal sites in the south-eastern USA. Bagheri and Dios (1990) discussed the utilisation of GIS technology in the selection of hazardous waste disposal site in the Piedmont Province, New Jersey, USA. Weber and Ware (1990) discussed the practical use of GIS technology in the municipal scale environmental management in Loudoun County, Virginia, USA. GIS has been used to support environmental management activities primarily related to water resource management and landfill siting. Siderelis (1991) has outlined the procedures and results of state-wide screening using GIS for a hazardous waste site for the North Carolina Hazardous Waste Management Commission. Carver and Openshaw (1992) used GIS to locate landfill for hazardous waste in the UK. Carver (1991) has integrated multi-criteria evaluation techniques and GIS in the site selection process. The integration of this technique with GIS for spatial decision making purposes will further enhance the results, especially when complex siting decisions involving multi-criteria are used. Expert systems and GIS have been used to locate new landfill sites in the Miaoli Perfecture, Taiwan (Miaoli Perfecture, 1996).

GIS can play an important role in the monitoring of existing and closed landfill sites. In developed countries such as the UK, numerous European Community (EU) directives and UK legislation have forced contractors to get maximum capacity out of the given volume of their landfill sites with minimum cost and minimal environmental impact (Green, 1996). GIS can also be used to display the layout of landfill, keep a record of filling (volume of waste) and a record of the waste densities across the site and to monitor the post closure settlement of the closed sites.

As discussed in the earlier papers (Erb *et al.*, 1981; Lyon, 1987; Herman *et al.*, 1994; Stohr *et al.*, 1994; Vincent, 1994; Weil *et al.*, 1994) aerial photographs and remote sensing images have been used widely in the landfill studies. In Vincent (1994), aerial photogrammetry was used to manually delineate depression while thermal infrared imagery was used to classify depressions according to infiltration characteristics. Studies by Lyon (1987), Erb *et al.* (1981) and Herman *et al.* (1994)

have shown that aerial photogrammetric techniques can be a useful tool to assess the historical environmental impact of the landfill sites which have had known or suspected releases of harmful contamination.

The use of digital photogrammetry in GIS can be divided into two main types; those requiring height information (the DEM) or derived products (e.g. slope and aspect) and those requiring high precision base maps (orthoimage) either as backdrops or as a source of vector data. The digital photogrammetric method has great potential in the management of solid waste especially for locating new landfill sites and monitoring existing sites. In locating new landfill sites, high-resolution DEMs can be used to estimate the capacity of potential landfill, assess areas of unsuitable slope and perform visibility analysis to determine areas highly visible from potential sites. Orthoimage mosaics can be used as backdrops for on-screen updating of features around the potential sites. The combination of orthoimage mosaic and DEMs in perspective views can be used to create a more realistic viewing of the potential site and subsequently assist in deciding the most suitable site. According to Vincent (1994), high-resolution DEMs taken from photos obtained at different dates can be used to monitor volume change due to subsidence and or additional filling at existing landfill. Besides that, DEMs can also be used as input to surface run-off model.

4.3 Proposed strategy of data collection and data analysis for locating new landfill sites

Earlier discussions have identified the importance and the potential of digital photogrammetry, satellite remote sensing and GIS in the landfill site selection process. A careful data management, data collection and data analysis strategy must be devised to utilise the potentials and the limitations of these technologies fully.

The stage-by-stage approach using suitable siting criteria for locating new landfill sites can help decision-makers and planners in the region to eliminate unsuitable areas systematically and later select the best possible alternative site or sites for further considerations. As mentioned earlier, the only attempt to implement this approach was carried out by the Pulau Pinang and Seberang Perai Municipality. As outlined in the Solid Waste Management Study for Pulau Pinang and Seberang Perai Municipality (JICA, 1989a) the process of identifying suitable areas was done manually by overlying maps of different themes.

The data collection methodology to be adopted in this study must be able to provide data cheaply, quickly, accurately and easily without the need of highly specialised skill as most local authorities or planning authorities do not have specialised mapping units or skill personnel to generate new maps or update existing maps. As outlined in Figure 4.1, three different types of spatial data collection methods are to be used, that is i) vector line digitising, ii) vector on-screen digitising with Landsat TM digital as the backdrop and iii) digital photogrammetry. The vector line digitising method is to be used to convert topographic and thematic maps to digital format. Since Landsat TM digital data can easily be acquired from the Malaysian Centre for Remote Sensing (MACRES), the on-screen vector digitising method is to be adopted to update existing vector digital data digitised earlier. Digital image classifications of Landsat TM data using image processing methods is not to be used as this will require extra equipment (digital image processing system) to be acquired and further specialised staff training will be needed. On-screen digitising will be carried out using a low-cost digital photogrammetric workstation. These two data collection methods are mainly to be used to supply data needed in the preliminary evaluation of potential areas that cover the whole of the study area.

The final data collection method is digital photogrammetry. This method is to be used to supply high-resolution data sets needed in the site-specific evaluation. Hardcopy aerial photographs are to be scanned in low-cost A4 format DTP scanners. The automatically generated DEMs are to be used to generate contours and to perform volumetric and visibility analysis. Volumetric analysis will allow the calculation of the capacity (i.e. volume available to place solid waste) of the few potential sites. From this, the life expectancy of the selected sites can be calculated. Visibility analysis will allow areas visible from the proposed site to be determined and displayed. The orthoimage mosaic combined with the contours generated from DEM will allow the exact boundary of the selected site to be determined. Besides this, orthoimage mosaic combined with DEM can be used to display the proposed site in perspective view.

Although digital photogrammetric technology has great potential in providing data required for many mapping applications accurately and efficiently, it is not proposed to be adopted as the main source of data collection for this study. A digital photogrammetric method is be used only to provide high resolution data, that is, DEM and orthoimages, to be used in the detailed site evaluation. The reasons for not proposing the digital photogrammetric method for collecting data for large geographical area are as follows; i) the availability of a geo-referenced TM satellite image of the Klang Valley Region ii) too much effort is needed to establish Ground Control Points (GCPs) either through aerial triangulation or ground survey methods and iii) the problems associated with data storage. Massive data storage is required to store the scanned and processed aerial images. Typical data storage required to scan an aerial photograph (monochrome) at 300 and 600 dpi are 8 and 32 Mbytes respectively.

Data analysis is to be carried out in GIS. Evaluation of potential sites is to be performed in three main stages. Preliminary evaluation that covers the whole of the study area is intended to exclude areas that are not suitable for further consideration. Exclusionary and some restrictive criteria are to be applied at this stage. The application of exclusionary criteria is intended to eliminate areas from further considerations. A second stage evaluation process using digital photogrammetric data is to be carried out on the few selected potential areas to determine the most favourable site/sites. Having identified the most favourable site/sites, on-site analysis or EIA of the site can be carried out. The site selection criteria to be formulated and the analysis carried out in this study are subject to the limited availability of data so only limited criteria and analysis can be made. Ideally the whole range of site selection criteria and analysis are required to select the best possible site/sites.

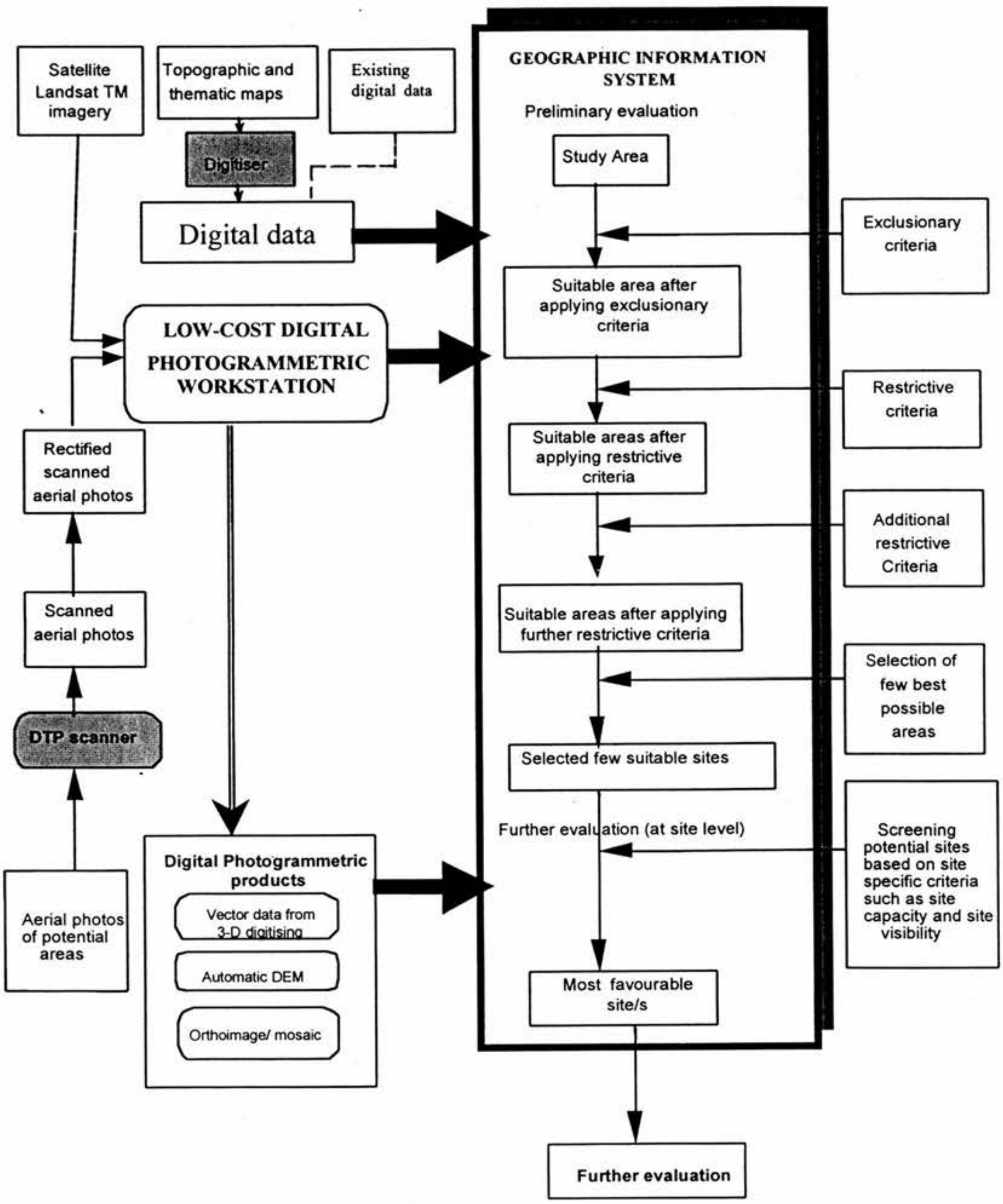


Figure 4.1 Overall data collection and data analysis methodology

4.4 Proposed software

As mentioned in Chapter 3, there are many DPWs and GISs available in the market today varying in terms of their functionality and capability. For this study a powerful hybrid GIS software (ARC/INFO version 6.1) and a low-cost digital photogrammetric system, that is, Desktop Mapping System (DMS) version 3.1 were selected. The main reasons for selecting ARC/INFO software are as follows:

- its ability to integrate raster and vector data in one environment,
- its common use in many government organisations in Malaysia,
- its ability to perform powerful surface analysis such as visibility analysis and volume calculation, and
- its availability with the University of Edinburgh.

DMS is one of the cheapest DPW available in the market today. The following sub-sections describe the chosen software, that is, ARC/INFO version 6.1 and DMS version 3.1.

4.4.1 Description of ARC/INFO Version 6.1

ARC/INFO is powerful GIS software, which enables the user to access, integrate, manipulate, and visualise both graphic and tabular data for better analysis and decision making. The ARC system, developed by the Environmental Systems Research Institute (ESRI), stores cartographic data while INFO, a relational database by Henco Software, Inc., stores the attributes data (Korte, 1992). ARC/INFO also allows other Relational Database Management System (RDBMS) software such as ORACLE, INGRES, and INFOMIX to be used. This software runs on a variety of platforms, ranging from PC to mainframes. As any other GIS software, ARC/INFO can perform five main functions, that is: data input, data integration, data management, data analysis and data display. The data analysis tools available in ARC/INFO include:

- topological map overlay
- buffer generation

- proximity analysis
- hydrological modelling
- spatial and logical query
- surface analysis
- network modelling
- raster modelling
- cartographic map production
- report generation
- sophisticated tabular analysis.

a. ARC/INFO modules

The ARC/INFO software comprises a series of programs that group functionality into useful operating environments. These programs allow the user to access, visualise and query both geographic and tabular data for analysis and decision making. Individual programs consist of commands to enable geo-processing operations to be performed. The functions of individual programs are summarised below. (ESRI, 1993 and ESRI, 1994)

ARC is the overall GIS manager. The functions of this program are as follows:

- to perform data conversion from other raster or vector digital format (e.g. DXF,SIF, TIFF, LAN and img)
- to generate and manage data layers or coverages in the database,
- to manipulate spatial and non-spatial data in one or more coverages, and
- to create data relationships between coverages.

ARCEDIT is used for interactive digitising and editing system. The main functions are to digitise and edit a coverage and correct errors in spatial and non-spatial data. This module also allows the georeferenced images (e.g. orthoimage and satellite remote sensing image) to be displayed as background images for on-screen digitising.

ARCPLOT is used for map display and query as well as for performing sophisticated spatial operations such as surface analysis, dynamic segmentation and spatial selection.

INFO or TABLES is used to operate on tabular file and feature attribute tables. It allows users to create, store, edit and query attribute data.

ARC Macro Language (AML) software module provides tools to allow users to build macros and custom menu interface with ARC/INFO. This will allow users to automate frequently performed command operations, create own commands and communicate with other programs on the network.

In addition to these programs, there are also other complementary programs such as GRID, NETWORK, Triangulated Irregular Network (TIN), COGO and Relational Database Interface (RDBI). The functions of these programs are as follows:

GRID is used to operate on grid data sets (raster) to perform analysis and display. Although GRID uses geo-relational model for geographic data, it differs from other modules because it is based on a combined relational attribute model and a raster-based spatial data. The main applications of GRID are for hydrological analysis, economic analysis, environmental analysis, and social analysis.

NETWORK supports the analysis of a network of linear features such as roads, rivers, power cables, water pipelines and other utilities. The main operations involved in NETWORK are: geocoding, pathfinding and location-allocation.

Triangulated Irregular Network (TIN) is a surface modelling program. Analytical capabilities of this program includes: contouring cross-sectional and 3-D display, cut and fill calculation, analysis terrain mobility, identifying drainage networks, analysing visibility, and calculating sun intensity. This program consists of specialised ARCPLOT and ARC commands, and AMLs are entirely integrated into the ARC/INFO system.

Coordinate Geometry (COGO) is an extension program which allows automated survey information from various data sources and engineering formats to be converted to ARC/INFO. High-precision ARC/INFO coverages can be generated using COGO for parcel mapping, cadastral mapping and subdivision planning.

Relational Database Interface (RDBI) is used to independently associate cartographic data in ARC/INFO to other relational databases such as Ingres and Oracle

In the context of this study, important modules are ARC, ARCEDIT, ARCPLOT, INFO, AML and TIN. TIN is a useful module for this study as it can be used to generate slope map, contours, display in 3D the area surrounding the selected landfill sites, calculate landfill capacity and perform visibility analysis.

b. ARC/INFO data models

Database forms an important component of a GIS. In ARC/INFO a number of geographic data models can be used to represent spatial information. These include coverage, grid, table, tin and image. Brief explanations on the different data models or data types are given below. (ESRI, 1993 and ESRI, 1994)

Coverage is a digital map (single layer or theme) forming the basic unit of vector data in ARC/INFO. Different geographic features such as points, lines and polygons (areas) can be stored in different coverages. Features such as tick points, map limits, links and annotation can also be represented in a coverage.

Grid is an ARC/INFO raster data set, used to represent categorical data such as forest type and to represent a continuous surface such as height points. This data type is suitable for the following applications: spatial analysis and modelling, spatial process modelling (e.g. surface runoff and fire spreads) and surface representation.

Image is a graphic representation of an object. Two types of information represented by an image are map images and descriptive images. Typical examples of map images are orthoimage mosaic and geo-referenced satellite imagery. Important applications of such images in GIS are as backdrop for on-screen digitising and for further use in a digital image processing. Descriptive images such as scanned photos and scanned documents can be used to describe features.

Tin is a surface representation derived from irregularly spaced points and breakline features. This surface can be used for surface modelling and display (e.g., contouring, visibility analysis, 3-D display and profiles).

Lattice is a surface representation that uses a rectangular array of points spaced at constant sampling interval in the x and y directions relative to a common origin (ESRI, 1993). Like tin, lattice can also be used for surface modelling and display (e.g., cut and fill, shaded relief, slope/aspect and 3-D display).

Computer-aided drafting (CAD) systems are mainly used to create maps, pictures, and drawings that can be readily be integrated into a GIS database. These drawings are particularly suitable to display maps of facilities (e.g. water pipelines and electric cables) and civil engineering drawings as a graphic backdrop to other spatial data in ARC/INFO.

A summary on the geographic data models that can be utilised in the ARC/INFO version 6.1 software is given in Table 3.1.

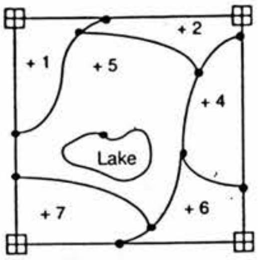
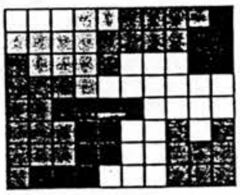
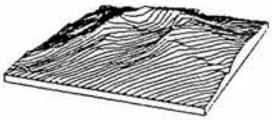
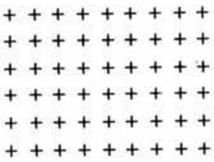
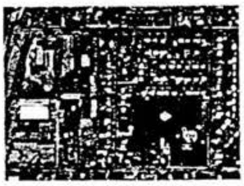
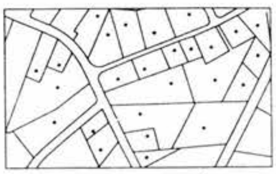
4.4.2 Desktop Mapping System (DMS) Version 3.1

This software package is a PC-based digital photogrammetric system that was first introduced in 1987 at the ASPRS-ACSM Conference in Baltimore, Maryland by R-WEL, Inc. Although DMS was first developed to be used with SPOT and LANDSAT images, an air photo module introduced in 1993 provides a rigorous photogrammetric capability for photos/images captured by aerial cameras. Stereomodels generated can be used for the following applications: planimetric mapping, thematic mapping, interactive contouring (contour and spot height), generation of DEMs, orthoimages and orthoimage mosaic generations, terrain visualisation, and GIS applications (refer to Figure 4.2). DEMs are created using the automated stereocorrelation techniques. The DEM grid spacing can be specified by the user. The automatically generated DEM can then be rectified (data from stereo SPOT images only), used for orthoimage production or overlaid with the original image for terrain visualisation. DMS can also perform some GIS routines such as aggregate, rasterise, overlay and image scaling. Stereo display and viewing at full screen resolution (1024 x 768 pixels) in DMS are accomplished by anaglyph methods.

a. DMS modules

This software consists of eleven modules, which are, SYSTEM, VIEW, ENHANCE, GEOCODE, MAP, Softcopy Photogrammetric Mapper (SPM), GIS, MANAGE, UTILITIES, DATA and EDIT. The functions of these modules are summarised below. (R-WEL Inc., 1992)

Table 4.1 Geographic data models

Geographic data set	Structure	Applications
Coverage 	• Vector • arc-node topology • georelational	• Cartographic database • Automation and update of spatial data • Linear feature modelling • Area feature modelling • Feature boundary definition • Base maps for cartography • Spatial database management
Grid 	• Raster • Georelational	• Spatial analysis and modelling • Spatial process modelling (runoff, fire spread, corridor calculation) • Surface representation • Scanning for data automation
Tin 	• Surface, • Triangulated irregular network	• Surface representation (especially terrain) • Surface modelling and display (e.g., contouring, visibility, 3-D display, profiles)
Lattice 	• Surface, • Digital elevation model • Grid • Raster	• Surface representation • Surface modelling and display (e.g., cut-fill, shaded relief, 3-D display, slope/aspect)
Image 	• Raster	• Images as map pictures • Images and attributes • Data automation • Display • Change detection • Multimedia databases
Drawing 	• CAD	• Drawings as map backdrops

(Source: Adapted from ESRI, 1993 and ESRI 1994)

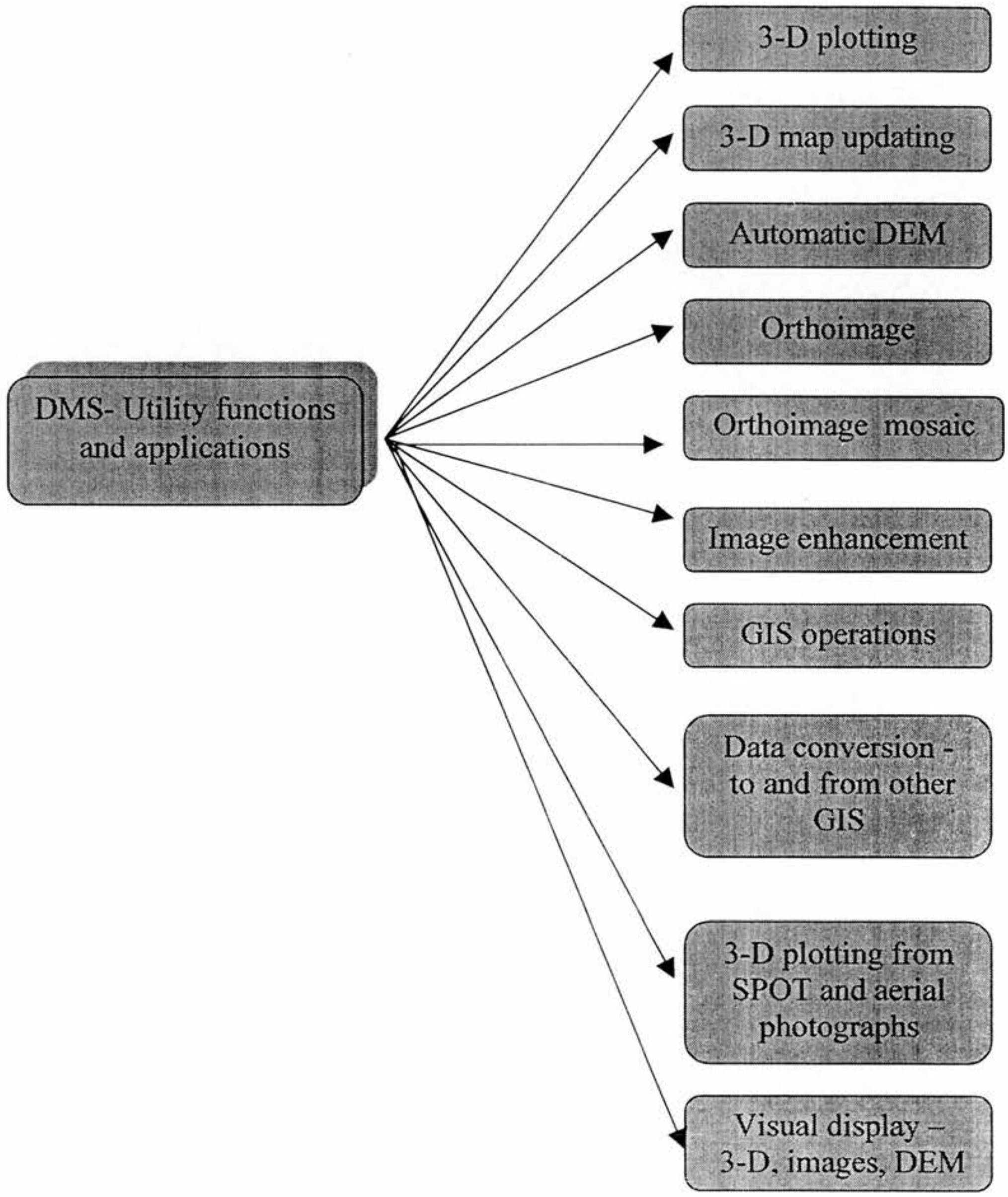


Figure 4.2 Utility functions and applications of the DMS

SYSTEM permits temporary access to Disk Operating System (DOS) level commands and programs to enable operations such as DMS file listing, installing digitiser, shelling to DOS, changing project directory and quitting.

VIEW allows the user to display raster and vector files on the monitor for visual examination. Options available include:

- Image - display a raster format file
- GIS - display a GIS file
- DEM - display a GIS file
- Vectors - display a vector map
- 3D perspectives - display a 3D perspective view of a DEM

ENHANCE allows one to maximise image contrast and improve interpretability. Histogram equalisation, intensity-to-hue (I-H-S) transformation, image ratio or image filter can be applied to the image. Filters can be used to smooth or sharpen detail in an image or DEM.

GEOCODE allows the user to geometrically correct for deformations in raster data files and to geocode or create new geometrically correct (rectified) data files referenced to standard coordinate systems such as Universal Transverse Mercator (UTM) or State Plane. First or second order polynomials can be used to perform image rectification.

MAP allows compilation of new planimetric and topographic maps, revision of existing maps and production of thematic maps. In this module stereoimages can be viewed in 3D and a floating mark is used for contour compilation and other measurements.

SPM allows the user to map from scanned aerial photographs. In general, this module requires two aerial photographs (left and right) obtained from standard photogrammetric camera. A rigorous photogrammetric solution is employed to rectify each photograph and produce a stereo pair. Options available include:

- Planimetric - allows on-screen digitising of vector data to be generated.
- Thematic - allows automatic image classification to be carried out
- Stereoplotting - allows interactive plotting of contours, details (X and Y) and spot heights (Z) from a stereoimage model.
- Stereocorrelation - allows the generation of DEMs using automatic stereocorrelation technique
- Orthoimage - creates an orthoimage
- Orthomap - creates an orthomap from a rectified orthoimage

GIS allows basic GIS operations on raster files. These operations include image aggregation, image rescaling, image or image overlay. Options available in this module include:

- Aggregate - designed to average pixels is a raster file to create a smaller file of larger pixel size.
- Rasterize - to convert a vector file to a raster GIS file.

MANAGE provides options for managing images and vector files. The options available in this module include:

- Mosaic - to mosaic image files together to create a single large image.
- Subset - to create a subset of a larger image
- Bands - to either extract, merge or blend bands of image files.

UTILITIES provides a facility for producing hardcopy and softcopy output, compute image or vector files statistics and also other options such as computing slope and aspect from an input DEM, profiling and image superimposition.

DATA provides a number of facilities for collecting or converting both raster and vector formatted data for use with DMS. Options available are as follows:

- Tablet - allows rectification of points, lines and/or closed polygons traced with a digitiser from maps, aerial photographs or other hardcopy.
- Conversion - allows user to convert data to and from standard file interchange format.

EDIT allows user to edit image headers, text files, DMS files used as look-up tables, and DEMs using a stereo image as a backdrop. The DEM editing options in this module only for DEMs created from stereo satellite images not from scanned aerial photographs.

b. Hardware and software requirements

To enable the DMS software to run properly the following minimum configuration is required:

1. IBM compatible 386/486 or Pentium-based computer configured with
   - 640 K RAM minimum (8-32 Mb recommended)
   - Hard disk (259 minimum 1 GB or more recommended)
   - Mb floppy disk drive
   - Microsoft-compatible mouse
   - Super-VGA, Display Adapter capable of displaying 256 colours at resolutions up to 1280 x 1024. Supported displays include VESA 1.2 compliant boards and those having the following chip sets: Tseng ET3000, ET4000, ET4000/W32: Paradise/western Digital: Video 7; Trident, IBM XGA and others.

- Colour monitor which is compatible with all modes provided by the display adapter

2. Digitiser (optional)
3. Dot matrix, colour Inkjet or Laser printer (optional)
4. Scanner, video camera and tape drive (optional)

Other utility programs are also needed to enable DMS to run properly. The programs are as follows:

1. Disk Operating System (DOS) 6.2 or higher (available from IBM and Microsoft)
2. Microsoft-compatible mouse driver provided by the mouse manufacturer
3. ANSI.SYS, SORT.EXE, MORE.COM and COMMAND.COM programs provided with DOS.
4. Microsoft Windows version 3.1 or higher, OS/2 Warp 3.0 or Windows NT version 3.5 or higher.

c. Interface with GIS

The main function of any digital photogrammetric workstation is to generate data (vector or raster) for various GIS or other mapping software for data update and analysis. For such functions, the ability to read and write data in different formats is important. DMS can read/write to various vector or raster data formats. Vector file formats that can be read in DMS include the ERDAS DIG format, Arc/Info Generate format, USGS DLG-3 format, AutoCAD DXF format, TIGER format, Intergraph SIF format and IDRISI ASCII format. The DMS ASCII vector files may be exported to several formats. These formats include ERDAS DIG format, Arc/Info Generate format, AutoCAD DXF format, DLG-3 format, SIF format, Hewlett Packard Graphics Language (HPGL) format and IDRISI ASCII format. Raster formatted files can be converted to and from several standard interchange formats. These formats include: ACSII USGS DEM, binary Band Interleave by Line (BIL) or Band Sequential (BSQ), Tag Interchange Format File (TIFF), GRASS ASCII interchange files and ERDAS 7.4 LAN files.

4.5 Summary and conclusions

Many earlier studies have indicated the potential of GIS, aerial photography and satellite remote sensing in landfill studies. The use of conventional vector digitising, digital photogrammetric methods and GIS have been proposed for this study. Aerial photo images are to be scanned using relatively cheap A4 format DTP scanners. Satellite TM digital data will be used to update a few map layers such as land use and roads, while high resolution digital photogrammetric products such as DEMs and orthoimage mosaics will be used to evaluate the suitability of the individual selected sites further. ARC/INFO version 6.1, a powerful hybrid GIS, and DMS version 3.1, a low-cost digital photogrammetric workstation are proposed to be used.

CHAPTER 5

ASSESSMENT OF A4 FORMAT DESKTOP PUBLISHING SCANNERS

5.1 Introduction

One of the objectives of this study is to evaluate the suitability of low-cost A4 format DTP scanners to scan aerial photographs. As most local authorities and planning authorities in Malaysia are unlikely to be able to afford specialised photogrammetric scanner, the use of a much cheaper scanner is desirable. The methodology and results presented in this chapter are intended to demonstrate the sorts of tests that might be needed and the expected accuracy in order to use such equipment successfully. The discussion will concentrate on geometric accuracy assessment. This chapter begins with the methodology adopted for the geometric accuracy testing. The later part of this chapter describes a series of tests to assess the suitability of using the A4 format desktop publishing scanners as a substitute for precision photogrammetric scanners.

5.2 Geometric accuracy testing

Although A4 format scanners are cheap, the user community is widely unaware of their limitations. The issues relating the accuracy need to assessed and publicised before such scanner can properly be used. Among the issues that need further investigations are the pattern and magnitude of image distortions before and after calibration, suitable mathematical models and control point configurations to perform image calibration or rectification and stability of these type of scanners.

To respond to the issues above, five tests were devised the aims of which were to determine:

- the distortion pattern and the magnitude of distortion of images scanned using desktop scanners,
- the effect of the scanning resolution on the pattern and magnitude of image distortion,
- the most suitable mathematical model to minimise image distortion,
- a suitable configuration of control points to minimise distortions,
- the differences in distortion pattern and the magnitude of image distortion resulting from repeat scanning.

The tests presented in this study differ from previous studies as these tests concentrate on the A4 format DTP scanners and also address wider issues of image accuracy such as the effect of scanning resolution on the image accuracy and the scanner stability.

5.2.1 Overall testing methodology

Although there are many types of A4 format scanners available in the market today with ranging prices and resolutions only four different types of A4 format DTP scanners were selected for the purpose of accuracy testing. These scanners are as follows:

- the Apple Colour OneScanner
- the HP Scanjet IIc scanner
- the Epson GT-9000 scanner
- the HP Scanjet 4C (two scanners of this type were used)

The choice of these scanners was based strictly on their availability within the University of Edinburgh. To quantify the errors, a calibrated glass plate with a regular 1-2 cm grid spacing as suggested in Baltsavias (1994a) and Baltsavias (1996) is required. The second grid plate with 1 mm spacing at each border (left and right) as suggested in Baltsavias (1996) was not used as it was not available during the tests. Since a glass plate was not available, a high resolution stable Estar thick base film (photographically produced) with a regular grid of 1 cm was used. The accuracy of this film based grid was first tested using the AP190 analytical plotter to monitor possible film deformation. The accuracy of grid intersections measured at 49 points were found to be less than ± 10 microns. This accuracy is sufficient as the highest image resolution used throughout these tests is only 600 dpi (42.5 µm).

The overall geometric accuracy testing involved three main stages, that is;

- data acquisition,
- data processing and measurement, and
- data analysis

In the acquisition stage the film based grid was scanned using four different types of scanners, resulting in an output of thirteen different test images of this film-based grid. Six of these images were obtained from the Apple scanner, two of which (Images 1 and 2) were scanned for the whole area of the film-based grid at 300 dpi on two different dates while Image 3 was scanned at 600 dpi. Images 4, 5 and 6 were scanned in the Apple scanner at three different scanning resolutions, that is, 300, 400 and 600 dpi respectively. Only a small central portion of these images was scanned. Image 7 was scanned in HP Scanjet IIc scanner. Four images, that is, images 8, 9, 10 and 11 were scanned in the Epson GT-9000 scanner. The other two images (images 10 and 11) were scanned in two different HP Scanjet 4c scanners. A summary of the scanned images used in the tests is given in Table 5.1. Image 1 was used in Tests 1, 3, 4 and 5. Images 1, 2, 8 and 9 were used in Test 5. Image 3 was used in Tests 1 and 3. Image 7 was used in Tests 1 and 3 while Image 8 was used in Tests 1, 3 and 5. In Test 2, Images 4, 5, 6, 10 and 11 were used. Images 12 and 13 were used in Tests 1 and 3. The overall scanner testing methodology is given in Figure 5.1. In the data processing stage, the scanned images were transferred to the ERDAS image processing software for image measurement.

Before image measurements were carried out the original scanned image format was converted to a format suitable for the ERDAS image processing software. The final stage involved data analysis. Three types of coordinate transformation were used for data analysis that is, linear conformal, affine and polynomial.

Table 5.1 Summary of scanned images used in the tests

Image No.	Descriptions
1	Scanner : Apple Colour OneScanner Resolution : 300 dpi (whole image) Scan date : March 1994
2	Scanner : Apple Colour OneScanner Resolution : 300 dpi (whole image) Scan date : April 1996
3	Scanner : Apple Colour OneScanner Resolution : 600 dpi (whole image)
4	Scanner : Apple Colour OneScanner Resolution : 300 dpi (small portion of image)
5	Scanner : Apple Colour OneScanner Resolution : 400 dpi (small portion of image)
6	Scanner : Apple Colour OneScanner Resolution : 600 dpi (small portion of image)
7	Scanner : HP Scanjet Iic Resolution : 300 dpi (whole image)
8	Scanner : Epson GT-9000 Resolution : 300 dpi (whole image) Scan date : April 1996
9	Scanner : Epson GT-9000 Resolution : 300 dpi (whole image) Scan date : June 1996
10	Scanner : Epson GT-9000 Resolution : 600 dpi (subset of image) Scan date : August 1996
11	Scanner : Epson GT-9000 Resolution : 300 dpi (subset of image) Scan date : August 1996
12	Scanner : HP Scanjet 4c Resolution : 300 dpi (whole image) Scan date : August 1996
13	Scanner : HP Scanjet 4c Resolution : 300 dpi (whole image) Scan date : August 1996

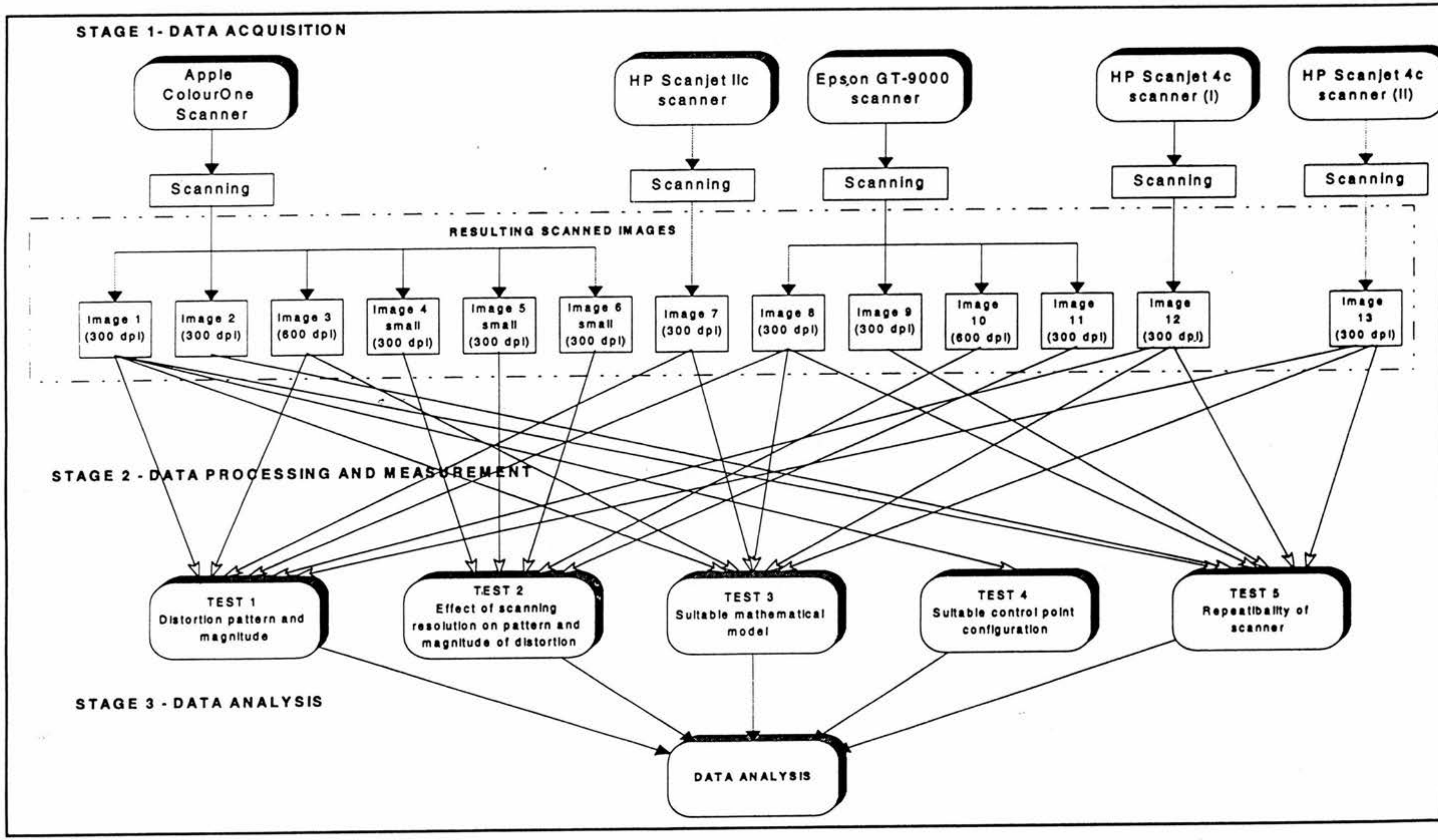


Figure 5.1 Overall scanner testing methodology

5.2.2 A4 format DTP scanners used

As mentioned earlier four different types of colour DTP scanners have been used, all of which were available in different locations within the University of Edinburgh. These scanners are the Apple Colour One Scanner (available in the Resource Centre situated in the main library), the HP Scanjet IIc Scanner (available in the Graphics Workshop situated in King's Buildings), the HP Scanjet 4c scanners (one available in the Resource Centre situated in the main library and the other in the Graphics Workshop situated in King's Buildings) and the Epson Scanner GT-9000 (available in the Geography Department). The software supporting these scanners include various image formats such as PIC (PC Paint), EPS (Encapsulated Postscript file format), DIB (Device-Independent Bitmap format), RAW (Raw file format) and Tagged Interchange File Format (TIFF) and can be used to scan colour or panchromatic photos. Only the binary uncompressed TIFF format was used by the author as it can be readily be exported to ERDAS for image processing and a digital photogrammetric system such as Desktop Mapping System (DMS) for further processing.

The Apple Colour OneScanner features a fast, single-pass scanning process that provides accurate colour registration. The scanner is provided with Ofoto 2.0 software, which allows colour support, background scanning, image enhancement such as image sharpening, exposure balancing and has an easy-to-use interface. Although there are 5 initial scan resolution settings (i.e. 75, 150, 300, 600 and 1,200 dpi) other resolution settings in 1 dpi increments can be accomplished through software interpolation. The maximum interpolatable scanning resolution of this scanner is 1200 dpi. In contrast, the HP Scanjet IIc scanner allows images to be scanned up to only 400 dpi resolution. The scanner is provided with HP DeskScan II software. The third scanner used, the Epson GT-9000 DTP scanner (Plate 5.1), is a full-colour flatbed image scanner with an A4 format scanning area. It has the ability to scan in colour or gray scale monochrome. The optical resolution of this scanner is 600 dpi. The output resolution is selectable to suit the resolution of the intended output device. There are twenty nine resolution settings available, ranging from 50 dpi to 2400 dpi. The Epson Scan II scanner utility program is used to control the scanner. The final type of scanner used was the HP Scanjet 4c scanner. A special transparency adapter can be attacted to the Epson GT-9000 and the HP Scanjet 4c scanners to allow scanning in transmissive mode. The technical specifications of the four DTP scanners used in the tests are given in Table 5.2.

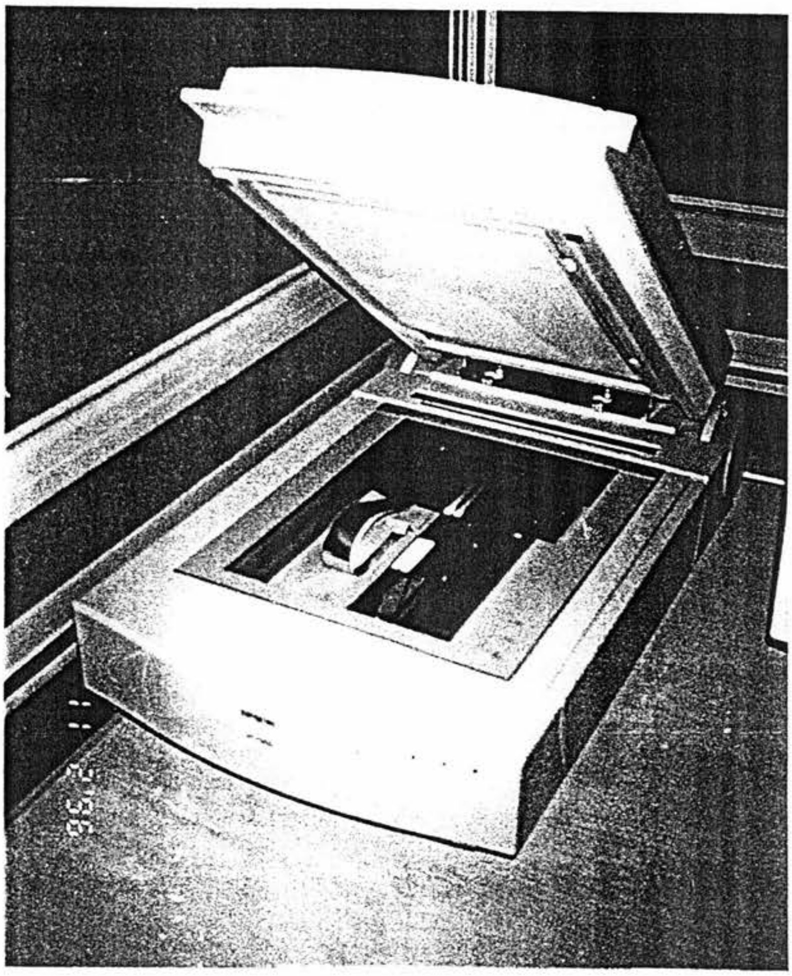


Plate 5.1 Epson GT-9000 DTP scanner

Table 5.2 Summary of characteristics of the A4 format DTP scanners used

Brand/model	**[A] Apple Colour OneScanner**	**[B] HP Scanjet IIc**
Colour choice	16.7 millions	16.7 millions
Resolution setting	75, 150, 300, 600 and 1200 dpi. Resolution can be adjusted in 1dpi increment	75, 150, 300 and 400 dpi. (max. resolution)
Max.scan area	A4 format (216mm x 365 mm)	A4 format (216mm x 365 mm)
Scanning software	Ofoto Version 2.0	HP DeskScan II
Hardware	Macintosh computers	PC and Macintosh
Sensor	Three 300 dpi CCDs	Three 300 dpi CCDs
Interface	SCSI	SCSI adapter for PC and Macintosh
Type	Flatbed	Flatbed
Scanning mode	Reflective	Reflective
Brand/model	**[C] Epson GT-9000**	**[D] HP Scanjet 4c**
Colour choice	16.7 millions	16.7 millions
Resolution setting	50, 60, 72, 75, 80, 90, 100, 120, 133, 144, 150, 160, 175, 180, 200, 216, 240, 300, 320, 360, 400, 480, 600, 800, 900, 1200, 1600, 1800 and 2400 dpi	3 to 400% in 1% increments at 600 dpi
Max.scan area	A4 format (216mm x 365 mm)	A4 format (215 mm x 356 mm)
Scanning software	Epson Scan II	HP DeskScan II
Hardware	PC	PC and Macintosh
Sensor	Three 600 dpi CCDs	Three 600 dpi CCDs
Interface	SCSI adapter for PC and Macintosh	SCSI adapter for PC and Macintosh
Type	Flatbed	Flatbed
Scanning mode	Reflective	Reflective and transmissive

5.2.3 Mathematical formulae for data analysis

The data analysis mentioned in Section 5.2.1 earlier was undertaken using three different types of coordinate transformation. The three transformations are the linear conformal, affine and polynomials. The linear conformal transformation was used to compute the distortion pattern and the magnitude of image distortion in Tests 1 and 5. The other two transformations were utilised in Tests 2, 3 and 4. In the linear conformal transformation the shape of the resultant image is preserved. This transformation is particularly suitable to determine the pattern and magnitude of scanner distortion. The different scale factors in the x and y directions used in the affine transformation allows different corrections to be applied in both directions of the image. The polynomial transformation allows a more complicated distortion pattern inherent in the images to be eliminated. The mathematical formulae for these transformations are as follows:

a. Linear conformal transformation

$$X = ax - by + c \qquad \text{.......................................(5.1)}$$
$$Y = bx + ay + d$$

where X, Y - calibrated grid intersection coordinates
x, y - image coordinates
a, b, c, d - transformation coefficients

b. Affine transformation

$$X = a_1 + a_2x + a_3y$$

$$Y = b_1 + b_2x + b_3y \qquad \text{.......................................(5.2)}$$

where X, Y - calibrated grid intersection coordinates
x, y - image coordinates
$a_1, a_2, a_3, b_1, b_2, b_3$ - transformation coefficients

c. Two-dimensional polynomial transformation

$$\begin{aligned}
X = \; & a_1 \\
& + a_2x + a_3y && \text{constant term} \\
& + a_4xy + a_5x^2 + a_6y^2 && \text{1st order terms} \\
& + a_7x^2y + a_8xy^2 + a_9x^3 + a_{10}y^3 && \text{2nd order terms} \\
& + a_{11}x^3y + a_{12}xy^3 + a_{13}x^4 + a_{14}x^2y^2 + a_{15}y^4 && \text{3rd order terms} \\
& + \ldots\ldots\ldots\ldots && \text{4th order terms}
\end{aligned}$$

.........(5.3)

$$\begin{aligned}
Y = \; & b_1 \\
& + b_2x + b_3y \\
& + b_4xy + b_5x^2 + b_6y^2 \\
& + b_7x^2y + b_8xy^2 + b_9x^3 + b_{10}y^3 \\
& + b_{11}x^3y + b_{12}xy^3 + b_{13}x^4 + b_{14}x^2y^2 + b_{15}y^4 \\
& + \ldots\ldots\ldots\ldots
\end{aligned}$$

where X, Y - calibrated grid intersection coordinates
x, y - image coordinates
$a_1, a_2 \ldots\ldots a_{15}$ - transformation parameters
$b_1, b_2 \ldots\ldots b_{15}$ - transformation parameters

All the three transformations given above have been programmed in QBASIC by the author for use in personal computer (PC). The three programs are as follows:

- LINCON (LINear CONformal),
- AFFINE (AFFINE transformation), and
- POLY15 (POLYnomial transformation with 15 terms).

The listing of these programs is given in Appendix E. The POLY15 program is arranged so that any specific groups of terms can be used to transform the measured image coordinates to calibrated grid intersection coordinates. This allows the effects of adding a new term to be monitored and evaluated. Since the number of measured points to be used in the transformation is more then the absolute minimum to perform the transformation, the programs provide a least squares solution.

5.3 Test 1 - Distortion pattern and magnitude of image scanned in desktop scanners

The main aim of this test was to determine the distortion pattern and magnitude of image distortions scanned in five DTP scanners. Two of these scanners were of the same model, that is, the HP Scanjet 4c scanner. For the purpose of this test 47 grid intersection points were measured, of which 25 points were used as control points while the other 22 points were assigned as check points. The control points are points used in linear conformal coordinate transformation to compute the transformation parameters while the check points are points other than the control points with known coordinates used to compute the accuracy of observation or image distortions. Control points were selected at 5 cm grid intervals and the check points were selected in between the control points. The control and the check point configuration is shown in Figure 5.2.

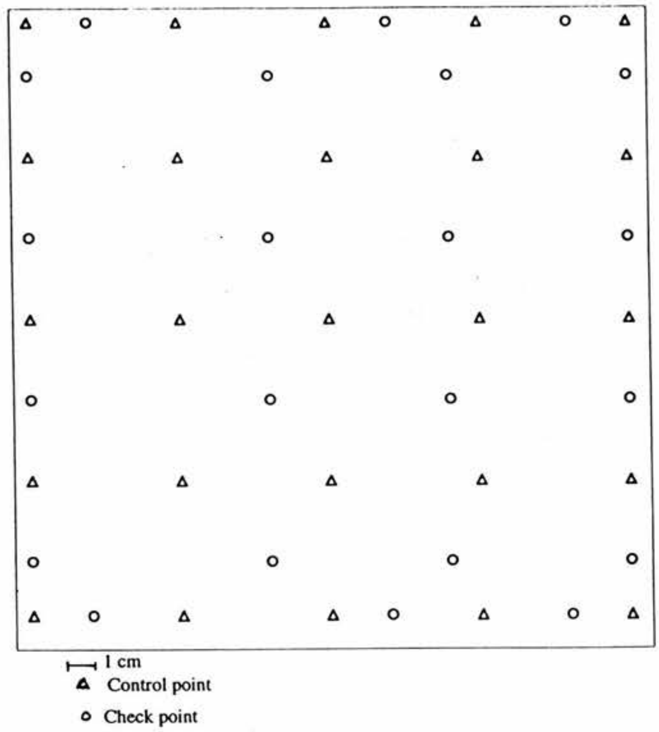


Figure 5.2 Distribution of control and check points

5.3.1 Methodology

The high resolution stable Estar thick base film was scanned at 300 dpi resolution using the 8 bits grey level in the Apple, HP Scanjet IIc, Epson and HP Scanjet 4c scanners. Beside this, another image of this film was scanned at 600 dpi in the Apple scanner. The scanned images were stored in the uncompressed TIFF (Tagged Image File Format) format. The images scanned at 300 dpi and 600 dpi resolution consumed 6.5 Mbytes and 27.5 Mbytes of disk storage respectively. Since the size of the file generated is large and scanning was carried out on different university sites, transfer of image between different hardware using conventional media, e.g. floppy diskettes was not possible. These files were transferred to the central server in the Geography Department for further analysis.

The CORE module in the ERDAS digital image processing software was used to measure the image coordinates of all the 25 control and 22 check points. To allow easy and accurate coordinate measurement of these points the images were magnified eight times. The calibrated grid intersection coordinates and the measured image coordinates were then entered into data files to be read into the LINCON program. Using this program the measured image coordinates were converted to calibrated grid plate coordinates. Errors at the control and check points, and the overall root mean square error (r.m.s.e.) in terms of x and y were then computed. A sample of the input and output data files of the LINCON program is given in Appendix E5.

5.3.2 Results and analysis

The resultant vector error plots of the image distortion pattern at the control points for the 300 dpi images scanned in the Apple, HP Scanjet IIc, Epson and the two HP Scanjet 4c scanners are shown in Figures 5.3, 5.4, 5.5, 5.6 and 5.7 respectively. Figure 5.8 shows the resultant vector error plot of the distortion pattern for the 600 dpi image scanned in the Apple scanner. Since the grid is considered error free, the distortion pattern and the magnitude of distortion of the scanned image can be considered as due to scanner error. In all the figures, the systematic nature of the distortion pattern can clearly be seen, although the distortion patterns of images scanned in different scanners differ significantly (including images scanned in two scanners of the same model). Only the distortion patterns of images scanned at 300 and 600 dpi in the Apple scanner are similar.

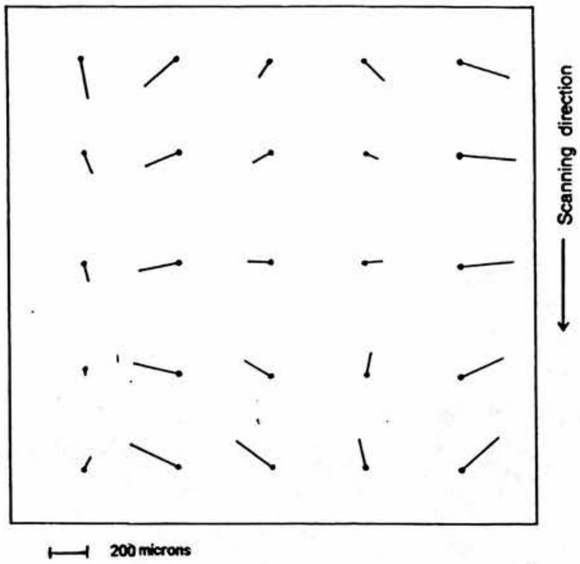


Figure 5.3 Distortion pattern of image scanned in Apple Colour OneScanner

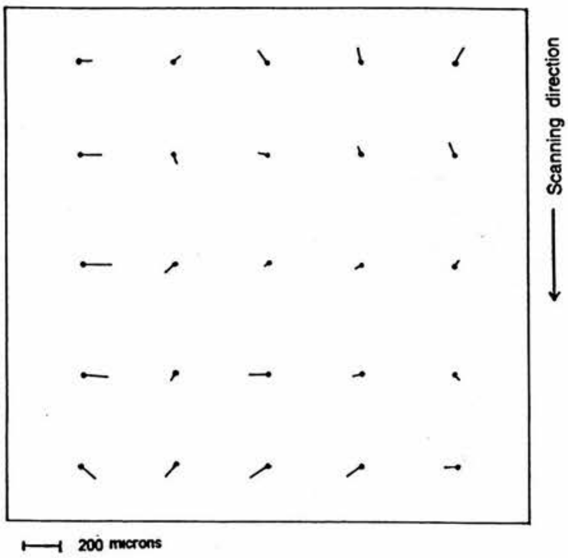


Figure 5.4 Distortion pattern of image scanned in HP Scanjet IIc scanner

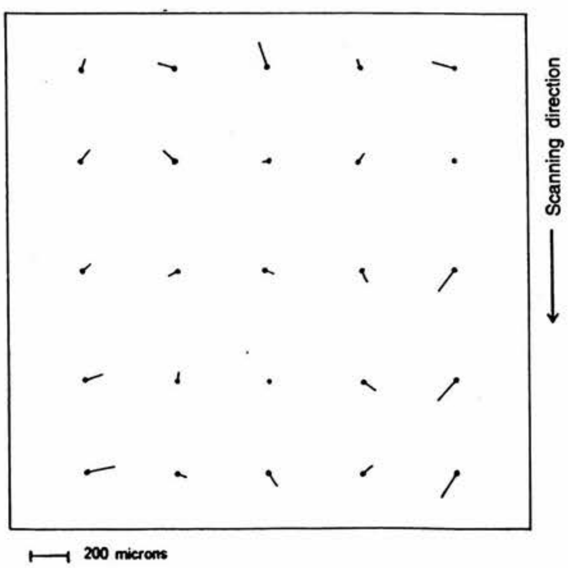


Figure 5.5 Distortion pattern of image scanned in Epson GT-9000 scanner

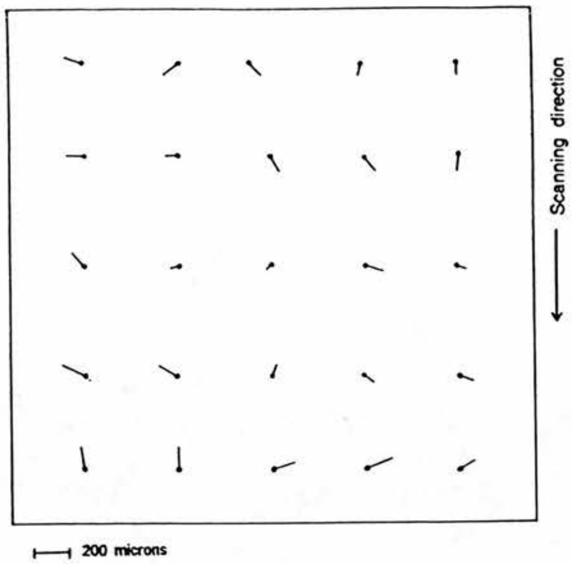


Figure 5.6 Distortion pattern of image scanned in HP Scanjet 4c (Scanner No.1)

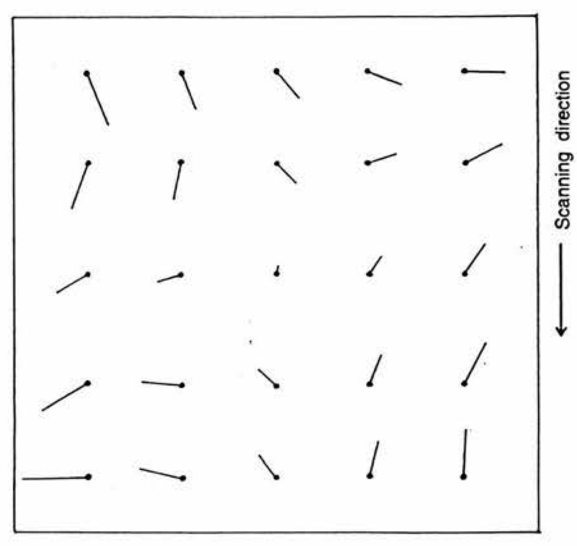


Figure 5.7 Distortion pattern of image scanned in HP Scanjet 4c (Scanner No.2)

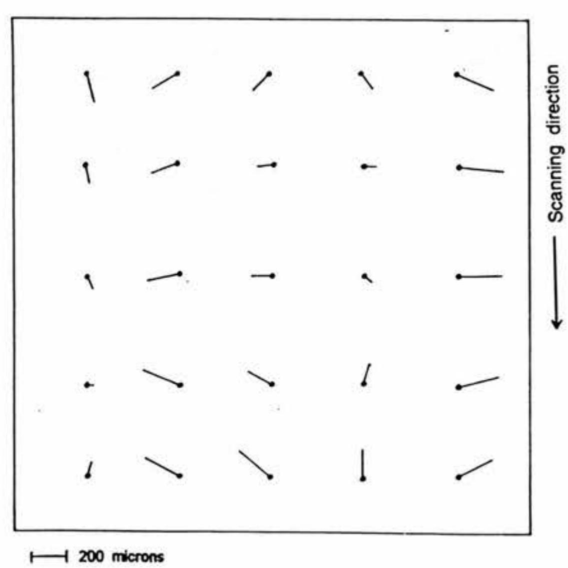


Figure 5.8 Distortion pattern of the 600 dpi image scanned in Apple ColourOne scanner

The summary of results on the magnitude of image distortions for the Apple, HP, Epson and HP Scanjet 4c scanners is given in Table 5.3. The magnitude of image distortion is given in units of pixels. For the 300 dpi image scanned in the Apple scanner, the magnitude of image distortion at both the control and check points in the x direction (left to right) is larger than in the y direction (top to bottom i.e. scanning direction). The maximum errors in the resultant vector measured from the image at the control and check points are significantly large, that is more than ± 3.5 pixels. As in the 300 dpi image, the magnitude of image distortion of the 600 dpi image at the control and check points in the x direction is also more significant then in the y direction. No measurements were taken at the check points. The maximum error in the resultant vector (in microns) measured from the image at the control points is almost the same to that of image scanned at 300 dpi.

Table 5.3 Magnitude of distortions at the control and check points in desktop scanners

	R.m.s.e. at Control points (in pixel unit)			R.m.s.e. at Check points (in pixel unit)			Max. Error at Control points (in pixel unit)			Max. Error at Check points (in pixel unit)		
Scanner	Mx	My	Mv	Mx	My	Mv	Ex	Ey	Ev	Ex	Ey	Ev
Apple Colour OneScanner*	3.41	2.27	4.01	3.35	2.20	4.00	6.03	5.98	6.03	5.92	5.61	5.92
Apple Colour OneScanner	1.97	1.21	2.31	1.80	1.34	2.24	3.51	2.63	3.65	3.35	2.33	3.59
HP Scanjet IIc	0.83	0.50	0.97	0.79	0.45	0.91	2.02	1.08	2.02	1.96	0.93	1.96
Epson GT-9000	0.80	0.75	1.19	0.71	0.71	1.00	2.01	1.62	2.06	1.49	1.67	2.19
HP Scanjet 4c (Scanner 1)	0.84	0.73	1.11	0.68	0.78	1.04	1.56	1.42	1.61	1.33	1.59	1.62
HP Scanjet 4c (Scanner 2)	1.89	1.82	2.62	1.87	1.93	2.67	4.21	3.28	4.41	3.82	3.75	3.82

Note : * - scanning at 600 dpi

For the image scanned in the HP Scanjet IIc scanner, the magnitude of image distortion in the x direction is also more significant than in the y direction. The magnitude of image distortion at the control and check points in the x direction is almost 1.5 times larger than in the y direction. The resultant vector errors at both the control and check points are approximately ± 1 pixel. The maximum errors in the resultant vector measured from the image at the control and check points are approximately ± 2 pixels.

For the image scanned in the Epson scanner, the magnitude of image distortion in the x direction is the same as in the y direction. The r.m.s.e. at the control and check points is each approximately ± 0.8 pixel. The resultant vector errors at both the control and check points are approximately ± 1 pixel. The maximum errors in the resultant vector measured from the image at the control and check points are approximately ± 2 pixels.

For the images scanned in both the HP Scanjet 4c scanners, the magnitude of image distortion in the x direction is approximately the same as in the y direction. The r.m.s.e. at the control points for Scanner 1 in both the x and y directions is less than ± 1 pixel. At the check points the overall image distortions in the x and y directions are also less than ± 1 pixel. The resultant vector errors at the control and check points are almost ± 1 pixel. The maximum errors in the resultant vector measured from the image at the control and check points are approximately ± 1.6 pixel. For Scanner 2, the r.m.s.e. at the control and check points are almost twice as large as that of Scanner 1. The resultant vector errors at both the control and check points are also more than twice as large as for Scanner 1. The maximum errors in the resultant vector measured from the image at the control and check points are significantly large, that is, almost three times larger than for Scanner 1.

This test has shown that the distortion patterns and magnitude of image distortion of the five scanners tested differ from one another. Although the distortion patterns in all the five scanners tested are systematic in nature, each pattern is significantly different. The original magnitude of image distortions in the Apple Colour OneScanner is more than twice the scanning resolution while for the HP Scanjet IIc and Epson scanners the distortion is approximately the same as the scanning resolution. Compared to the HP Scanjet IIc, Epson and HP Scanjet 4c (Scanner 1) scanners, the magnitude of image distortions in the Apple Colour OneScanner is approximately twice as large. Different scanners of the same model (HP Scanjet 4c) give a different pattern and magnitude of image distortions. Although the overall magnitude of image distortion in HP Scanjet IIc, Epson and HP Scanjet 4c (Scanner 1) scanners is not significant, the maximum resultant error at certain location within the image is still large (approximately twice the scanning resolution).

5.4 Test 2 - Effect of the scanning resolution on the pattern and magnitude of image distortion

The main aim of this test was to determine whether scanning resolution has any effect on the magnitude or pattern of distortion. The test was carried out on the Apple Colour OneScanner and the Epson GT-9000 scanner. For the Apple scanner twenty five control points with no check points were used, while for the Epson scanner sixteen control and eighteen check points were used.

5.4.1 Methodology

For the Apple scanner, the calibrated grid intersections at three different resolutions i.e. 300, 400 and 600 dpi were scanned, using only the centre portion of the image (approximately 7 cm by 7 cm) to minimise the amount of data storage required. The file sizes for the 300, 400 and 600 dpi were 0.8, 1.4 and 3.2 Mbytes respectively. Control points were selected at 1 cm grid intervals. In the Epson scanner, only two different scanning resolutions were tested, that is, the 300 and 600 dpi images. Only a limited area of the calibrated grid (approximately 16 cm by 18 cm) was scanned. Image coordinates of the control and check points were measured in the

ERDAS digital image processing software. The linear conformal coordinate transformation program (LINCON) was used to convert the measured image coordinates to calibrated grid intersection coordinates. The overall r.m.s.e. at the control and check points (only for images scanned in Epson scanner) were computed.

5.4.2 Results and analysis

The distortion patterns of images scanned in the Apple scanner at 300, 400 and 600 dpi are given in Figures 5.9, 5.10 and 5.11 respectively, while the distortion patterns of the other two images scanned in Epson scanner at 300 and 600 dpi are given in Figures 5.12 and 5.13 respectively. From all these figures, it can clearly be seen that the patterns of distortions from the same scanner are almost identical and follow a systematic pattern. The magnitudes of distortions for the images scanned in the Apple and Epson scanner are given in Table 5.4. Results for this table shows only slight differences in the magnitude of image distortions when images are scanned in the same scanner.

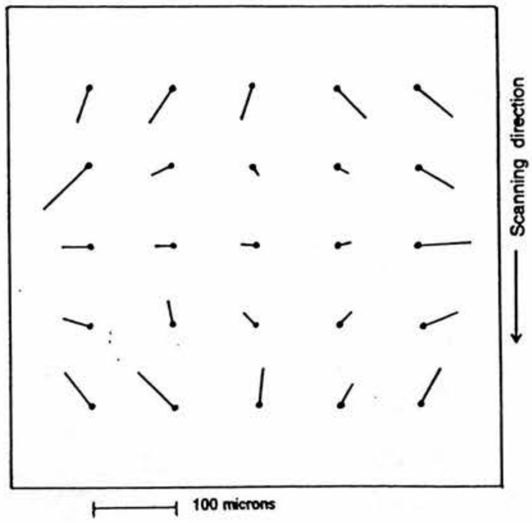


Figure 5.9 Distortion pattern of image scanned in Apple scanner - 300 dpi

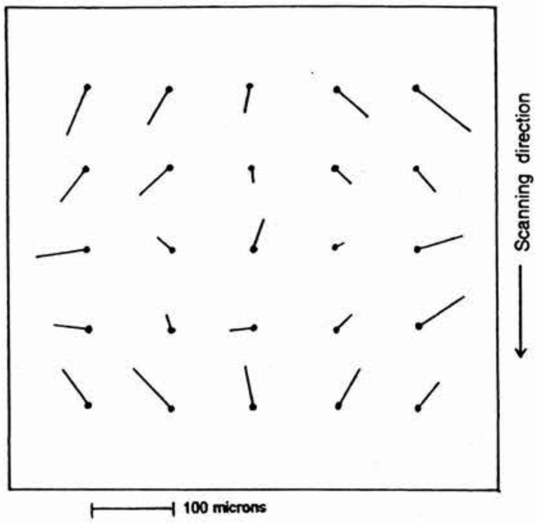


Figure 5.10 Distortion pattern of image scanned in Apple scanner - 400 dpi

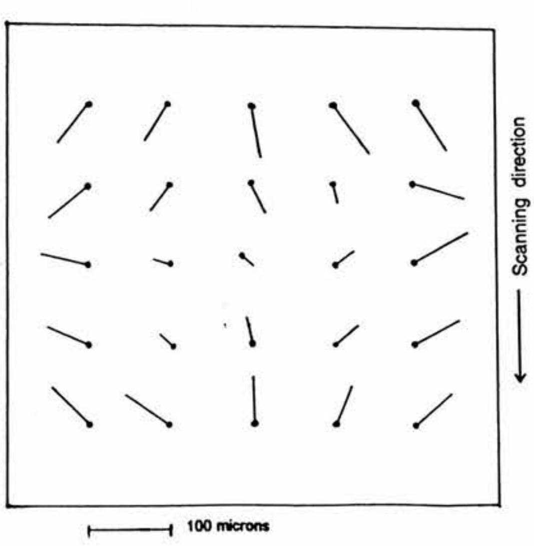


Figure 5.11 Distortion pattern of image scanned in Apple scanner - 600 dpi

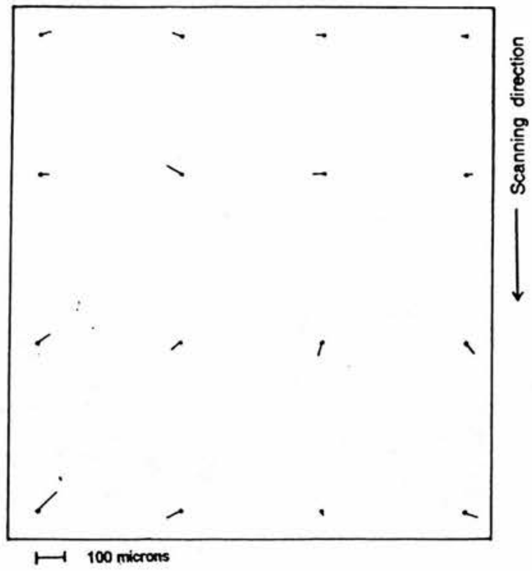


Figure 5.12 Distortion pattern of image scanned in Epson scanner - 300 dpi

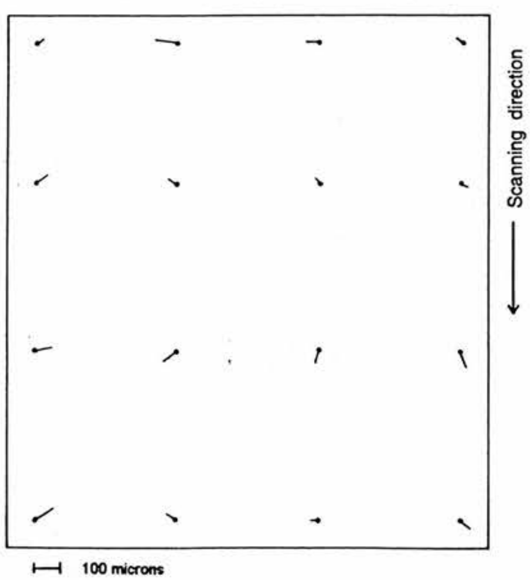


Figure 5.13 Distortion pattern of image scanned in Epson scanner - 600 dpi

Table 5.4 R.m.s.e. of the control and check points at different scanning resolution.

Scanner	Resolution	R.m.s.e. at control points (in micron)			R.m.s.e. at the check points (in micron)		
		Ex	Ey	Ev	Ex	Ey	Ev
Apple Colour OneScanner	300 dpi (85 μm)	32	32	46	-	-	-
	400 dpi (70 μm)	40	40	57	-	-	-
	600 dpi (43 μm)	37	37	52	-	-	-
Epson GT-9000	300 dpi (85 μm)	43	30	52	43	20	48
	600 dpi (43 μm)	46	31	56	35	23	42

This test has indicated that there is not much difference in the pattern and magnitude of image distortion even though scanning is carried out at a resolution higher or lower than the scanner optical resolution. Slight differences in the pattern and magnitude of image distortion observed in this test could be due to the image interpolation process introduced in the software to produce the images at a resolution higher or lower than the scanner optical resolution or error introduced during measuring the grid intersection points.

5.5 Test 3 - Suitable mathematical model to eliminate distortion

Test 1 shows that distortions of images scanned in desktop scanners are quite significant, which poses the question of how distortion of images scanned in these scanners can be minimised. Test 3 was aimed to test the suitability of using a mathematical model to minimise image distortions. Two mathematical models, the affine and polynomial transformations, have been used in this test. A detailed explanation of these coordinate transformations has been given in Section 5.2.3.

5.5.1 Methodology

The calibrated grid intersection film was scanned at 300 dpi resolution in the HP Scanjet IIc, Epson and both the HP Scanjet 4c scanners. In the Apple scanner the film was scanned at 300 and 600 dpi. The image coordinates of the control and check points were then measured using the ERDAS digital image processing software. Two different sets of control and check points were used for this test. The first set consisted of 72 control and 29 check points while the other used only 25 control and 22 check points (the same as in Test 1). The former set was used only for the 300 dpi image scanned in the Apple scanner, while the later set was used for images scanned in all five scanners. Using the affine and polynomial coordinate transformation programs AFFINE and POLY15 respectively, the measured image coordinates were converted to calibrated grid coordinates. The errors (r.m.s.e. and maximum errors) in terms of x and y were then computed. Graphical plots of the resultant vector errors at the control points were used to show the magnitude and direction of image distortions after transformation.

5.5.2 Results and analysis

Results of image distortion correction using the affine and polynomial transformations and the first set of control and check points are given in Appendix G1. Appendix G2 show the comparison between the magnitude of image distortions in the Apple, HP Scanjet IIc and Epson scanners when different coordinate transformations were applied. The magnitude of image distortions in the two HP Scanjet 4c scanners when different coordinate transformations were applied is given in Appendix G3.

From Appendix G1, the original magnitude of image distortion in terms of x, y and the resultant vector are ± 1.90, ± 1.29 and ± 2.29 pixels while at the check points the values are ± 1.88, ± 1.36 and ± 2.32 pixels respectively. When the affine transformation is applied significant improvement in the y direction (scanning direction) can be seen. The r.m.s.e. at both the control and check points are reduced by three quarters of the original image distortion. In the x direction the improvement is not significant (approximately to two-thirds). The use of a 5 term polynomial (up to the x^2 term) reduced image distortion in both the x and y directions significantly. The distortion in the x direction is reduced approximately by half while the resultant r.m.s.e. is reduced by more than two thirds. Further regular reductions were apparent when polynomials in up to 9 terms (x^3) were introduced. The distortion in the x direction is then reduced to more than one tenth of the original distortion. No further significant improvement occured when a polynomial of higher order than 10 terms was introduced. Overall the maximum distortions at any control and check points after applying coordinates transformation are reduced to ± 0.36 and ± 0.45 pixels respectively.

It can clearly be seen that the application of the affine transformation to the images scanned in the Apple and HP Scanjet IIc scanners causes drastic reduction of the distortion magnitude in the y direction (Appendix G2). In the x direction, the magnitude of distortion is still large. As in Appendix G1, the r.m.s.e. at both the control and check points are reduced by three quarters of the original image distortion. In the x direction the improvement is not significant (approximately to two-thirds). The introduction of the x^2 term in the polynomial transformation reduces the distortion in the x direction significantly. The other term which caused significant improvement in the distortion values in both scanners is the x^2 term. The use of x^3 (third order) polynomial term helps to reduce distortion to a minimum. After that there is no further reduction in the magnitude of image distortion.

For the image scanned in the HP Scanjet IIc scanner, the application of an affine transformation only reduced the magnitude of distortion in y direction by half. The introduction of the x^2 term in the polynomial transformation reduced the magnitude of distortion in both the x and y directions approximately by half. The application of other polynomial terms makes no significant improvement in the magnitude of image distortion and the error in x after transformation is still double the error in y.

In the Epson scanner, the reduction of the distortion magnitude in both the x and y directions as the result of affine transformation is not as significant as with the other two scanners. The application of the third order polynomial to the image reduces the distortion in x and y directions to a minimum. No improvement can be observed when the fourth order polynomial is applied.

Appendix G3 gives the r.m.s.e. at the control and check points of the two HP Scanjet 4c scanners. The application of affine transformation to the image scanned in the first scanner (Scanner 1) significantly reduced the magnitude of distortions in both the x and y directions by almost half, while for the image scanned in another scanner (Scanner 2), the magnitude of distortions in the x and y directions were reduced to only one third and one sixth of the original distortions respectively. In Scanner 1, no further reduction in the resultant magnitude of distortion at the check points can be observed when higher polynomial orders were introduced. The minimum distortion occurred when the x^2 term was introduced. A slight increase in the distortion error occurred when more than 9 polynomial terms were used. In Scanner 2, the introduction of the second order term (i.e. xy term) reduced the distortion at the check points to a minimum. The effect of applying different polynomial terms on the r.m.s.e. and maximum errors at the check points in all the five DTP scanners are graphically illustrated in Figures 5.14 and 5.15 respectively.

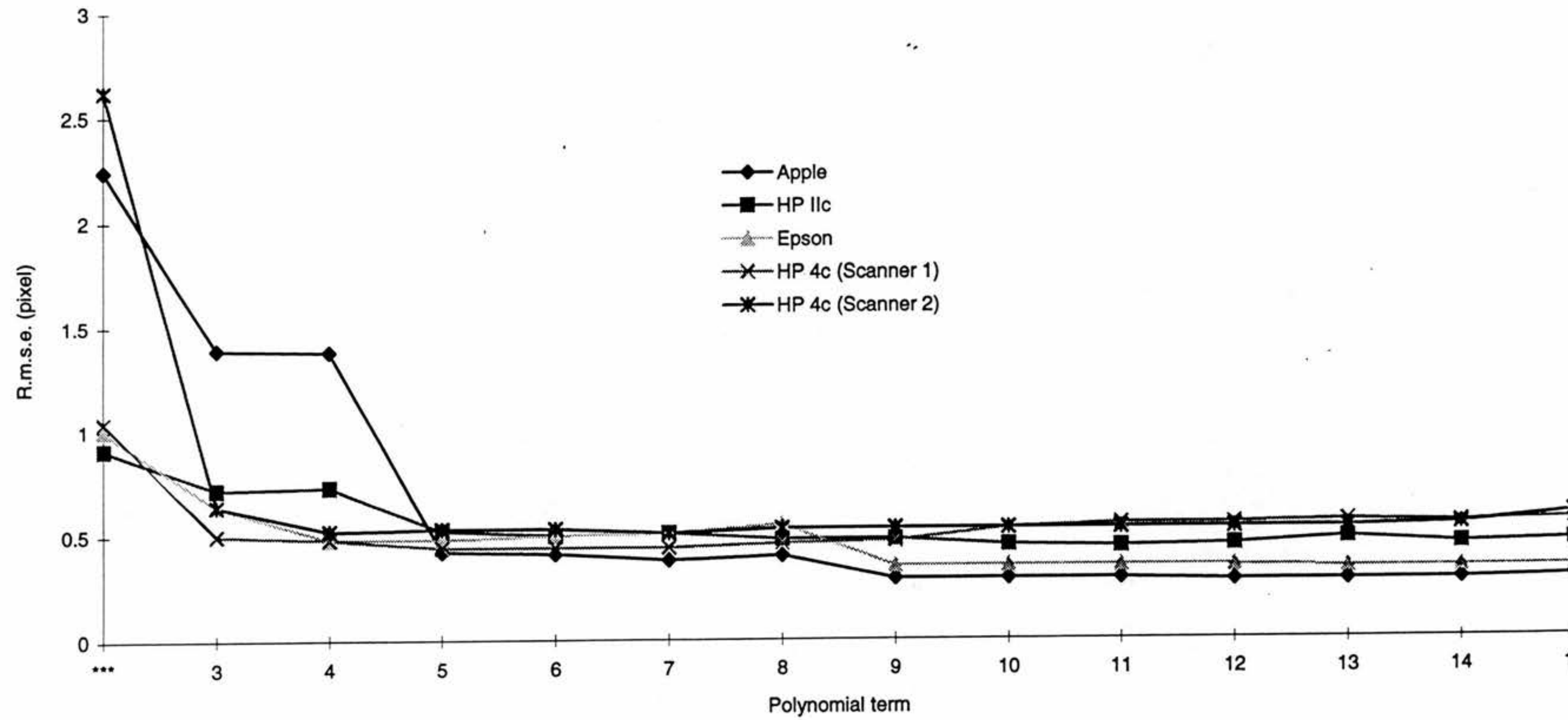


Figure 5.14 Polynomial terms against r.m.s.e. at the check points

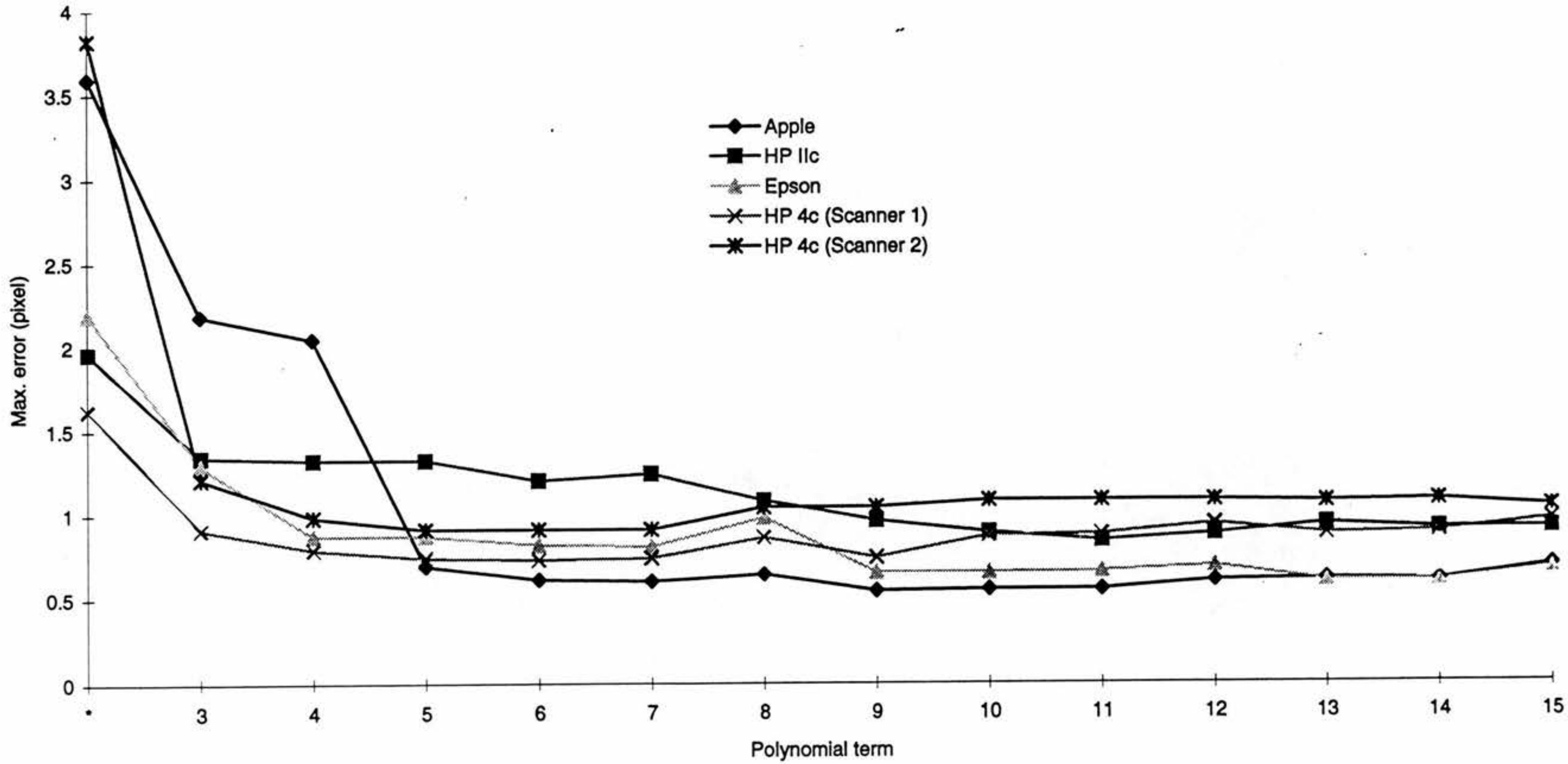


Figure 5.15 Polynomial terms against maximum error at the check points

The maximum errors at the control and check points of all the five scanners are summarised in Appendix G4 . It can clearly be seen that the maximum magnitude of image distortion at any control point decreases as the number of polynomial terms used increases. At the check points, a similar trend can be observed when certain polynomial terms were applied. In the Apple scanner the lowest value for the maximum magnitude of image distortion at any check point occurred when third order polynomial (x^2 term) was introduced. For HP Scanjet IIc scanner, the lowest value occurred when the fourth order polynomial (x^3y term) was introduced, while for the Epson scanner the lowest value occurred when the fourth order polynomial (x^4 term) was used. Lowest values in both the HP Scanjet 4c scanners occurred when the second order polynomial (y^2 term) was used.

The results above have shown that while the magnitude of distortion of images scanned in some DTP scanners is significant it can be minimised by using a suitable mathematical model. The use of an affine transformation only helps to reduce the effect of image distortions in the y direction for images scanned in the Apple and HP scanners. The x^2 term in the polynomial transformation helps to reduce the effect of distortion in the x direction. For the images scanned in Apple and HP Scanjet IIc scanners, the use of a third order polynomial helps to reduce image distortion to a minimum. The application of a third or fourth order polynomial makes the magnitude of distortions in the x and y directions the same and the resultant vector errors at the check points for the images scanned in Apple, HP Scanjet IIc and Epson scanners were found to be less than half a pixel. In both the HP Scanjet 4c scanners, the use of only a second order polynomial helps to reduce the image distortion to a minimum. There is no further improvement in the magnitude of distortions when higher order polynomials are used. A summary of suitable polynomial terms to be used in image rectification to obtain the best results (lowest r.m.s.e and lowest "maximum error") in different DTP scanners is given in Table 5.5. This test has also shown that a suitable mathematical model can be used to reduce the magnitude of distortions to less than half a pixel. However, the maximum errors at the check points were still large (i.e. more than half a pixel).

Table 5.5 Summary of suitable polynomial order term for different DTP scanners

	Polynomial order term	
Scanner	Lowest r.m.s.e.	Lowest "Maximum error"
Apple Colour OneScanner	Third/fourth	third/fourth
HP Scanjet Iic	Third	third
Epson GT-9000	Third/fourth	third/fourth
HP Scanjet 4c (Scanner 1)	Second	second
HP Scanjet 4c (Scanner 2)	Second	second

Using the appropriate polynomial order terms mentioned above, the distortions at the control points were computed and the vector plots were plotted. Figures a, b, c, d and e in Appendix G5 shows the vector plots of the Apple, HP Scanjet IIc, Epson, HP Scanjet 4c (Scanner 1) and HP Scanjet 4c (Scanner 2) scanners respectively.

It can clearly be seen that the magnitudes of image distortions were significantly reduced and the distortion patterns in all the scanners were no longer systematic after the application of appropriate order of polynomial coordinate transformations.

5.6 Test 4 - Suitable control point configurations

This test was intended to determine the optimum configuration of the control points and the optimum numbers to be used in the transformation process. Five different sets of control point configurations have been tested. A total of 17 check points were used, carefully selected so that their locations are furthest away from the control points. The five control point configurations tested (Figure 5.16) are as follows:

- Test A Twelve (12) control points only at the edges of the scanned image
- Test B Fourteen (14) control points, with 12 points at the edges and an additional 2 points at the middle of the scanned images.
- Test C Sixteen (16) control points evenly distributed in a square grid pattern (6 cm by 6 cm)
- Test D Twenty five (25) control points evenly distributed in a square grid pattern arranged diagonally
- Test E Forty nine (49) control points evenly distributed in a square grid pattern (3 cm by 3 cm)

5.6.1 Methodology

The calibrated grid intersection film was scanned at 300 dpi resolution in the Apple scanner. The TIFF format scanned image file was transferred to the ERDAS digital image processing software. Image coordinates of the control and check points were then measured. All the five different sets of control point configurations (refer to Figure 5.16) were used in this test. Using the third order polynomial transformation in POLY15 program the image coordinates measured in the five different sets of control points configurations were converted to calibrated grid intersection coordinates. From these the errors at the check points and the overall r.m.s.e. in terms of x and y in the five sets were computed.

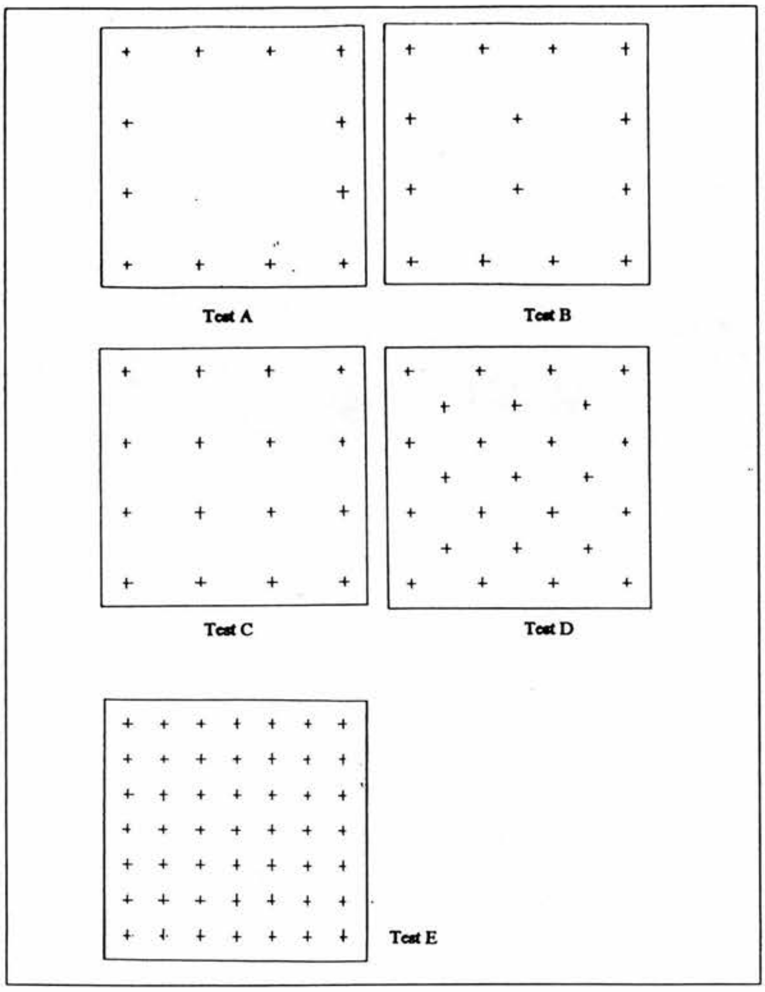


Figure 5.16 Control points configurations

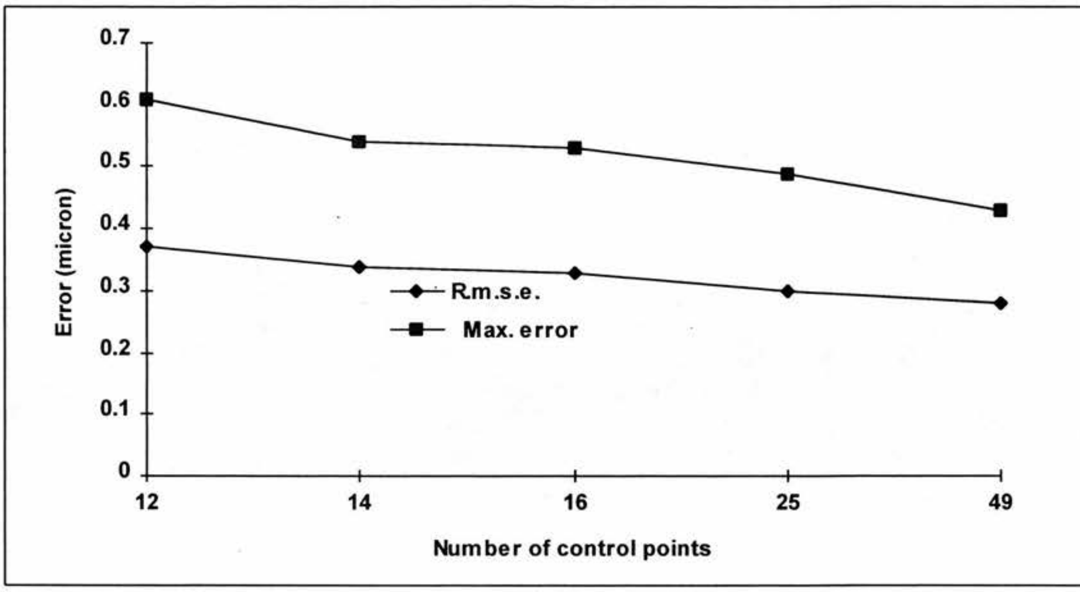
5.6.2 Results and analysis

The image distortions results using different control point configurations are given in Table 5.6 while Figure 5.17 graphically illustrated the results. It can clearly be seen from this figure that as the number of control points increases the magnitude of image distortions at the check points also increases. The overall distortions (r.m.s.e.) and the maximum distortion at the check points using any control point configuration were less than ± 0.40 and ± 0.61 pixels respectively. At any location within the image, an accuracy of ± 0.5 pixel can be achieved when the control points are located at i) 6 cm grid interval plus additional controls in the middle of the grid (refer Test D in Figure 5.16) and ii) 3 cm grid interval (Test E in Figure 5.16) An evenly distributed control points throughout the image (in grid pattern of 3 cm apart) produce the best results (Test E in Figure 5.16).

As the pattern and magnitude of distortion in the scanned image varies from one place to another, the configuration and number of control points used to correct the image are critical factors to be considered. This test has shown that different accuracies were achieved when different sets of control points were used. As the number of control points increases the magnitude of image distortion decreases. Although all the control point configurations used in this test allow an overall sub-pixel accuracy to be achieved it is recommended to use more than the minimum number of control points. It is important to note that as this test is carried out for images scanned in the Apple scanner only, the results might not be valid for other DTP scanners.

Table 5.6 The r.m.s.e. and maximum magnitude of image distortions at the check points using different sets of control points.

		R.m.s.e			Max Distortion		
Test	No of Control Points	Mx (pixel)	My (pixel)	Mv (pixel)	Ex (pixel)	Ey (pixel)	Ev (pixel)
Test A	12	0.24	0.28	0.37	0.48	0.55	0.61
Test B	14	0.24	0.24	0.34	0.39	0.47	0.54
Test C	16	0.23	0.23	0.33	0.40	0.47	0.53
Test D	25	0.21	0.21	0.30	0.38	0.43	0.49
Test E	49	0.20	0.20	0.28	0.36	0.36	0.43



F

Figure 5.17 Number of control points against distortion at check points

5.7 Test 5 - Differences in distortion pattern and the magnitude of image distortion resulting from repeat scanning

This test was intended to examine the difference in distortion pattern and the magnitude of image distortion resulting from repeat scanning.

5.7.1 Methodology

The calibrated grid intersection film was scanned in two different scanners at two different dates. In this test only the Apple and Epson scanners were used. The first (Image 1) was scanned in April 1994 while the second (Image 2) in April 1996 using the Apple scanner. The main reason for scanning images two years apart is also to determine whether DTP scanner can maintain its distortion pattern and the magnitude of image distortion over a long period of time. The other two images (Images 8 and 9) were scanned in the Epson GT-9000 scanner. Scanning was carried out at 300 dpi resolution. The image coordinates at the control and check points were measured using the ERDAS image processing software. The same set of control and check points as used in Test 1 was used. The linear conformal transformation program (LINCON) was used to convert the measured image coordinates to calibrated grid intersection coordinates. The errors at the control and the check points and the overall r.m.s.e were then computed.

5.7.2 Results and analysis

The results of this test for magnitude of image distortions are summarised in Table 5.7. From this table it can be seen that there are only minor differences in the image distortions in both the scanners. The amount of image distortion changes from 2.31 pixels (for images scanned in April 1994) to 2.01 pixels (for images scanned in April 1996). For images scanned in the Epson scanner, the amount of distortion changes from 1.19 pixels (for images scanned in April 1996) to 0.87 pixels (for images scanned in June 1996). The distortion patterns of images scanned using the Apple (Image 2) and Epson (Image 8) are given in Figures 5.18 and 5.19 respectively. The original distortion patterns (Images 1 and 7) are given earlier in Figures 5.3 and 5.5 respectively. From these two pairs of Figures it can clearly be seen that there are no significant differences in the pattern of image distortion.

Table 5.7 R.m.s.e. and maximum errors at the control points

Scanner type	Date of scanning	R.m.s.e. Mx (pixel)	My (pixel)	Mv (pixel)	Max. error Ev (pixel)
Apple ColourOne	April 1994	1.97	1.21	2.31	3.63
	April 1996	1.75	1.05	2.01	3.08
Epson GT-9000	April 1996	0.80	0.75	1.19	2.06
	June 1996	0.65	0.58	0.87	1.41

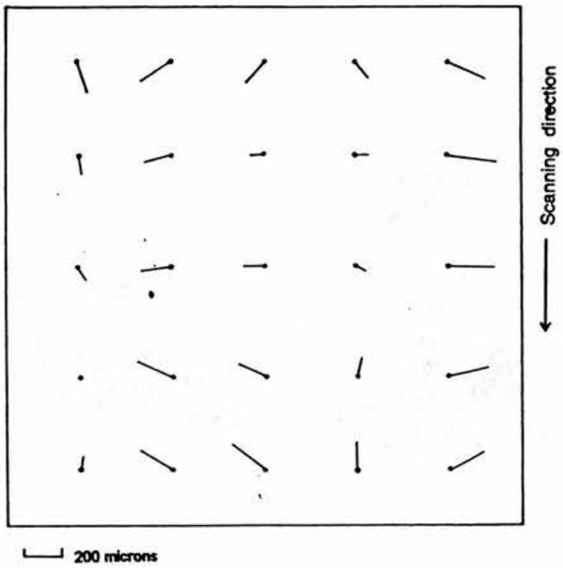


Figure 5.18 Distortion pattern of image scanned in Apple Colour OneScanner (April 1996)

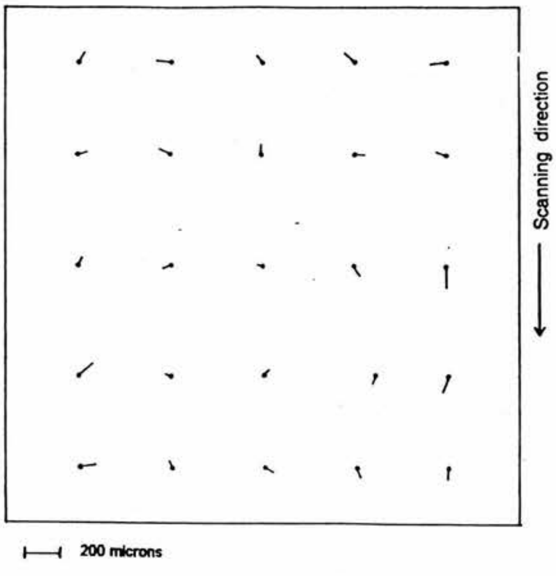


Figure 5.19 Distortion pattern of image scanned in Epson GT-9000 scanner (June 1996)

This test has shown that there is a marginal difference in the amount of distortion when the image scanning is repeated. The general pattern of distortion remained unchanged. It is unknown whether the difference in the magnitude of image distortion is due to scanner imperfection or error of not being able to reposition the calibrated grid intersection film exactly as previously. However, from this limited experiment on repeatability, it appears that the DTP scanners exhibit distortion that are consistent in direction but variable in amount. The variability in the amount of distortion indicates an ultimate limitation to these less expensive designs of equipment.

5.8 Conclusions and recommendation

The tests carried out, though not comprehensive, have highlighted a number of points to be considered before a DTP scanner is used to scan aerial photographs. The points will be summarised as follows.

- Different DTP scanners have different distortion patterns and different magnitudes of image distortion. In the Apple Colour OneScanner and HP Scanjet 4c (Scanner 2) scanners the magnitude of distortions are quite significant, that is, more than twice the size of the scanning resolution. In other scanners, that is, the HP Scanjet IIc, Epson GT-9000 and HP Scanjet 4c (Scanner 1) the magnitude of image distortion is significantly less (approximately the same as scanning resolution or optical scanner resolution).

- Different scanners of the same model (HP Scanjet 4c scanner) also have a different pattern and magnitude of image distortion.

- Although the overall magnitude of image distortions in the HP Scanjet IIc, Epson GT-9000 and HP Scanjet 4c (Scanner 1) scanners are almost the same size as the scanner optical resolution, the maximum resultant vector error at certain locations within the scanned image is still significant.

- Scanning at a resolution higher or lower than the scanner optical resolution will not decrease or increase the magnitude of image distortion and will not change the pattern of image distortion. This result indicates that the geometric accuracy of DTP scanner is largely dependent on the optical resolution of individual scanners.

- The introduction of a suitable mathematical model can help to reduce the effect of image distortions. In the Apple and Epson scanners the magnitude of image distortions can be reduced to approximately 0.3 pixel of the original scanning resolution. For all the three HP scanners the magnitude of image distortion can be reduced to approximately 0.5 pixel. These results are consistent with results of earlier studies on A3 format scanners (Sarjakoski, 1992; Baltsavias, 1994b; Finch and Miller, 1994) where an accuracy of less than ± 0.5 pixel was achieved.

- Different orders of polynomial coordinate transformation are required for different scanners. The second order polynomial coordinate transformation is suitable for both the HP Scanjet 4c scanners while the third order polynomial coordinate transformation is suitable for the Apple Colour OneScanner, HP Scanjet IIc and Epson GT-9000 scanners.

- Tests on images scanned in the Apple Colour OneScanner indicated that different levels of accuracy were achieved using different control point configurations. Since image distortion is most significant at the edges of the scanned image, it is always essential to locate control points at the edges of the image. A pattern of evenly distributed control points throughout the test image was found to be the best configuration to be used.

- The Apple and Epson scanners consistently show the same general distortion pattern but with slight differing amounts when scanning is repeated.

Since not all the five tests carried out utilised images of all the five scanners, the results presented here are only valid for the appropriate scanner/s used. These tests have shown that, although the geometric accuracy of DTP scanners is not comparable to the accuracy of photogrammetric scanners, images scanned in these scanners can still be used to scan hardcopy aerial photographs provided appropriate image rectification to the distorted scanned images is carried out. To enable such image rectification to be carried out, the distortion characteristics (pattern and magnitude), appropriate mathematical models and appropriate control point configurations to rectify for image distortion of the DTP scanner to be used must first be determined. Since there is always a slight difference in the pattern and magnitude of image distortion each time an image is scanned in a DTP scanner, it is highly recommended that a calibrated grid intersection plate/film is scanned before the DTP scanner is used to scan hardcopy aerial photographs. An alternative method is to incorporate squared reseau onto the glass plate of an aerial camera. This reseau can later be used to eliminate errors due to the film flatness, differential expansion and contraction of the film and could possibly be used to eliminate image distortions due to imperfection of DTP scanners. It is important to note that the incorporation of reseau into the image can potentially be a problem in DEM generation process. Full details of the proposed procedure to scan and rectify aerial photo in a DTP scanner given in Appendix F.

The use of DTP scanners to scan aerial photographs can potentially provide a cost effective solution to a wide range of users. In the context of the Klang Valley Region, where the cost of acquiring and maintaining a photogrammetric scanner is high the use of such scanners by the local authorities or planning authorities seems to be an economical and feasible solution. The question now is whether the rectified aerial images can subsequently be used to produce high quality digital photogrammetric products such as automatically generated DEMs and ortho-images. The following chapter will concentrate on the geometric accuracy assessment of digital photogrammetric products produced from images scanned in the DTP scanners.

CHAPTER 6

ASSESSMENT OF DIGITAL PHOTOGRAMMETRIC PRODUCTS

6.1 Introduction

The assessments presented in Chapter 5 for the accuracy of DTP scanners have indicated their potential as an alternative to expensive photogrammetric scanners to provide images required for digital photogrammetric applications. The question now is whether the geometric accuracy of digital photogrammetric products such as automatically generated DEMs and orthoimages to be used in GIS or other mapping applications is comparable to that obtained from analytical or analogue stereoplotters. Earlier studies have indicated that the products generated in high-end DPWs with images scanned in photogrammetric scanners are comparable to that of low-order analytical plotters. As this study proposed the low-cost digital data acquisition approach an understanding on the expected accuracy and problems are essential.

This chapter considers a series of tests carried out to assess the accuracy of digital photogrammetric products generated from a PC-based DPW with images scanned in the A4 format DTP scanners (i.e. Apple Colour OneScanner and Epson GT-9000 scanner) as opposed to the Zeiss PS1 PhotoScan photogrammetric scanner.

6.2 Geometric accuracy assessment of digital photogrammetric products

Most of the earlier studies described in Chapter 3 concentrate on the planimetric and height accuracy of stereomodels rather than the geometric accuracy assessment of automatically generated DEMs and orthoimages. The planimetric and height accuracy of individually measured points from a stereomodel in a DPW have shown a variable but promising result. Results from some of these tests can be considered comparable to those from some lower order stereoplotters. The planimetric accuracy of an orthoimage generated at a small scale is found to be within the allowable standard.

Prior to the date of this thesis, there has been no comprehensive published report on the geometric accuracy assessment of an automatically generated DEM and orthoimage using a Desktop Mapping System (DMS) with aerial images scanned in an A4 format DTP scanner. Earlier published works on the accuracy of digital photogrammetric products generated in DMS by Welch (1987) and Welch (1989) concentrate on products generated from stereo SPOT imagery, not from scanned aerial photographs. The only indication of the expected geometric accuracy as given in the DMS Version 3.1 User Manual is in terms of its planimetric and height accuracy for stereo-image digitising. With adequate control, mapping accuracies equivalent to approximately 1 pixel in X, Y and ± 1.5 to 2 pixels in Z can be obtained (R-Wel, 1992). Since a low-cost DPW (i.e. DMS) is proposed for use in this study to generate DEMs and orthoimages, understanding of the problems and the expected accuracy of these products is necessary.

To satisfy the need to assess the geometric accuracy of digital photogrammetric products produced in DMS, four tests were devised, the objectives of which were to determine:

- the effect of scanning resolution and the effect of GCP accuracy on stereomodel set-up;
- the planimetric accuracy of measurement from stereoimages;
- the accuracy of automatically generated height points;
- the accuracy of an automatically generated orthoimage.

The first test on steremodel set-up was not primarily intended to assess the accuracy of digital photogrammetric products, but rather to understand the effects of scanning resolutions and GCP accuracy on the stereomodel set-up. The other three tests were designed to assess the geometric accuracy of digital photogrammetric products generated from aerial images scanned in a photogrammetric scanner and in A4 format DTP scanners. Description on the test sites and test data used, the overall testing methodology, hardware configuration of the DMS used, and the tests carried out are given in the following sections.

6.2.1 Test sites and test data

For the purpose of testing, aerial photographs of two different test sites were chosen. The first site is located within the Holyrood Park in Edinburgh Scotland while the other is within the Petaling District Malaysia. A more detailed description of the test sites and test data used in the tests is given in the following section. The main criteria used for selecting these sites were the availability of suitable aerial photographs with ground control points, scale of photography and nature of the terrain. Two different scales of aerial photos, that is, 1:5,000 and 1:20,000, were selected because these would be suitable photo scales to investigate the landfill site selection process in Malaysia. The 1:20,000 photo scale is the most widely available photo scale in Malaysia as it is used by the Department of Surveying and Mapping for topographic map revision of urban areas. It is important to note that although 1:5,000 scale aerial photographs of Malaysia were available at the time of the test, they were not used because existing ground control points and / large-scale topographic maps of the area were not available. A brief description of the aerial photographs used for the tests is given in Table 6.1.

Table 6.1 Aerial photograph specifications

Test site	Photo scale	Date of photography	Type of photography	Aerial camera	Camera focal length (mm)
1 Holyrood Park, Edinburgh	1:5,000	24 July 1990	Natural colour	Zeiss Oberkochen RMK A 30/23 with Forward Motion Compensation	304.771
2 Petaling District, Malaysia	1:20,000	29 Dec. 1989	Panchromatic	WILD SAG II 2132	88.03

Test Site 1 - Holyrood Park in Edinburgh

Holyrood Park within the city of Edinburgh, Scotland was selected as the first test site. The area has a variable land cover, ranging from open fields to built up areas and variable topography ranging from flat to gradual undulating, steep slope and cliff. The terrain height ranges from approximately 27 m to 110 m above mean sea level (MSL). Colour photographs at 1:5,000 scale of this test site were selected to form a stereomodel. The photographs and the related camera calibration parameters were acquired from Geonex UK Limited. As shown in Table 6.1, the aerial photographs for Test Site 1 were acquired using a Zeiss Oberkochen RMK A 30/23 aerial camera with Forward Motion Compensator and a normal angle lens (i.e. 304.771 mm focal length). The aerial photographs are of higher quality and higher spatial resolution than the aerial photographs used in the other test site. The determination of the coordinates of ground control points (GCPs) was carried out by Chanlikit in earlier research (Chanlikit, 1991). Chanlikit obtained the planimetric control points of this site by ground survey work using electronic distance measurement while the heighting was carried out using levelling. The location of the test site is shown in Figure 6.1.

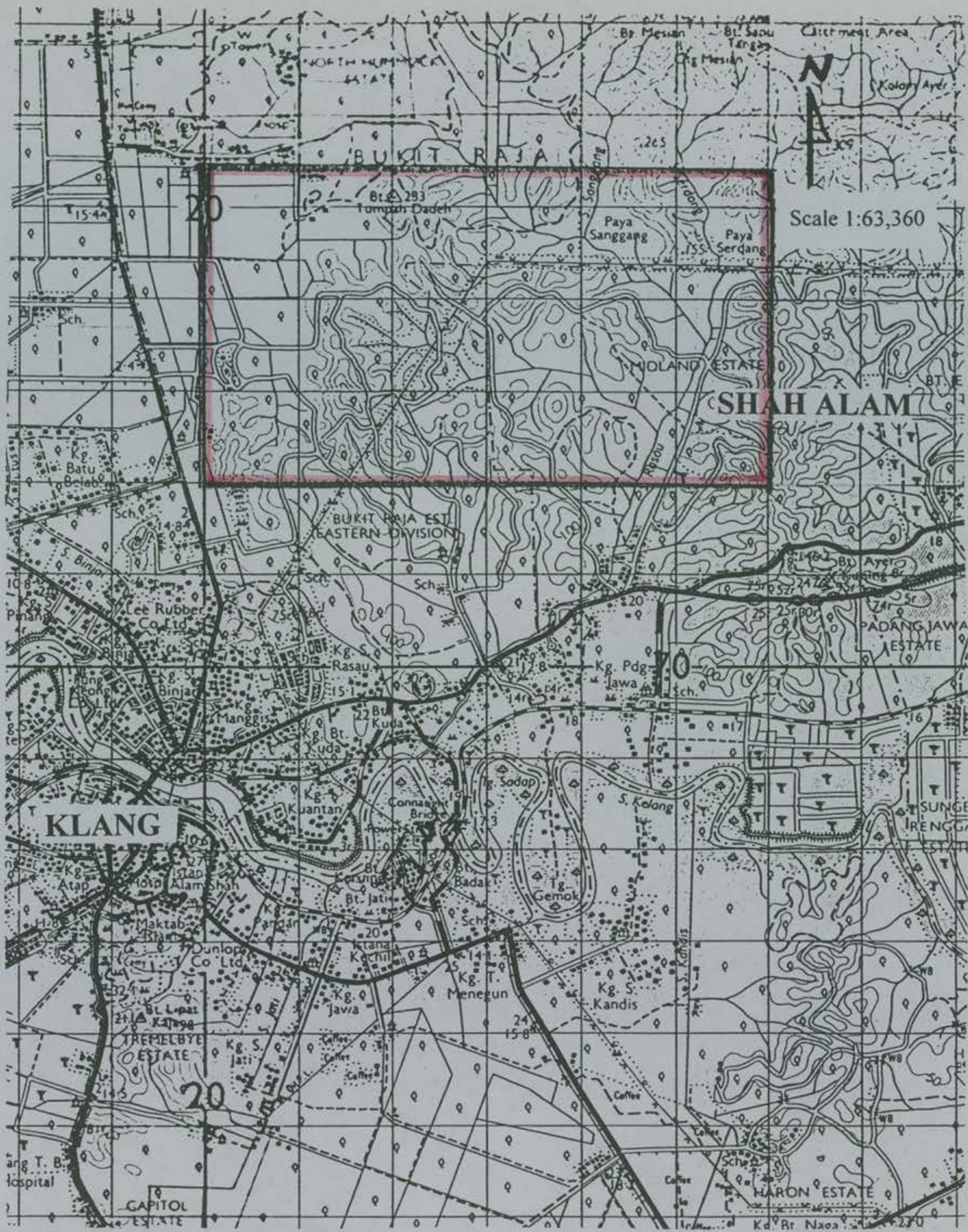
Test Site 2 - Bukit Tumpah Dadeh area

Test Site 2 is located to the west of Petaling District, Klang Valley Region, Malaysia. The northern area of the test site consists of agricultural land and forest reserve, while the southern part consists of agricultural, residential and industrial land. The new Kuala Lumpur-Klang Federal highway runs through the test site from north-east to south-west. The terrain height ranges from approximately 2 to 87 m above MSL. A stereopair of 1:20,000 scale panchromatic aerial photographs taken on the 29th December 1989 was used. The photographs were taken using a Wild SAG II aerial camera with super wide angle lens (i.e. 88.03 mm focal length). These are not ideal aerial photographs as they are slightly underexposed at the edges. The coordinates of three ground control points (derived by aerial triangulation) of the test site were obtained from the Department of Survey and Mapping, Malaysia. Other additional control points to be used to orientate stereo images in the DMS were obtained from the AP190 analytical plotter. Location of Test Site 2 is given in Figure 6.2.

Test Site 1

Source: 1:25,000 OS map

Figure 6.1 Locations of Test Site 1 – Holyrood Park, Edinburgh



Test Site 2

(Source: Topographic map of Klang, 1966)

Figure 6.2 Location of Test Site 2 - Bukit Tumpah Dadeh area, Petaling District.

6.2.2 Overall testing methodology

As outlined in Figure 6.3, the overall geometric accuracy testing of digital photogrammetric products involved three main stages:

- data acquisition,
- data processing, and
- measurement and data analysis.

Stage 1 - Data acquisition

The data acquisition stage involved the scanning of aerial photographs and the film-base calibrated grid (as described earlier in Chapter 5) in scanners that were used in the tests. Aerial photographs were scanned in a photogrammetric scanner as well as in DTP scanners. The photogrammetric scanner used in this test was the Zeiss PS1 PhotoScan while the DTP scanners used were Apple Colour OneScanner and Epson GT-9000. Two different scanning resolutions were used, 300 and 850 dpi. Aerial photographs were only scanned at 300 dpi in the DTP scanners due to limited PC Random Access Memory (RAM). The scanning at 850 dpi resolution was carried out by the Hunting Aerofilms bureau service using the Zeiss PS1 PhotoScan photogrammetric scanner. As discussed earlier, all scanning using DTP scanners was carried out within Edinburgh University. For Test Site 1, images were scanned in both the Apple DTP scanner and Zeiss PS1 photogrammetric scanner. For Test Site 2, the images were scanned in the Epson scanner at 300 dpi only. Details of scanned aerial photographs used in these tests are given in Table 6.2.

Table 6.2 Details of scanned aerial photographs

Test site	Scanning resolution	Scanner	File size/photo
1 Holyrood Park, Edinburgh	i) 300 dpi	Apple Colour One scanner	6.8 Mbytes
	ii) 850 dpi	Zeiss PS1 PhotoScan	56 Mbytes
2 Bukit Tumpah Dadeh, Petaling District	300 dpi	Epson GT-9000 scanner	6.8 Mbytes

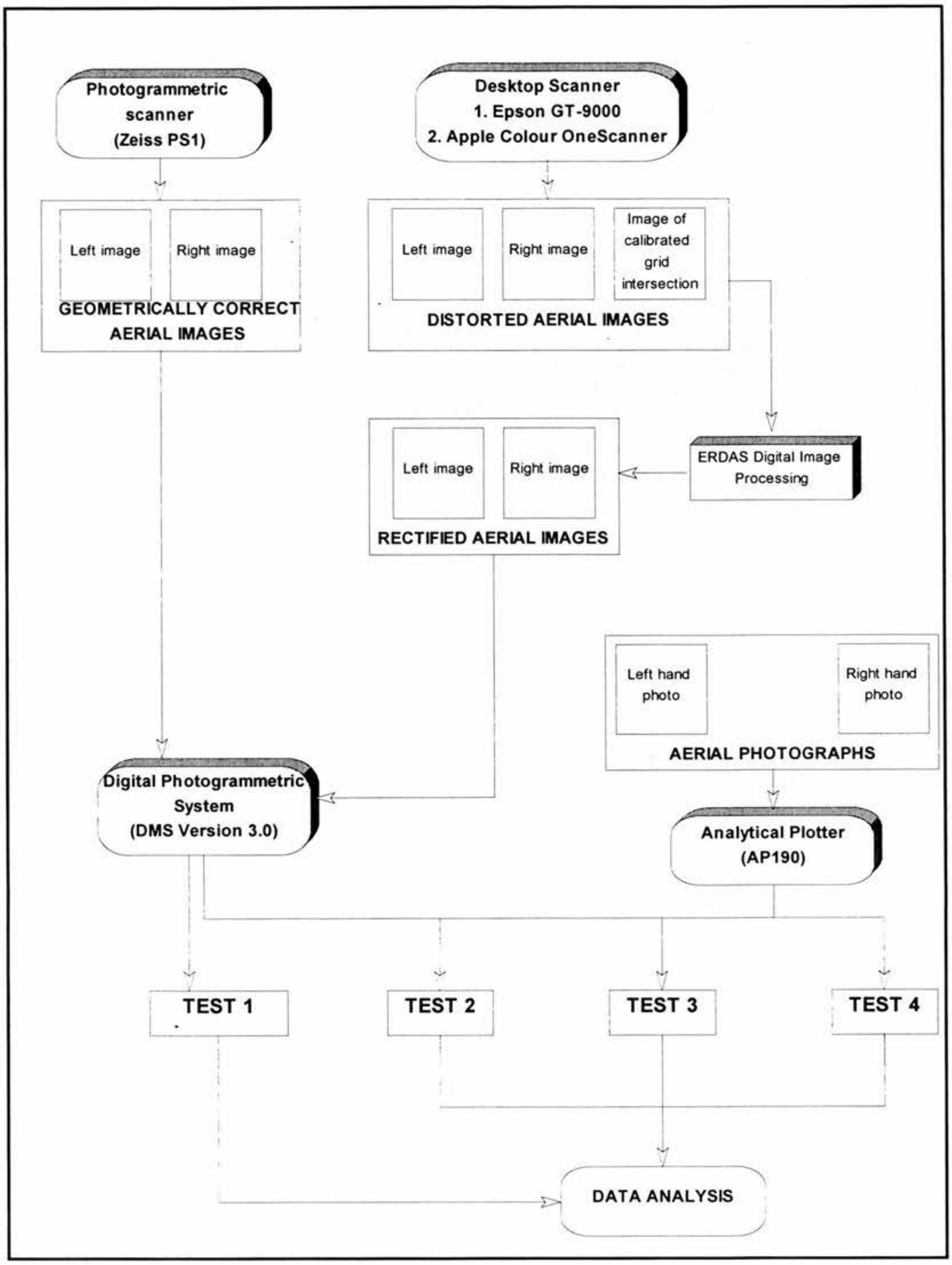


Figure 6.3 Overall testing methodology of digital photogrammetric products

Stage 2 Data processing

The processes involved in this stage include image enhancement, image rectification, and transforming the raw images scanned in various scanners into a suitable format required by the DMS and ERDAS digital image processing system. All aerial photographs as given in Table 6.3 were scanned in uncompressed TIFF format. Other output formats supported by DMS include the 8-bit ERDAS (version 7.3/7.4) .LAN and 8-bit bare BINARY.

Since aerial photographs were scanned in full colour (red, green and blue - RGB band) in the Zeiss PS1 photogrammetric scanner, a suitable image band for each of the left and right scanned images was selected because DMS can accept only one band for further photogrammetric application. The filenames for images scanned in the Zeiss PS1 scanner were addressed as 292.TIF (left photo) and 291.TIF (right photo). To enable the best band to be selected, image statistics of these images (RGB band) have to be generated. This process was carried in the ERDAS 7.5 image processing system using the BSTATS command. Results obtained from running this statistics command are given in Table 6.3.

Based on the statistics given in Table 6.3, Band 2 was selected because it shows the highest standard deviation value (i.e. the best image contrast). The resultant image files are addressed as ROTAT292.LAN (left image) and ROTAT291.LAN (right image). All the images to be used in DMS must either be in LAN or TIFF format.

Table 6.3 Statistic for 850 dpi images of Holyrood Park area

Statistics	**Band 1 (RED)**	**Band 2 (GREEN)**	**Band 3 (BLUE)**
Left Image -292.LAN			
Min	0	0	0
Max	255	255	232
Mean Value	50.88	60.86	49.02
Std. Deviation	40.77	43.94	41.25
Median	42	53	35
Mode	0	0	0
Right Image -291.LAN			
Min	0	0	0
Max	255	254	234
Mean Value	54.31	63.03	49.62
Std. Deviation	40.30	43.74	41.33
Median	46	56	36
Mode	0	0	0

Image rectification or image calibration process is required to obtain a geometrically correct aerial image. In this study only images scanned in DTP scanners were rectified. No image rectification was carried out for images scanned in the Zeiss PS1 PhotoScan as images scanned in this scanner are considered geometrically correct. As suggested earlier, a third or fourth order polynomial is required to perform rectification of images scanned in both the Epson and Apple DTP scanners. Since image rectification cannot be performed in DMS software (because only first and second order polynomial can be used), the process of image rectification was carried out using the ERDAS digital image processing system. A total of twenty five control points were used to rectify the scanned images. The detailed procedure for aerial image rectification is given in Appendix F. The rectified images from ERDAS were later transferred to the DMS software. As in an analogue or analytical stereoplotter, the stereomodel formation in a DPW has to undergo the three orientation stages of interior, relative and absolute orientation. The SPM module in the DMS software is used to perform image orientation and to form a stereomodel on the screen. To enable a stereomodel to be formed a minimum of five X, Y and Z control points are required for each photo.

Stage 3 Image measurement and data analysis

Once a stereomodel is formed in the DMS, the following procedures are carried out: i) 3-d measurement of check points required for planimetric accuracy assessment, ii) stereo-correlation to generate DEM for accuracy assessment of automatically generated DEM, and iii) generation of orthoimage. The same procedures are repeated for the other test data. Accuracy assessment of point digitising (X and Y) from a stereomodel in the DMS and the accuracy of an automatically generated orthoimage was made by comparing the coordinates (X and Y) of the corresponding points in the AP190 analytical plotter. The accuracy of automatically generated height points in DMS was made by comparing the corresponding heights (Z) obtained in the AP190 analytical plotter. Detailed explanations on the aim and methodology of the four tests are given in Sections 6.3, 6.4, 6.5 and 6.6.

6.2.3 Hardware configuration for DMS

Although the DMS requires a minimum hardware configuration of 2 Mbytes RAM, 286 processor, and 30 Mbytes hard disk, a much higher configuration is recommended to enable efficient running of the software. Ideally the software should be run on a high performance Pentium processor PC, at least 16 Mbytes RAM and 4 Mbytes screen memory, together with a large hard disk storage of 1 to 2 Gigabytes and tape backup storage to store scanned aerial photographs. For this study, the Dell PC with the following configuration was used.

- 486 DX33 processor
- 4 Mbytes RAM
- 250 Mbytes hard disk
- 1.44 Mb floppy disk drive
- Microsoft- compatible mouse
- Super-VGA
- 17 inch flat screen colour monitor

6.3 Test 1 - Accuracy of model orientation set-up

The purpose of this test was to determine the effects of different scanning resolutions and the GCPs' accuracy on the stereomodel set-up in DMS. For this test only images of Test Site 1 were used. Three different sets of images were used i) unrectified images scanned in Apple Colour scanner - HOLYLFT.LAN and HOLYRGT.LAN ii) rectified images scanned in Apple Colour scanner - HOLYRECL.LAN and HOLYRECR.LAN, and iii) images scanned in Zeiss PS1 scanner - ROTAT292.LAN and ROTAT291.LAN.

6.3.1 Methodology

Although the absolute minimum number of GCPs required to perform image orientation for each photo is five, more points are preferred. Since there were only five existing ground surveyed GCPs available within the stereomodel test area more points were required to give redundant observations. Using the existing GCPs, a stereomodel of the test area was established in the AP190 analytical plotter, and additional GCPs were measured from this stereomodel. Two sets of GCPs were used in this test (refer to Table 1 and 2 in Appendix H1). The first set consisted of eight GCPs (including five original GCPs) while the second consisted of nine GCPs. Seven of the GCPs for the second set were new GCPs derived from the AP190 analytical stereoplotter. The first set of GCPs were points that can be identified on the 300 dpi image (for example, junction of foot-path) while the second set of GCPs were points that are clearly identified on the 850 dpi image (for example, corner of man-hole). Using these two sets of GCPs and different sets of scanned images, the image orientation parameters were computed. The r.m.s.e. of both the left and right images for all the different sets of images were later analysed.

6.3.2 Results and analysis

Results on the accuracy of stereomodel set-up using different scanners and different scanning resolutions are given in Tables 1 and 2 in Appendix H1. Table 1 (Appendix H2) shows the accuracy at individual control points of the left and right images scanned in both the Apple and the Zeiss PS1 scanner. The results given in this Table were obtained from stereomodel orientation using GCPs of Set 1. The accuracy of the stereomodel set-up of images scanned in the Zeiss PS1 scanner using a more accurate set of GCPs (Set 2) is given in Table 3 (Appendix H2). A summary of the overall planimetric accuracy of the stereomodel orientation set-up for this test is given in Table 6.4.

The stereomodel set-up accuracy at the control points for the left and right images (rectified 300 dpi images scanned in Apple DTP scanner) are ± 0.28 and ± 0.29 m respectively. For the 850 dpi images (which were scanned in the Zeiss PS1 scanner) the stereomodel set-up accuracy for the left and right images are only slightly better than the 300 dpi rectified image. The accuracy for the left and right images (unrectified images scanned in Apple DTP scanner at 300 dpi resolution) are lower than that of the two, that is ± 0.52 and ± 0.38 pixel respectively. This could be due to varying distortion at different portions of the desktop scanner. Although the resolution of images scanned in the Zeiss scanner was almost three times better than the resolution of images scanned in the Apple scanner, the differences in accuracy of model orientation set-up in terms of ground values are not significant. This could be due to the quality of the GCPs. Errors in the rectified left and right images scanned at 300 dpi are significantly less than the original pixel size, that is, ± 0.64 and ± 0.68 pixels respectively.

When the second set of GCPs was used to set up images scanned in the Zeiss PS1 scanner, there was a significant improvement in the model accuracy. The accuracy in terms of easting and northings improved from ± 0.24 and ± 0.23 m to ± 0.17 and ± 0.16 m respectively (refer to Table 2 in Appendix H2). The overall model orientation accuracy obtained from this test is given in Table 6.4.

Table 6.4 Overall accuracy of model orientation set-up at different scanning resolution

Scanning Resolution	R.M.S.E of Left image In pixel	R.M.S.E of Right image in pixel	R.M.S.E of Left image In metres	R.M.S.E of Right image in metres
i) 300 dpi #	0.64	0.68	0.28	0.29
ii) 300 dpi # (unrectified image)	1.18	0.87	0.52	0.38
iii) 850 dpi #	1.57	1.51	0.24	0.23
iv) 850 dpi **	1.08	1.03	0.17	0.16

Note # - using the Set 1 GCPs
** - using the Set 2 GCPs

This test has shown that different stereomodel set-up accuracy was achieved when images of different resolution and different GCP accuracy levels were used. In all the images (except for the unrectified images originally scanned in Apple Colour OneScanner) the stereomodel set-up accuracy for the left and right images was found to be similar. With 850 dpi images scanned in the Zeiss PS1 scanner, the use of well defined GCPs improves the stereomodel set-up significantly.

6.4 Test 2 - Planimetric accuracy from stereo digitising

The aim of this test was to determine the planimetric accuracy of digitising from stereoimages in DMS. Images at two resolutions, that is 300 dpi and 850 dpi were used in this test. Accuracy testing for images scanned at different resolutions is based on the difference between the coordinates measured on the DMS and the AP190 analytical stereoplotter. No attempt was made to determine the height accuracy because of the difficulty in obtaining accurate height measurements in DMS. For this test, data from both the test sites were used.

6.4.1 Methodology

To enable planimetric accuracy assessment to be carried out, ground check points are required. These points are points which can clearly be identified on both the stereomodel in the DMS and AP190 analytical stereoplotter. For images of Test Site 1, a total of twenty and nineteen check points were selected for the 300 dpi and 850 dpi images respectively. Using the Set 1 GCPs, two stereomodels from the two sets of images of Test Site 1 (refer to Table 6.2) were set up in the DMS and another was set up as a stereomodel in the AP190 analytical stereoplotter. The ground coordinates of the selected check points on both the AP190 and DMS were measured. The coordinates measured in the DMS were then compared to those measured in the AP190 analytical stereoplotter. A similar procedure was carried out on images of Test Site 2 except the aerial photographs were scanned only at 300 dpi. As mentioned earlier, scanning at a higher resolution was not possible due to limited PC memory. For Test Site 2, ten GCPs and thirteen check points were used. List of GCPs used for Test Site 2 is given in Table 3 (Appendix H1).

6.4.2 Results and analysis

Results on the planimetric accuracy of point digitising from stereoimages in the DMS are given in Tables 1, 2, 3 in Appendix H3 and Table 6.5. Table 1 in Appendix H3 shows the results of the actual coordinate measurements in both the AP190 analytical plotter and DMS at all the check points using images of Test Site 1. In this case, both the rectified and unrectified images are scanned at 300 dpi. Table 2 (Appendix H3) shows the results of check point coordinates measured from images scanned at 850 dpi. Results of coordinate measurements using images of Test Site 2 are given in Table 3 (Appendix H3).

A summary of the overall planimetric accuracy of point digitising from stereomodels created in DMS is given in Table 6.5. The accuracies in terms of eastings, northings and the resultant vector component obtained from the rectified aerial images of

Test Site 1 were ± 0.35 m (± 0.75 pixel), ± 0.32 m (± 0.70 pixel) and ± 0.47 m (± 1.04 pixel). When the unrectified images were used, the accuracies obtained were significantly lower, that is, ± 0.54 m (± 1.18 pixel), ± 0.61 (± 1.32 pixel) and ± 0.81 m (± 1.80 pixel) in terms of eastings, northings and in the resultant vector component respectively. The planimetric accuracy obtained when the 850 dpi stereoimages were used was found to be twice as good than that scanned at 300 dpi, that is ± 0.15 m (0.97 pixel), ± 0.16 m (0.99 pixel) and ± 0.22 m (± 1.30 pixels) in terms of eastings, northings and the resultant vector respectively. Using images of Test Site 2, the planimetric accuracy in the eastings, northings and in the resultant vector component were ± 0.97 m (± 0.57 pixel), ± 0.80 m (± 0.47 pixel) and ± 1.26 m (± 0.74 pixel) respectively.

Table 6.5 Summary of the planimetric accuracy of point positioning

Test Site	Scanning Resolution	Mean Error in Eastings (m)	Mean Error in Northings (m)	R.m.s.e. in Eastings (m)	R.m.s.e. in Northings (m)	Vector r.m.s.e. (m)
1	300 dpi (rectified)	0.28 (0.60 pixel)	0.27 (0.58 pixel)	0.35 (0.75 pixel)	0.32 (0.70 pixel)	0.47 (1.04 pixel)
1	300 dpi (unrectified)	0.38 (0.83 pixel)	0.52 (1.12 pixel)	0.54 (1.18 pixel)	0.61 (1.32 pixel)	0.81 (1.80 pixel)
1	850 dpi	0.12 (0.76 pixel)	0.12 (0.75 pixel)	0.15 (0.97 pixel)	0.16 (0.99 pixel)	0.22 (1.30 pixel)
2	300 dpi	0.87 (0.51 pixel)	0.60 (0.35 pixel)	0.97 (0.57 pixel)	0.80 (0.47 pixel)	1.26 (0.74 pixel)

This test clearly shows that higher planimetric accuracy can be achieved when the images are scanned at higher resolution. The accuracy (in terms of ground coordinates) obtained from scanning at 850 dpi is twice as good as that obtained from scanning at 300 dpi (images rectified for scanner distortion). The use of unrectified images to create a stereomodel and hence make planimetric measurement in the DMS gives the lowest accuracy, with errors almost twice and four times larger than those of the rectified images and images scanned in the Zeiss PS1 scanner.

6.5 Test 3 - Accuracy of automatically generated height points

Accuracy testing was based on the difference in heights generated automatically using auto-correlation in DMS as compared to heights manually measured in the AP190 analytical stereoplotter. Height measurement in the AP190 is regarded as the standard. Only height differences along cross-section/s were compared as measurements of all points generated were not possible. The main aim of this test was to determine the accuracy of automatically generated height points in different terrain characteristics, for different original photo scales and at different scanning resolutions.

6.5.1 Methodology

Two DEMs were generated in the DMS using the CORRELATION command in the SPM option for each of the test sites. Throughout these series of tests the 7 by 7 pixels size correlation was used. For Test Site 1 only the rectified 300 dpi images were used to generate DEM. Two cross-sections were selected from the DEM: i) along a relatively flat open field, and ii) along a hilly part of the test site. For Test Site 2 only one cross-section was selected from the generated DEM. The locations of the extracted cross-sections for Test Site 1 and 2 are given in Figures 6.4 and 6.5 respectively. The uncorrelated region at the edges of both the stereomodels were not excluded. The EXTCS computer program (Appendix J1) written by the author was used to extract the heights along the cross-sections. Stereomodels at each of the two test sites were set-up in the AP190 analytical plotter and heights at the same locations as those generated in the DMS were measured along the selected cross-sections. The difference in heights measured in the DMS and AP190 stereoplotter were computed. Note that no attempt was made to edit or filter the heights obtained from automatically generated DEM.

The time taken to generate a DEM of 210 rows by 264 columns (55,650 height points) from the 1:20,000 scale aerial photographs scanned at 300 dpi on a PC (486 DX33) is typically 1580 seconds, that is to say approximately 35 height points per second.

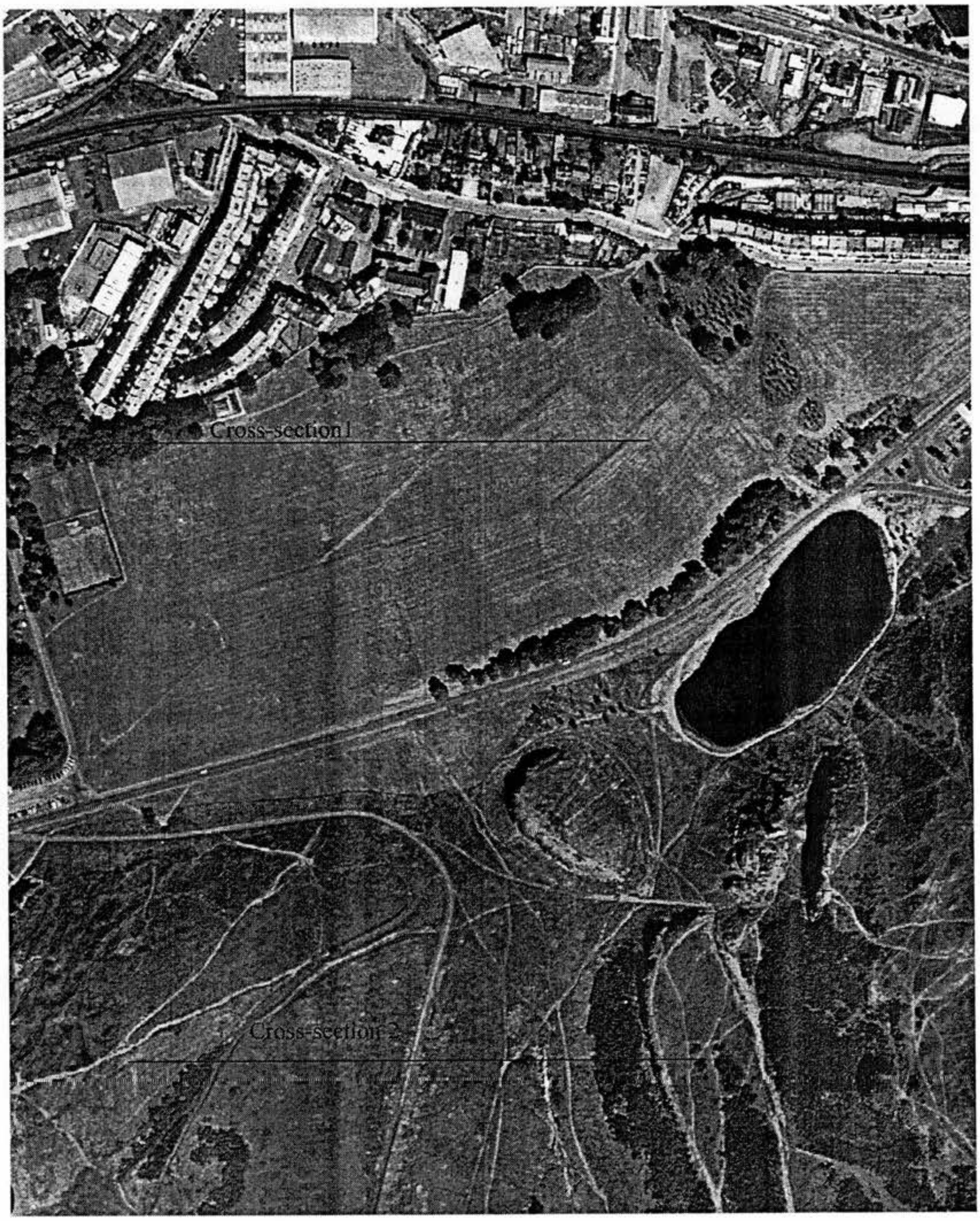


Figure 6.4 Locations of the two selected cross-sections for Test Site 1

Figure 6.5 Location of the selected cross-section for Test Site 2

6.5.2 Results and analysis for Test Site 1

The DEMs of Test Sites 1 and 2 generated in the DMS are given in Figures 6.6 and 6.7 respectively. The results of the height comparison between measurements made in the AP190 and DMS for Test Site 1 are given as Appendices H5 and H6. Figures 6.8 and 6.9 graphically show the height comparison of points measured manually in the AP190 and automatically generated in the DMS along Cross-sections 1 and 2 for Test Site 1 respectively.

In both the cross-sections, automatic correlation in areas with good contrast of the surrounding features gives relatively accurate heights. For heights along Cross-section 1, the height accuracy to less than a pixel (that is, ± 0.4 m) was obtained. In open fields, automatic correlation fails to give good results. An average height difference in these areas is more than ± 1.5 m or three times larger than the original scanning resolution. At the left and right hand boundaries of the stereomodel no correlation or an incorrect correlation takes place, resulting in wrong terrain heights being automatically assigned as computed mean terrain heights of the stereomodel. The problem of uncorrelated regions at the stereomodel boundaries can easily be overcome in DMS by taking only a subset of the generated DEM. The SUBSET command in MANAGE module is used to eliminate the uncorrelated regions.

For Cross-section 2, a height accuracy to less than ± 1 pixel can be achieved in areas of good contrast with the surrounding features. At the bottom of the valley, a height difference of more than ± 2.4 m (5 pixels) was obtained even in areas with good image contrast. This could be due to poor height control at the bottom of the valley, creating a significant error. As in Cross-section 1, gross errors in heights at the areas at the edges of the cross-section are clearly visible, because no correlation or an incorrect correlation takes place at the boundaries.

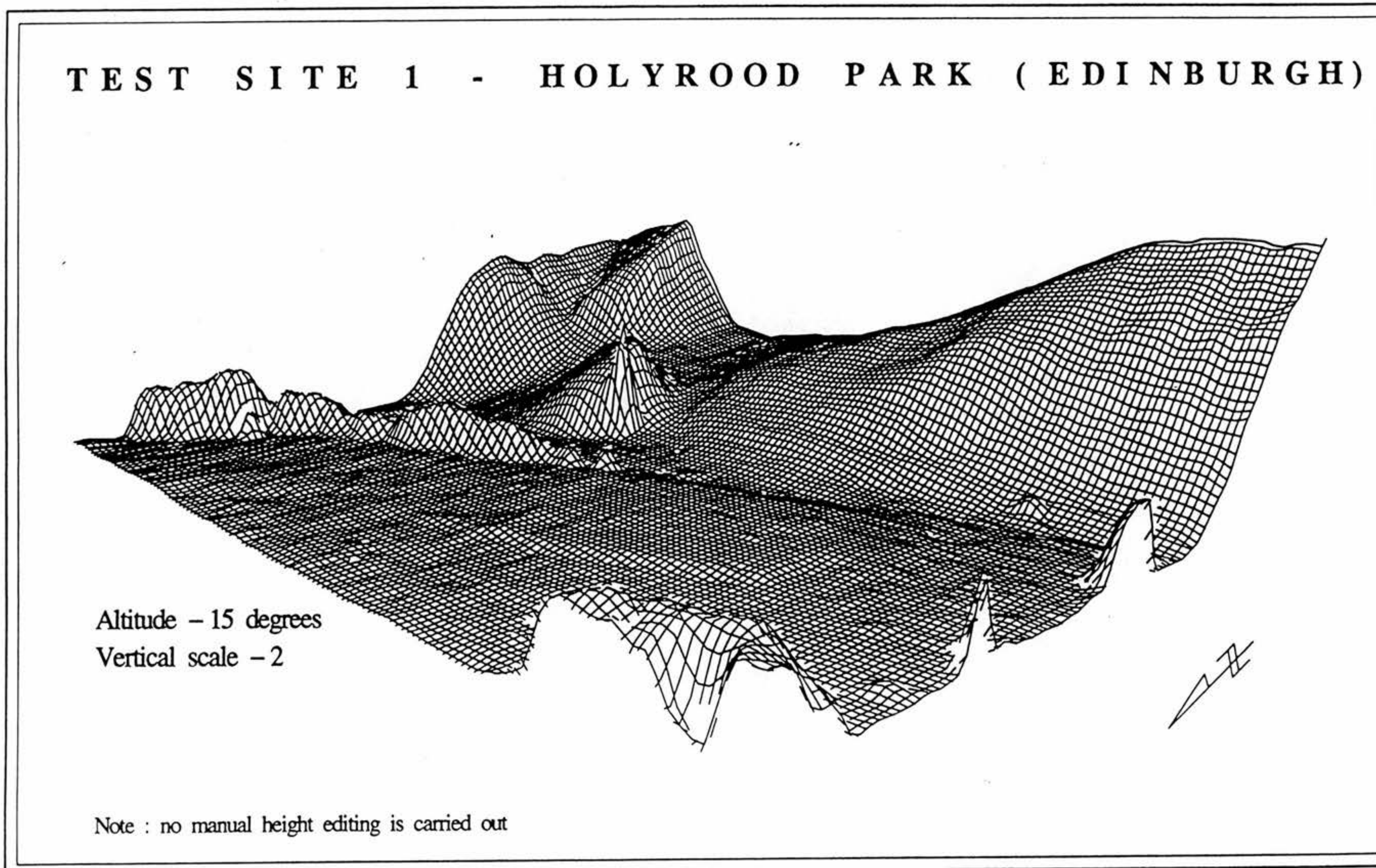


Figure 6.6 Automatically generated DEM of Test Site 1

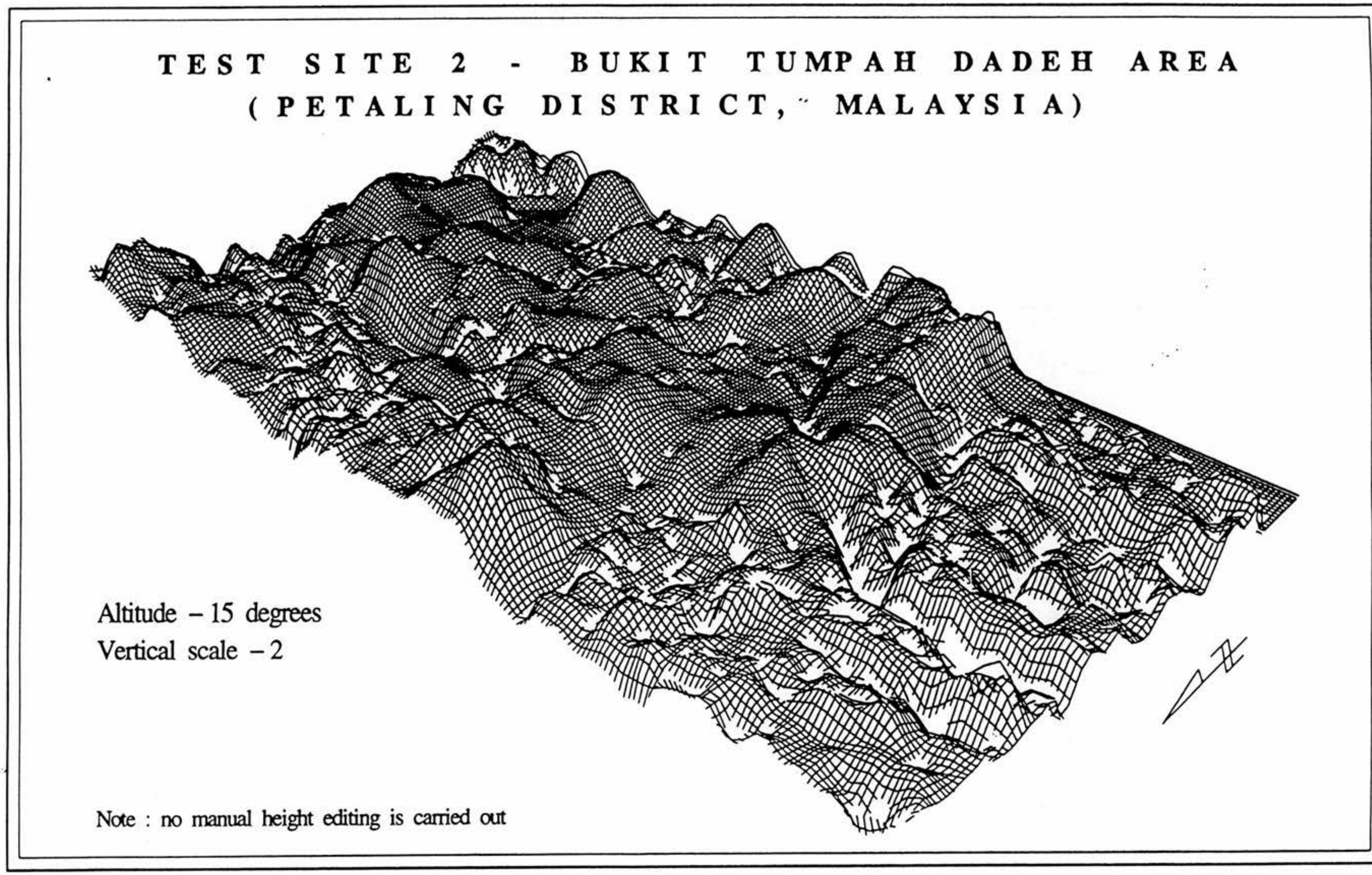


Figure 6.7 Automatically generated DEM of Test Site 2

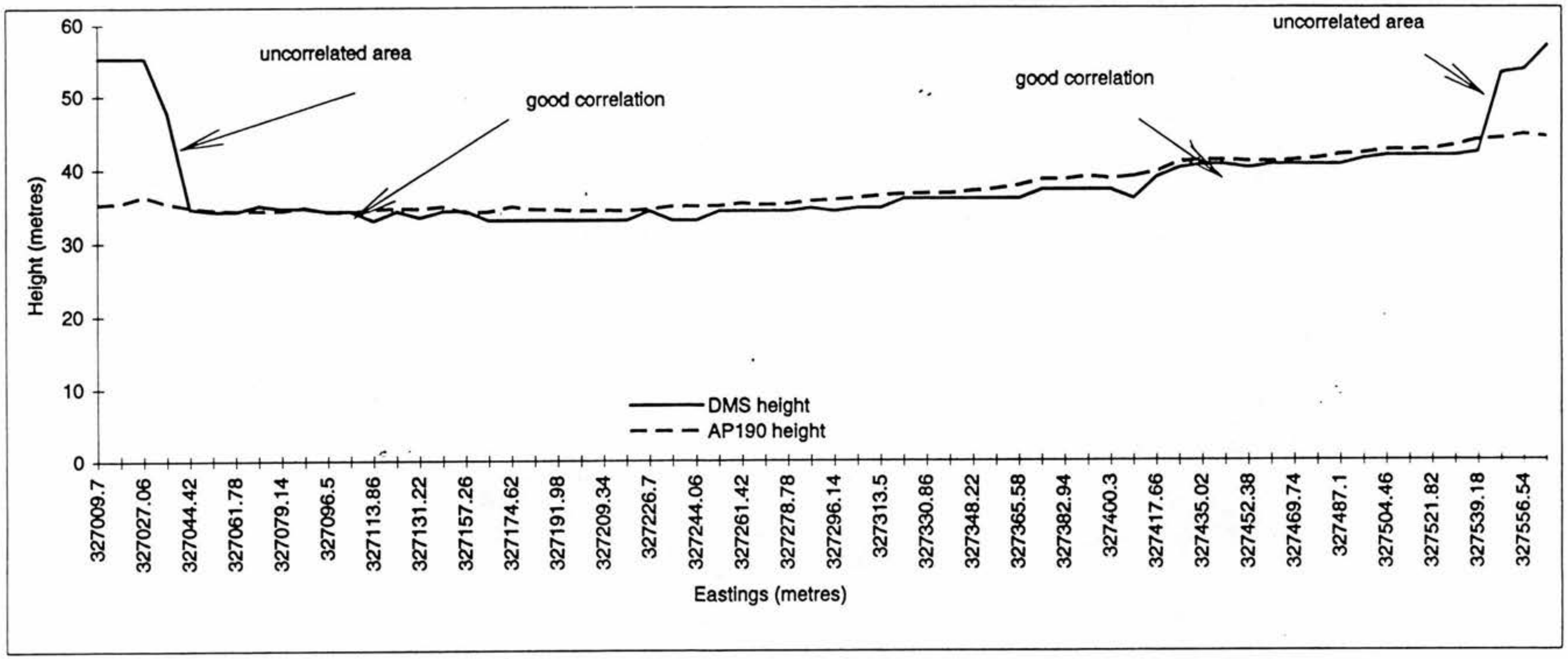


Figure 6.8 Comparison of manually measured heights in the AP190 and automatically generated heights in DMS along Cross-section 1- relatively flat area

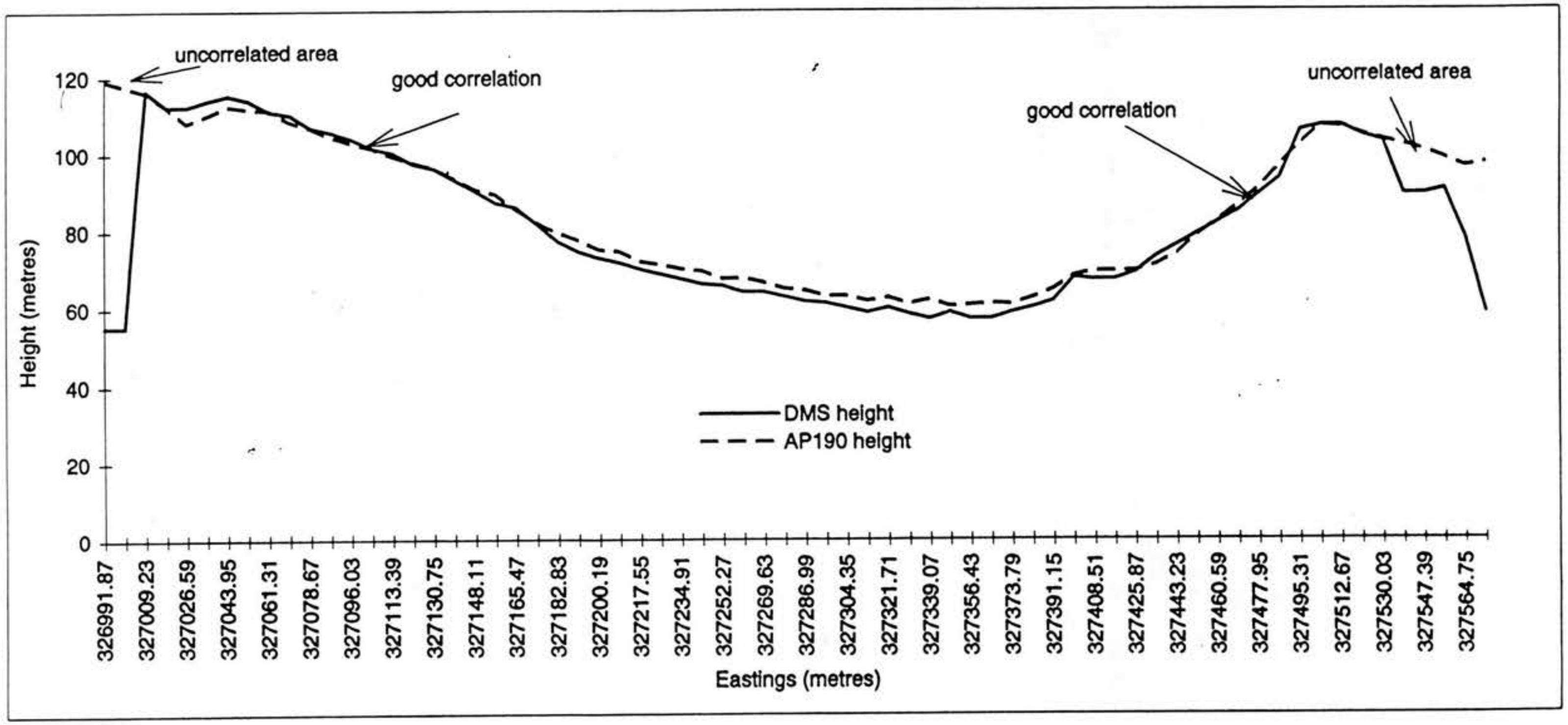


Figure 6.9 Comparison of manually measured heights in the AP190 and automatically generated heights in DMS along Cross-section 2 - hilly area

6.5.3 Results and analysis for Test Site 2

The result of the height comparison between measurements made in the AP190 and DMS for Test Site 2 is given as Appendices H7, while Figure 6.10 graphically shows the height comparison of points manually measured in the AP190 and automatically generated in the DMS along a cross-section. As with earlier results, the height accuracy is high in areas of good contrast with the surrounding features and sufficient height controls. Along the valley (that is, from distance 883.54 to 1233.27 m along the cross-section) where there is excellent contrast with the surrounding features, sufficient height controls and no shadows, a height accuracy to approximately ± 0.70 m (0.4 pixel) was achieved. The height accuracy along the cross-section, that is, from distance 202.48 to 515.50 m, was approximately ± 1.30 m (0.8 pixel). In areas of poor image quality such as shadow areas, under-exposed region at the edges of aerial photographs used in this test, and over-exposed region (due to land clearing) the errors vary and can be as high as 20 m (approximately 12 pixels).

This test has shown that height accuracy to less than ± 1 pixel can be achieved in areas with good image quality, good contrast of the surrounding features and with sufficient height controls. In areas of poor image quality, auto-correlation fails to function properly, resulting in gross errors in the generated heights. The magnitude of height accuracy varies with the scanning resolution.

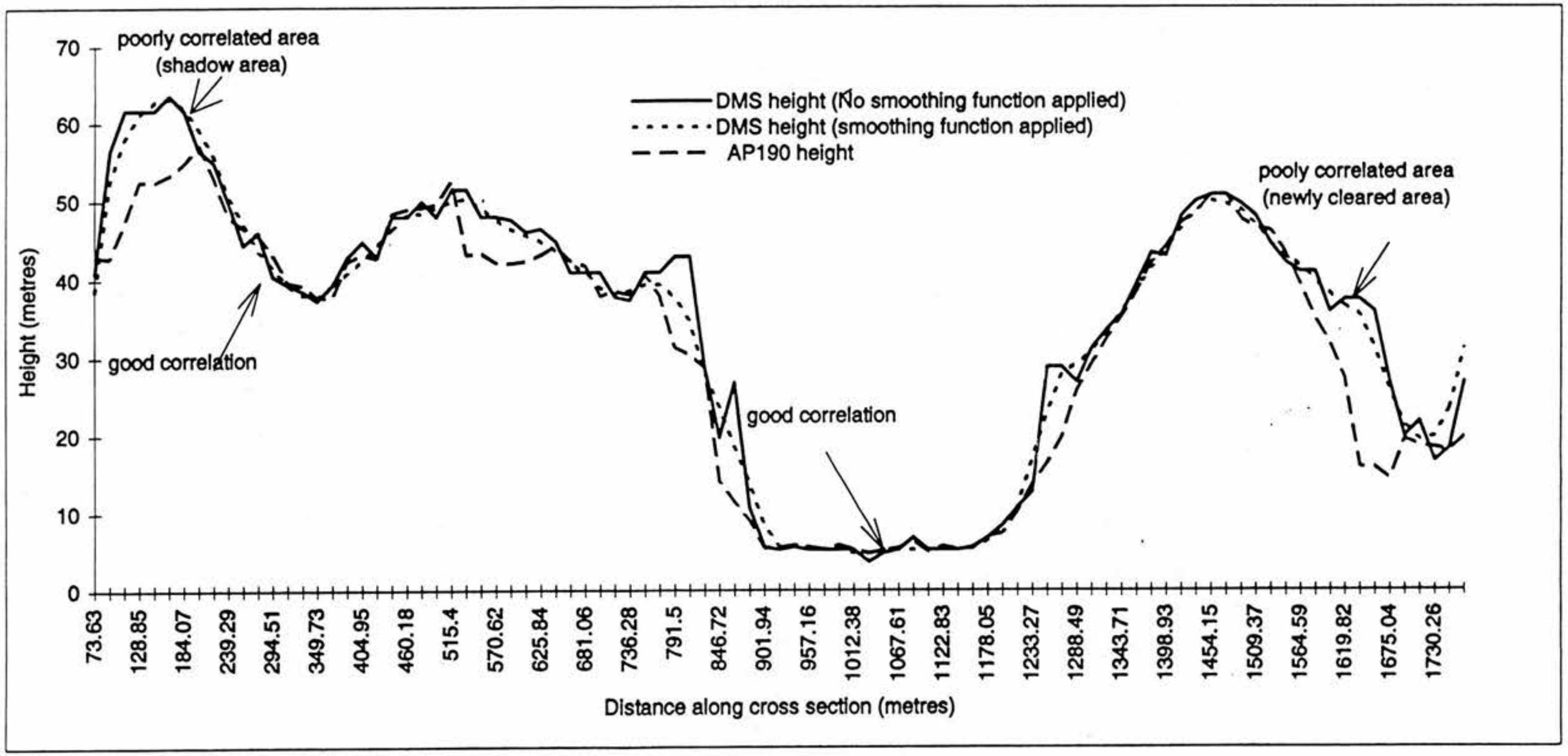


Figure 6.10 Comparison of manually measured heights in the AP190 and automatically generated heights in DMS along cross-section - Test Site 2

6.6 Test 4 - Accuracy of automatically generated orthoimage

The main aim of this test was to determine the planimetric accuracy of the automatically generated orthoimage. As there is no editing facility to correct for heights generated from aerial photographs within the DMS, no other effort was made to correct the generated DEM. For this test, images of both the test sites were used. For Test Site 1 only the 300 dpi scanning resolution images scanned in the Apple Colour OneScanner were tested. Areas where there are abrupt changes in elevation (that is, in the build-up areas) have been excluded from this test.

6.6.1 Methodology

For Test Site 1, an orthoimage based on the previously generated DEM with two pixel spacing (approximately 0.9 meter) was generated. The check points in both the AP190 analytical stereoplotter and DMS were selected and measured. Only twelve check points were used in this test. Check points within the built-up areas were not selected due to the poor DEM and orthoimage quality. The difference between the eastings and northings of the check points measured in both the DMS and AP190 analytical stereoplotter were later computed.

For Test Site 2, two orthoimages were generated. The first orthoimage covers only a subset of the whole stereomodel of the test site. Orthoimage generation was based on a 2 by 2 pixel grid DEM. This area was purposely selected because of the high accuracy DEM. The second orthoimage covers the whole of the stereomodel. A 5 by 5 pixel grid DEM generated earlier was used to ortho-rectify the image. A total of twelve and sixteen check points were used to evaluate the planimetric accuracy of the first and second orthoimages respectively. Locations of the orthoimages within the test sites is given in Figure 6.11.

The specifications of orthoimages used in this test are given in Table 6.6. The eastings and northings of the check points of all the orthoimages were measured in the DMS, while coordinates of the equivalent check points were measured in the AP190 analytical plotter.

Table 6.6 Specifications of orthoimages used in this test

Test Site	Scanning Resolution	Photo scale	DEM grid spacing (m)	Generated Orthoimage size
1	300 dpi	1:5,000	0.9 (2 pixel)	580 lines by 500 pixels
2 #	300 dpi	1:20,000	3.6 (2 pixel)	840 lines by 882 pixels
2##	300 dpi	1:20,000	8.5 (5 pixel)	1312 lines by 2305 pixels

Note :- # - Orthoimage of small area of stereomodel with good quality DEM
- Orthoimage of the whole of stereomodel

6.6.2 Results and analysis

Orthoimages generated from these tests are shown in Figures 6.12, 6.13 and 6.14. Results of coordinates measurement from these orthoimages are given in Tables 1, 2 and 3 (Appendix H4). Table 6.7 summarises the results from planimetric accuracy assessment of all the generated orthoimages used in this test.

The planimetric accuracy of orthoimage generated from the 1:5,000 scale aerial photographs scanned at 300 dpi is ± 0.21 m (0.6 pixel), while for orthoimages generated from 1:20,000 scale aerial photographs scanned also at 300 dpi the planimetric accuracies are ± 1.36 m or 0.8 pixel (for small area) and ± 2.68 m or 1.6 pixels (for larger area). Although the same images were used to generate orthoimages, the planimetric accuracy was found to be significantly different. The accuracy obtained from the small area image of the test site was twice as good as that of the whole stereomodel. The main reason for this difference is the difference in the quality of DEMs used to generate these orthoimages.

Table 6.7 Summary of planimetric accuracy of the generated orthoimages

Test Site	Scanning Resolution	Photo scale	Mean Error in Easting s (m)	Mean Error in Northings m)	R.m.s.e. in Eastings (m)	R.m.s.e. in Northings (m)	Vector r.m.s.e. (m)
1	300 dpi	1:5,000	0.13 (0.3 pixel)	0.14 (0.3 pixel)	0.14 (0.3 pixel)	0.19 (0.4 pixel)	0.21 (0.6 pixel)
2 #	300 dpi	1:20,000	0.76 (0.4 pixel)	0.93 (0.5pixel)	0.91 (0.5 pixel)	1.01 (0.6 pixel)	1.36 (0.8 pixel)
2##	300 dpi	1:20,000	1.86 (1.1 pixel)	1.33 (0.8 pixel)	2.08 (1.2 pixel)	1.69 (1.0 pixel)	2.68 (1.6 pixel)

Note :- # - Orthoimage of small area of stereomodel with good quality DEM
- Orthoimage of the whole of stereomodel

Since all the check points used in this test were located in areas with good quality DEMs, the results obtained might not represent a true overall accuracy of the generated orthoimages. Visual inspection of the generated orthoimages of Test Site 2 (Figures 6.13 and 6.14) clearly shows large image displacement in some areas especially in areas with sudden height changes (for example, at the boundary of trees and cleared land) and in areas with very poor image quality (newly cleared land).

This test has shown that high planimetric accuracy to within a pixel of the original scanning resolution can be achieved especially in areas with a high quality DEM and good image quality.

Figure 6.11 Locations of the two orthoimages of Test Site 2

Figure 6.12 Automatically generated orthoimage of Test Site 1

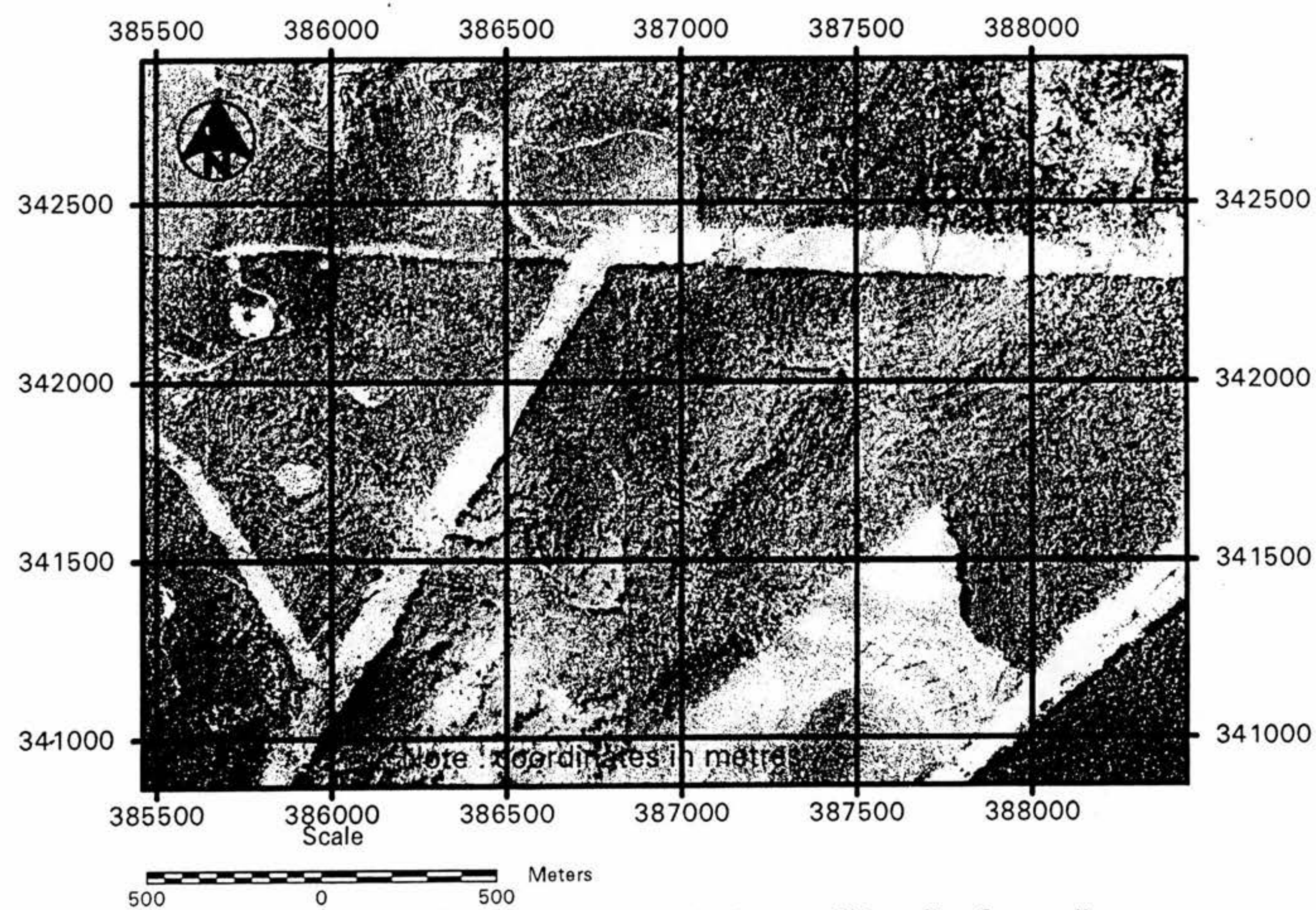


Figure 6.13 Automatically generated orthoimage of Test Site 2 - small area

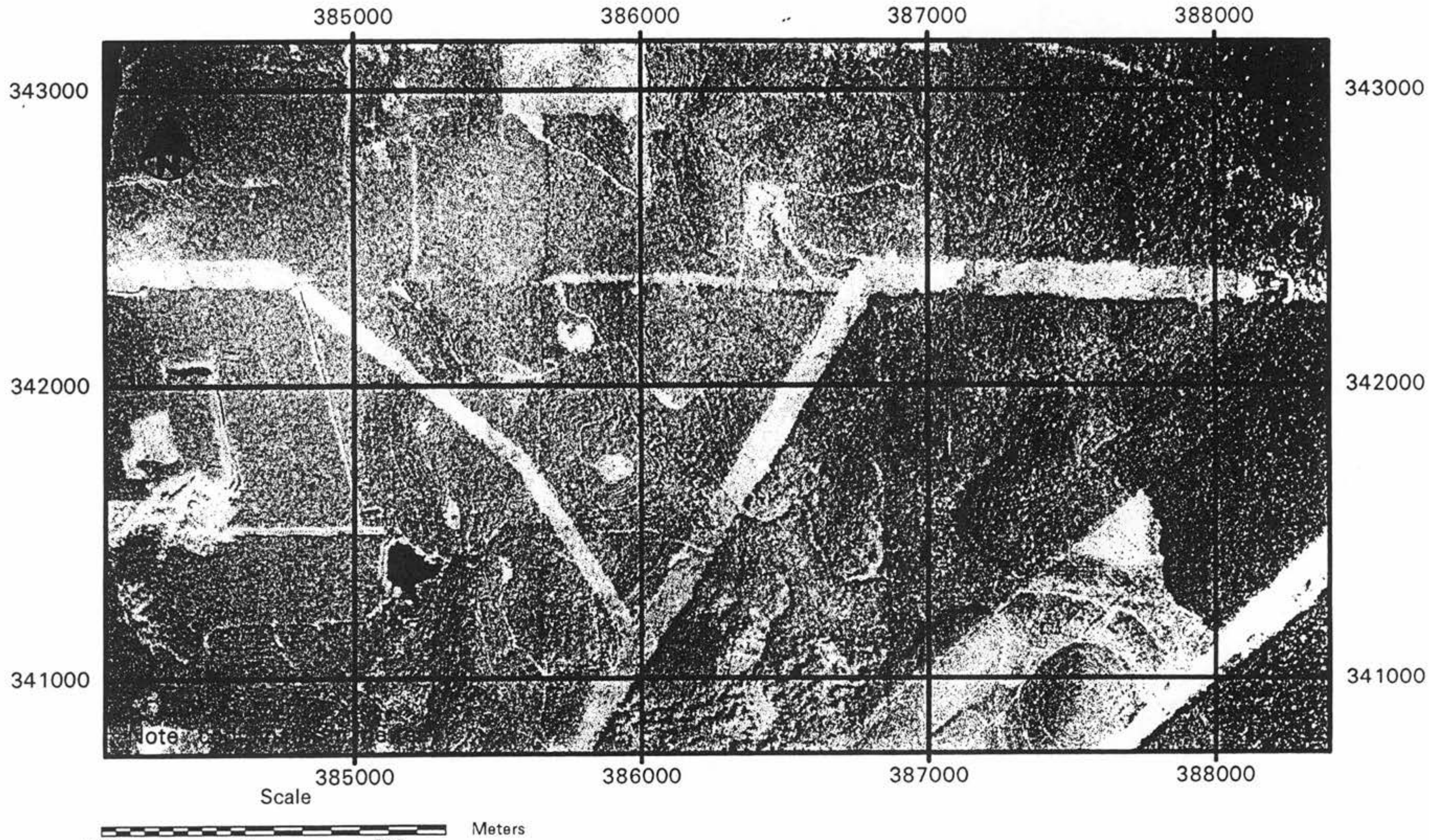


Figure 5.14 Automatically generated orthoimage of Test Site 2 - large area

6.7 Summary and conclusions

The four tests carried out have highlighted a number of points to be considered before using digital photogrammetric products as a source for a GIS. The points will be summarised as follows.

- The errors at the control points in the overall model orientation set-up using unrectified images (that is, images not corrected for scanner distortion) were significantly higher than those measured from rectified images. The use of the image rectification method (using a calibrated grid intersection film and suitable mathematical model) adopted by the author significantly improves the accuracy of the stereomodel set-up and hence subsequently helps to improve the overall accuracy of digital photogrammetric products.

- When high resolution images are to be used for stereo-digitising or to generate digital photogrammetric products, well defined and accurate GCPs are essential to orientate the stereomodel. If the accuracy level of the ground control points is not comparable to the scanning resolution then scanning at high resolution has no significant advantage in terms of planimetric accuracy. As a general rule, the GCP coordinates must be more accurate than the ground dimension of the scanning resolution.

- The use of images scanned in a DTP scanner (without proper image rectification) results in the lowest accuracy level compared to images scanned using a photogrammetric scanner or DTP scanner but rectified for image distortion

- Higher planimetric accuracy of point digitising from a stereoimage in DMS can be achieved if the aerial photographs are scanned at higher resolution.

- The accuracy of the automatically generated heights using auto-correlation largely depends on the quality of GCPs, image quality (both the original quality of aerial photographs and the radiometric quality of scanner used) and the scanning resolution used. The autocorrelation algorithm in DMS fails to give correct heights in shadow areas, in overexposed areas and in areas with poor image quality. If high quality DEMs are required, manual post-editing of automatically generated heights should be performed. It is important to note here that manual editing of automatically generated heights from scanned aerial photographs in DMS is not possible.

- Direct on-screen digitising from the generated orthoimage in the DMS can be an excellent way of map updating as an accuracy of less than a pixel of the original scanning resolution can be achieved provided the problem of incorrectly generated heights is sorted before an orthoimage is generated. The planimetric coordinate accuracy of well-defined points in an orthoimage generated automatically from the 1:5,000 scale aerial photographs scanned at 300 dpi was found to be within 1:1,000 map accuracy limit, while in the area with the good quality DEM the 1:20,000 aerial photographs scanned at 300 dpi were found to be just outside the 1:5,000 map accuracy limits.

The series of tests carried out indicates that rectified images from some desktop scanners can be used as data input to a digital photogrammetric system. At suitable scanning resolution, a comparable accuracy to that of a high performance scanner can be achieved. Other factors that must be taken into consideration to obtain the best possible accuracy are the quality of the original image and the accuracy of ground control points.

For local authorities and planning authorities which require regular updating of spatial data, desktop scanners can be used as an input device to scan aerial images for digital photogrammetric applications provided proper image rectification due to scanner distortion is carried out. The accuracy of products (DEM and orthoimage) obtained from a PC based digital photogrammetric system is sufficient for most mapping applications. With high quality GCPs, aerial photographs and DEMs, the 1:5,000 aerial photographs scanned at a scanning resolution 300 dpi or higher can be used to generate orthoimages for updating or creating large scale plans (between

1:1,000 and 1:2,000 scale). The orthoimage generated from 1:20,000 scale aerial photographs can be suitable to update or create smaller scale plans (between 1:5,000 and 10,000). Depending on the type of terrain and post-processing, heights generated from the auto-correlation process in the DMS can directly be used to create DEMs.

Since most of the procedures for generating digital outputs such as DEM and orthoimage in a DPW are automatic, there is no need for a skilled operator to measure X-parallax to obtain correct heights. The basic requirement for an operator to handle a DPW is the ability to view stereoscopically for which less technical training and experience are required. As local authorities or planning authorities are not specialised mapping organisations and operate within limited mapping budgets, the use of a low-cost digital photogrammetric system can be a suitable alternative for updating or creating new spatial data accurately and easily.

CHAPTER 7

INTEGRATION OF GIS AND DIGITAL PHOTOGRAMMETRY IN THE LANDFILL SITE SELECTION PROCESS

7.1 Introduction

Earlier discussions have indicated the suitability of using a low cost DTP scanner and a PC-based digital photogrammetric workstation to update and generate new map information. This chapter is intended to demonstrate how the integration of GIS and digital photogrammetric technology can help in the stage-by-stage landfill site selection process in Malaysia. As indicated earlier the methodology presented in this chapter is only intended to demonstrate the practicality of the proposed data collection and data analysis strategy in the landfill site selection process and not as an exact model of how the technologies developed in Chapters 5 and 6 could be applied practically and directly for landfill site selection in Malaysia.

The first section gives an overview of the selected study area (Petaling District). The following section briefly outlines the steps involved in using digital photogrammetric technology and GIS in the landfill site selection process. The criteria to be used in this case study will be given in the second section. The third section gives a brief description of the available data sets. The fourth section outlines the steps involved in the database construction. The following section describes the preliminary evaluation by GIS methods for selecting suitable areas based on the proposed siting criteria, and results obtained from this evaluation will also be presented. In the sixth section further evaluation on specific sites using digital photogrammetric data will be discussed. The summary and conclusions are given in the final section.

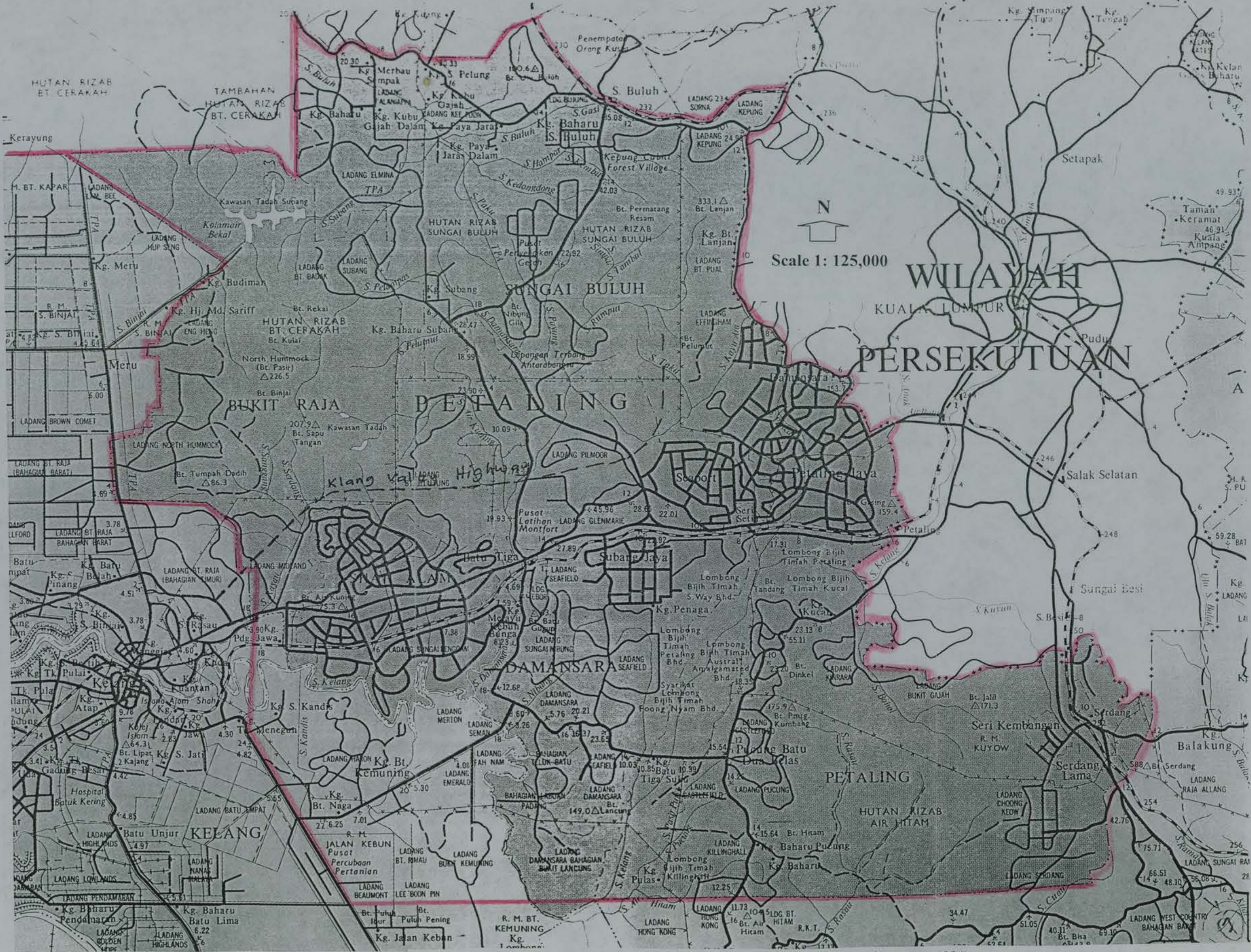
7.2 Overview of study area - Petaling District

An area within the Klang Valley Region was selected as the study area to demonstrate the practicality of the proposed data collection and data analysis strategy. The selected area is the Petaling District (refer to Figure 7.1). The study area comprises part of the Klang Valley Region, which includes the jurisdiction of three local authorities, that is, the Shah Alam Municipality, the Petaling Jaya Municipality and the Petaling District Council (currently known as Subang Jaya Municipality). The area is situated to the west of the Federal Territory of Kuala Lumpur. The area of the region is 54,418 hectares.

The main reasons for selecting this area were the availability of different theme maps such as the 1:50,000 scale topographic maps, the 1:10,000 scale town maps, geology maps and soil maps, as well as substantial aerial photographic coverage and satellite remote sensing imagery. Other factors which influence the selection of this area are the availability of existing ground control points and the author's prior knowledge of the study area.

The study area is situated mainly on a relatively flat area with an average height in its centre of 20 metres above mean sea level (MSL). Only the north-eastern, north-western and south-eastern parts of the study area are higher, bounded by a series of hills which rise to heights of 330 metres above MSL. The terrain above 100 metres MSL is predominately covered with primary forests. Part of the Shah Alam area is located at heights less than 5 metres above MSL and is subject to frequent flooding.

In 1980 the population of the Petaling District was 379,575. By 1985, the population had increased to 489,890, that is an increase of 5.1 percent per year compared to only 3.7 for the Selangor State and 2.5 percent for Peninsular Malaysia. By 1990, the population was 811,429. According to the Draft Structure Plan for Petaling and Part of Klang District 1988-2010 published in 1994, the projected population of this district will continue to rise steadily to 2010 (Table 7.1).



(Source: Selangor State map, 1984)

Study area

Figure 7.1 Location of study area – Petaling District

Table 7.1 Current and projected population of the Petaling District

Year Municipality	1980	1985	1990	1995	2000	2005	2010
Petaling Jaya Municipality	247,229	319,241	475,418	548,917	631,238	724,392	767,180
Shah Alam Municipality	66,824	104,590	218,177	258,343	306,270	356,336	412,107
Petaling District Council	65,521	66,059	117,834	163,180	276,799	394,870	563,467
Total	379,574	489,890	811,440	970,440	1,214,307	1,475,598	1,742,754

(Source: Draft Structure Plan for Petaling District and Part of Klang District 1988-2010, 1994)

The study area is covered by a good transportation network of federal highways, state roads and local roads. Currently there are two federal highways that link Klang and Kuala Lumpur. A third highway is under construction. The total lengths of state road and other local roads are approximately 180 and 420 kilometres respectively.

According to the Draft Structure Plan for Petaling District and Part of Klang (1994), the major land use categories within the study area are residential, industrial, commercial, recreational, government institution, agriculture and forest. Until June 1993, agricultural land and forest reserve constituted 39.3 percent of the total land in the study area. The agriculture consists mainly of oil palm and rubber plantations. Residential, commercial, government institution and industrial areas constitute 8.1, 0.7, 5.5 and 3.3 percent of the total area respectively. A total of 16.7 percent of the land area has been assigned for future development. The proportions of residential, commercial, industrial and recreational areas are 3.7, 0.7, 5.3 and 1.1 percent respectively. There have been substantial changes in land use, especially at the urban fringes. Much agricultural land has been converted to residential, industrial and commercial use. There are three forest reserves and one water catchment area within the study area. The three forest reserves are the Bukit Cerakah forest reserve, the Sungai Buluh forest reserve and the Air Hitam forest reserve while the water catchment area is located to the north of Bukit Cerakah forest reserve. Most of the land at the edge of these forest reserves has been converted legally or illegally to agricultural land. A summary of the current and designated land use for the Petaling District until June 1993 is given in Table 7.2.

Table 7.2 Current and designated land use (in hectares) until June 1993

Land use	Area (Hectares)	Percentage (%)
Current land use		
Commercial	380	0.7
Residential	4,438	8.1
Industrial	1,816	3.3
Recreation	2,271	4.2
Institution	3,006	5.5
Mining	884	1.6
Agriculture	17,151	31.4
Forest	4,306	7.9
Public Utilities	649	1.2
Others	10,556	19.4
Sub-total	**45,457**	**83.3**
Land designated for development		
Residential	2,006	3.7
Commercial	365	0.7
Industrial	2,911	5.3
Recreational	605	1.1
Others	3,247	5.9
Sub-total	**9,134**	**16.7**
Total	**54,591**	**100.0**

(Source: Draft Structure Plan for Petaling District and Part of Klang District 1988-2010, 1994)

There are three drinking water intake points within the Petaling District, two of which are located on the Buloh river while the other is on the Damansara River (refer to Table 7.3). The main drinking water supply for the district comes from Ulu Klang Reservoir, which is located outside the study area. In traditional villages wells are still used as the source of drinking water.

Table 7.3 Location of water intake within the Petaling district

Location of water intake		Name of river/reservoir/well	Water supply scheme
Longitude (East)	Latitude (North)		
101° 31' 06"	3° 11' 42"	River Buloh	Subang
101° 35' 12"	3° 13' 42"	River Buloh	Sungai Buloh
101° 33' 12"	3° 05' 00"	River Damansara	Bukit Jelutong

(Source : Environmental Quality Act 1974 and regulations, 1991)

As of 1994, there were three legal waste disposal sites within the study area. The Petaling Jaya Municipality waste disposal site is located in Kelana Jaya. This site is a depression excavated by former mining and located near the residential area. Access to the waste disposal site is through a residential area. The Petaling District Council waste disposal site is located at Puchong Batu 12 and is actually a privately owned ex-mining pool. The district council was given permission by the owner to dump waste in the pool. Upon closure the site will be used for further development. The Shah Alam Municipality waste disposal site is located on the Klang River bank at Bukit Kemuming. The Kelana Jaya and Bukit Kemuming sites currently exceed their official capacity limits.

Since the closure of these waste disposal sites in 1996, all wastes from these municipalities have to be disposed of at a new landfill (Air Hitam landfill). Although this new site is designed to cause minimum environmental and social problems, its location is quite far from many waste collection centres. This has caused considerable transportation problems to both the local authorities and waste collection contractors. It is not surprising that many private contractors have decided to dump illegally in old mining ponds located within the municipality.

7.3 Steps involved in the landfill site selection process

Section 4.3 has outlined the overall proposed data collection and data analysis strategy to be adopted for the Klang Valley Region. Landfill sites to be selected using a two-step approach consisting firstly of GIS and secondly of photogrammetric techniques. The main steps were:

- formulate the site selection criteria;
- identify types of data to be used in the preliminary (GIS) site selection process;
- construct the spatial and non-spatial database;
- carry out preliminary evaluation of potential areas using GIS techniques (for the whole of study area) based on exclusionary and restrictive criteria;

- carry out further site-specific evaluations of the selected few suitable areas based on the economic criteria and visibility analysis, using photogrammetric techniques to produce orthoimages and DEMs for detailed analysis.

7.3.1 The site selection criteria

The first step in the GIS site selection process is to formulate the site selection criteria to be used. As discussed in Chapter 2, there are no proper national criteria for locating landfill sites in Malaysia. Different local authorities tend to formulate their own guidelines but none have actually used the guidelines. Most of the proposed criteria in the earlier studies (Engineering Science Inc., SEATEC International and Department of Environment of Malaysia, 1987; Technical Section, Local Government Division, Ministry of Housing and Local Government,1988; Department of Town and Rural Planning and Klang Valley Planning Unit, 1988; JICA, 1989a; Kielbrer Burger and Perunding Sdn. Bhd., 1990; Engineering and Environmental Consultant Ltd., 1991) were developed by foreign consultants or adopted from foreign criteria.

Ideally all criteria discussed in Chapter 2 should be included in the landfill site selection process. Since there are limited spatial and non-spatial data available, only important criteria gathered from previous studies and informal discussions with officers from various waste management related agencies in Malaysia were considered in this case study (refer to Table 2.10). Some important criteria such as future land use restrictions (based on structure plan), land ownership (either government land or privately owned land), land value, site development costs cannot be included because the related data are not available. Another factor that limits the number of criteria to be used is the time required to convert diverse types and large quantities of hardcopy maps of the study area into digital format. A total of only fifteen criteria were used in this study, seven of which are the exclusionary criteria while the other eight are restrictive criteria. No attempt was made to assign different weights (as suggested in Converse/TenEch, 1981; Roger *et al.*, 1985 and Engineering and Environmental Consultant Limited, 1991) to the selected criteria. Neither multi-criteria decision making (MCDM) methods as discussed in Periera and

Duckstein, (1993), Jankowski, (1994), Carver, (1991), Malczewski, (1996) or Expert System method as used by the Miaoli Perfecture, Miaoli Perfecture, (1996) were utilised. All criteria used in this case study were considered to have equal weight. Polygon overlay method was used in this study.

The criteria suggested in Table 7.4 are mainly intended to demonstrate the diversity of data required and suitability of using GIS and digital photogrammetry for selecting a potential landfill site or sites. Based on the exclusionary criteria, landfill sites are constrained from locating in environmentally sensitive areas, including 100-years flood plain, nature conservation areas, surface water area (water intake point and reservoir), or in unstable, areas that is, within a karst area, near a fault line or a landslide prone area. Other exclusionary criteria include safety distances from an airport and from a developed area. The restrictive criteria include distance from water bodies, distance from rivers, distance from existing disposal site, and distance from residential area. Other criteria include economic criteria such as haul distance, size and capacity of site and distance from existing road network. All the criteria suggested are based on the availability data for this study.

7.3.2 Available data

Having defined the siting criteria, it is necessary to specify the types of data required in the analysis. As mentioned earlier in this thesis, the main problem of implementing a computerised system for site selection in Malaysia is associated with the availability and suitability of existing data sets. Only three major data sources, that is, existing maps (topographic and thematic), aerial photographs and Landsat TM digital data, were used in this study. A summary of the available data sets is given in Table 7.5.

Table 7.4 Proposed siting criteria to be used in this study

Criteria no.	Exclusionary Criteria
1	• Site must not be located within 3,048 metres from an airport used by turbojet aircraft and 1,524 metres from an airport used by piston-engine aircraft.
2	• Site must not be located within 610 metres (2000 ft) from water supply intake point.
3	• Site must not be located within 610 metres (2000 ft) from a reservoir or lake used as water supply.
4	• Site must not be locate within karst area or limestone area
5	• Site must not be located within a 100-years flood plain.
6	• Site must not be located within landslide prone areas. The recommended slope gradient for landfill is less then 10%
7	• Site must not be located within a wild life forest, water catchment area, nature conservation area, developed areas such as residential, commercial and residential area, within special reserves (for example native reserve land, Malay reserve land and agricultural research area) or also within existing or planned recreational areas.
	Restrictive Criteria
8	• Site must not be located within 200 metres from any water bodies such as ex-mining pond or lakes.
9	• Site must not be located within 200 metres from existing dump site
10	• Site must not be within 154 metres (500 ft) from the river bank
11	• Selected site must not be more than 500 m from a major road
12	• If no mitigation measure were to be taken the recommended buffer distance from the nearest residential area should be 1500 metres, otherwise the minimum distance should be 200 metres.
13	• The size of site must be more than 50 acres
14	• Minimum lifespan of five years
15	• Must not be visible from public

Table 7.5 List of data sets available

Data	Scale	No. of sheets	Year Published/ Acquired	Source
State (Selangor) map	1:125,000	2	1984	Dept. of Surveying and Mapping
Soil (Selangor State) map	1:253,440	1	1966	Agriculture Dept
Geology (Selangor State) map	1:63,360	2	1976	Geology Dept.
Topographic map	1:50,000	2	1990	Dept. of Surveying and Mapping
Town map	1:10,000	12	1984	Dept. of Surveying and Mapping
Land use map				
• Klang Valley	1:125,000	1	1990	Agriculture Dept.
• Klang Valley	Not to scale	1		Klang Valley Planning Unit
• Petaling district	Not to scale	1	1991	Selangor State Planning Dept.
Hydrogeological map	1:250,000	1	1975	Geology Dept.
Future land use map	not to scale	1	1989	Dept. of Town and Regional Planning
Landsat TM image (covers the major part of Petaling District)	Georeference to MRSO	-	1992	National Remote Sensing Centre
Aerial photographs of selected areas of the study area only	1 : 24,000 1 : 20,000 1 : 10,000 1 : 5,000	-	1992 1989 1993 1993	Dept. of Surveying and Mapping

A. Existing maps

Available maps for this study include the Selangor State maps, topographic maps, soil map, geology maps, town maps, hydro-geological map, and land use maps (current and future). For most planning applications, land use maps are the most important source of thematic information. Although these maps are available for this study they are not used for making accurate measurement for two main reasons: i) the maps produced by the Town and Regional Planning Department and the Klang Valley Planning Unit are not to scale and ii) the map produced by the Agriculture Department, although produced to scale, is not correctly registered to the Malayan Rectified Skew Orthomorphic (MRSO) projection. These maps were only used as a guide for visual land use classification using a Landsat TM satellite image.

The town maps and topographic maps for the study area were acquired from the Department of Surveying and Mapping, Malaysia. A total of sixteen 1:10,000 scale town map (series L808) sheets and two 1:50,000 scale topographic maps (series L7030) were available. The town maps and topographic maps were published in 1984 and 1991 respectively. Information on the town maps is based on the 1969 aerial photography and field completion carried out in 1975 while information on the topographic maps is compiled graphically from 1:10,000 Sheet Series L7010-1969 and L808-1984 with major roads updated from aerial photographs in 1991. Both the L808 and L7030 map series were compiled on the MRSO projection. The contour intervals in the L7030 and L808 map series are 10 metres and 25 feet respectively. Although more detailed information can be obtained from the 1:10,000 scale maps, they were not used as the basis for creating most data layers required for this study for two main reasons: i) the information in these maps are too out-of-date, and ii) too much time would be taken if all the sixteen sheets were to be digitised. These town maps were only used to derive height information (spot heights). The two sheets (Sheets 3657 and 3757) of the L7030 series topographic maps were used to generate most of the data layers required for this study.

The geological maps (Sheet 93 and 94) of the study area were published by the Geological Department of Malaysia in 1976. The maps were compiled in 1961 onto the 1:63,360 scale topographic maps. Information regarding the geological formation, structural and mineral deposit is given. Other maps such as the 1:250,000 scale hydrogeological map and the 1:125,000 scale soil map of the study area were also available. Unfortunately textual information regarding the feature class is not available.

B. Landsat TM satellite image and aerial photographs

Landsat TM digital data with 30 metres resolution of the major part of the study area were acquired from the MACRES. The data have been geometrically corrected to MRSO projection. Accuracy testing of this digital image using 30 check points shows that the corrected image is accurate to within 1 to 2 pixels. SPOT Panchromatic and SPOT Multispectral digital data of the study area are available but was not purchased by the author due to their high cost. The information regarding the Landsat TM digital data acquired is summarised in Table 7.6. Figure 7.2 shows the available satellite imagery.

Table 7.6 Information on Landsat TM digital data

Date acquired	26th Febuary 1993
Scene no.	Sub-scene of 127/58 (path 127 row 58)
No. of rows	556
No. of columns	1110
Scene centre	Latitude : 2.889707° N
	Longitude : 101.8398° E
Map projection	Malayan Rectified Skew OrthomorphiC
Map coordinate of image	U/L corner (Eastings) : 376392 m
	U/L corner (Northings) : 347426 m
	L/R corner (Eastings) : 409692 m
	L/R corner (Northings) : 330746 m
Bands available	All the seven bands

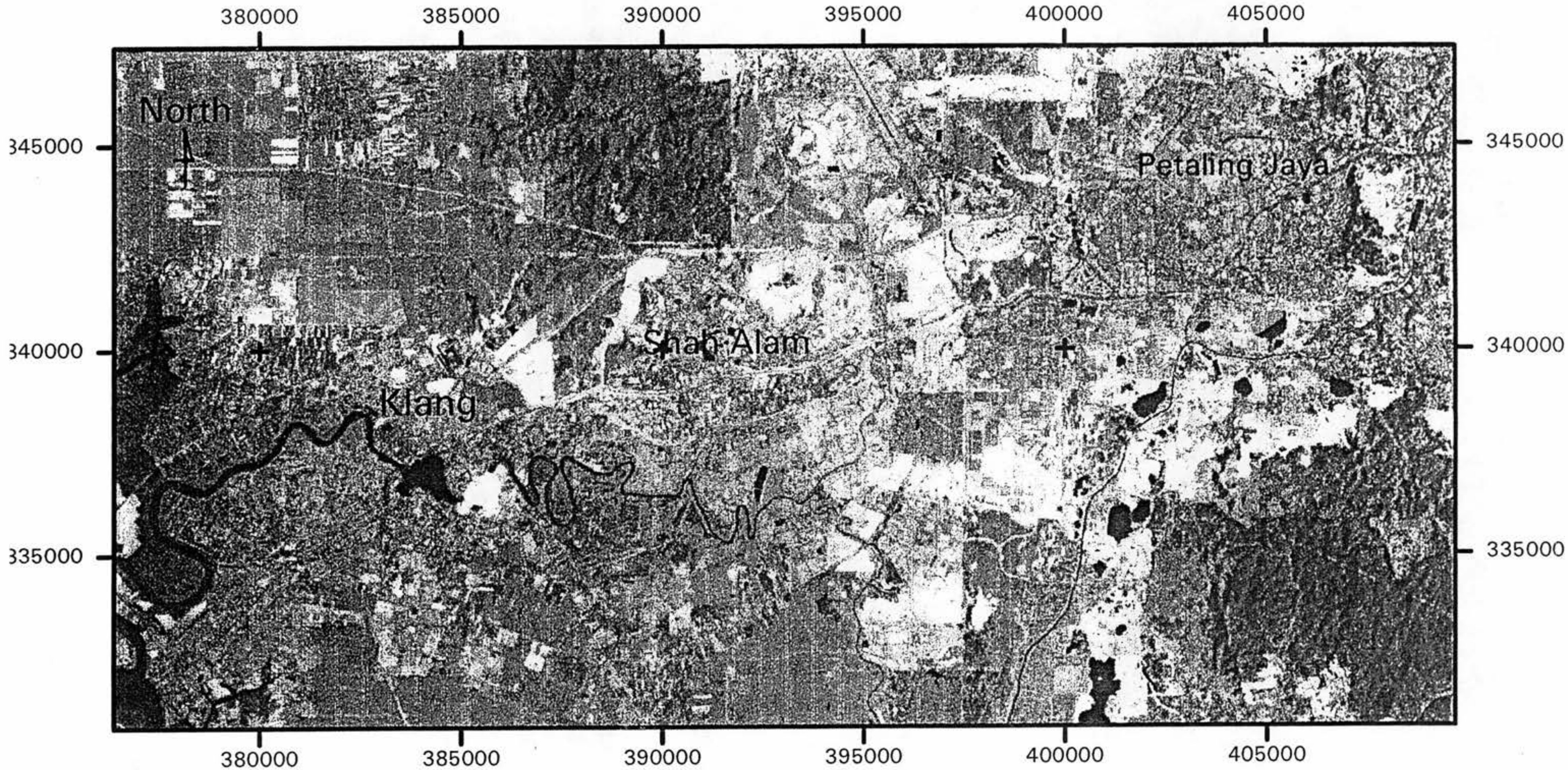


Figure 7.2 Satellite imagery of part of Petaling District

Four different scales of black and white aerial photographs of the selected area were acquired from the Department of Survey and Mapping, Malaysia. The photographic scales are 1:5,000, 1:10,000, 1:20,000 and 1:25,000. Only the 1:20,000 scale aerial photographs were utilised in this study. The use of large scale aerial photographs (that is, 1:5,000 and 1:10,000) was not possible because of their limited coverage and because the high positional accuracy GCPs needed to orientate the stereomodels were not available.

7.3.3 Database construction

The process of database building can be considered as the most critical and the most time-consuming part of any GIS project. Usually the process of building a digital database includes the following stages: i) design the database, which usually includes the determination of the coordinate system to be used, identification of data layers and features to be included in each layer and the attributes each feature type needs; ii) convert data into digital format, which includes getting spatial data into the database through digitising and/or converting data from other systems or formats and verifying, editing and creating topology of the digitised coverages; and iii) transfer the attributes data into the digital database.

A. Database design

For this study, data are organised in separate data layers. A data layer in GIS can be considered as a digital map which contains a layer of feature type (points, lines or polygons). These layers include administrative boundary, geology type, land use classification, water bodies, transportation network, river, environmentally sensitive area, slope classification, contour, spot height and water intake point. Table 7.5 lists the coverages and attributes used in this study. The existing land use is classified into eleven categories. These categories are i) residential, ii) industrial, iii) agricultural, iv) government institution, v) commercial, vi) recreational, vii) forest reserve, viii) agricultural reserve, ix) abandoned tin mine, x) existing dump site and

xi) special reserve (Malay reserve and native reserve). Geology types are classified according to the classifications given in the 1976 geology map. These classifications includes i) alluvium, ii) granitic rock, iii) quartzite and phyllite, iv) phyllite and schist, v) vein quartz, vi) schist with minor intercalations of limestone (marble) and phyllite, and vii) limestone (marble) with minor intercalations of phyllite. The land use and geological suitability for landfill are rated using three ranges: i) not suited, ii) marginal suited and iii) suited. Three features, that is, i) lakes, ii) reservoir and iii) ex-mining ponds are considered under the water bodies layer. The boundary coverage is classified into administrative boundaries, that is, i) state boundary, ii) district boundary and iii) local authority boundary. Slope is classified into three main categories, that is i) slope less than 5 per cent, ii) slope between 5 to less then 10 per cent, and iii) slope more than 10 per cent. The transportation network is classified into i) federal highway, ii) state road (or major road), iii) minor road (local road) and iv) railway.

A data dictionary, which includes all the coverages, the names of the attributes and a description of the attribute values (including a description of each code) used for this study is given as Appendix I.

Table 7.7 The coverages and their attributes

Layer	Coverage Name	Feature Class	Feature attributes
1. Existing land use	LANDUSE	POLYGONS	land use code suitability
2. Geology	GEOLOGY	POLYGONS	Geology code Suitability
3. Water body	WATERBODY	POLYGONS	Water body code
4. Boundary	BOUNDARY	POLYGONS	Boundary code
5. Sensitive areas	SENSIT_AREA	POLYGONS	Sensitive area code
6. Flood prone area	FLOOD_AREA	POLYGONS	Flood area code
7. Slope	SLOPE	POLYGONS	Slope class
8. River	RIVER	LINES	River code
9. Transportation system	TRANSPORT	LINES	Transportation code
10. Contours	CONTOUR	LINES	Contour
11. Spot height	SPOT_HT	POINT	Elevation of points
12. Drinking Water Intake Point	WATERIN_PT	POINT	

B. Coordinate transformation

Although all base maps used in this study were prepared to a common projection, that is MRSO, the grid references are not the same. The grid references on the topographic maps and town maps are given in metres of eastings and northings while, for the geology map, grid reference is given in terms of geographical latitude and longitude. Since the ARC/INFO software used in this study does not have the facility to convert the grid reference in latitude and longitude of the MRSO projection to its equivalent metres of eastings and northings, a computer program (LLATRSO) has been written by the author to allow this conversion to be carried out. Based on a test carried out, a second order polynomial transformation was found to be sufficient to transform TIC point coordinates to be used to digitise geology maps from geographical latitude and longitude to metres of northings and eastings. The methodology adopted and results from the test given in the following section.

To allow a suitable coordinate transformation to be determined, a suitability test using POLY15 program (as used in Chapter 5) was carried out. Coordinates of points both in northings and eastings and in geographical latitude and longitude are required. For this purpose coordinates of twenty five existing Global Positioning System (GPS) network stations for the Selangor State and three other surrounding states, that is Negeri Sembilan, Pahang and Perak obtained from the Department of Surveying and Mapping, Malaysia were used. Fifteen of these points were selected as control points, while the other ten were used as check points. The distribution of the 25 selected GPS network stations is given in Figure 7.3. Lists of control and check point coordinates are given in Appendix K1. Based on the results summarised in Table 7.8, it is clear that an accuracy of less than 1 metre can be achieved from the second order polynomial transformation. Using the transformation parameters generated from this POLY15 program the LLATRSO program will then compute the coordinates (in metres of eastings and northings) of TIC points.

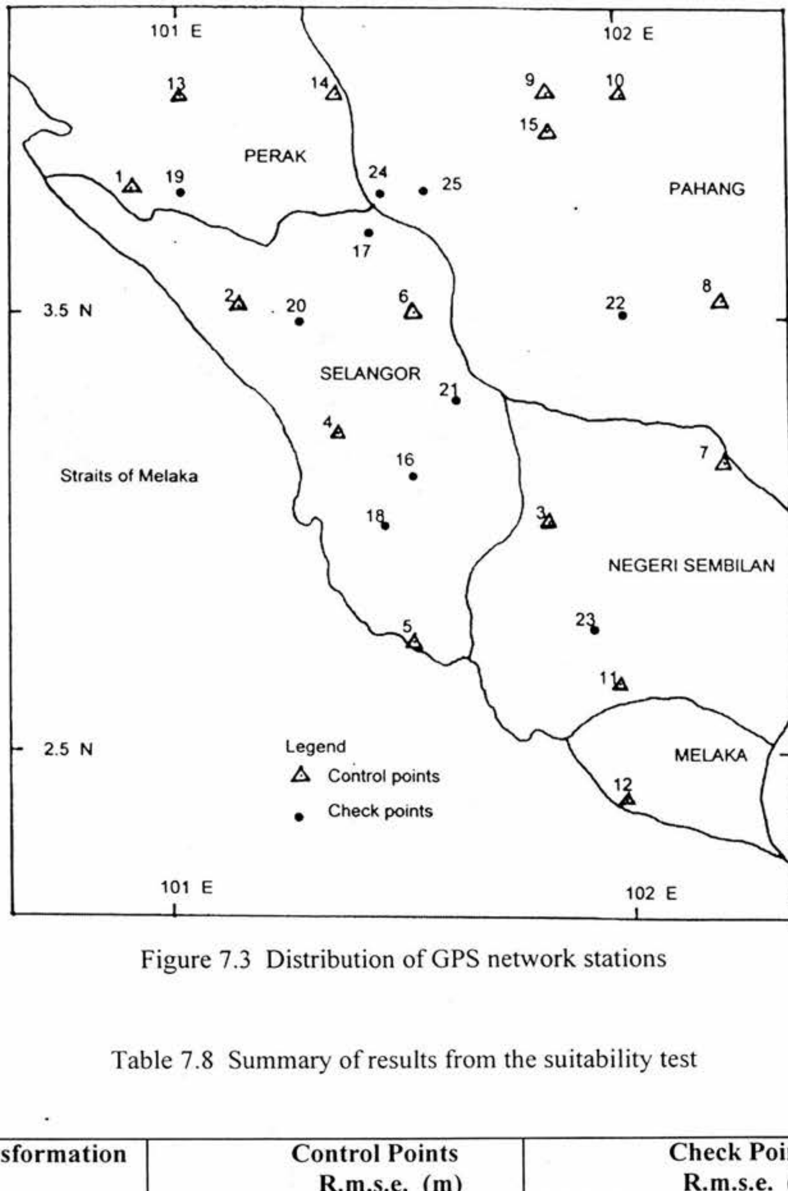


Figure 7.3 Distribution of GPS network stations

Table 7.8 Summary of results from the suitability test

Transformation	Control Points R.m.s.e. (m)				Check Points R.m.s.e. (m)			
	No. of points	Ex	Ey	Ev	No. of points	Ex	Ey	Ev
Polynomial								
4 terms (xy)	15	3.94	12.66	13.26	10	1.67	8.99	9.14
5 terms (x^2)		3.16	1.67	3.57		2.37	1.51	2.81
6 terms (y^2)		1.06	0.84	1.35		0.40	0.53	0.66
7 terms (x^2y)		1.01	0.77	1.27		0.37	0.29	0.47
8 terms (xy^2)		0.43	0.33	0.55		0.33	0.36	0.42
9 terms (x^3)		0.33	0.26	0.42		0.27	0.21	0.34
10 terms (y^3)		*0.00*	*0.00*	*0.00*		*0.00*	*0.00*	*0.00*
11 terms (x^3y)		*0.00*	*0.00*	*0.00*		*0.00*	*0.00*	*0.00*
12 terms (xy^3)		*0.00*	*0.00*	*0.00*		*0.00*	*0.00*	*0.00*
13 terms (x^4)		*0.00*	*0.00*	*0.00*		*0.00*	*0.00*	*0.00*
14 terms(x^2y^2)		*0.00*	*0.00*	*0.00*		*0.00*	*0.00*	*0.00*

C. Digitising of existing maps

Having identified the data required for the site selection process, it is necessary to convert hardcopy maps into a format that can be interrogated and analysed digitally in ARC/INFO. Since there are no existing digital data available for the study area, all map information had to be converted into digital format.

Vector digitising of map information based on the coverages organised earlier was carried out using the ARC/INFO ADS digitising modules. The 1:50,000 scale topographic maps, 1:10,000 scale town maps and geology maps were used as the basis for digitising the coverages mentioned earlier. All the coverages, except the GEOLOGY, SPOT_HT and WATERIN-PT, were digitised from 1:50,000 scale topographic maps. The GEOLOGY coverage was digitised from 1:63,360 scale geology maps. SPOT_HT coverage was digitised from 1:10,000 scale town maps. Digitising was carried out according to the coverages suggested earlier. The LANDUSE, WATERBDY, GEOLOGY, BOUNDARY, SENSIT_AREA coverages were digitised as polygon coverages; the TRANSPORT, RIVER AND CONTOUR as line coverages while SPOT-HT coverage was digitised as points. The topology of digitised coverages can be created using CLEAN or BUILD command in ARC. Digitising errors identified on screen were corrected using NODESNAP, MOVE and EXTEND commands in ARCEDIT. After all errors were corrected topology was reconstructed. The CALCULATE command was used to correct label-ID errors. The INFO command in ARC was used to create and add the attribute values to the INFO data file.

D. Update map information using on-screen digitising

Because there have been substantial changes in the land use and patterns of new roads, map updating of land use changes and mapping of new roads are needed. As proposed earlier (refer to Section 4.3), Landsat TM satellite digital data were used by the author to update these changes. New land use and road data were manually digitised on-screen in DMS with Landsat TM image of the study area as the backdrop. The digitising procedure as follows:

a) Load TM image of the study area into DMS. The geo-referenced TM image is in .LAN format.

b) Load LANDUSE and TRANSPORT coverages into DMS. Before loading into DMS these ARC/INFO coverages must first be converted into ASCII file format. The UNGENERATE command in ARC/INFO creates ASCII files containing the vector coordinates of the two coverages. The output filename must have the extension .LIN to signify to the DMS that it is an ARC/INFO file. An example of the command used in ARC/INFO is given below:

   Arc : ungenerate LINE coverage_name output_file.LIN

   Arc : ungenerate LINE landuse landuse.LIN

c) Use the PLANIMETRIC command in the MAP module to read, overlay and update vector files on the TM image in the DMS. The updated DMS vector files can be converted into ARC/INFO format using either of the two commands.

   i. Convert DMS binary (.BIN) vector file to DMS ASCII file format (.VEC) using VECTOR EXPORT option in DATA module. The ASCII file format can later be converted to ARC/INFO (.LIN) file format using the same option.

   ii. When .LIN file generated in ARC/INFO is used as input in DMS and the updated vector file is directly saved as .LIN file it will automatically be in ARC/INFO GENERATE format.

The following ARC/INFO commands are used to read .LIN file back into ARC/INFO.

Arc : GENERATE <Coverage_Name>

Arc : INPUT <filename.LIN>

Arc : LINES

Arc : QUIT

Digitising can be also carried out in the ARC/INFO or ERDAS digital image processing system. The procedure for on-screen digitising of LANDUSE coverage in ARC/INFO is as follows :

a) Display the georeferences LANDSAT TM image in ARCEDIT

    Arcedit : mapextent LANDUSE

    Arcedit : image tmdata.lan composite 4 5 3 (4 5 3 indicates TM band used)

b) Load vector coverage and overlay on the TM image

    Arcedit : edit LANDUSE

    Arcedit : editfeature poly

    Arcedit : drawenvironment poly

    Arcedit : draw

c) Use the ADD command in ARCEDIT to add new features or update existing features

E. Slope map and flood prone area map

Since there is no information available in Malaysia regarding slope classification and the 100-years flood plain, new maps had to be generated; they were a slope map (SLOPE coverage) and a map of the area subject to flooding (FLOOD_AREA coverage). Both of the maps require heights points in order that a DEM can be generated subsequently, and five existing coverages, that is, CONTOUR, WATERBODY, SPOT_HT, RIVER and BOUNDARY coverages were used to create the DEM. The commands used to generate the DEM of the study area are as follows.

Arc: CREATIN TINPETA 50 50

Createtin : cover SPOT_HT point spot

Createtin : cover CONTOUR line spot

Createtin : cover BOUNDARY poly spot 6

Createtin : cover WATERBODY poly spot 8

Createtin : cover RIVER spot 2

Createtin : END

The SLOPE coverage of the study area was generated using the TINARC command. The ARC DISSOLVE command was used to combine adjacent polygons with the same classifications into a single polygon. As mentioned earlier, the slope was classified into three main classes. Flood areas were derived from contour bands (polygons representing zones of similar elevation) with elevation less than 7 metres above MSL area. These contour bands were generated from a lattice with LATTICEPOLY commands using the RANGE option. Polygons with elevation less than 7 metres were later extracted. The adopted procedure for generating SLOPE and FLOODAREA coverages is given in Figure 7.4.

F. The generated ARC/INFO coverages

Results from vector digitising and on-screen digitising are given as ARC/INFO coverages. Figures 7.5 to 7.9 provide only some of the coverages or combination of few coverages digitised for the study area. Other coverages are too trivial to include. The generated SLOPE coverage is shown in Figures 7.10.

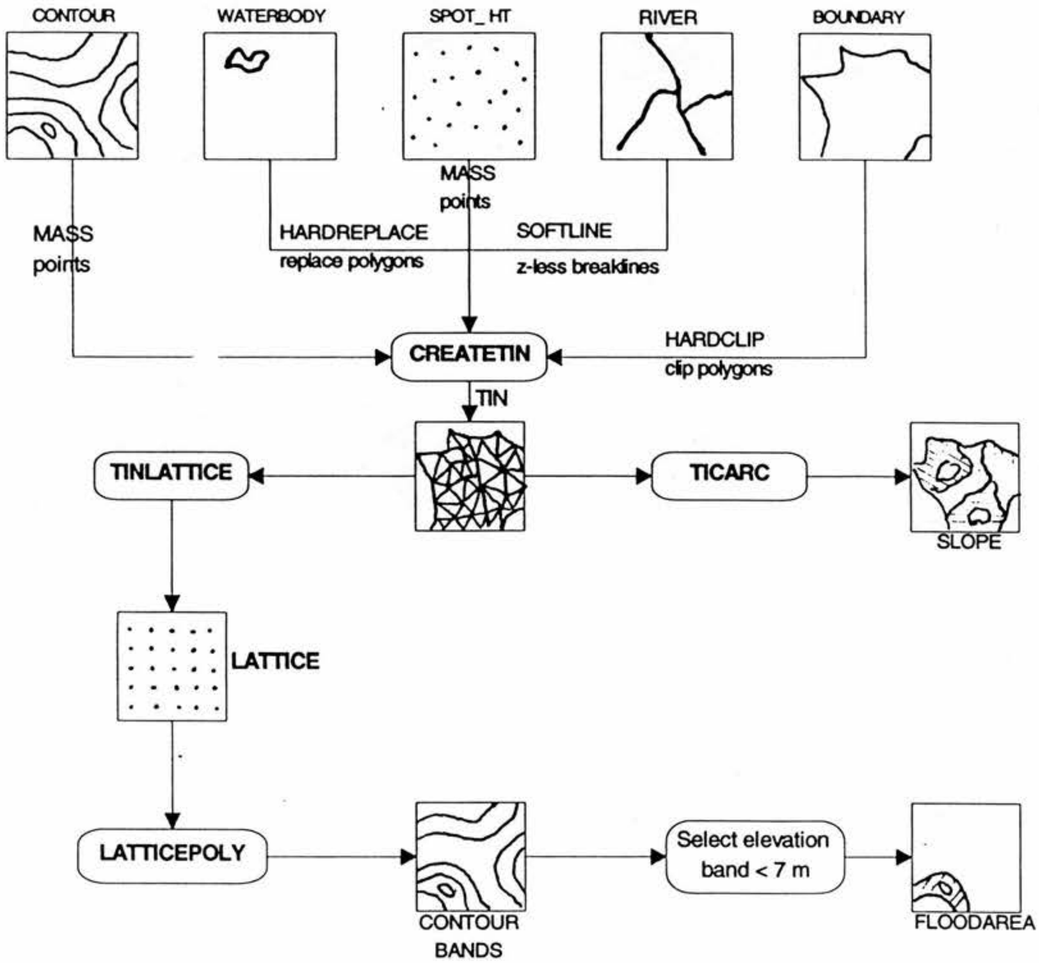


Figure 7.4 Procedure for generating SLOPE and FLOODAREA coverages

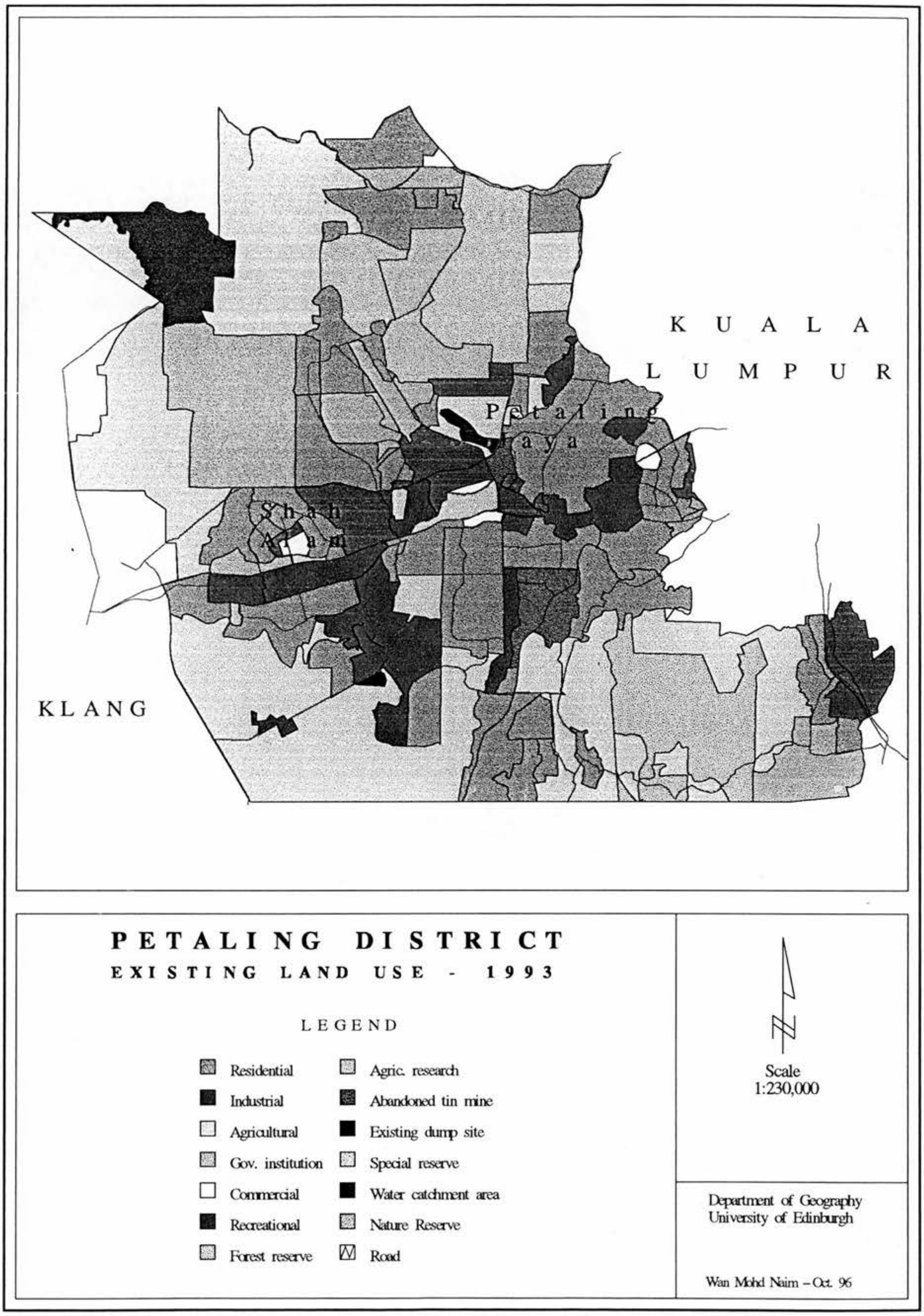


Figure 7.5 Existing land use of the study area

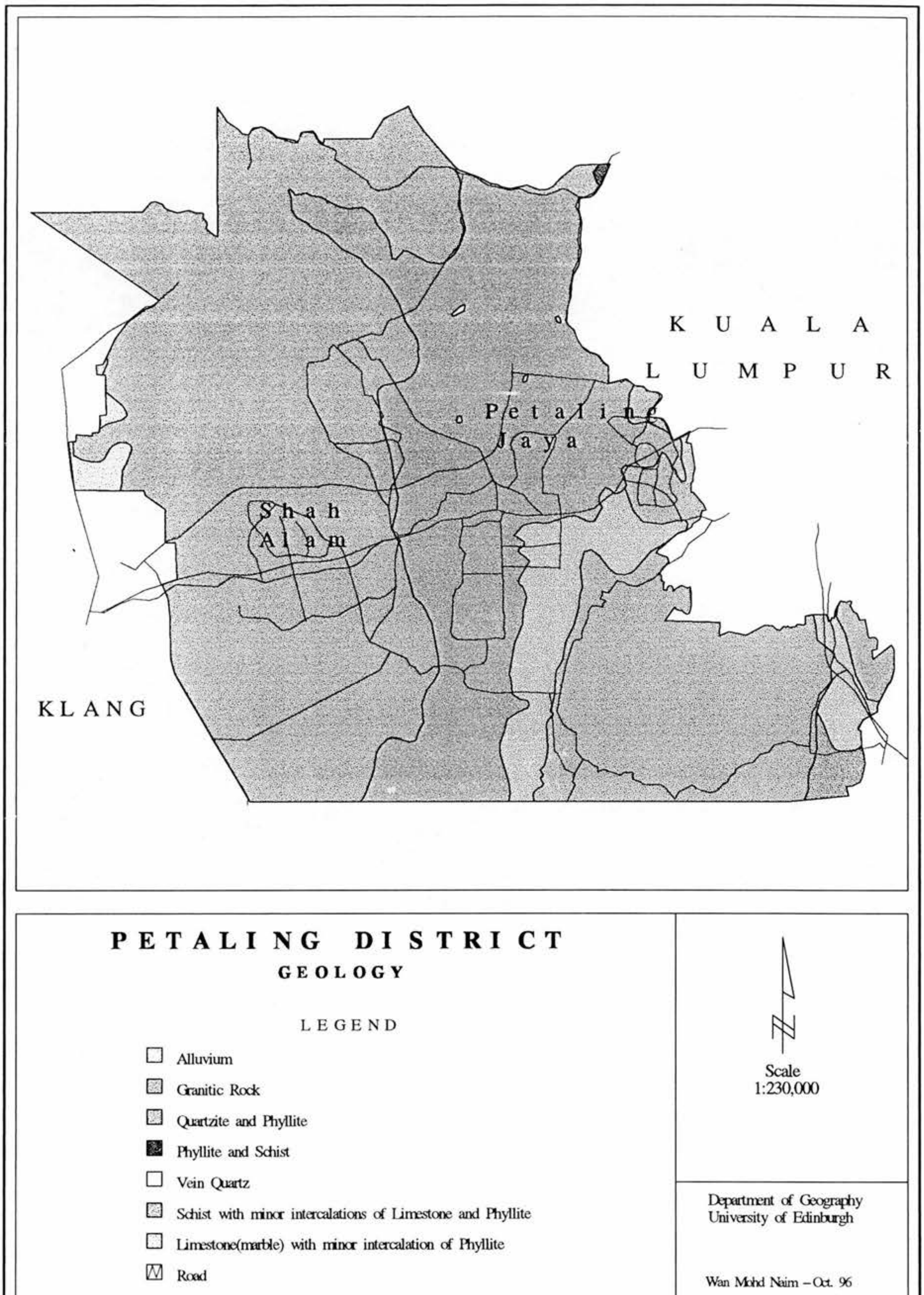


Figure 7.5 Geology of the study area

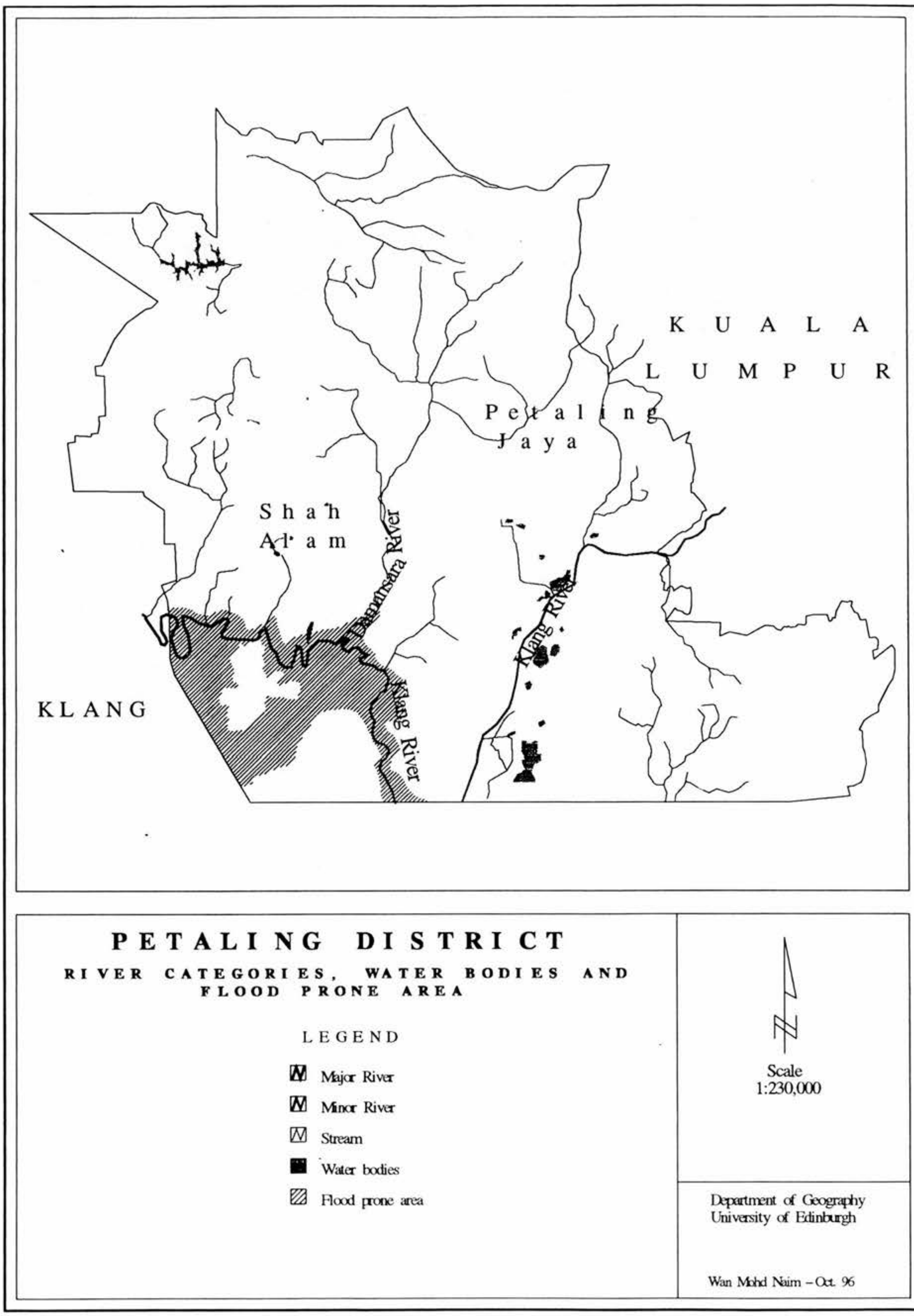


Figure 7.7 Rivers, water bodies and flood prone area in the study area

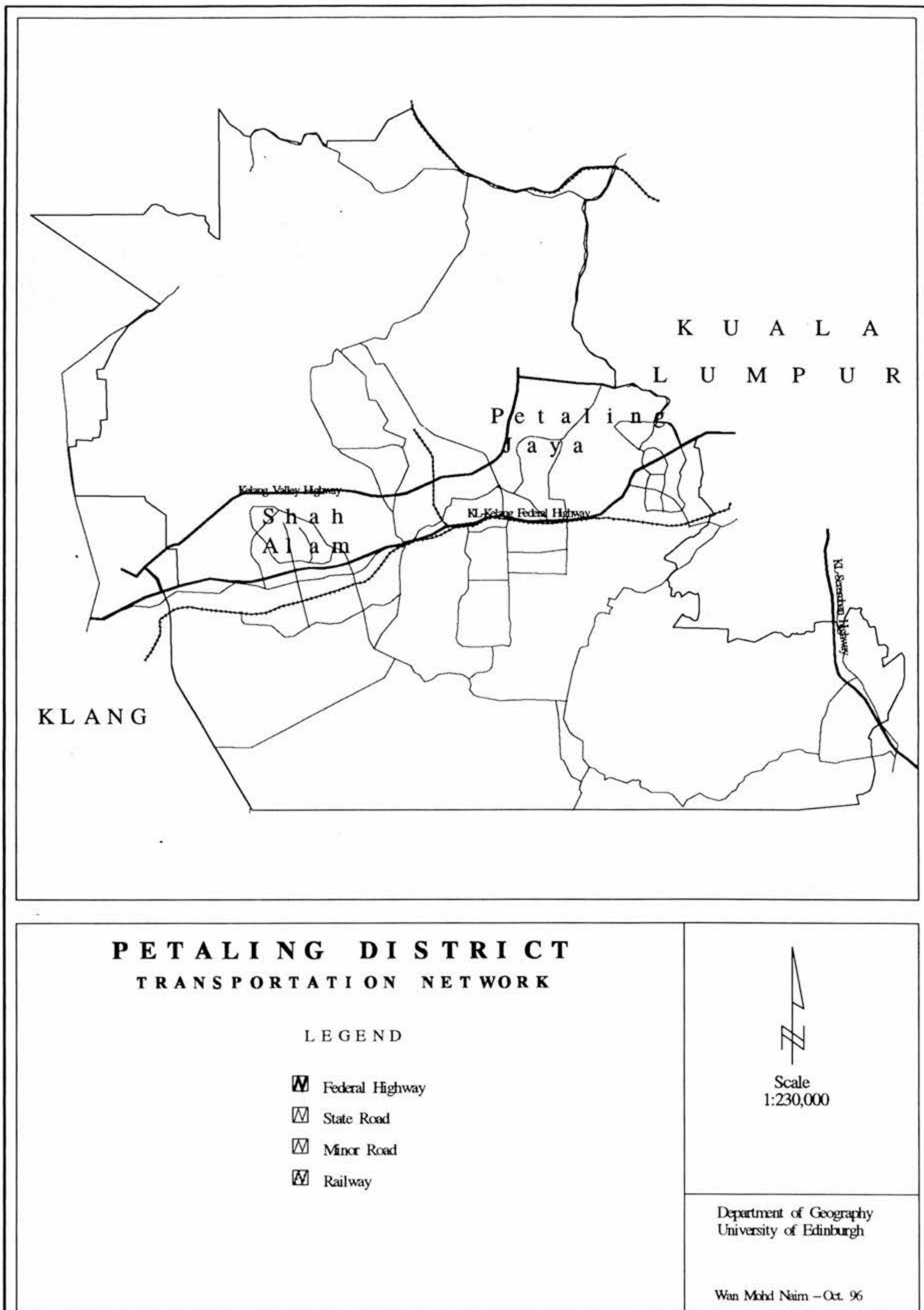


Figure 7.8 Road and railway transportation systems in the study area

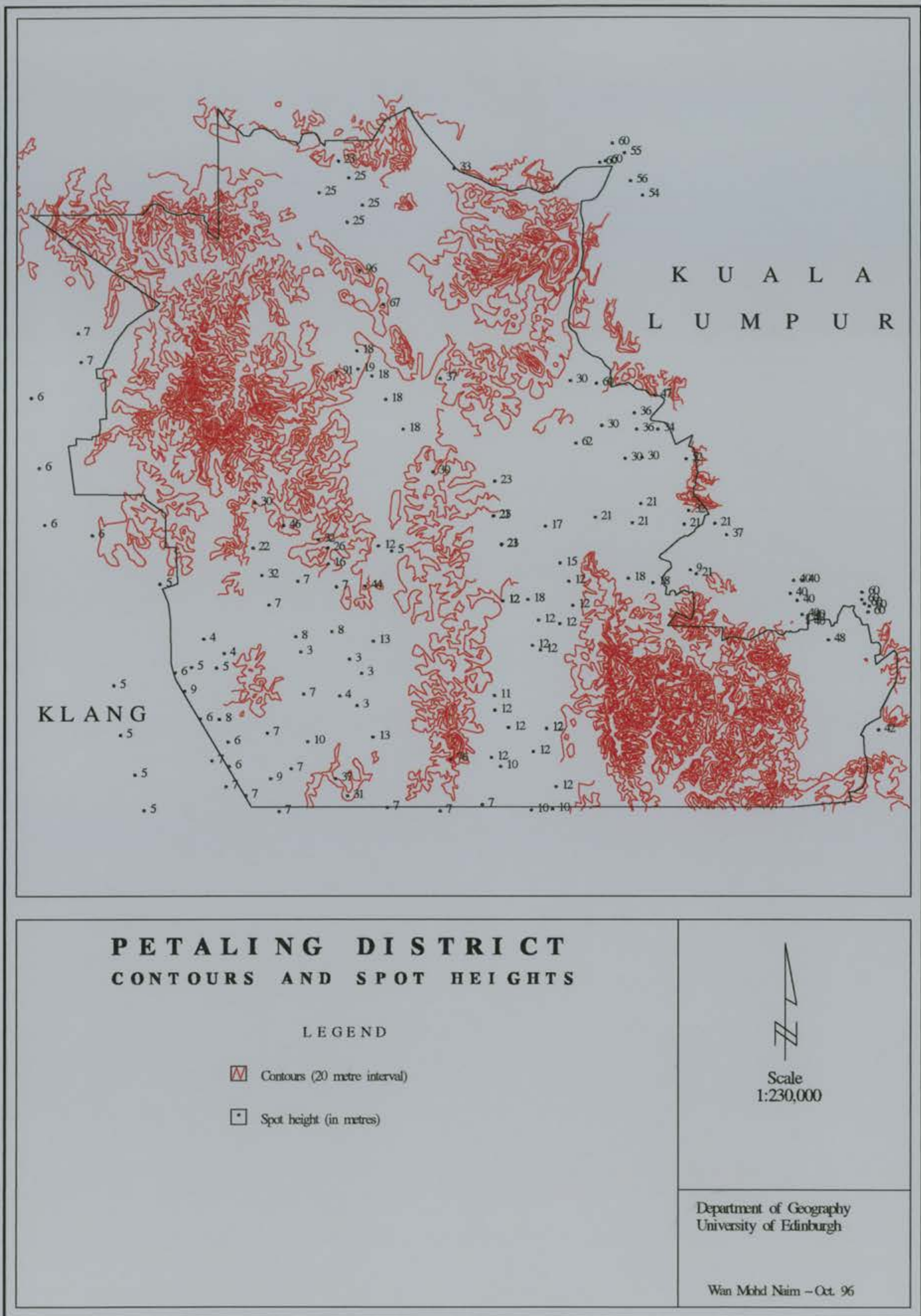


Figure 7.9 Digitised contours and spot heights

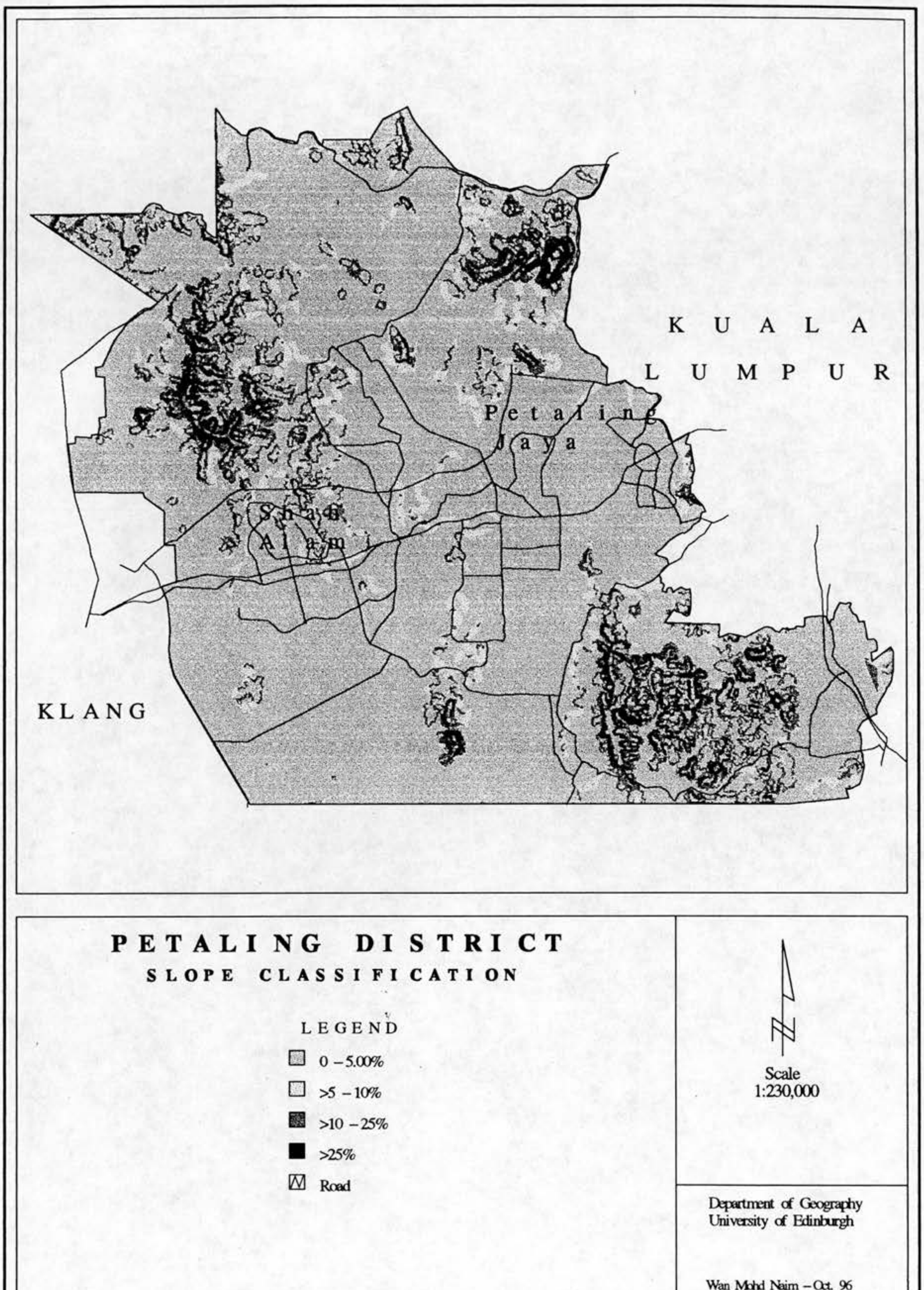


Figure 7.10 Slope classifications of the study area

7.4 Preliminary evaluation of potential areas

Preliminary evaluation is intended to eliminate unsuitable areas from the study area. This evaluation stage involved four main steps

- Evaluation using exclusionary criteria (i.e. Criteria 1 to Criteria 7)
- Evaluation using restrictive criteria (i.e. Criteria 8, 9 and 10)
- Evaluation using other restrictive criteria (i.e. Criteria 11, 12 and 13)
- Further evaluation based on haul distance (i.e. Criterion 14)

In this evaluation stage only data derived from manual vector map digitising and on-screen digitising from Landsat TM digital data were used.

7.4.1 Methods of analysis

To allow evaluation of potential areas in the first three steps four main GIS operations were utilised, that is, proximity analysis, map extraction, spatial data manipulation and map overlay. In the final evaluation step to determine suitable areas, that is areas which have the shortest aggregated travel distances from the waste generation centre to the potential area determined in the earlier evaluation steps, an external computer program (WASTEDIS) written by the author was used. The network analysis method as described in Brainard *et al.* (1996), to determine suitable routes to transport waste to the proposed sites, was not utilised. A brief explanation of this program and the program listing is given in Appendix J3.

Proximity analysis was used to locate buffers around certain features, for example, land within 3,048 metres of an airport runway and land within 200 metres or 1,500 metres of residential areas. The ARC/INFO command used to create a buffer is BUFFER. All the three buffer types were used, that is, point buffer, line buffer and polygon buffer. Point buffer was used to create the 610 metres buffer zones around the water intake point. Line buffers were mainly used to create buffer zones along rivers and along the road network, while polygon buffers were used to create buffers around residential areas and water bodies.

The map extraction operation was used to select appropriate classes from a coverage, for example, to select only residential areas from LANDUSE coverage. The command used to perform map extraction is RESELECT.

There are four commands that can be used to manipulate spatial features, These four commands are UPDATE, CLIP, SPLIT and ERASE. The UPDATE command is used to update a coverage by merging new features using a cut-and-paste operation. The CLIP command is used to cut out a piece of coverage using a 'cookie cutter' while the SPLIT command is used to split a coverage into a number of smaller coverages. The ERASE command was the most frequently used command at this preliminary evaluation stage. This command was mainly used to remove part of the inside (exclude buffer zones) of a coverage.

There are three main commands in ARC/INFO that can be used to perform map overlay: UNION, IDENTITY and INTERSECT. The UNION command overlays polygons and keeps all areas from both coverages. The IDENTITY command overlays points, lines, or polygons and keeps all input coverage features. The INTERSECT command overlays points, lines and polygons on polygons but keeps only portions of the input coverage features falling within the overlay coverage features. For this study only the IDENTITY command was used, mainly to compare maps and locate areas which conform to multiple landfill site selection criteria. Spatial operations undertaken in the first three evaluation steps are shown in Figures 7.11 and 7.12.

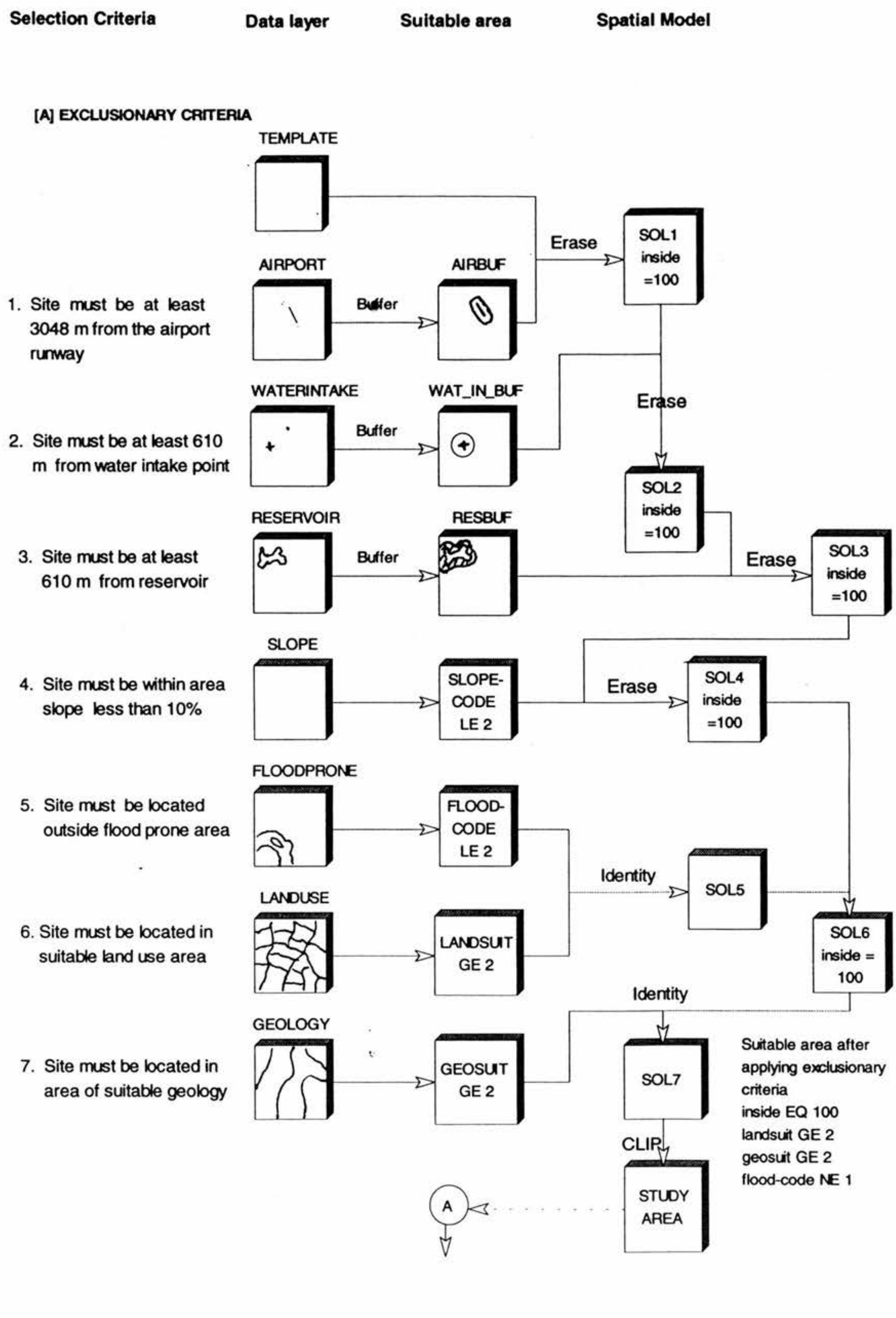


Figure 7.11 Spatial operations involved in applying exclusionary criteria

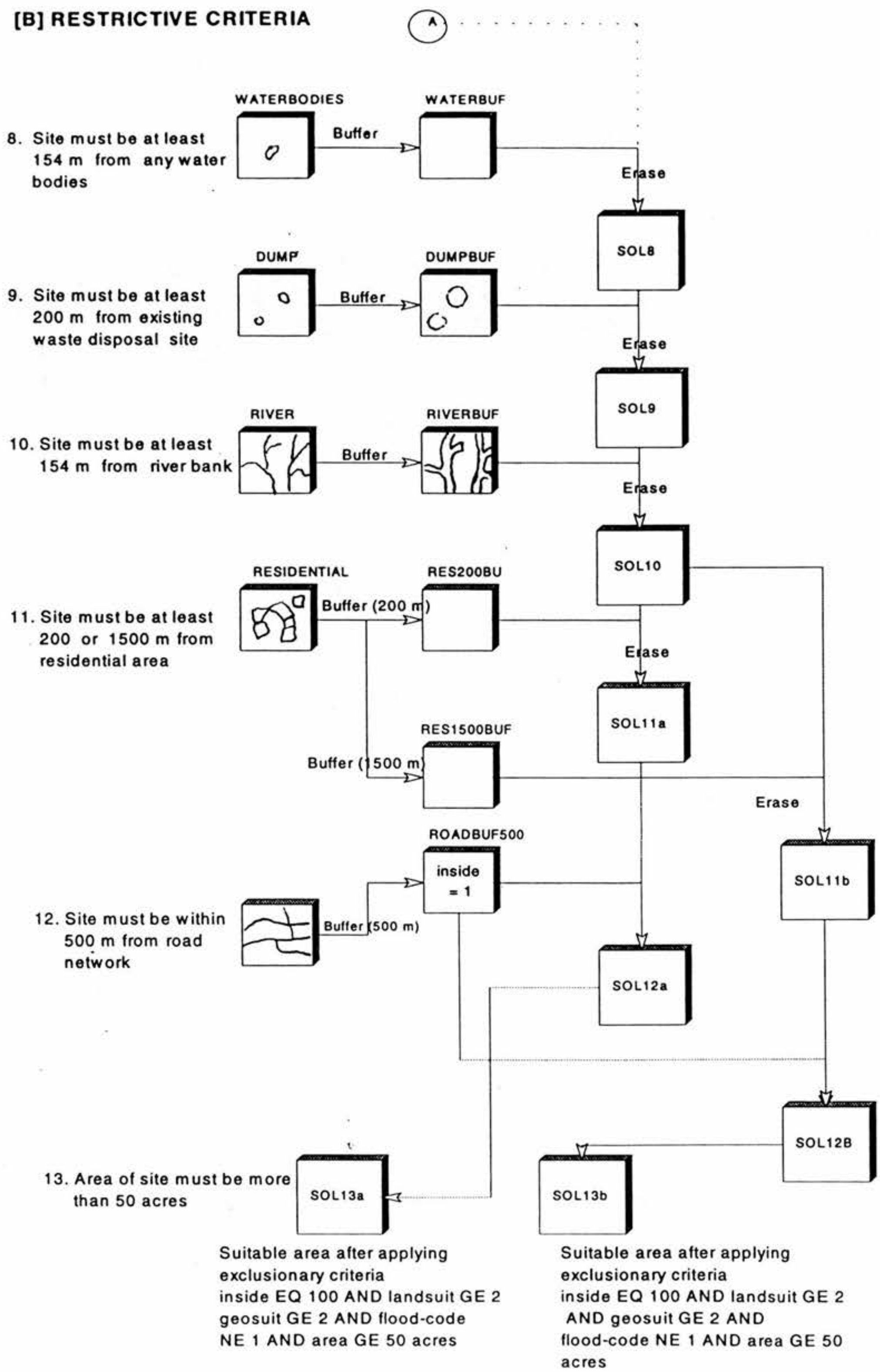


Figure 7.12 Spatial operations involved in applying restrictive criteria

To determine the number of trips required, data regarding the amount of waste generated at each waste generation centre are required. Since no data regarding the amount of waste generated at each waste generation centre and the actual location of the waste generation centres are available, the following assumptions are made:

- The same amount of waste is generated at each waste generation centre.
- The central locations of the residential, commercial and industrial areas are considered as the waste generation centres.
- Travel distance is linear.

The minimum aggregated travel distance is determined by the number of trips required to send waste from the waste generation centre to the potential landfill areas. Travel distance from the waste generation centre to potential landfill areas can be calculated using Formula 7.1, while the total aggregated travel distance from all the waste generation centres to the potential site can be calculated using Formula 7.2.

$$D_{ic} = W_i.[(x_i - x_c)^2 + (y_i - y_c)]^{1/2} \quad ....(7.1)$$

where,

D_{ic} is the total aggregated distance travelled to the potential landfill site

W_i is the amount of waste generated at each waste generation centre

(since same amount is assumed, $Wi = 1$)

x_i is the x coordinate at the centre of the waste generation centre

x_c is the x coordinate at the centre of the potential landfill area

y_i is the y coordinate at the centre of the waste generation centre

y_c is the y coordinate at the centre of the potential landfill area

$$AD = \Sigma\ W_i\ .\ D_{ic} \quad ....(7.2)$$

where,

AD is the total aggregated distance travelled to the potential landfill area

To compute the total aggregated distance, coordinates at both the waste generation centres and at the centre of the proposed landfill sites are required. Coordinates at the centre of the waste generation centres (residential, commercial and industrial areas) polygons and coordinates at the centre of all the potential landfill areas polygons were written to two separate ASCII files using UNGENERATE command in ARC/INFO. These two sets of coordinates were used as the basis for calculating the distances between the waste generation centres and all the identified potential sites.

7.4.2 Results and analysis from preliminary evaluation

Maps were produced to show areas that were excluded from further consideration and reports were printed to summarise the acreage excluded by each individual criterion, by exclusionary criteria, restrictive criteria and in total. Table 7.9 summarises the acreage of unsuitable areas on applying each individual criterion. The total acreage excluded in applying all the criteria will not be the same as the sums of all acreage given in this table because unsuitable areas covered by each criterion often overlaps with areas identified in previous criteria. For example, many unsuitable land use areas are located in areas with unsuitable slope.

Unsuitable land use accounts for the largest portion of the excluded areas in applying both the exclusionary and restrictive criteria (30,546 hectares or 56 per cent of total study area). The areas covered by the airport buffer zone, drinking water intake point buffer zone and reservoir buffer zone account for 5,351 hectares (9.8 per cent), 116 hectares ((0.2 per cent) and 835 hectares (1.5 per cent) of the study area respectively. Other unsuitable areas, that is, areas with unsuitable slope, areas prone to flooding and areas with unsuitable geology, cover areas of 8,180 (15.0 per cent) 3,519 (6.5 per cent) and 3,385 (6.2 per cent) hectares respectively.

Table 7.9 Acreage excluded on each criterion

Criteria	Acreage excluded on this criterion (hectares)
[A] Exclusionary criteria	
1. Area within airport run buffer	5,351
2. Area within 610 metres from drinking water intake point	116
3. Area within 610 metres from reservoir	835
4. Area within unsuitable slope i.e. > 10%	8,180
5. Flood prone areas	3,518
6. Unsuitable land use i.e. developed area, and special reserve	30,546
7. Unsuitable geology	3,385
[B] Restrictive criteria	
8. Area within water body buffer	805
9. Area within existing waste disposal site buffer	387
10. Area within river buffer	7,828

The application of exclusionary criteria (Criteria 1 to 7) eliminated 40,886 hectares (75.1 per cent) of the study area and another 1,316 hectares (2.5 per cent) were eliminated when restrictive criteria (Criterion 8, 9 and 10) were applied. Figure 7.13 and 7.14 shows suitable and unsuitable areas when exclusionary and restrictive criteria were applied.

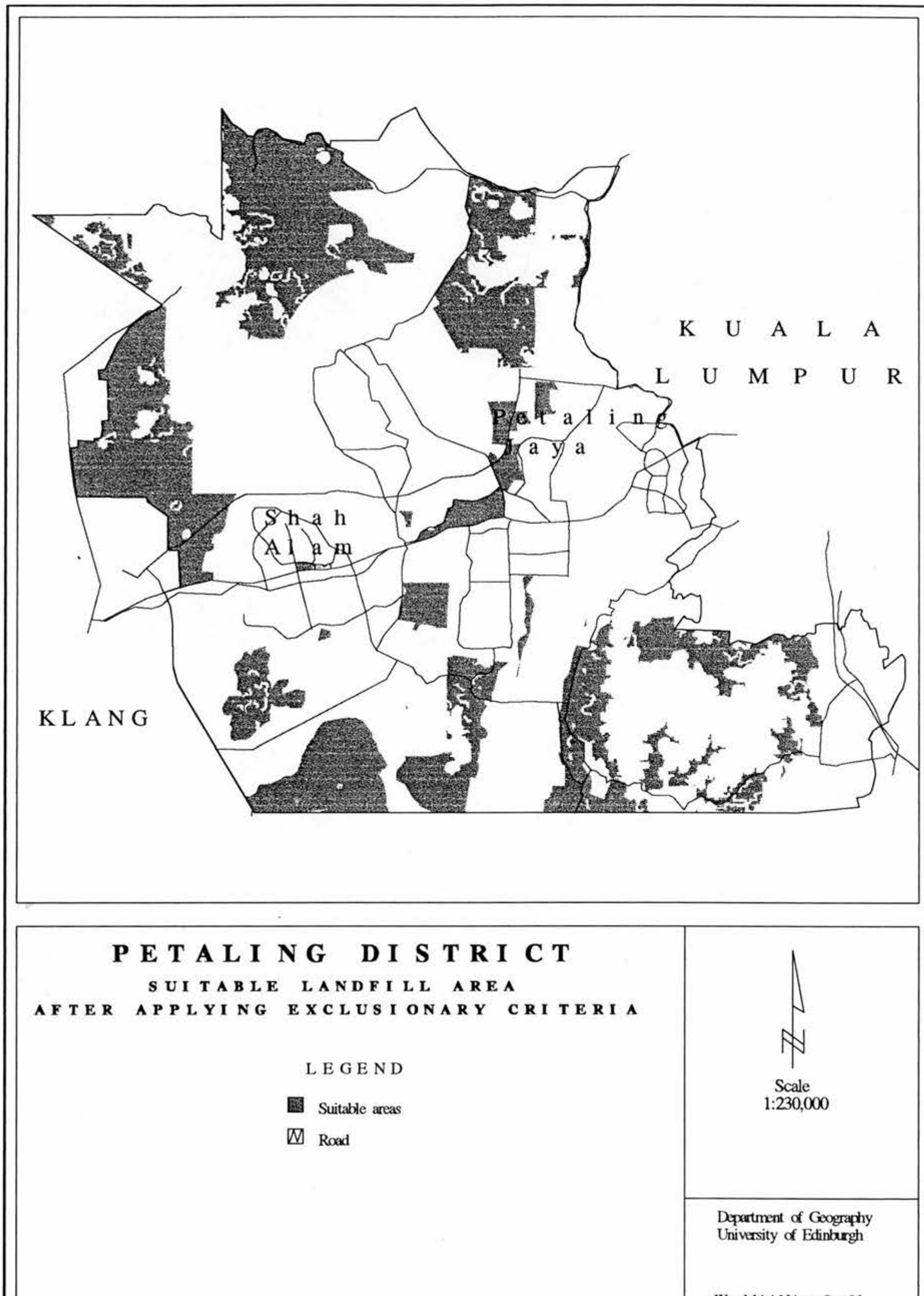


Figure 7.13 Map showing suitable areas after applying exclusionary criteria

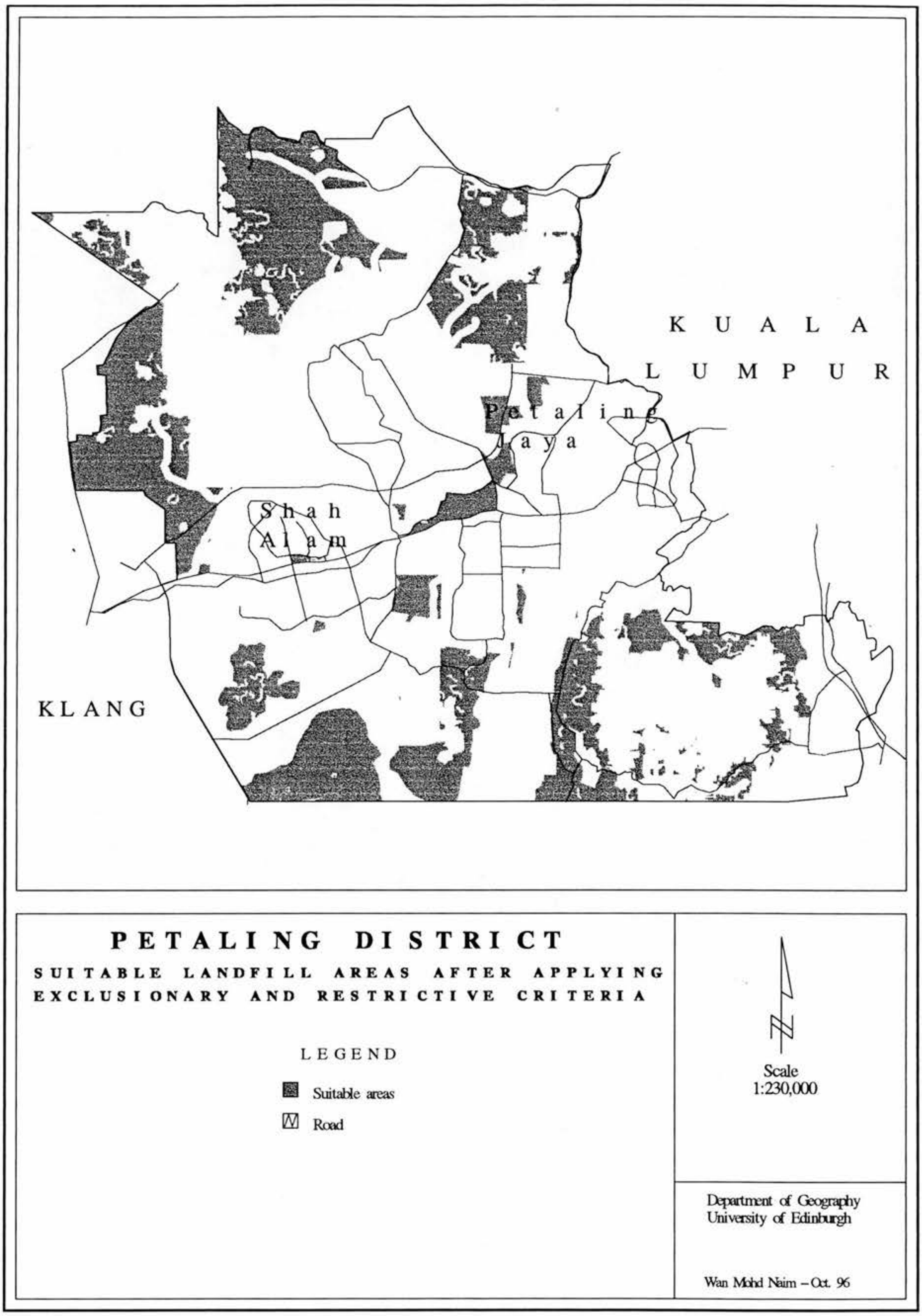


Figure 7.14 Map showing suitable areas after applying exclusionary and restrictive criteria

When further criteria (Criteria 11 and 12) were applied, suitable areas were reduced to a number of isolated locations. A combination of six alternative residential and road buffer criteria were tested. The number of potential areas selected when alternative criteria were used is summarised in Table 7.10. Since the results of applying these criteria (i.e. up to Criterion 12) did not reduce the number of potential sites to a few sites, further evaluation was carried out. Criterion 13 was used to select only potential areas with acreage of more than 50 acres (20 hectares). This criterion significantly reduced the number of potential areas to less than thirty. The number of potential areas selected when Criterion 13 was introduced is summarised in Table 7.11. Reports on individual potential areas using alternative criteria in terms of their land use, geological formation and acreage are given in Table 7.12 and 7.13. Figures 7.15 and 7.16 shows locations of potential landfill areas using alternative criteria, that is, Criteria 13 a) and 13 d).

Table 7.10 Number of potential areas based on alternative residential and road buffer criteria

Criteria	No. of potential areas
a. At least 1500 m from residential areas and within 500 m from road	34
b. At least 1500 m from residential areas and within 1000 m from road	49
c. At least 1500 m from residential areas and within 1500 m from road	74
d. At least 200 m from residential areas and within 500 m from road	94
e. At least 200 m from residential areas and within 1000 m from road	106
f. At least 200 m from residential areas and within 1500 m from road	135

Table 7.11 Number of potential areas based on alternative residential buffer, road buffer and size of site criteria.

Criteria	No. of potential areas
a. At least 1500 m from residential areas and within 500 m from road	8
b. At least 1500 m from residential areas and within 1000 m from road	10
c. At least 1500 m from residential areas and within 1500 m from road	13
d. At least 200 m from residential areas and within 500 m from road	22
e. At least 200 m from residential areas and within 1000 m from road	26
f. At least 200 m from residential areas and within 1500 m from road	29

Table 7.12 Information on potential areas generated using alternative criterion (a)

Site-ID	Land use class	Geology type	Total area (Hectares)
1	Agriculture	Quartzite and phyllite	235
5	Forest reserve	Granitic rock	69
49	Agriculture	Quartzite and phyllite	90
60	Agriculture	Quartzite and phyllite	25
61	Agriculture	Alluvium	67
67	Agriculture	Quartzite and phyllite	23
74	Forest reserve	Quartzite and phyllite	70
97	Agriculture	Quartzite and phyllite	37

Table 7.13 Information on potential areas generated using alternative criterion (d)

Site-ID	Land use class	Geology Type	Total area (hectares)
1	Agriculture	Quartzite and phyllite	322
4	Agriculture	Quartzite and phyllite	26
23	Forest reserve	Granitic rock	59
33	Forest reserve	Granitic rock	37
49	Forest reserve	Granitic rock	41
78	Agriculture	Granitic rock	26
81	Forest reserve	Granitic rock	74
128	Agriculture	Quartzite and phyllite	90
211	Agriculture	Granitic rock	54
236	Agriculture	Quartzite and phyllite	26
241	Agriculture	Alluvium	67
242	Abandon tin mine	Granitic rock	73
264	Agriculture	Granitic rock	202
288	Agriculture	Quartzite and phyllite	197
371	Agriculture	Quartzite and phyllite	59
415	Agriculture	Quartzite and phyllite	359
434	Agriculture	Granitic rock	196
446	Agriculture	Quartzite and phyllite	25
485	Agriculture	Quartzite and phyllite	56
507	Forest reserve	Quartzite and phyllite	70
516	Agriculture	Quartzite and phyllite	27
541	Agriculture	Quartzite and phyllite	37

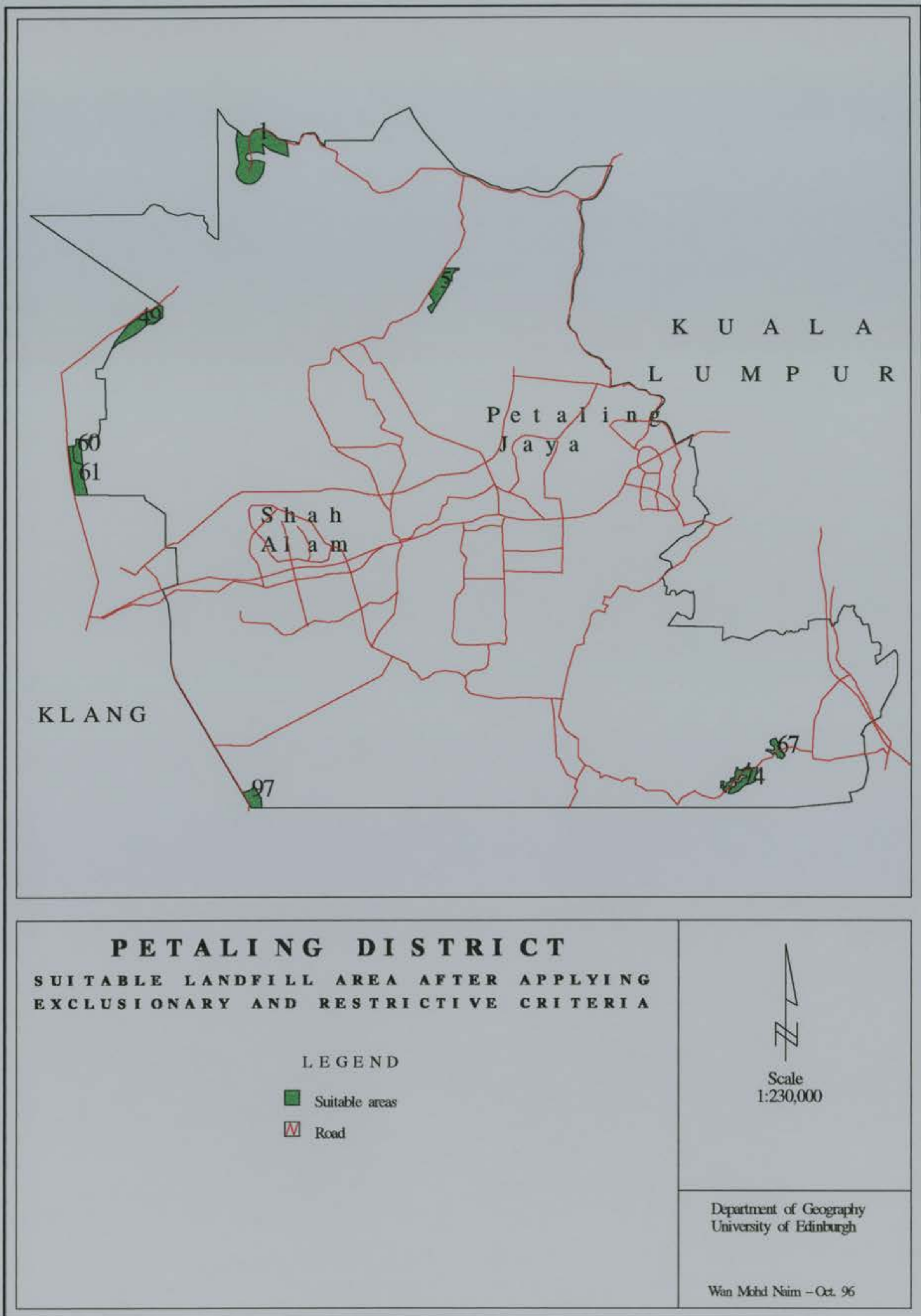


Figure 7.15 Map showing potential areas after applying alternative criteria a)

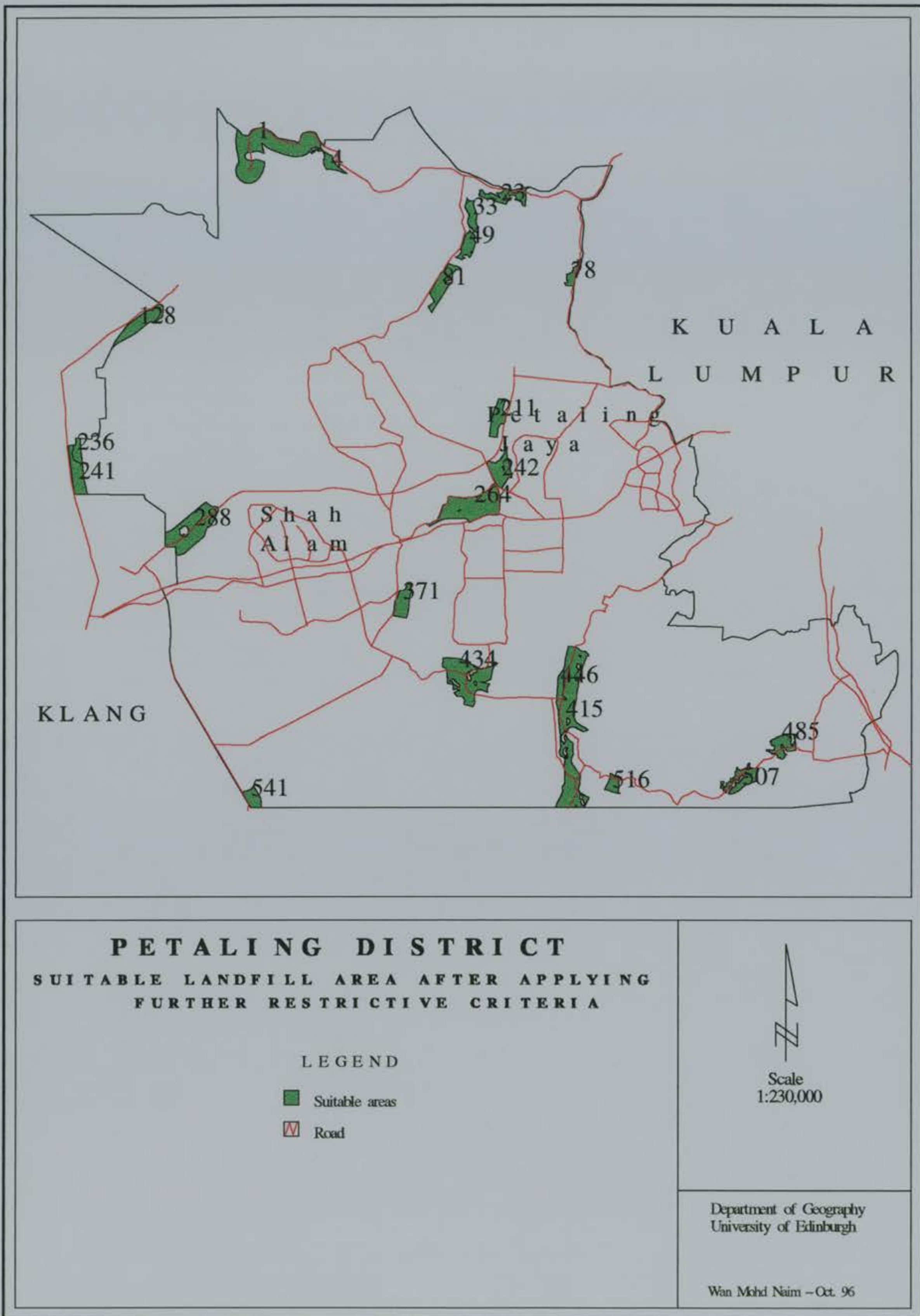


Figure 7.16 Map showing potential areas after applying alternative criteria d)

Analysis based on the shortest aggregated travel distance (refer to A in Tables 7.14 and 7.15) and analysis based on the number of waste generation centres located within a certain distance range from the potential waste generation centres to the potential landfill site (refer to B in Tables 7.14 and 7.15) will help planners or decision makers to locate the most centrally located area. The site with the shortest aggregated distance can be considered as the most economical site for hauling waste. Using Criterion a), the minimum aggregated distance was found to be higher than using Criterion d). This was obviously because a larger residential buffer distance was specified. The minimum and maximum aggregated distances obtained when Criterion a) was used are 517 and 957 kilometres respectively. When Criterion d) was used the minimum and maximum aggregated distances are 309 and 957 kilometres respectively. Site 1 was found to be the most centrally located potential area when Criterion a) was used. When a different criterion was applied, that is, Criterion d), Site 434 was found to be the most centrally located and hence can be considered as the most economical.

Table 7.14 Analysis A) linear distance of potential sites from waste generation points and analysis B) number of waste generation centres from potential site using criterion (a)

Site-ID	A) Total Distance (km)	B) Range of distance (km)			
		< 5	5 - 9.99	10 -14.99	> 15
1	517	20	25	12	8
5	696	13	22	18	12
49	802	5	20	21	19
60	957	1	15	20	29
61	954	1	15	20	29
67	813	8	12	25	20
74	736	10	15	23	17
97	528	20	23	14	8

Table 7.15 Analysis A) linear distance of potential sites from waste generation points) and analysis B) number of waste generation points from potential site using criterion (d

Site-ID	A) Total Distance (km)	B) Range of distance (km)			
		< 5	5 - 9.99	10 -14.99	> 15
1	517	20	25	12	8
4	388	35	18	8	4
23	328	38	18	9	0
33	310	37	23	5	0
49	309	37	23	5	0
78	408	25	25	15	0
81	692	14	21	18	12
128	802	5	20	21	19
211	327	38	18	9	0
236	957	1	15	20	29
241	954	1	15	20	29
242	328	38	18	9	0
264	310	37	23	5	0
288 ***	663	14	21	18	12
371	311	39	20	2	4
415	400	26	26	13	0
434	306	39	21	4	1
446	392	27	24	14	0
485	824	7	12	25	21
507	736	10	15	23	17
516	474	21	27	16	1
541	528	20	23	14	8

*** - Site selected to demonstrate the role of digital photogrammetric data in further site specific evaluation.

7.5 Further site specific evaluation using photogrammetric data

After the number of potential areas has been reduced on the basis of exclusionary and restrictive criteria, further site specific criteria can be applied to rank the potential sites. Two further evaluations based on individual site capacity or life expectancy (Criterion 14) and its visibility to the public (Criterion 15) are used to assist planners or decision makers to choose the best alternative site/s. To allow such evaluation DEMs are required. A high resolution DEM within the site boundary is found to be required to determine the capacity (volume) of the site accurately. A second DEM with a lower resolution was generated for visibility analysis. The final evaluation involved visual inspection of the potential site on a monitor screen. Perspective viewing of orthoimage mosaic onto DEM of the site will allow planners or decision makers to see the true appearance of the potential site and its surrounding area.

Since a large amount of data and computer storage is required to store digital photogrammetric data, only one site, Site 288, determined from earlier evaluation, was considered. The choice of this site was not based on the best alternative site but rather on the availability of suitable aerial photos and GCPs of the area. It is important to note that the use of Site 288 was mainly intended to demonstrate the methodology whereby digital photogrammetric data can help in the site selection process.

The following sub-sections are intended to discuss the steps involved in deriving the required digital photogrammetric data and in evaluating a potential site based the site capacity and its visibility to the public.

7.5.1 Steps involved to generate DEMs and orthoimage mosaic of the selected potential site

As mentioned earlier in Chapter 4, a digital photogrammetric technique has been proposed to generate DEMs and orthoimage mosaics required for further analysis. The steps involved in generating digital data required for site specific evaluation can be summarised as follows:

- acquire aerial photographs and GCPs of the selected potential areas
- generate DEMs and orthoimage of selected potential area using DMS
- convert DEMs to ARC/INFO TIN

Detailed steps involved in generating the DEMs and orthoimage mosaic in the DMS version 3.1 are shown in Figure 7.17.

Three 1:20,000 scale aerial photographs of the potential area (Site 288) were used to generate DEMs and orthoimages. Two of these were used earlier in the assessment of digital photogrammetric products photographs (refer to Section 6.2.1 - Test Site 2). The third aerial photograph was also scanned in the Epson GT-9000 scanner and image rectification was carried out in ERDAS. The same procedure as explained in Appendix F was adopted to scan and rectify the scanned image of the third aerial photograph. The GCPs required to orientate the aerial photographs were obtained from previous aerial triangulation work carried out by the Department of Survey and Mapping, Malaysia. Additional control points were generated in the AP190 analytical plotter.

Two DEMs were generated, one for each stereomodel at 5 pixel (approximately 8.5 metres) spacing of the potential site. The DEMs were generated automatically in DMS using the Air Photo Stereocorrelation option in the SPM module. Based on these DEMs, two orthoimages were produced, one for each stereomodel. Two further high resolution DEMs at 1 pixel spacing, aligned exactly to the defined orthoimage boundary, were generated in the process of orthoimage generation. The SUBSET option in the MANAGE module was used to create a subset of the orthoimage while the MOSAIC option was used to join the orthoimages into a single large image or mosaic. The same option was used to join the DEM files into a single file. Since the DEM at 1 pixel spacing is so dense, it can cause considerable storage and processing problems when transferred to ARC/INFO. The AGGREGATE option in the GIS module was used to create two lower resolution DEMs, with 18.5 by 18.5 metres and 37 by 37 metres grid squares.

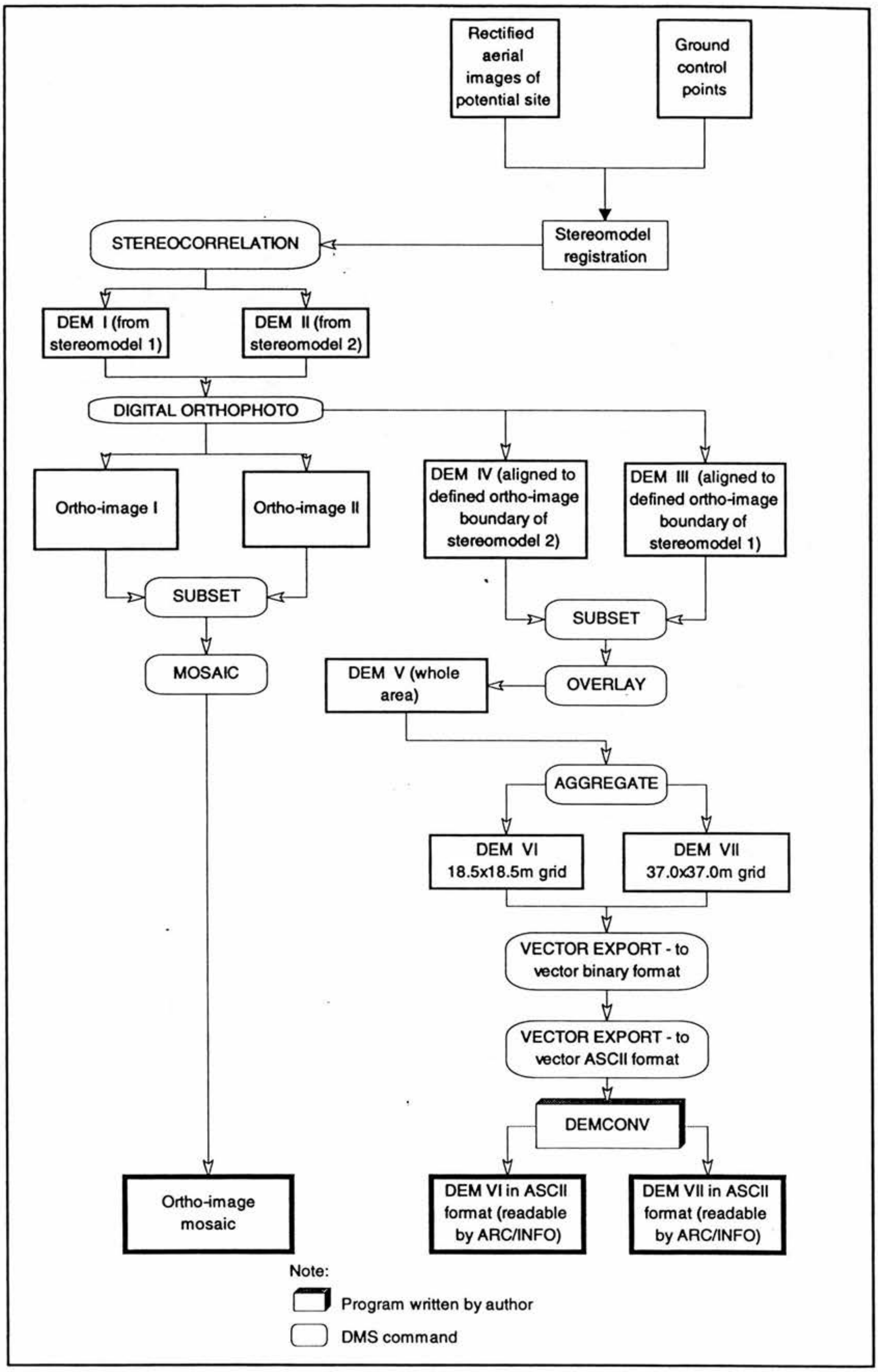


Figure 7.17 Steps involved in generating DEMs and orthoimage mosaic in DMS

To allow further analysis in ARC/INFO, the DEMs and orthoimage mosaic generated in DMS must be converted into ARC/INFO format. The orthoimage mosaic file (.LAN format) generated in the DMS can readily be read in ARC/INFO but DEM files cannot be readily read into ARC/INFO. As the direct data conversion option in DMS to convert DEM file format to X, Y, Z ASCII file format does not work, the following steps were adopted to convert data into ARC/INFO ASCII format:

- Convert DMS DEM format to DMS vector binary format in DMS
- Convert DMS vector binary to vector ASCII format using VECTOR EXPORT option in DATA module of DMS
- Convert X, Y, Z ASCII format to ARC/INFO ASCII file format (file name is SITE1DEM.DAT). A computer program, DEMCONV.BAS, written by the author was used to perform this conversion. The program listing is given in Appendix J2.

An example of ARC/INFO ASCII data file format is given below.

ID, X, Y, Z
ID, X, Y, Z
....
....
ID, X, Y, Z
END

7.5.2 Data processing in ARC/INFO

The steps outlined in Section 7.5.1 are mainly used to generate the required data for further evaluation. Before evaluation of potential sites based on Criterion 14 and 15, further data processing in ARC/INFO must be carried out. As given in Figure 7.18 the following data processing and evaluation steps were followed:

- Convert the ASCII formatted DEM of the area surrounding the potential area into ARC/INFO tin format
- Generate contour map of the potential area

- Identify and digitise the boundary of the proposed site within the selected potential area
- Generate DEM within the selected site boundary.

The first step involved the conversion of ASCII formatted DEM of the area surrounding the potential site into ARC/INFO tin format. The CREATETIN command was used to perform the data conversion. perspective view of the DEM of the area surrounding the selected site is given in Figure 7.19. Based on this DEM (SITE1AREATIN) a 5 m interval contour map (SITECOUNTOUR coverage) of the potential area was generated using the TINCONTOUR command. This contour map and orthoimage mosaic of the area were used as the basis for the boundary selection. The SITECONTOUR coverage was overlaid on the orthoimage mosaic in ARCEDIT and the site boundary was identified and digitised as a new polygon coverage (SITEBOUNDARY) on-screen. An orthoimage mosaic with overlaid contour is shown in Figure 7.20.

After the exact boundary of the site was identified and digitised, the DEM within the boundary was generated. Figure 7.21 shows the perspective view of the generated DEM. This DEM was used to calculate the capacity (volume) of the selected site. The following are the commands used to create DEM within the site boundary:

Arc: createtin SITE1TIN

Createtin : generate SITE1DEM.DAT

Createtin : cover SITE1BOUNDARY poly SPOT 6

Createtin : END

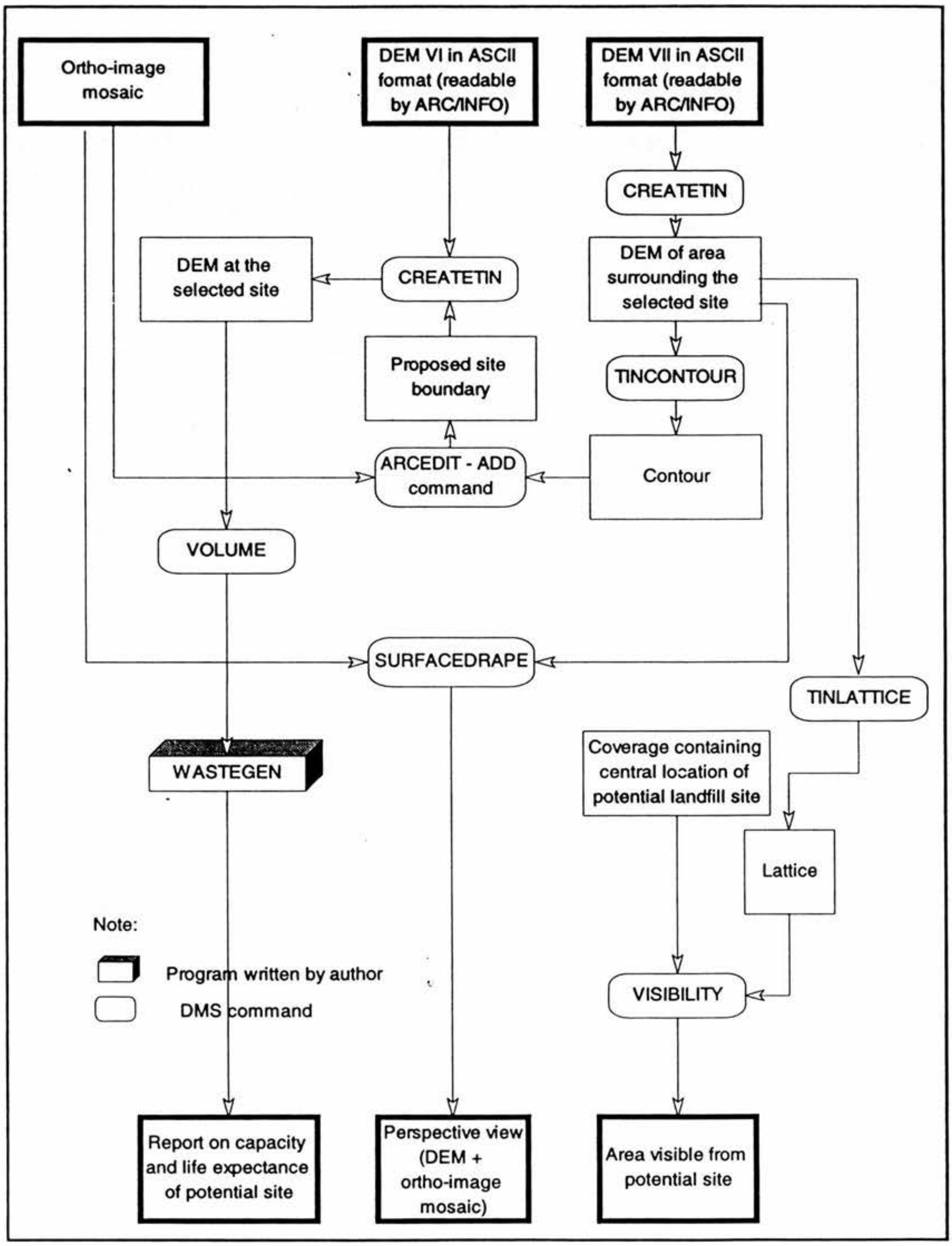


Figure 7.18 Steps involved to process digital photogrammetric data and to evaluate potential site

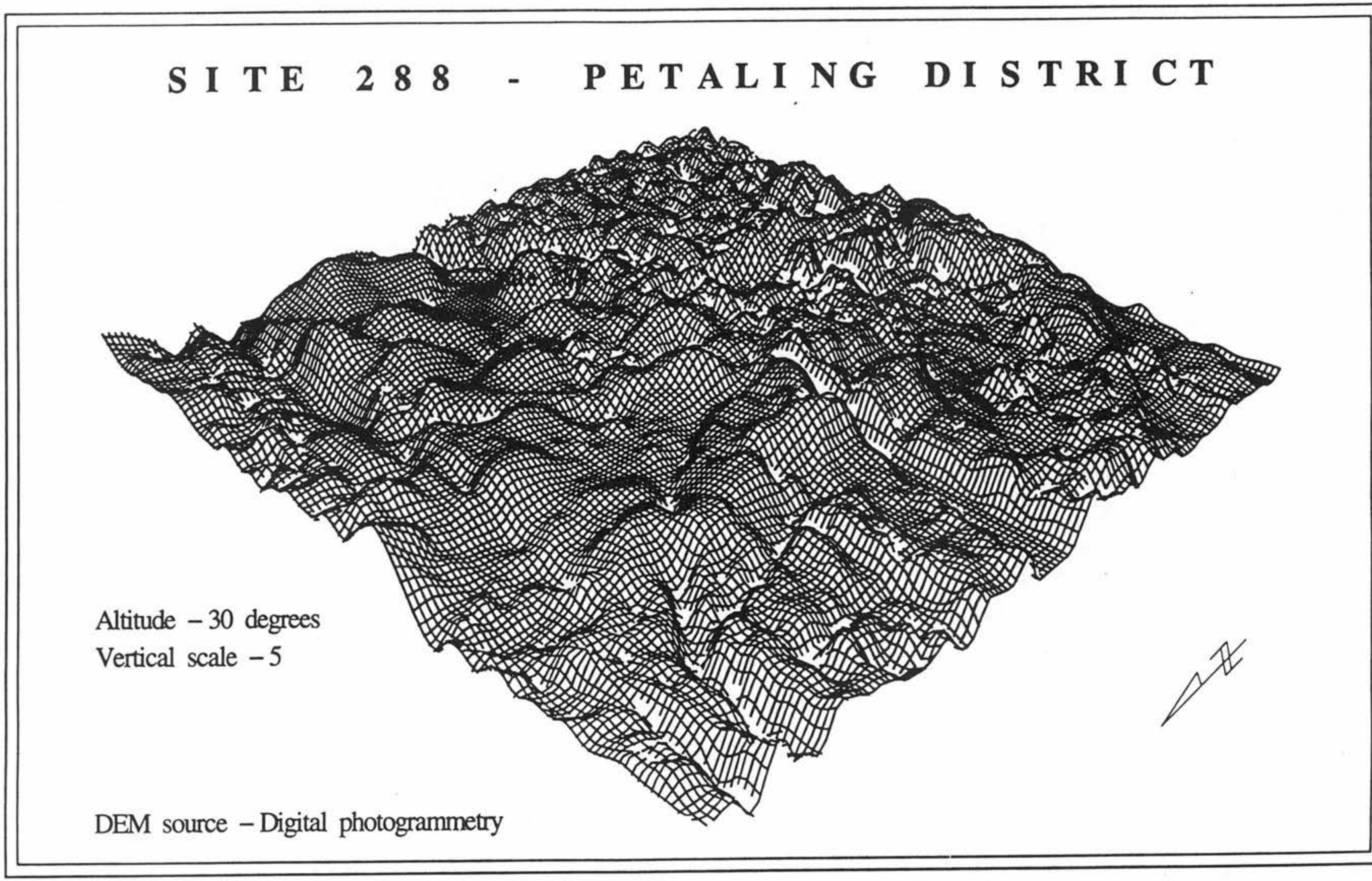


Figure 7.19 Perspective view of area surrounding Site 288

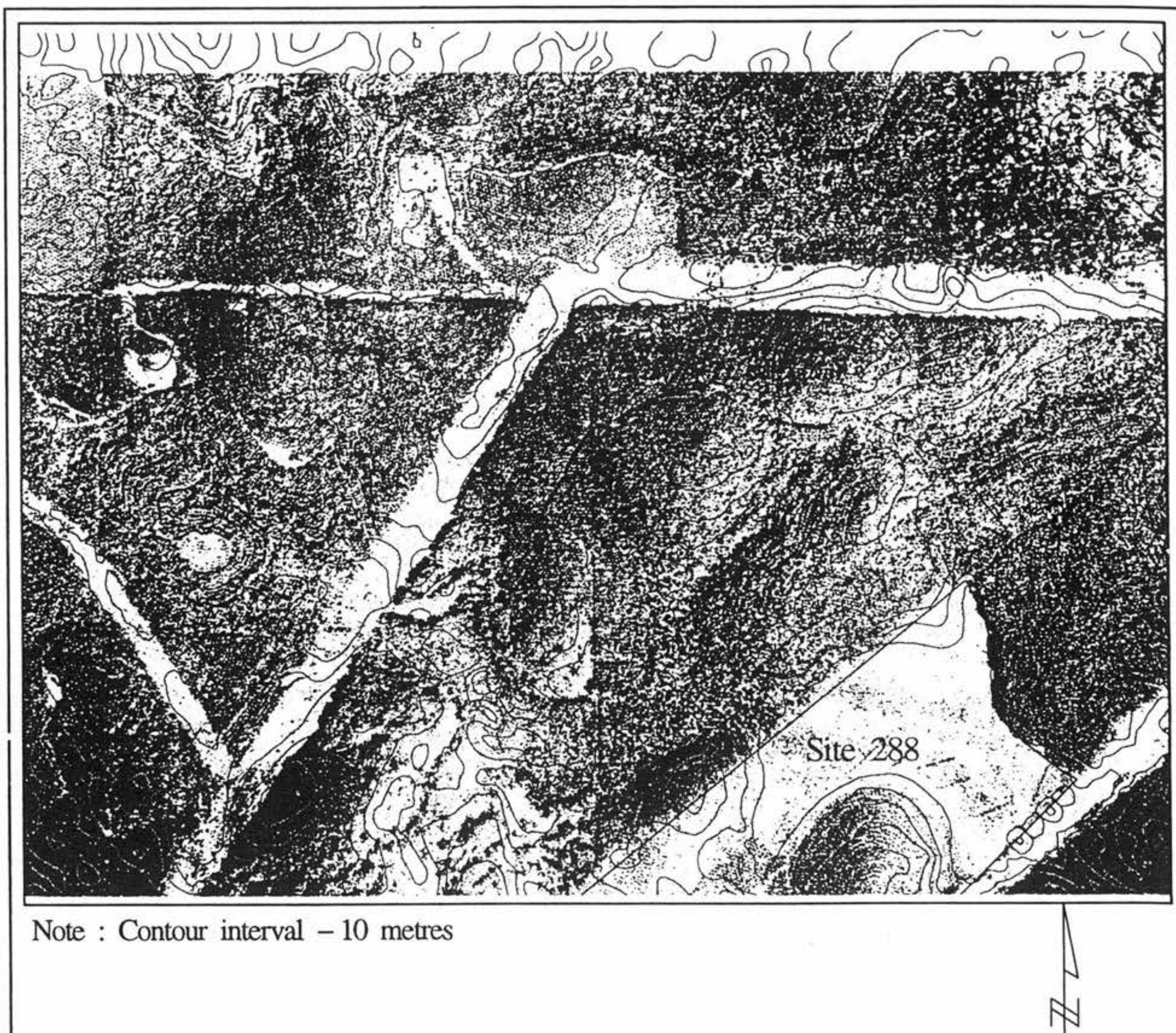


Figure 7.20 Part of orthoimage mosaic with contour overlay

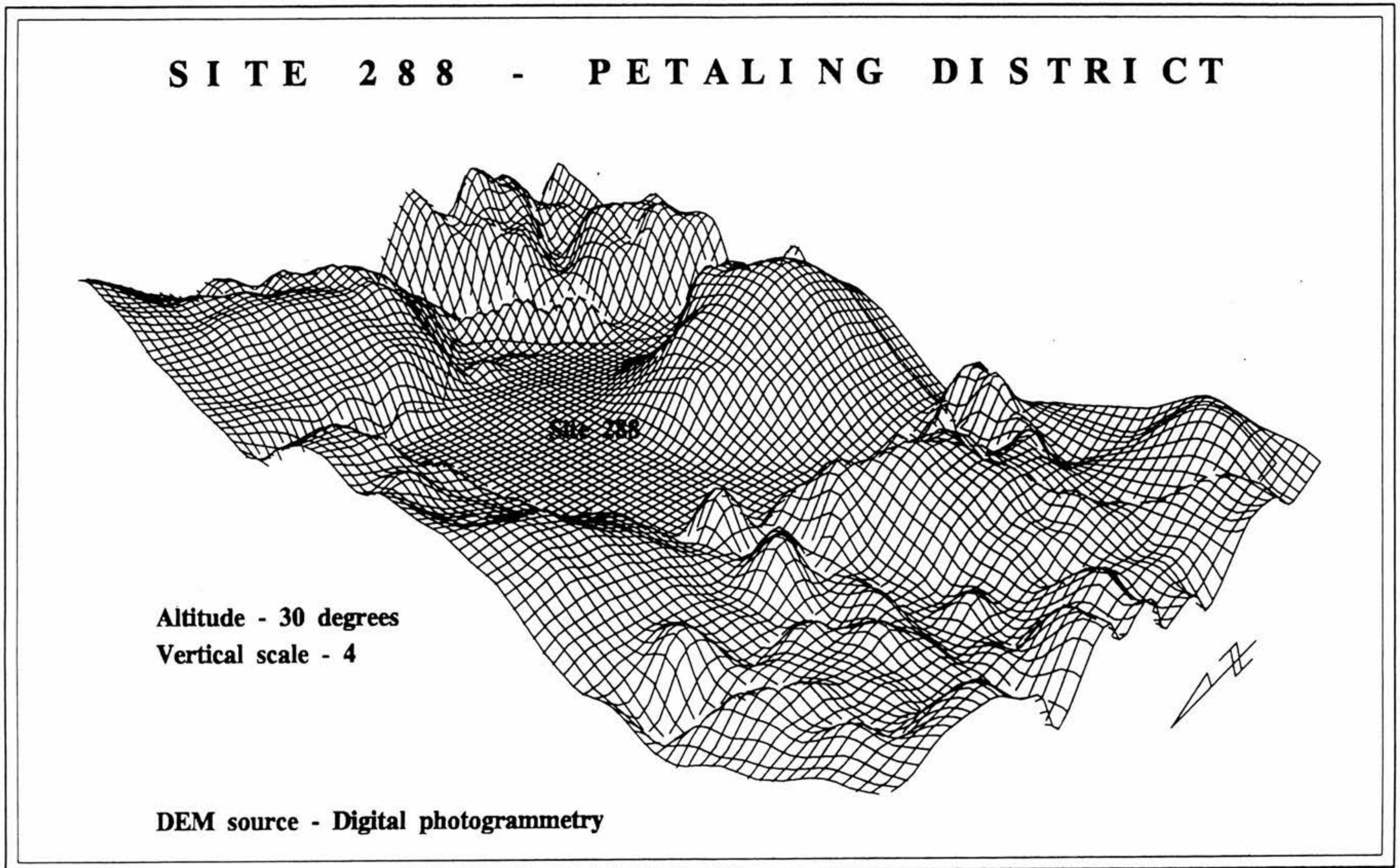


Figure 7.21 Perspective view of Site 288

7.5.3 Methods of site evaluation in ARC/INFO

The evaluation of Criteria 14 and 15 in ARC/INFO were carried out in two main steps. The steps involved are as follows:

- Perform volumetric analysis and calculate the life expectancy of potential site
- Perform visibility analysis

Beside these two main steps, visual inspection of the potential site was also carried out.

A. Volumetric analysis and life expectancy of potential site

The volume calculation was based on the DEM of the potential site (SITE1TIN). The VOLUME command in ARC/INFO was used to estimate site capacity (volume). Beside determining the capacity of the site this command can also be used to determine the maximum and minimum heights within the site, surface area above or below a proposed final grade level of the site, and volume of earth above the final landfill grade level. For example, if the proposed final grade level of the proposed site is 10 metres above MSL, the capacity (volume) of the waste (waste and cover material) of the site can be determined using this command.

Arc : VOLUME <tin> <base_value> {out_info_file} {z_factor}
Arc : VOLUME SITE1TIN -10 VOL2 -1

The calculation of the volume of earth above the final grade level was done using the command given below.

Arc : VOLUME SITE1TIN 10 VOL3 1

To determine the life expectancy of the site, apart from the information regarding site capacity (volume), other information such as the projected population, the daily estimated amount of waste per person, the projected amount of waste generated each year, the cover material-to-waste ratio and waste compacting rate for the Petaling District are also needed. The projected population data were obtained from the Draft Structural Plan for the District of Petaling and Part of Klang 1988-2000 (refer to Table 7.1) and the projected amount of waste generated within this period has been estimated by multiplying the total population by the estimated amount of waste generated per person. Information regarding the daily estimated amount of waste per person, cover material-to-waste ratio and waste compacting rate was obtained from the Klang Valley Environmental Improvement Project report (1988). According to this report, the daily estimated amount of waste per person, cover material-to-waste ratio and waste compacting rate are 0.843 kg, 1:5 and 711 kg/cubic metre respectively. Based on this information the annual volume of space required at the proposed landfill, for example for the year 1998, can be calculated as follows:

Waste generation rate per person per day (W)	=	0.843 kg
Waste compacting rate (WC)	=	711 kg/cubic metre
Projected end of year population (P)	=	1116759
Projected waste generated/year (YW)	=	P x W x 365days
	=	1,116,759 x 0.843 x 365
	=	343,621,161 kg
Volume of waste generated/year (WV)	=	YW /WC
	=	483,293 cubic metres
Volume of waste and cover material	=	WV x 1.25
	=	604,116 cubic metres

Life expectancy can be estimated from the yearly cumulative volume of waste and cover material required and maximum capacity (volume) the site can accept. A computer program WASTEGEN was written by the author to calculate the life expectancy of the proposed potential site. The program listing is given in Appendix J4.

B. Visibility analysis

Visibility analysis is one of the more powerful surface analysis operations available in TIN. There are three methods of analysing visibility in ARC/INFO, the VISIBILITY command in ARC, and the SURFACEVIEWSHED and SURFACEDRAPE commands in ARCPLOT (ESRI, 1991). For this study the VISIBILITY command in ARC was used.

Before visibility analysis can be carried out, DEM of the area surrounding the selected site (SITE1AREATIN) must first be converted to lattice (SITE1AREALAT). The TINLATTICE command in ARC was used to perform this conversion. A coverage (SITE1OBS_PT) containing observation point within the site must be created. An extra SPOT item must be added to the Point Attribute Table (PAT). The height of observation point was added in the SITE1OBS_PT.PAT using ADD command in INFO.

The only visibility analysis carried out in this study was to determine regions that can be seen from a single point within the proposed site. The proposed final grade level of the site was assigned as the height of observation point required in the analysis. By changing the value of the proposed final grade level, different alternative results can be obtained. The result from this analysis is a polygon coverage identifying areas which are visible from the specified observation point. The command used to perform visibility analysis is given below.

Arc : VISIBILITY <in_lattice> <in_cover> <POINT | LINE>
<out_cover | out_GRID> {POLY | GRID}
{FREQUENCY | OBSERVATIONS} {horizon_tolerrance}

Arc : VISIBILITY SITE1AREALAT SITE1CENTRE POINT SITE1VISI POLY

7.5.4 Results and discussions

A. Volumetric analysis and calculation of life expectancy of potential sites

Reports were used to summarise the results obtained from the volumetric analysis, while maps were produced to show the area visible from the proposed site. The total surface areas (area above and below the proposed final grade level) and volumes (maximum volume the site can take and volume of earth above the proposed final grade level) based on variable proposed grade were calculated. The results from the volumetric analysis are given in Table 7.16. It can clearly be seen that, as the proposed final grade level is increased, the site capacity also increases and the volume of earth (cover material) available decreases. The calculation of the volume of earth above the proposed final grade is required by planners or engineers to estimate the cost of importing material from other sites if necessary. In addition an optimum final grade level of the site based on its capacity and the amount of cover material available within the site can be decided.

Table 7.16 Surface area and volume based on different proposed grade level

Proposed grade level (m)	Area below proposed final grade level (hectares)	Capacity (volume) of proposed site (cu. m.)	Area above proposed final grade level (sq. m.)	Volume of earth above proposed final grade level (cu. m.)
3	0.066	55.47	50.077	6,854,665.00
4	5.477	16,422.59	46.036	6,369,606.50
5	13.636	111,755.90	36.506	5,963,514.50
6	18.761	279,330.78	31.381	5,629,664.00
7	20.494	476,073.16	29.648	5,324,980.50
8	21.831	687,912.81	28.317	5,035,395.00
9	22.952	911,962.06	27.191	4,758,018.50
10	23.971	1146,664.63	26.171	4,412,955.00
11	24.917	1,391,090.13	25.226	4,234,292.50
12	25.854	1,644,969.00	24.288	3,986,749.00
13	26.741	1,908,005.63	23.402	3,748,360.25
14	27.565	2,179,602.00	22.577	3,518,531.00
15	28.295	2,458,970.75	21.847	3,296,475.50
16	28.965	2,745,275.75	21.177	3,081,354.00
17	29.679	3,038,471.75	20.453	2,873,124.50
18	30.443	3,330046.50	19.699	2,672,273.75
19	31.252	3,647,493.00	18.891	2,479,294.50
20	32.077	3,964,112.25	18.066	2,294,488.50

Table 7.17 shows the estimated yearly cumulative volume of wastes (waste plus cover material) generated at Site 288 if wastes are collected from all the three local authorities within the study area. The estimated yearly cumulative volume of wastes (waste plus cover material) generated at Site 288 if the wastes are to be collected from only the Petaling Jaya Municipality is given in Table 7.18. Similar results for the Shah Alam Municipality and Petaling District Council are given in Tables 7.19 and 7.20 respectively. All the results given here were calculated based on the following assumptions:

- the site will start its operation in early 1998
- the compacting rate is 711 kg/cubic metres
- cover material-to-waste ratio is 1:5
- the final grade level is 20 m above MSL

Table 7.17 Estimated yearly cumulative volume of wastes (waste plus cover material) generated at the landfill - whole of study area

Year	Projected end of year population	Waste generated/ year (kg)	Volume of waste generated (cubic m)	Cumulative vol. of waste generated (cubic m)	Cumulative volume of waste occupied at landfill (cubic m)
1998	1116759	343621158	483293	483293	604116
1999	1165534	358628982	504401	987694	1234617
2000	1214307	373636190	525508	1513202	1891502
2001	1266565	389715715	548123	2061325	2576656
2002	1318773	405779856	570717	2632042	3290053
2003	**1371082**	**421875073**	**593355**	**3225397**	***4031746***
2004	1423340	437954599	615970	3841366	4801708
2005	1475598	454034124	638585	4479952	5599940
2006	1529029	470474575	661708	5141660	6427075
2007	1582460	486915027	684831	5826491	7283114
2008	1635892	503355786	707955	6534446	8168057
2009	1689323	519796237	731078	7265524	9081905
2010	1742754	536236689	754201	8019724	10024655

Table 7.18 Estimated yearly cumulative volume of wastes (waste plus cover material) generated at the landfill - Petaling Jaya Municipality only

Year	Projected end of year population	Waste generated /year (kg)	Volume of waste generated (cubic m)	Cumulative volume of waste generated (cubic m)	Cumulative volume of waste occupied at landfill (cubic m)
1998	598309	184096687	258926	258926	323658
1999	614774	189162885	266052	524978	656223
2000	631238	194228775	273177	798155	997694
2001	649869	199961441	281240	1079395	1349244
2002	668450	205678721	289281	1368676	1710845
2003	687130	211426464	297365	1666041	2082551
2004	705761	217159130	305428	1971468	2464336
2005	724392	222891795	313491	2284959	2856199
2006	732950	225525049	317194	2602153	3252692
2007	741507	228157995	320897	2923051	3653813
2008	**750065**	**230791249**	**324601**	**3247651**	**4059564**
2009	758622	233424195	328304	3575956	4469944
2010	767180	236057449	332008	3907963	4884954

Table 7.19 Estimated yearly cumulative volume of wastes (waste plus cover material) generated at the landfill - Shah Alam Municipality only

Year	Projected end of year population	Waste generated /year (kg)	Volume of waste generated (cubic m)	Cumulative volume of waste generated (cubic m)	Cumulative volume of waste occupied at landfill (cubic m)
1998	287099	88338926	124246	124246	155308
1999	296685	91288491	128395	252641	315801
2000	306270	94237747	132543	385183	481479
2001	316283	97318697	136876	522059	652574
2002	326296	100399647	141209	663268	829085
2003	336310	103480905	145543	808811	1011013
2004	346323	106561855	149876	958687	1198358
2005	356336	109642805	154209	1112896	1391120
2006	367490	113074835	159036	1271932	1589915
2007	378644	116506865	163863	1435796	1794745
2008	389799	119939203	168691	1604487	2005608
2009	400953	123371233	173518	1778005	2222506
2010	412107	126803263	178345	1956349	2445437

Table 7.20 Estimated yearly cumulative volume of wastes (waste plus cover material) generated at the landfill - Petaling District Council only

Year	Projected end of year population	Waste generated /year (kg)	Volume of waste generated (cubic m)	Cumulative volume of waste generated (cubic m)	Cumulative volume of waste occupied at landfill (cubic m)
1998	231351	71185546	100120	100120	125150
1999	254075	78177607	109954	210075	262593
2000	276799	85169668	119789	329863	412329
2001	300413	92435577	130008	459871	574839
2002	324027	99701487	140227	600098	750123
2003	347642	106967705	150447	750545	938181
2004	371256	114233614	160666	911211	1139014
2005	394870	121499524	170885	1082097	1352621
2006	428589	131874692	185478	1267574	1584468
2007	462309	142250167	200071	1467645	1834556
2008	496028	152625335	214663	1682308	2102885
2009	529748	163000810	229256	1911564	2389455
2010	563467	173375977	243848	2155412	2694265

By comparing the volume of waste generated, the life expectancy of the proposed site can be estimated. Table 7.21 summarises the life expectancy of the proposed site based on different final grade levels. Three different final grade levels, that is, 10 m, 15 m and 20 m above MSL, were used in the calculation. If all the wastes generated within the study area are to be sent to this proposed landfill site and the final grade level is 10 metres above MSL, the life expectancy of the site will be less than 2 years. As the final grade level is increased, the life expectancy will also increase. The life expectancy will be increased to less than 4 and 6 years if the final grade level is increased to 15 and 20 metres respectively. The life expectancy of the proposed site will be increased significantly if the wastes from only one local authority are to be sent to this site. If the final grade level is set to 20 metres and wastes from any one of the local authorities are to be sent to this site, the life expectancy will be more than 10 years.

Table 7.21 Life expectancy of the potential site (Site 288)

	Life expectancy		
Municipality/district council	final level = 10 m above MSL	final level = 15 m above MSL	final level = 20 m above MSL
1. All	< 2 years	< 4 years	< 6 years
2. Petaling Jaya Municipality only	< 4 years	< 7 years	< 11 years
3. Shah Alam Municipality only	< 7 years	< 14 years	-
4. Petaling Dictrict Council only	< 8 years	< 13 years	-

B.Visibility analysis

Visibility analysis from two different observation points (proposed final grade level) of the potential site, that is, 20 and 30 metres above MSL, were carried out (Figures 7.22 and 7.23). As mentioned earlier, the output from visibility analysis is a coverage showing areas visible from a specified point. The higher the final grade point, the larger will be the area visible from that point. This coverage can later be overlaid with other coverages such as LANDUSE coverage and SITE1BOUNDARY coverage to assist planners or decision maker in deciding the suitability of the selected site.

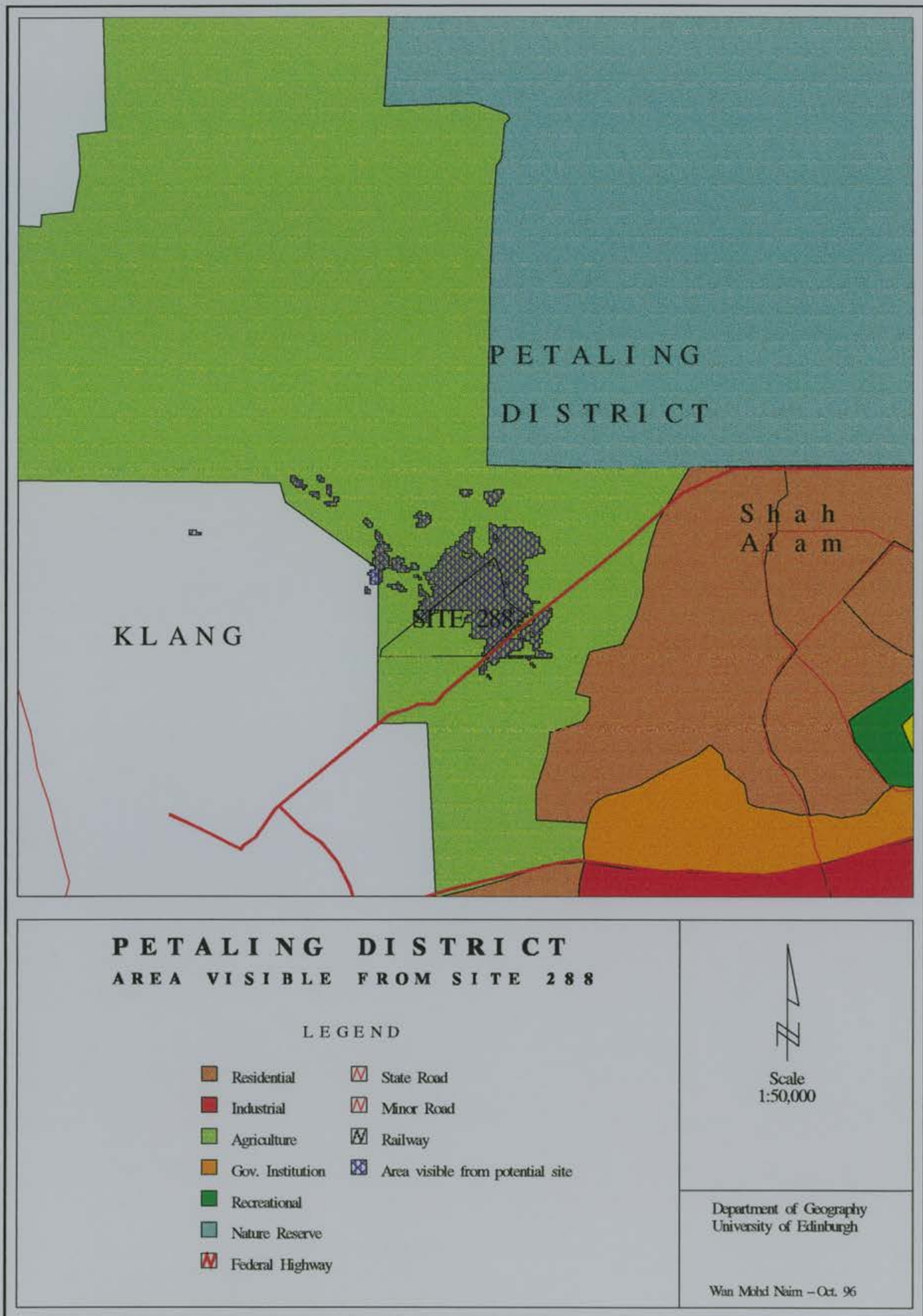


Figure 7.22 Map showing area visible from Site 288 (final grade is 20 m above MSL)

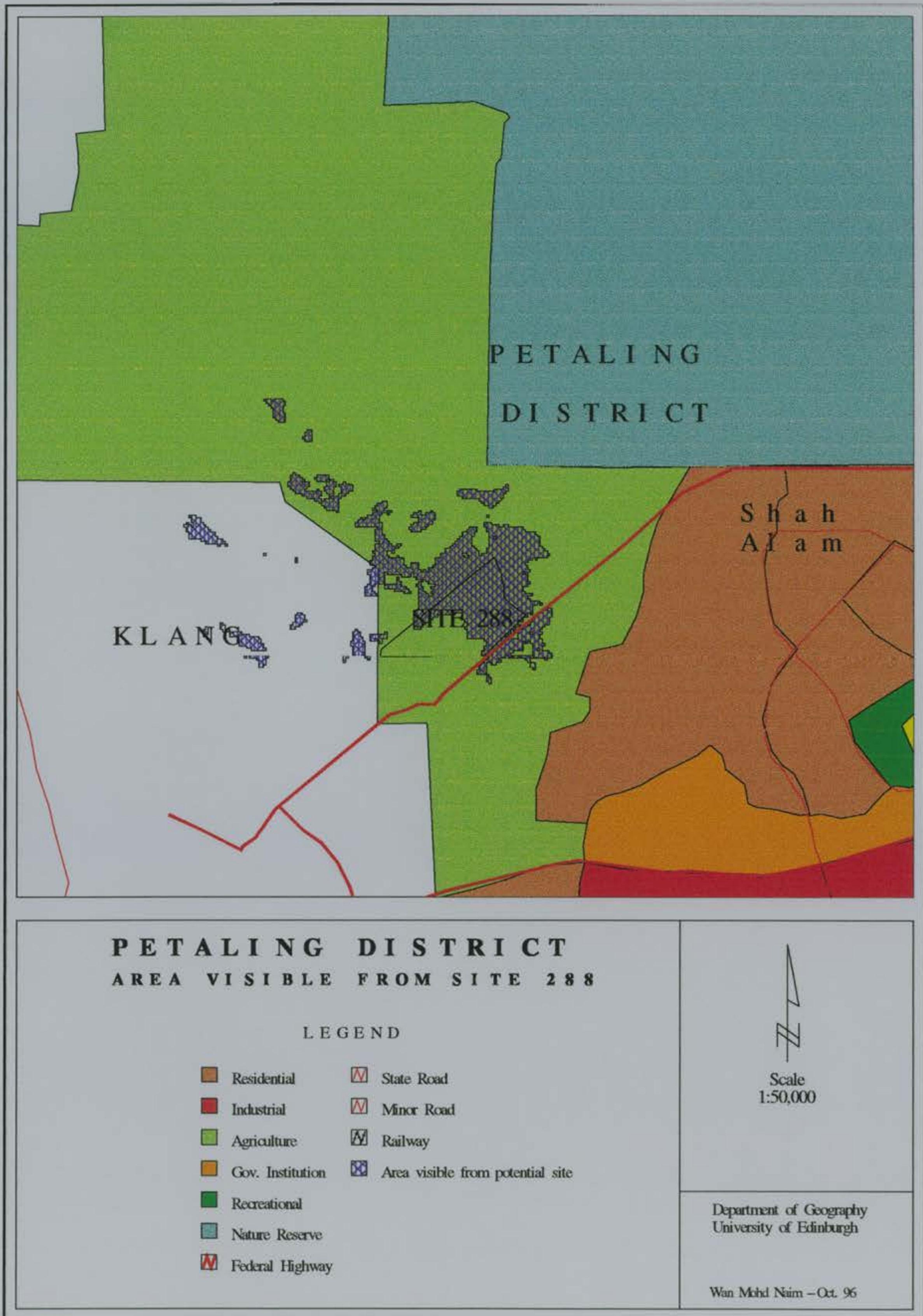


Figure 7.23 Map showing area visible from Site 288 (final grade is 30 m above MSL)

C. Visual inspection of the potential site on the monitor screen

Beside volumetric and visibility analysis, perspective viewing of an orthoimage mosaic on the DEM of the area will further assist planners and decision makers to inspect the suitability of the site more realistically rather than examining line maps. The orthoimage mosaic and orthoimage of Site 288 draped on the DEM are given in Figures 7.24 and 7.25, respectively.

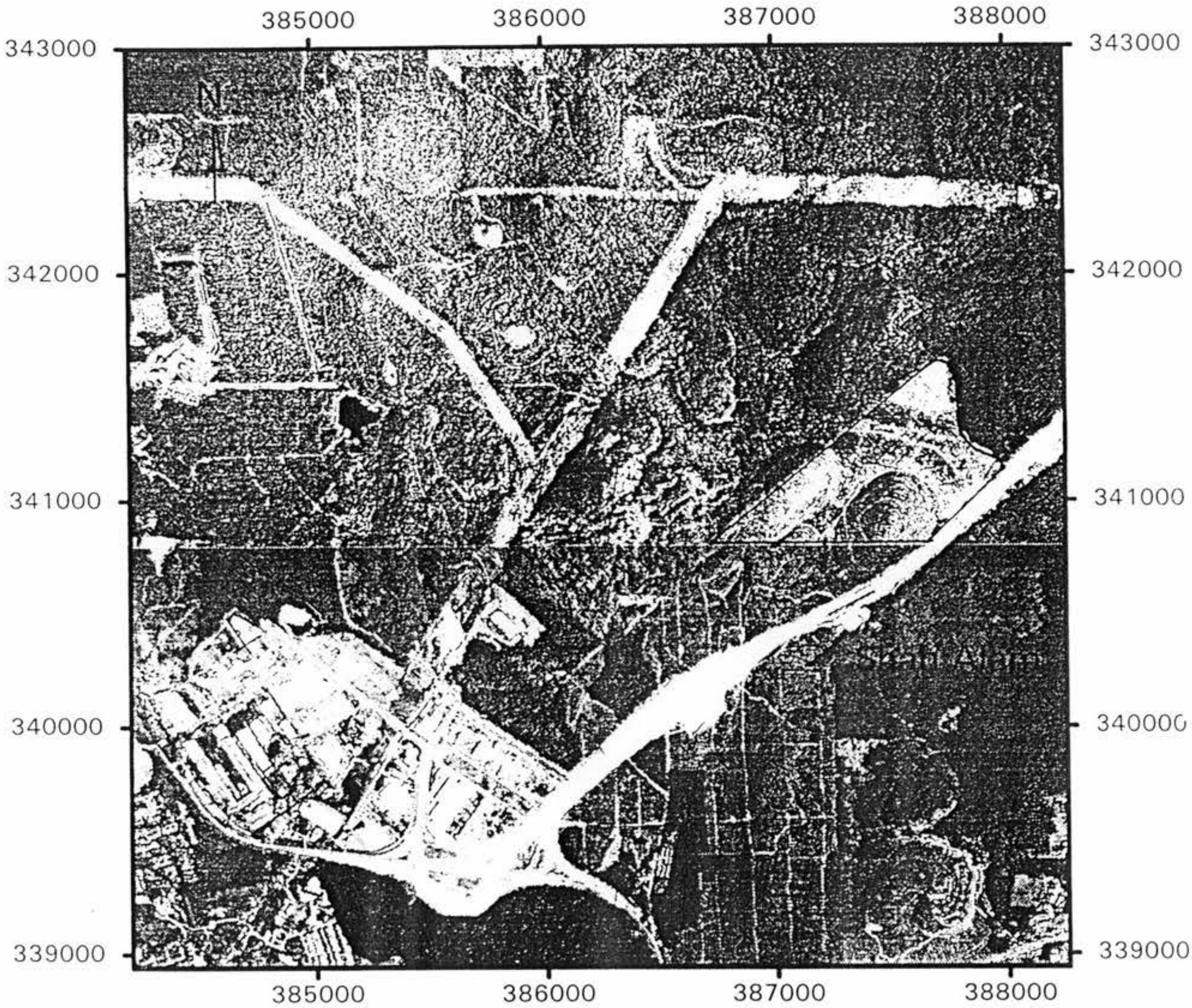


Figure 7.24 Orthoimage mosaic of area surrounding Site 288

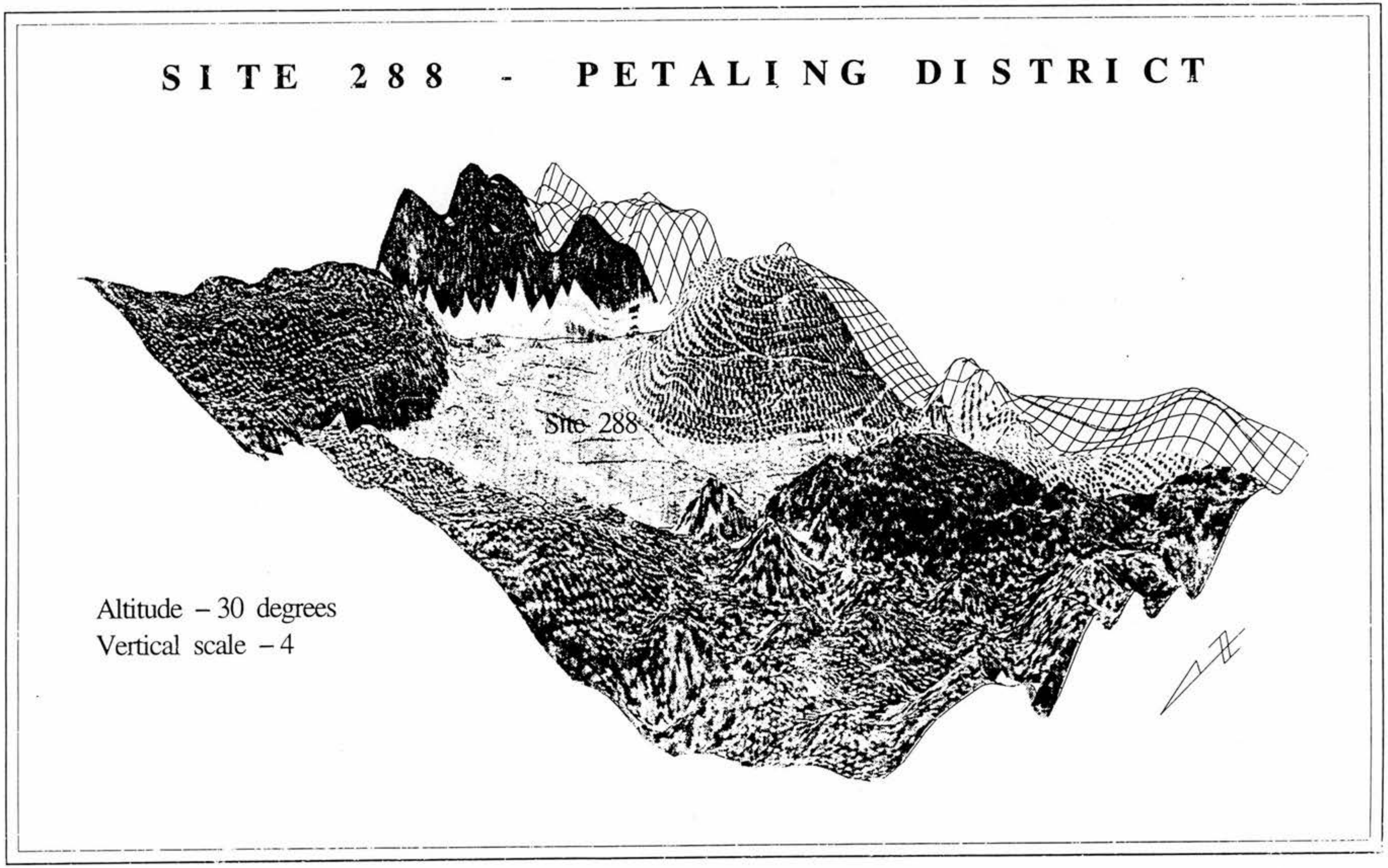


Figure 7.25 Orthoimage of Site 288 draped on DEM

7.6 Discussion and conclusion

This case study identified the fundamental logic and procedures applied when using GIS and digital photogrammetry to locate new landfill sites. The study has dealt with the Petaling District within the Klang Valley Region and eventually concentrated on a single site, Site 288, in order to demonstrate the method that has been developed. As with other siting studies, the siting criteria to be used were specified first. Based on the specified siting criteria, types of data required were identified. In this case study three types of map data were used, that is, existing maps, Landsat TM satellite digital data and digital photogrammetric data (automatically generated DEMs and orthoimage mosaic).

Having identified the criteria and types of data to be used, a database was constructed. The process of database construction involved three stages, that is, database design, data conversion from analogue to digital format and attribute data transferred into database. Existing maps were digitised and organised as data layers in ARC/INFO GIS. Satellite remote sensing data were used as a back-drop for on-screen digitising in DMS to update information in some of the earlier digitised data layers. Evaluation of potential sites was carried out in two stages. Preliminary evaluation was carried out to eliminate all unsuitable land areas.

At this stage exclusionary and some restrictive criteria were applied. The application of exclusionary criteria eliminated 75 per cent of land areas as unsuitable while a further application of some of the restrictive criteria eliminated 2.5 per cent of land area within the study area. Based on a few alternative residential and road buffer criteria and the minimum site size criterion, potential areas were significantly reduced to a few isolated areas. An external computer program (WASTEDIS) was written to evaluate the potential areas further based on shortest aggregated travel distance. Reports on individual potential areas were generated to assist the decision maker to select a few alternative potential areas manually for a more detailed evaluation. This further site specific evaluation involved two main analyses, that is, the estimation of individual site capacity and its visibility to the public. Another external computer program (WASTEGEN) was used to estimate the life expectancy of the selected site. In both of the analyses, the automatically generated digital photogrammetric data (that is DEM and orthoimage mosaic) were employed.

Diverse and multi-disciplinary data sets are needed to locate the most suitable landfill site effectively. Since not all the required data sets necessary to address the criteria outlined in the earlier siting studies are available for this case study, only limited criteria were used. The selection of criteria be used need a careful and detailed study as it would determine the final outcome of the analysis. As mentioned earlier some important criteria such as land ownership, planning restrictions, economic and land values and future use were not used due to limited data sets available. In a real situation, all these important criteria must be considered. The inclusion of these important criteria could have significantly influence the results presented in this chapter.

If different weightings to be applied (as suggested in Engineering and Environmental Consultant Ltd., 1991) to the selected criteria, different approach should be adopted. GIS-MDCM approach (as mentioned earlier in Periera and Duckstein, 1993; Jankowski, 1994; Carver, 1991; Carver and Openshaw, 1992 and Malczewski, 1996) is a more suitable approach as compared to the polygon overlay approach. Since all GIS software do not have buil -in MDCM routines (except for IDRISI software) linking programs needed. In ARC/INFO software, AML programs can be used to link together GIS functions with external MDCM routines.

Even with these limited criteria, the example demonstrated in this chapter has shown that the use of digital photogrammetry and GIS as data acquisition and data analysis tools provide several benefits that are not just theoretically attractive but also significantly enhance the decision making. These benefits include:

- The geo-reference satellite data obtained from the Malaysian Centre for Remote Sensing can be easily and readily input into a digital photogrammetric workstation to allow on-screen updating of ARC/INFO data layers.

- The scanned aerial photographs at 1:20,000 scale or larger can be used to generate DEMs and orthoimage mosaic of the potential site automatically in a digital photogrammetric workstation. The integration of these digital photogrammetric products proved to be a powerful tool in site specific analysis such as volumetric and visibility analysis.

- By overlying contours at 5m vertical interval generated from a high resolution DEM onto an orthoimage mosaic of the potential area on the monitor screen, the exact site boundary can be identified and digitised on-screen in ARC/INFO.

- The use of GIS is well suited for managing and analysing diverse and large volumes of multi-disciplinary and multi-format data sets needed in the landfill site selection process.

- Volumetric analysis options in GIS will not only allow the capacity of potential site (volume) to be estimated but will also estimate the amount of cover material available within the site.

- Visibility analysis allows engineers or planners to identify areas surrounding the site which are visible from a proposed final grade level (ground level) of a landfill. By varying the value of the proposed final grade level an optimum level can be determined.

- A more realistic viewing of the potential site can be achieved by overlying an orthoimage mosaic onto the DEM and this can certainly assist planners and decision makers to inspect the suitability of the site further.

- GIS proves to be a valuable tool for evaluating alternative solutions to landfill site selection. In this case study, alternative road and residential criteria have been used to generate several alternative scenarios. The process of generating alternative scenarios was easily achieved, unlike the manual process where new maps have to be drawn, requiring much more time.

- The most important benefit of using GIS in the stage-by-stage landfill site selection process would be in demonstrating to the public or decision makers that a series of rational criteria were applied to eliminate systematically all unsuitable areas within a study area.

The example presented in this chapter demonstrated the practicality of integrating GIS and digital photogrammetry in the landfill site selection process. In the specific context of implementing such technological integration, in the local authorities or planning authorities within the Klang Valley Region, the author strongly feels that although there is no skilled mapping personnel within these authorities, these methods can be used for the following reasons: i) a low-cost digital photogrammetric system as compared to the traditional analogue stereoplotter or even analytical plotter which requires a skilled photogrammetrist to operate, ii) up-to-date aerial photo coverage and satellite remote sensing data are available from the Department of Survey and Mapping and MACRES respectively, and iii) personnel trained in software and hardware for GIS already exist in many local authorities or planning authorities.

CHAPTER 8

SUMMARY AND CONCLUSIONS

8.1 Introduction

This thesis sets out to evaluate the potential and the possible role of digital photogrammetry and GIS in the stage-by-stage landfill siting process in the context of a Developing Country like Malaysia. Particular emphasis has been given to the evaluation on the geometric capabilities of low-cost scanning and mapping technologies to be used by small local authorities or planning authorities with limited mapping budgets and limited numbers of skilled personnel to acquire relevant digital data. The A4 format DTP scanners were used to convert hardcopy aerial photographs into the digital format required in any digital photogrammetric workstation. A PC-based DPW, that is, the Desktop Mapping System version 3.1, was used to generate the high resolution DEMs and orthoimage mosaic required to evaluate the potential of the selected landfill sites. GIS was used as a tool to integrate, manipulate and analyse the digital data.

Against this background, this final chapter synthesises the findings and conclusions presented in Chapters 2 through 7.

8.2 Summary of major findings and discussion

8.2.1 Problems related to solid waste management in Malaysia

In Malaysia, the problem of waste disposal is a most important and urgent environmental issue, need immediate attention. A review of previous environmental studies and solid waste management studies carried out in Malaysia together with the author's field visit and informal discussions with officers from various government organisations on the problems of solid waste management in Malaysia, particularly in the Klang Valley Region, has identified the problem of locating new landfill sites as the single most important issue in the waste disposal process. Since the mid 1980's more frequent attempts by planners and administrators at various administrative levels (federal, state and local) have been made to improve the methods of locating waste disposal sites. The earlier studies have proposed the use of a regional and stage-by-stage approach using multi-criteria to locate new landfill sites. In this study the author has identified a few major problems faced by the local authority or planning authority in trying to implement these proposals. The following are the major problems identified:

1. To be able to implement the stage-by-stage site selection process effectively at regional level, large amounts of information of diverse types have to be available. Unlike the situation in a more developed country, digital map data are not readily available. Important data sets such as detailed current and future land use maps and land ownership information are not accessible to the general public or between government departments. Even where map data are available most of them are out-of-date. The current national mapping programme fails to provide up-to-date maps or maps at the appropriate scales required many land management and planning applications, including the landfill site selection process. The largest map scale available is 1:10,000. Although digital map data for certain areas are available the coverage is very limited. On the other hand

there are extensive aerial photo coverages and satellite remote sensing imagery in Malaysia.

2. Modern mapping and spatial data analysis technologies are required to acquire, manage, store, integrate and analyse the large amounts of diverse information in an effective manner. Such information is required in the multi-criteria stage-by-stage site selection process. Although to some of these authorities GIS is not new, it has never been used other than as a tool for automated mapping and inventory tasks. Current practice of data acquisition is limited to line digitising of existing maps except in large government organisations where satellite remote sensing methods are used. Photogrammetric data acquisition technologies using analogue or analytical stereoplotters are mainly used in the Department of Survey and Mapping, Malaysia. Digital photogrammetric methods are only utilised for generating maps for military applications. Manual photogrammetric methods cannot be introduced within local authorities and planning authorities as these organisations are non-mapping organisations and operate with limited mapping budgets and without any skilled mapping personnel.

3. There are no internationally or nationally agreed standard siting criteria. The siting criteria are much influenced by the local environmental, social and political factors. In Malaysia, there is no national landfill site selection criteria. Different organisations tend to formulate their own site selection criteria. Most of these criteria were adopted from foreign countries. If the stage-by-stage site selection process is to be implemented a proper study of the site selection criteria, which suit local needs, must be carried out. Important criteria such as land ownership, planning restrictions, economic and land values and its future use must be considered.

8.2.2 The suitability of low-cost A4 format DTP scanners to acquire data for digital photogrammetric systems

Earlier studies on geometric accuracy assessment have concentrated on the photogrammetric and A3 format DTP scanners. Although photogrammetric scanners provide the excellent quality images (radiometrically and geometrically) required for photogrammetric applications their price is quite high for most organisations. With a proper calibration procedure, some A3 format DTP scanners were found to be suitable for scanning hardcopy aerial photographs. Unlike other studies of geometric accuracy assessment, this study concentrates on the low-cost A4 format DTP scanners. A series of tests carried out on five DTP scanners has provided a clearer understanding of the distortion characteristics of the scanned images. The following are the major findings that can be drawn from the tests reported in Chapter 5:

1. Tests carried out have shown that the pattern and magnitude of image distortion varies from one DTP scanner to another. The variations do not only apply to scanners of different models but also scanners of the same model. In some scanners the magnitude of image distortion can be quite significant. In some DTP scanners the magnitude of image distortion is three times larger than the scanner resolution.

2. Although some later models of DTP scanners allow scanning up to 2400 dpi (approximately 10 microns) through software interpolation, scanning at higher resolution than the original optical resolution of the scanner will not help to improve the overall geometric accuracy of the scanned image. The geometric accuracy largely depends on the original optical resolution of the CCDs.

3. Although the image distortions in some scanners are significant, distortion can be minimised. The proposed image rectification or image calibration method, that is, scanning the calibrated grid plates (as used to calibrate stereoplotters) and later applying a suitable mathematical model to rectify the scanned images, helps to minimise the effect of image distortion. In all the DTP scanners tested the overall magnitude of image distortions can be reduced to less than a half of the optical

resolution of the scanner. For example in a 600 dpi (43 microns) optical scanner, the overall magnitude of image distortion can be reduced to less than 21 microns.

4. Polynomial transformation was found to be the most suitable coordinate transformation to minimise image distortions in DTP scanners. The order of polynomial transformation to be applied in the rectification procedure varies from one scanner to another. As a general rule a third order polynomial transformation is suitable to rectify images scanned in all the scanners tested.

In summary, the geometric accuracy assessment has shown that images scanned in low-cost A4 DTP scanners are not suitable to be input directly into a digital photogrammetric system because of the large image distortions. However, with proper image rectification as adopted in this study, the overall geometric accuracy of the images scanned in these scanners can be significantly reduced, making it a more suitable alternative to an expensive photogrammetric scanner. If a DTP scanner is to be used to scan aerial photographs it is important to understand fully the characteristics of the image distortion of that particular scanner. It is also essential to scan the calibrated grid plate every time scanning work is carried out as the pattern and amount of image distortions differs slightly when scanning is repeated.

8.2.3 The suitability of low-cost DPW to generate digital map data

Many of the previous studies on the geometric accuracy assessment of digital photogrammetic products generated from scanned aerial photographs have dealt with accuracy assessment of the stereomodel set-up and point positioning from a stereomodel. In comparison to these studies on accuracy assessment there are relatively few studies which deal with the evaluation of automatically generated products. Most of the earlier studies were based on high-end expensive DPW using images scanned in precision scanners. There are limited studies on the accuracy assessment of low-cost DPW using images scanned in low-cost A4 format DTP scanners.

The accuracy assessment of digital photogrammetric products as described in Chapter 6 has not made any original contributions but rather, it has provided additional corroboration of previous studies that a DPW is able to generate digital photogrammetric data such as DEMs and orthoimages at an accuracy comparable to some lower order analytical plotters but at a much faster speed. The quality or accuracy of such products largely depends on factors such as the scale of photography, the quality of photography, the geometric and radiometric quality of scanner used, the accuracy of ground control points and the scanning resolution. Geometric accuracy assessment was based on scanned aerial photographs of two different test sites. Among lessons that can be learned from these tests are:

1. The geometric accuracy of the stereomodel set-up and point positioning using rectified images was found to be significantly higher than by using images directly scanned in the DTP scanner. This shows that the image rectification procedure as adopted by the author can be used to improve the overall geometric accuracy of the input images and will subsequently improve the accuracy of digital photogrammetric products.

2. As in other currently available DPWs, it is impossible to achieve 100 per cent success with autocorrelation. The success of any autocorrelation process in a DPW depends on a number of factors such as the autocorrelation algorithm used, image quality and image contrast. In areas of good contrast with the surrounding features, highly accurate DEMs and orthoimages can be obtained. In areas with poor image quality or poor contrast with the surrounding features, autocorrelation fails to give a good result. Errors in the automatically generated height in such areas can be significantly large. An incorrect DEM will subsequently result in an inaccurate orthoimage being generated.

3. The main advantages of a digital photogrammetric workstation as compared to an analogue plotter or most analytical plotters are its ability to generate digital products (i.e. DEM and orthoimage) automatically at a high speed and the facility of inputting the generated digital output into a GIS for further analysis.

The maximum speed to measure heights in an analogue stereoplotter by an experienced operator is approximately 6 to 10 points per minute, while in DMS (with 486/33DX PC and 4 Mb RAM) the speed is approximately 2100 points per minute. In a PC with more powerful processor the speed will be increased significantly.

4. The main drawback of using a digital photogrammetric workstation is still associated with data volume. Massive data storage is required for scanned images and other digital outputs such as digitised vector data, DEMs, orthoimages and orthoimage mosaics. The number of medium-scale aerial photographs required to cover the whole of the Petaling District study area is approximately 50. If hardcopy aerial photographs were to be scanned at 300 dpi, the data storage required to store all the scanned images of the aerial photographs is approximately 350 Mbytes. The storage required to store the processed images and other digital outputs will be approximately 3 times larger (i.e. more than 1 Gigabytes). If the aerial photographs were scanned at 600 dpi storage space of more than 4 Gigabytes are required.

Results from a series of tests as explained in Chapter 6 have shown that rectified aerial photo images originally scanned in an A4 format DTP scanner with low-cost PC-based DPW such as the Desktop Mapping System can be used in generating reasonably accurate digital photogrammetric products. Since it is impossible to generate correct heights automatically throughout a stereomodel, manual height editing of poorly correlated heights is always necessary in digital photogrammetry. Unfortunately a manual editing facility for heights generated using scanned aerial photographs is not available in DMS. From the author's direct correspondence with R-Wel. Inc. in October 1996, the company have given an assurance that the manual editing facility will be developed in the near future. The existing editing facility for SPOT stereoimages can be used to correct for large height errors obtained from scanned aerial photographs.

8.2.4 The suitability integrating digitised vector data, remote sensing data and digital photogrammetric data for the site selection process in Malaysia

Although GIS has been used before in the landfill site selection process in Developed Countries, such technology has never been used in Malaysia. The example described in Chapter 7 has evaluated the suitability of integrating digital photogrammetric data and remote sensing data into the stage-by-stage landfill site selection process to enhance decision making further. The Petaling District was used as the study area. The example began by defining the siting criteria to be used and was later followed by the identification and collection of the required digital data. An evaluation of potential sites based on the exclusionary and restrictive criteria was then carried out in GIS. The example demonstrated that:

1. GIS has proved to be a valuable tool in the stage-by-stage site selection process. Among the benefits are:
    - the ability of GIS to manage and analyse the large volumes of diverse multi-disciplinary and multi-format data sets (i.e. vector, raster and DEM) needed in various stages of the landfill site selection, that is from appraisal of large geographical areas to evaluation of specific sites. Although the manual method as proposed by JICA to be used in the Penang and Seberang Perai Municipality can be applied to large geographical areas, it is not possible to use the method to evaluate at a more detailed level.
    - the ability of GIS to develop and test alternative solutions by changing the siting criteria. This will aid planners or decision makers to explore various alternative solutions to locate new landfill sites.
    - the ability of GIS to demonstrate to the public or to decision makers that a series of rational criteria were applied to eliminate all unsuitable areas for landfill construction systematically.

2. The use of digital photogrammetric data such as DEMs and orthoimage has added an extra dimension in the decision making. High resolution DEMs can be used to generate contours of the potential landfill area and can also be used in the volumetric and visibility analysis. By overlaying contours and an orthoimage mosaic of the potential area on the monitor screen, the potential site boundary can be identified and digitised on-screen. Volumetric analysis performed in ARC/INFO GIS allows an estimation of the amount of waste that can be dumped at a selected site and also the amount of available cover within the selected site. This can be the basis for evaluating the suitability of the selected potential sites on an economic basis. Based on the estimated volume, the life expectancy of each of the potential sites can be evaluated. Using DEMs of the area surrounding the potential sites, visibility analysis can be carried out. Visibility analysis can assist engineers or planners to choose a site that is least visible to the general public and also helps to identify extra measures needed to screen each landfill site from the general public. Another advantage of using a DEM and orthoimage mosaic is that it allows perspective viewing of potential sites. By overlying orthoimage and DEM a more realistic viewing of the potential sites can be achieved, giving an extra advantage to planners or engineers to determine the suitability of the selected potential site/s further.

3. In the context of local authorities or planning authorities in Malaysia, the method of on-screen vector digitising with TM Landsat remote sensing data as the backdrop in DMS or ARC/INFO to update data layers earlier digitised in ARC/INFO or to generate new map data for a large geographical area (i.e. at regional or sub-regional scale) can be a cost effective and easy solution for staff without proper training in digital image processing. In the author's opinion, it is not practical to use digital photogrammetric data generated from scanned aerial photographs to update or generate new digital map data for the whole region because of the massive data storage needed. Digital photogrammetry can better be utilised to supply data in the more detailed analysis of potential sites.

8.3 Practicality of implementing the proposed data collection and data analysis strategy

Earlier findings have shown that although the geometric accuracy of all the low-cost A4 format DTP scanners tested are relatively low as compared to photogrammetric scanners they can still be used to scan aerial photographs provided a careful image rectification or calibration is carried out. The image calibration procedure as suggested in this study can significantly improve the geometric accuracy of the scanned images. The proposed procedure can be an alternative for small organisations that wish to use the digital photogrammetric approach of data collection.

The use of the calibrated aerial images scanned in a DTP scanner significantly improves the accuracy of digital products. The use of DEMs generated in a DPW can be used not only in the landfill site selection process but also for detailed monitoring of landfill sites. DEMs and orthoimages or orthoimage mosaics can also be used as data sources for many other GIS applications.

This study has also shown that GIS can be used to integrate, manipulate and analyse data from various data sources to be used in the stage-by-stage site selection process. The remaining problem is whether this can be implemented in the context of a Developing Country like Malaysia. In the author's opinion, it would not be difficult to implement such a data collection and data analysis strategy because:

1. Availability of trained personnel

   Many local authorities or planning authorities within the Klang Valley Region have been using GIS as a tool for mapping and inventory tasks for the past few years. The only training required would be to handle a DPW. As most of the operations in a DPW are automatic (DEM and orthoimage generation), minimum training on the basic principles of photogrammetry and how to handle the system would be required.

2. Availability of hardware and software

   GIS software and hardware is widely available within the local authorities and planning authorities. The only extra items of equipment required are personal computer, A4 DTP scanner and additional calibrated grid plate. Digital photogrammetric software is also needed.

3. Availability of data

   The required aerial photographs and satellite remote sensing digital data (SPOT and TM) can be purchased from the Department of Survey and Mapping and Malaysian Centre for Remote Sensing, respectively. The cost of aerial photo prints (black and white) is M$10 each (approximately UK£2.50) while geo-referenced TM or SPOT satellite digital data cost M$400 (approximately UK£100) for a 512 by 512 pixel image. Local authorities or planning authorities can also request the Department of Survey and Mapping to fly new aerial photo coverage at a specified photo scale but the cost would have to be borne by the Department concerned. The main advantage of a DPW is that it can accept data from various sources. The introduction or stereo high-resolution satellite imagery (with ground resolution of less than 3 m) can also be an excellent data source to a DPW in the near future.

One potential difficulty of using digital photogrammetry is the problem of acquiring accurate GCPs to orientate each stereomodel. Unlike the situation in a more developed country such as the UK, topographic maps at scales of 1:1,250 or 1:2,500 from which GCPs coordinates can be derived are not available. The only solution for the local authorities or planning authorities is to employ private survey firms to carry out ground survey work or to use Global Positioning System (GPS) to establish GCPs.

Although this study was conducted in the specific context of the landfill site selection process within the Klang Valley Region, the digital photogrammetric approach using low-cost scanners and a low-cost DPW can also be used in other Developing Countries provided aerial photographs are available. The integration of digital photogrammetry and GIS can be utilised for many other land management and planning applications especially where surface analysis such as volumetric calculation, visibility analysis and visual inspection of the proposed sites are required.

8.4 Future research

1. This study focused on the accuracy assessment of digital photogrammetric products from only one PC-based DPW. However the study does provide the basis for evaluating the general accuracy of digital photogrammetric products generated from a PC-based DPW using aerial photographs. Further research should include evaluation of other PC-based DPWs to determine the most suitable DPW to be used.

2. An accuracy assessment of digital photogrammetric products was made by comparing results obtained from a DPW and from the AP190 analytical plotter. For height accuracy testing of automatically generated DEMs only points along a few cross-sections were compared. Further research should compare more planimetric and height points located throughout the stereomodel to give a better assessment. Height comparison against more accurate planimetric and height points generated from larger scale aerial photographs or ground surveyed points should also be made.

3. In this study, the geometric accuracy of digital photogrammetric products was only assessed based on the geometric aspect of the scanned images. It is also important to understand the effect of radiometric accuracy on the final products.

4. To implement the stage-by-stage multi-criteria process in Malaysia effectively, further detailed study on the criteria and the availability of data sets required

must be carried out. The present study used only some of the criteria from informal discussion and earlier studies carried out in Malaysia. Most of the existing criteria suggested in these studies was adopted from other overseas countries.

5. The development of an interactive spatial decision system would help planners and decision makers to utilise GIS more fully.

8.5 Final conclusion

This study has demonstrated that low-cost scanning and low-cost digital photogrammetric technologies can help in the production of high-accuracy spatial data required for a GIS and their integration with GIS is a practical possibility to aid planning and decision making particularly in the specific context of locating new landfill sites in the Klang Valley Region, Malaysia. It is hoped that the procedures, advantages and problems highlighted in this study can be used as a guide in using low-cost digital data acquisition techniques. This approach could be used to generate digital data for a GIS and in using GIS for land management and planning applications not only in the context of Malaysia but also other Developing Countries where skilled mapping personnel and budget constraints are the main obstacles to the implementation of a more modern approach to mapping and decision making.

BIBLIOGRAPHY

Abdul, M. M., 1994. National GIS/LIS Framework and Infrastructure. *National Land Information System (NALIS) Symposium and Exposition*, Kuala Lumpur. No pagination.

Ackermann, F., 1996. Digital Photogrammetry: Challenge and Potential. *Photogrammetric Engineering and Remote Sensing*, vol. 62(6), pp. 679.

Adeniyi, P. O., 1980. Land-Use Changes Analysis Using Sequential Aerial Photography and Computer Techniques. *Photogrammetric Engineering and Remote Sensing*, vol. 46(11), pp. 1447-1446.

Agouris, P. and A. Stefanidis, 1996. Integration of Photogrammetric and Geographic Databases. *International Archives of Photogrammetry and Remote Sensing,* vol. 31(4), pp 24-29.

Ahac, A. A., R. Defoe and M. C. Van Wijk, 1992. Considerations in the Design of a System for the Rapid Acquisition of Geographic Information. *Photogrammetric Engineering and Remote Sensing*, vol. 58(1), pp. 95-100.

Ahmad, N., 1991. Vision and View Search: The Case of LIS/GIS in Malaysia. *4th South East Asian Survey Congress*. Kuala Lumpur.

AISIST, 1993. *What is GIS? Why GIS?* AISIST Training Modules, Unit 1.0101, Australian Institute of Spatial Information Science and Technology, Land Information Centre, New South Wales.

Al-Garni, A. M., 1995. The Fourth Dimension in Digital Photogrammetry (DP). *Photogrammetric Engineering and Remote Sensing*, vol. 61(1), pp. 57-62.

Amin, A. M. and G. Petrie, 1994. Design Characteristics and Geometric Calibration of Video Frame Scanners. *ISPRS Journal of Photogrammetry and Remote Sensing,* vol. 49 (1), pp. 12-24.

Antenucci. J. C., K. Brown, P. L. Croswell, M. J. Kevany and H. Archer, 1991. Geographic Information Systems – A Guide to the Technology. Van Nostrand Reinhold. 301 pages.

Armenakis, C. and A. M. Regan. 1996. Map Revision Using Digital Orthophotos. *International Archives of Photogrammetry and Remote Sensing*, vol. 31(4), pp. 95-99.

Azizi, A., M. J. Clark and J. Davenport, 1991. Airphoto or Video Input to Vector or Raster GIS. *Proceeding of AGI Third National Conference and Exhibition,* pp. 1.20.1-1.20.5.

Bagheri, S. and R. A. Dios, 1990. Utilisation of Geographic Information System in Selection of Hazardous Waste Disposal Site in New Jersey Piedmont Province. *Proceeding GIS/LIS'90,* vol. 1 and 2, pp. 299-306.

Baltsavias, E. P., 1994a. Test and Calibration Procedures for Image Scanners. *International Archive of Photogrammetry and Remote Sensing,* vol. 30(1), pp. 163-170.

Baltsavias, E. P., 1994b. The Agfa Horizon Scanner - Characteristics, Testing and Evaluation. *International Archive of Photogrammetry and Remote Sensing* , vol. 30(1), pp 171-179.

Baltsavias, E. P., 1994c. Integration of Ortho-images in GIS. *International Archive of Photogrammetry and Remote Sensing, vol. 30(3) pp. 261-272.*

Baltsavias, E. P., 1996. Digital Ortho-Images - A Powerful Tool for the Extraction of Spatial and Geo-Information. *ISPRS Journal of Photogrammetry and Remote Sensing*, vol. 51(2), pp. 63-77.

Baltsavias E. P. and D. Stallmann, 1991. From Satellite Images to GIS with Digital Photogrammetry Using SPOT Data. *European Conference on Geographical Information Systems (EGIS),* pp. 945-946.

Baltsavias, E. P., and R. Bill, 1994. Scanner - A Survey of Current Technology and Future Needs. *International Archive of Photogrammetry and Remote Sensing,* vol. 30(1), pp. 130-143.

Baltsavias, E. P., H. Li, A. Stefanidis, M. Sinning and S. Mason, 1996. Comparison of Two Photogrammetric Systems with Emphasis on DTM Generation: Case Study Glacier Measurement. *International Archives of Photogrammetry and Remote Sensing,* vol. 31(4), pp. 104-109.

Benoit, S., 1990. Digital Spatial Capture and Revision - A Photogrammetric Solution for the 1990's. *European Conference on Geographical Information Systems (EGIS),* pp. 1080-1087.

Bentley, W. H., 1990. Implementing Geographic Information in the Small Municipility. *Proceeding GIS/LIS'90*, pp. 167-173.

Bernard, M., 1990. SIG34: A Regional Application of GIS. *European Conference on Geographical Information Systems (EGIS)*, pp. 54-58.

Bethel, D. J., 1990. Digital Image Processing in Photogrammetry. *Photogrammetric Record,* vol. 13(76), pp. 493 - 504.

Bethel, D. J., 1993. Geometric Allignment and Calibration of a Photogrammetric Scanner. *Journal of Photogrammetry and Remote Sensing.*

Bethel, D. J., 1994. Calibration of a Photogrammetric Scanner Technology. *ASPRS/ACSM Annual Convention*, vol. 1, pp. 81-88.

Beurden, A. U. C. J. V. and H. J. Scholten, 1990. The Environmental Geographical Information System of the Netherlands and its Organisational Implications. *European Conference on Geographical Information Systems (EGIS),* pp. 59-67.

Boniface, P. R. J., 1992. PRISM - Softcopy Production of Orthophotos and DEM. *Photogrammetric Engineering and Remote Sensing,* vol. 58(1), pp. 91-94.

Boote, S., and G. Darwall, 1992. GIS in Environmental in Research. *Mapping Awareness and GIS in Europe*, vol. 6(1), pp. 57-59.

Bosma, M., J. Drummond, and B. Raidt, 1989,. Preliminary Report on Low-Cost Scanners. *ITC Journal,* no. 2, pp. 115 - 120.

Brainard J., A. Lovett and J. Paarfitt, 1996. Assessing hazardous waste transport risks using a GIS. *International Journal Geographical Information Systems*, vol. 10(7), pp. 831-849.

Brianard, J., A. Lovett and J. Parfitt, 1996. Assessing Hazardous Waste Transport Risks Using a GIS. *International Journal Geographical Information Systems*, vol. 10(7), pp. 831-849.

Brown, R. O., 1991. Photogrammetric GIS Technology: Feature Mapping on Digital Stereo Imagery. *Proceeding GIS/LIS'91,* vol. 1 and 2, pp. 882-890.

Buckley, D. J. A. and W. G. Hendrix, 1986. Use of Geographic Information Systems in Assessment of Site Suitability for Land Application of Waste. In *GIS in Government.* Deepak Publishing, pp. 645-655.

Burrough, P. A., 1986. *Principles of Geographical Information Systems for Land Resources Assessment*. Oxford University Press. 193 pages.

BW Perunding Sdn. Bhd. and Erinco Sdn. Bhd., 1993. *Preliminary Environmental Impact Assessment Study for the Proposed Sanitary Landfill at Mukim Krubong, Melaka Tengah, Melaka.* No pagination.

Carstensen, L. W., and J. B. Campbell, 1991. Desktop Scanning for Cartographic Digitisation and Spatial Analysis. *Photogrammetric Engineering and Remote Sensing,* vol. 57(11), pp. 1437-1446.

Carver, S. J., 1991. Integrating Multi-criteria Evaluation with Geographical Information Systems. *International Journal Geographic Information System*, vol. 5(3), pp.321-339.

Carver, S and S. Openshaw, 1992. A Geographic Information Systems approach to locating neclear waste disposal sites. In Clark, M., D, Smith and A. Blowers (eds) *Waste Location: Spatial Aspects of Waste Management, Hazards, and Disposal.* Routledge and Kegan Paul, London.

Cassettari, S. 1993. *Introduction to Integrated GeoInfo Management*. Chapman and Hall. 252 pages

Chanlikit, D., 1991. *An Evaluation of AP190 Analytical Photogrammetric Plotter as a Source of Spatial Data for a GIS.* M. Sc. Dissertation (unpublished). University of Edinburgh. 75 pages.

Chanlikit, D. and R. P. Kirby, 1993. The Use of Photogrammetric and GPS Techniques for Digital Mapping of Land Readjustment in Thailand. *Proceeding of the 2nd International Colloquium of LIESMARS on Advances in Urban Spatial Information and Analysis, Wuhan,* pp. 84-93.

Chapman, D., I. J. Dowman and J-P, Muller, 1991. Digital Photogrammetry - Interface with GIS. *Proceeding of AGI Third National Conference and Exhibition*, pp. 2.24.1-2.24.4.

Cheremisinoff, P., 1992. *Waste Incineration Handbook.* Butterworth-Heinemann Limited. 151 pages.

Clayton, K., 1995. The Land from Space. *Environmental Science for Environmental Management* Edited by O'Riordan, T. Longman Group Limited, pp. 198-222.

Cointreau-Lavine, S, 1996. *Sanitary lanfill design and siting criteria.* Transportion, water and urban development department of the World Bank. URL:http:/www.esd.worldbank.org/html/esd/twu/pub/intake/rd-ue12.htm.

Converse/TenEch, 1981. *Identifying Potential Sanitary Landfill Disposal Sites/Systems for Sussex County, New Jersey.* Prepared for the Sussex County Board of Chosen Freeholders.

Cowen D., 1990. *Unit 1- What is GIS?* NCGIA Core Curriculum.

Cowen, D. J. and W. L. Shirley, 1991. Integrated Planning Information Systems. In *Geographical Information System: Principles and Applications Vol. 2,* edited by

Maguire, D., M. F. Goodchild and D. W. Rhind. Longman Scientific and Technical. pp. 297-310.
Crawford, J. F. and P. G. Smith, 1985. *Landfill Technology*. Butterworths. 159 pages.

Dall, J. A., 1990. The Digital Orthophoto: The Cornerstone of GIS. *Proceeding GIS/LIS'90*, pp. 314-318.

Dams, R. V., and M. Larsson, 1993. New Fuel to Fire the GIS: Digital Orthoimagery. *Proceeding 7th Annual Symposium on Geographical Information Systems in Forestry, Environment and Natural Resources Management,* pp. 973-976.

Daniel, D. E., 1993. *Geotechnology Practice for Waste Disposal.* Chapman and Hall. 683 pages.

Day, T. and J.-P. A. L Muller, 1988. Quality Assessment of Digital Elevation Models Produced by Automatic Stereomatchers from SPOT Image Pairs. *Photogrammetric Record*, vol. 12(72), pp. 797-808.

Dent, D. and A. Young, 1980. *Soil Survey and Land Evaluation.* George Allen and Unwin Limited. 278 pages.

Department of Environment-Malaysia, 1985. *The Recommended Code of Practice for the Disposal of Solid Waste on Land.* 53 pages

Department of Environment-UK, 1986. *Waste Management Paper No. 26: Landfilling Wastes*. HMSO, London. 206 pages.

Department of Environment-UK, 1992a. *Development Plans and Regional Planning Guidance.* HMSO, London.

Department of Environment-UK, 1992b. *Digest of Environmental Protection and Waste Statistics.* No. 14, 1991. HMSO, London.

Department of Environment-UK, 1971. *Refuse Disposal-Report of the Working Party on Refuse Disposal.* 199 pages.

Department of Town and Rural Planning of Malaysia and Klang Valley Planning Secretariat, 1988. *Klang Valley Perspective Plan.* No pagination

Deventer, P. Van, 1994. Applying Photogrammetry and Remote Sensing for Environmental Monitoring in the State of Ohio and the Netherlands. *Mapping Awareness,* vol. 8(4), pp. 20-23.

Douglas, T. and K. Westhead, 1996. Seeing the Lie of the Land: Digital Photogrammetry Aids Geological Mapping. *Mapping Awareness*, vol. 10(10) pp. 34-37.

Dowman, I. J., 1990a. Digital Plotter: Current Status and Future Developments. *Photogrammetric Record,* vol. 13(75), pp. 331-345.

Dowman, I. J., 1990b. Remote Sensing in Topographic Mapping. *Mapping Awareness*, vol. 4(5), pp. 26 -27.

Dowman, I. J., 1992. Overview of European Development in Digital Photogrammetric Workstations. *Photogrammetric Engineering and Remote Sensing*, vol. 58(1), pp. 51-56.

Dowman, I. J., 1996. Market and Economics of Digital Photogrammetric Systems. *Photogrammetric Engineering and Remote Sensing*, vol. 62(6), p. 681.

Drummond J., D. A. Tait and z. Zamlope, 1997. Building a coastal GIS using digital photogrammtriy. Photogrammetric Record,, vol. 15(90), pp 863-873.

Dueker, K. J. and D. Kjerne, 1989. Multipurpose Cadastre: Terms and Definitions. *Annual ACSM/ASPRS Convention*, vol. 5, pp.94-103.

Dunn, R., A. R. Harrison and P. J. Turton, 1991. Rural-to-Urban Land-Use Change: Approaches to Monitoring and Planning using GIS. *Mapping Awareness,* vol. 5(4), pp. 26-29.

Duren, U., 1993. Digital Orthophoto Generation, *First Course in Digital Photogrammetry*, University of Bonn. No pagination.

Ebner, H. and H. Eder, 1992. State-of-the-Art in Digital Terrain Modelling. *European Conference on Geographical Information Systems (EGIS),* pp. 681-689.

Ecker, R., 1992. Digital Orthophoto Generation Based on a High Quality DTM. *ITC Journal*, vol. 1, pp 59-62.

Ehlers, M., M. A. Jadkowsli, R. R. Howard and D. E. Brostuen, 1990. Application and SPOT Data for Regional Growth Analysis and Local Planning, *Photogrammetric Engineering and Remote Sensing,* vol. 56(2), pp. 175-180.

Elliot, J. A., 1994. *An Introduction to Sustainable Development - The Developing World.* International Thompson Publishing Company. 121 pages.

Engineering and Environmental Consultant Ltd., 1991. *Proposed Masterplan on Solid Waste Management for the Petaling Jaya Municipality. No pagination.*

Engineering Science Inc., SEATEC International and Department of Environment of Malaysia, 1987. *Klang Valley Environmental Improvement Project : Final Report, vol. 1.* No pagination.

Environmental Protection of British Colombia, 1993. *Landfill Criteria for Municipal Solid Waste*. Environmental Protection Division, Ministry of Environment, Lands and Parks, Province of British Columbia.
URL:http://www.env.gov.bc.ca/epd/cpr/criteria/lcwsw.html

Erb, T. L., W. B., Philipson, W. L. Teng and T. Liang, 1981. Analysis of Landfills with Historic Airphotos. *Photogrammetric Engineering and Remote Sensing*, vol. 47(9), pp. 1363-1369.

ERDAS Inc., 1990 *ERDAS Image Processing Manual*. ERDAS Inc. Atlanta.

ERDAS Inc.,1992. *Digital Ortho Manual - version 7.5* . ERDAS Inc. Atlanta.

ESRI, 1993. *Understanding GIS the ARC/INFO Method.* Longman Scientific and Technical. England.

ESRI, 1994. *ARC/INFO Data Management.* Environmental Systems Research Institute, Inc.

Estes, *J. E., K. C. McGwire, G. A. Fletcher and T. W. Foresman* 1987. Coordinating hazardous waste management activities using geographical information systems. *International Journal Geographical Information Systems*, vol. 1(4), pp 359-377.

Estes, *J. E., K. C. McGwire, G. A. Fletcher and T. W. Foresman* 1987. Coordinating hazardous waste management activities using geographical information systems. *International Journal Geographical Information Systems*, vol. 1(4), pp 359-377.

National Land Information System (NALIS) Symposium and Exposition, Kuala Lumpur. No pagination.

Fairbairn, D. and B. Nkwae, 1991. GIS in Developing Botswanan Agriculture. *Mapping Awareness*, vol. 5(8), pp. 21-24.

Felus, P. T. Bouloucos and K. Tempfli, 1996. Photogrammetry and Field Completion – An Intelligent Approach. *International Archives of Photogrammetry and Remote Sensing*, vol. 31(4), pp. 143-148.

Finch, P. and D. Miller, 1994. A Model of DEM and Ortho-image Quality for Aerial Photography. *European Conference on Geographical Information System (EGIS),* pp. 263-270.

Fisher, P. F., 1991. Spatial Data Sources and Data Problems. In *Geographical Information System: Principles and Applications, vol. 1,* edited by Maguire, D., M. F. Goodchild and D. W. Rhind. Longman Scientific and Technical. pp. 175-189.

Gagnon, P. A., J. -P. Agnard, C. Nolette, and M. Baulianne, 1990. A Microcomputer Based General Photogrammetric System. *Photogrammetric Engineering and Remote Sensing,* vol. 56(1), pp. 623-625.

Geodetical Info Magazine, 1993. GIM Interviews Mr. Lawrie E. Jordan, III, President, ERDAS, Inc. *Geodetical Info Magazine*, vol. 7(8), pp. 70 - 73.

Ghanem, R., 1997. GIS for landfill management in Lebonan. http://venus.ce.jhu.edu/lebonan/landfill.html.

Gilpin, A., 1995. *Environmental Impact Assessment.* Cambridge University Press. 182 pages.

Gooding, R. W., J. J. Settle and N. Veitch, 1992. Improved Extraction of Information from Satellite Imagery for Use in GIS. *European Conference on Geographical Information Systems (EGIS),* pp. 1355-1365.

Gourlay, K. A., 1992. *World of Waste - Dilemmas of Industrial Development.* Zed Books Ltd. U.K. 247 pages.

Green, D. R. and D. C. Morton, 1994. Acquiring Environmental Remotely Sensed Data From Model Aircraft for Input to Geographic Information Systems. *Proceeding of AGI Sixth National Conference and Exhibition,* pp. 15.3.1-15.3.27.

Green, D. C., 1996. GIS and its use in waste management. *ESRI user Conference.* URL:http://www.esri.com/base/common/suerconf/europroc96/PAPERS/PN3

Greene, R. H., 1992. Digital Photogrammetric Mapping Integrating GPS in Acquisition and GIS Processing. *Proceeding GIS/LIS'92*, pp. 292-299.

Gruen, A. W., 1988. Digital Photogrammetric Processing Systems - Current Status and Prospects. *International Archive for Photogrammetry and Remote Sensing,* vol. 27(2), pp. 342-351.

Hadalski, J. M. Jr., 1983. The Influence of Computer Graphics on Local Government Productivity. *Computer Graphics and Environmental Planning.* Prentice Hall-Inc., pp. 171-186.

Han, C. S., 1993a. Digital Photogrammetry, on the Move. *Geodetical Info Magazine*, vol. 7(8), pp. 41-43

Han, C. S., 1993b. Photogrammetry: Evolving Towards GIS-Software. *European Conference on Geographical Information Systems (EGIS),* pp. 981-991.

Hanigan, F., 1988. GIS by any other name is still..... *The GIS Forum* 1:6.

Harris, R. C., 1991. Strategic Planning for New Waste Disposal and Ground Water Protection Policy. *The Planning and Engineering of Landfills Conference*, pp. 97-101.

Hassani, M. and J. Carlswell, 1992. Transition to Digital Photogrammetry. *European Conference on Geographical Information Systems (EGIS),* pp. 1121-1128.

Heipke, C., 1995. State-of –the-Art of Digital Photogrammetric Workstations for Topographic Applications. *Photogrammetric Engineering and Remote Sensing*, vol. 61(1), pp. 49-56.

Herman, J. D., J. E. Waites, R. M. Ponitz, and P. Etzler, 1994. A Temporal and Spatial Resolution Remote Sensing Study of a Michigan Superfund Site. *Photogrammetric Engineering and Remote Sensing,* vol. 60(8), pp. 1007-1017.

Heywood, D. I., M. F. Price and J. R. Petch, 1994. Mountain Regions and Geographic Information Systems: An Overview. In *Mountain Environments and Geographic Information Systems* Edited by Price M. F. and D. I. Heywood. Taylor and Francis Ltd., pp. 1-25.

Holmes, J. R., 1984. A Review of Municipal Waste Management Practices in Three South Asian Cities. In *Managing Solid Waste Management in Developing Countries* edited by Holmes, J. R. John Wiley and Sons Ltd., pp. 273-290.

Hsieh, P. Y., 1996. Development of Digital Orthophoto Mapping. *International Archives of Photogrammetry and Remote Sensing*, vol. 31(4), pp. 368-372.

Hughes, D., 1986. *Environmental Law*. Butterworths & Co Ltd. 390 pages.

Jankowski, P., 1995. Integrating Geographical Information Systems and Multiple Criteria Decision-Making Methods. *International Journal Geographical Information Systems*, vol. 9(3), pp. 251-273.

Jensen, J. R. and E. J. Christensen, 1986. Solid and Hazardous Waste Disposal Site Selection using Digital Geographic Information System Techniques. *The Science of the Total Environment*, vol. 56, pp. 265-276.

JICA, 1989a. *Report on Solid Waste Management Study for Pulau Pinang and Seberang Perai Municipalities.* Report prepared for the Pulau Pinang and Seberang Perai Municipalities. No pagination.

JICA, 1989b. *The Study on Applied Technology for Making City Plan.* Report prepared for the Department of Town and Country Planning, Ministry of Interior of Thailand. 138 pages.

Juppenlatz and Tian, 1996. Geographic Information Systems and Remote Sensing. McGraw-Hill Book Company Australia Pty Limited. 145 pages

Kamaruddin, R. 1974. *A National Land Data Bank and Information System for Development.* Report, Federal Land Administration Department, Kuala Lumpur.

Keinegger, D., 1992. Assessment of a Wastewater Service Charge by Integrating Aerial Photography and GIS. *Photogrammetric Engineering and Remote Sensing*, vol. 58(11), pp. 1601-1606.

Kielbrer Burger and Perunding Sdn. Bhd., 1990. *Solid Waste Masterplan of Ipoh for The Year 2010.* No pagination.

Kirov, N. Y., 1972. *Solid Waste Treatment and Disposal.* Ann Arbor Science Publishers Inc. 204 pages.

Korte, G. B., 1992. *The GIS Book.* OnWord Press. Second Edition.166 pages.

Krzystek, P., 1993. Automatic DEM Generation, *First Course in Digital Photogrammetry,* University of Bonn. No pagination.

Lane W. N., M. Asce and R. R. McDonald, 1983. Land suitability anlysis: landfill siting. *Journal of Urban Planning and Development*. Vol 109(1), pp. 50-62.

Lau, C-W., 1991. Design of Flexible Drainage System for Sai Tso Wan Landfill. *The Planning and Engineering of Landfills Conference,* pp. 243-246.

Laurini, R. and D. Thompson, 1992. *Fundamentals of Spatial Information Systems.* Academic Press Limited. 680 pages.

Le Poole, R. S., 1992. Potential and Limitations of Digitisation Of Photographs. *Geodetical Info Magazine,* vol. 6(5), pp. 58-60.

Leberl, F., H. Ebner and I. Dowman, 1992, Design Issues of Softcopy Photogrammetric Workstations, *Photogrammetric Engineering and Remote Sensing*, vol. 58(1), pp. 49.

Lemmens, M. J. P. M., 1988. GIS - Digital Image Interaction. *International Archives of Photogrammetry and Remote Sensing,* vol. 28(4), pp. 575-586.

Li, Z. 1988. On the Measure of Digital Terrain Model Accuracy. *Photogrammetric Record,* vol.12(72), pp. 873-877.

Li, Z., C. T. Hill, A. Azizi and M. J. Clark, 1993. Exploiting the Potential Benefits of Digital Photogrammetry: Some Practical Examples. *Photogrammetric Record,* vol. 14(8), pp. 469-475.

Lyon, J. G., 1987. Use of Maps, Aerial Photographs and Other Remote Sensor Data for Practical Evaluation of Hazardous Waste Sites. *Photogrammetric Engineering and Remote Sensing,* vol. 53(5), pp. 515-519.

Madani, M., 1992. The Intergraph Image Station Photogrammetric System. *ITC Journal*, vol. 1, pp. 87-92.

Madani, M., 1993. The State of Digital Photogrammetry. *Geodetical Info Magazine*, vol. 7(8), pp. 63-65.

Malczewski, J., 1996. A GIS-based Approach to Multiple Criteria Group Decision-Making. *International Journal Geographical Information Systems*, vol. 10(8), pp. 955-971.

Mansor, A. B., 1994. Building a Spatial Database - The Department of Agriculture Experiences. *National Land Information System (NALIS) Symposium and Exposition, Kuala Lumpur.* No pagination.

Manzer, G. B., 1993. High Resolution Scanning and Digital Orthocorrection of Aerial Photography and High Resolution Film Writing. *Proceeding 7th Annual Symposium on Geographical Information Systems in Forestry, Environment and Natural Resources Management,* pp. 1021-1026.

Manzer, G. B., 1995. Maximizing Digital Orthophoto Use - A Technical Overview. *GIS World*, vol. 8(12), pp. 50 - 55.

Marble, D. F., 1990. Geographic Information System: An Overview. In *Introductory Readings in Geographic Information Systems*, edited by D. J. Peuquet and D. F Marble. Francis and Taylor, pp. 9-17.

Masser, I., 1990. The Utilisation of Computers in Local Government in Less Developed Countries: A Case Study of Malaysia. *Proceedings of the 1990 Annual Conference of the Urban and Regional Information Systems Association,* vol. 1, pp. 235 - 245.

Mattravers, A. J., and K. Bewsey, 1991. North East New Territories Landfill, Hong Kong. *The Planning and Engineering of Landfills Conference*, pp. 241-242.

Mausel, P. W., J. H. Everitt, D. E. Escobar, and D. J. King, 1992. Airborne Videography: Current Status and Future Perspectives. *Photogrammetric Engineering and Remote Sensing*, vol. 58(8), pp. 1189-1195.

Mayr, W., 1992. Digital 3D Data Processing with New Carl Zeiss Systems. *ITC Journal*, vol. 1992-1, pp. 93-97.

McAulay, I., 1991. Environmental Impact Analysis: A Cost Effective GIS Application? *Mapping Awareness,* vol. 5(4), 36-39.

McDonald, A. J. W., 1994. Remote Mapping of UK Geology. *Proceeding of AGI Sixth National Conference and Exhibition, pp. 15.4.1-15.4.3.*

Mcfarland, R. 1990. GIS Implementation Strategies for the Small Municipal Environment. *Proceeding GIS/LIS '90*, vol. 1 and 2, pp. 167-173.

MDC Sdn. Bhd., 1994. *Environmental Quality Act 1974 and Regulations - Details on Environmental Quality Act 1974 and Regulations Amendments from 1980 to March 1994.* 159 pages.

Melbourne and Metropolitan Board of Works, 1985. *Off-site Industrial Waste Storage Treatment and Disposal Facilities: Proposed Siting Criteria.* Melbourne and Metropolitan Board of Works, Australia.

Mikhail, E. M.,.1996. From the Kelsh to the Digital Photogrammetric Workstation. *Photogrammetric Engineering and Remote Sensing*, vol. 62(6), p. 680.

Miller, D. R., 1996. Landscape Visualisation Using DEM Data Derived from Digital Photogrammetry. *Third International Conference/Workshop on Integrating GIS and Environmental Modelling CD-ROM.* No pagination.

Miller, S. B., U. V. Heleva and K. D. Heleva, 1992. Softcopy Photogrammetric Workstations. *Photogrammetric Engineering and Remote Sensing,* vol. 58(1), pp. 77-83.

Mills, J. and I. Newton, 1996. A New Approach to the Verification and Revision of Large-Scale Mapping. *ISPRS Journal of Photogrammetry and Remote Sensing*, vol. 51(1), pp. 17-27.

Ministry of Housing and Local Government and JICA, 1990. *Technical Report on Sanitary Landfill Design and Operation.* No pagination.

Ministry of Housing and Local Government, 1984. *A Guideline on Storage, Collection, Transportation and Disposal of Solid Waste in Malaysia.* No pagination.

Ministry of Housing and Local Government and Kumarisivam Tan and Ariffin Sdn Bhd., 1990. *Preliminary Environmental Impact Assessment: Proposed Sanitary Landfill Projects for Local Authorities, Bentong, Pahang.* No pagination.

Mioali Perfecture, 1995. *Landfill Siting Rule Guide.* Mioali Perfecture, Taiwan. URL:http://ev004.ev.nctu.edu.tw/ENGLISH/netgis/sitegis.html.

Montuori, J. S., 1980. Image Scanner Technology. *Photogrammetric Engineering and Remote Sensing*, vol. 41(1), pp. 49 -61.

Moran, M. M., M. D. Morgan and J. H. Weirsma, 1986. *Introduction to Environmental Science (Second Edition).* W. H. Freeman and Company. 709 pages.

Murray, A. T. and R. L. Church, 1995. Solid-Waste-Disposal Site Location. *Journal of Urban Planning and Development,* vol. 121(3), pp. 109-114.

Nale, D.K., 1995. How Accurate is Digital Orthophotography? *GIS World,* vol. 8(12), pp. 62-64.

Nolette, C., P.-A. Gagnon, and J. P. Agnard, 1992. The DVP: Design, Operation, and Performance. *Photogrammetric Engineering and Remote Sensing,* vol. 58(1), pp. 65-69.

O'Riordan, T., 1995a. Environmental Science on the Move. In *Environmental Science for Environmental Management* edited by O'Riordan, T. Longman Group Limited. pp. 1-15.

O'Riordan, T., 1995b. The Global Environment Debate. In *Environmental Science for Environmental Management* edited by O'Riordan, T. Longman Group Limited, pp. 16-29.

Ontario Waste Management Corporation, 1985. *Facility Development Process: Phase IVA Report. The Selection of a Preferred Site.* Ontario Waste Management Corporation, Toronto, Canada.

Oweis, I. S. and R. P. Khera, 1990. *Geotechnology of Waste Management.* Butterworth and Co. Ltd. 273 pages.

Parent, P. and R. Church, 1987. Evolution of Geographical Information Systems as Decision Making Tools. *Proceedings of GIS/LIS'87*, pp. 63-70.

Pereira, J. M. C. and L. Duckstein, 1993. A Multiple Criteria Decision-Making Approach to GIS-based Land Suitability Evaluation. *International Journal Geographical Information Systems*, vol. 7(5), pp. 407-424.

Petrie, G., 1994. Photogrammetric Input to an Environmental GIS. *Proceeding of AGI Sixth National Conference and Exhibition*, pp. 21.3.1- 21.3.7.

Petrie, G., 1997. Developments in Digital Photogrammetric Systems for Topographic Mapping Application. *ITC Journal,* vol. 2, pp. 121-135.

Petrie, G., 1997. The Current Situation in Africa regarding Topographic Mapping and Map Revision from Satellite Imagery. *ITC Journal*, vol. 1, pp. 49-62.

Petrie, G., and A. E. H. El Niweiri, 1992. The Applicability of Space Imagery to Small-Scale Topographic Mapping of Developing Countries: A Case Study - the Sudan. *ISPRS Journal of Photogrammetry and Remote Sensing,* vol. 47(1),. pp. 1-47.

Petts, J. and G. Eduljee, 1994. *Environmental Impact Assessment for Waste Treatment and Disposal Facilities.* John Wiley and Sons Limited. 342 pages.

Peuquet D. J. and D. Marble, 1990. *Introductory Readings in Geographic Information Systems.* Francis and Taylor, 371 pages

PlanGraphic, 1998. High Resolution Satellite imagery –Are You Ready? URL:http:///www.plangraphic.com.satellite3.html

Preston, S., and D. Unwin, 1992. SKIS: A GIS Approach to Ski Mapping. *Mapping Awareness and GIS in Europe*, vol. 6(10), pp. 24-29.

Ramly, M. K., 1995. Requirement for the Development of Teaching in Geographical Information Systems (GIS) in the Malaysian Higher Education System (MHES) : An Investigation into the Infrastructural and Curriculum Requirements. *M. Phil. Thesis (unpublished).* University of Edinburgh. 273 pages

Ranhill Bersekutu Sdn. Bhd.,1992. *Preliminary Environmental Impact Assessment - The Development of Sanitary Landfill Site at Jalan Puchong/Seri Kembangan (Site B), Petaling.* No pagination

Richardson, J. A., 1939. *The Geology and Mineral Resources of the Neighbourhood of Raub, Pahang, Federated Malay States, with an Account of the Geology of the Raub Australian Gold Mines.* Printers Limited. 166 pages.

Richason, B. J. and J. Johnson. 1990. GIS Application in the Siting Processing. *Proceedings GIS/LIS'90*, pp. 695-703.

Rogers, Golden and Halpern, 1985. *Hunterdon County Landfill Evaluation and Siting Study,* prepared for County of Hunterdon, Flemington, New Jersey.

Rusmani, A. R. 1987. Development of Land Information System in Malaysia. Unpublished Advance Diploma Dissertation. MARA Institute of Technology, Malaysia.

R-Wel. Inc., 1992. *Desktop Mapping System Manual-version 3.1.* No pagination.

Saleh, R. A., 1996. Photogrammetry and the Quest for Digitalization. *Photogrammetric Engineering and Remote Sensing,* vol. 62(6), pp. 675-678.

Samik, M. N., 1985. *Agriculture Information System.* Published by the Department of Agriculture, Malaysia.

Sarjakoski, T., 1992. Suitability of the Sharp JX-600 Desktop Scanner in Digitising of Aerial Colour Photographs. *International Archives of Photogrammetry and Remote Sensing*, vol. 29(1), pp. 79-86.

Schenk, T., 1988. The Effect of Digital Photogrammetry on Existing Photogrammetric Concept, Procedures and Systems. *International Archives of Photogrammetry and Remote Sensing*, vol. 29(2) , pp. 234-243.

Schenk, T., 1996. Current Status and Future Directions of Digital Photogrammetry: A Personal View. *Photogrammetric Engineering and Remote Sensing*, vol. 62(6), pp. 681.

Schenk, T. and C. K. Toth, 1992a. Computer Vision and Digital Photogrammetry. *ITC Journal,* vol. 1, pp. 34-38.

Schenk, T. and C. K. Toth, 1992b. Conceptual Issues of Softcopy Photogrammetric Workstations. *Photogrammetric Engineering and Remote Sensing*, vol. 58(1), pp. 101-110.

Seetharam, K. E., 1992a. GIS and its Applications in Urban and Regional Planning and Management. *Proceeding of the Mapping Awareness'92 Conference*, pp. 71-82.

Seetharam, K. E., 1992b. Global Environmental Concerns Illuminate GIS Development in Japan. *Mapping Awareness*, vol. 6(10), pp. 46-51.

Shah Alam Municipality, Petaling Jaya Municipality, Petaling District Council and Selangor State Department of Town and Rural Planning, 1994. *Draft Structure Plan for the District of Petaling and Part of Klang 1988-2010.* No pagination.

Shears, J. C. and J. W. Allan, 1996, 1996. Softcopy Photogrammetry and its Uses in GIS. *International Archives of Photogrammetry and Remote Sensing*, vol. 31(4), pp. 70-73.

Shepherd, I. D. H., 1991. Information Integration and GIS. In *Geographical Information System: Principles and Applications, vol. 1,* edited by Maguire D., M. F. Goodchild and D. W. Rhind, pp. 337-360.

Siderelis, K.C., 1991. Land Resources Imformation System. In *Geographical Information System: Principles and Applications, vol. 2,* edited by Maguire D., M. F. Goodchild and D. W. Rhind, pp. 261-273.

Skalet, C. D., G. Y. G. Lee and L. J. Ladner, 1992. Implementation of Softcopy Photogrammetric Workstation at the U.S. Geological Survey. *Photogrammetric Engineering and Remote Sensing*, vol. 58(1), pp.57-63.

Slangmaat, M. J. M. V. and A. A. V. D. Veen, 1990. Building an Environmental Information System for Local Authorities. The Remis-Project. *European Conference on Geographical Information Systems (EGIS),* pp. 1044-1053.

Small, W. E., 1971. *Third Pollution.* Pall Mall Press Limited. 173 pages.

Smith, D. R and J. H. Robinson, 1983. Computer-Aided Siting of Coal-Fired Power Plants: A Case Study. In *Computer Graphic and Environmental Planning* edited by Teicholz, E. and B. J. L. Berry. Prentice Hall-Inc., pp. 187-201.

Smith, M. J. and D. A. Waldram, 1996. Automated Digital Terrain Modelling of Coastal Zones. *International Archives of Photogrammetry and Remote Sensing*, vol. 31(4), pp. 919-923.

Smith, S. E. and D. W. Gibson, 1993. Country-Level Geographical Information Systems in Florida. *Geodetical Info Magazine*, vol. 7(2), pp. 55-57.

Stefanovic P., 1996. Digital Stereoplotters. *ITC Journal* 3-4.

Steiner, D. R, 1992. The Integration of Digital Orthophotographs with GIS in a Microcomputer Environment. *ITC Journal,* no. 1, pp. 65-71.

Sterling, E. P., 1994. Implementation of a Pilot Geographical Information System for National Spatial Planning in the Economic Planning Unit.

Stohr, C., R. G. Darmody, T. D. Frank, A. P. Elhance, R. Lunetta, D. Worthy and K. O. Shoresman, 1994. Classification of Depressions in Landfill Covers using Uncalibrated Thermal-Infrared Imagery. *Photogrammetric Engineering and Remote Sensing*, vol. 60(8), pp. 1019-1028.

Street, A., 1991. Landfilling in Europe - How Does the UK Compare? *Proceeding of the Planning and Engineering of Landfills Conference,* pp. 119-124.

Taher, B., 1994. GIS for Local Authorities. *National Land Information System (NALIS) Symposium and Exposition, Kuala Lumpur.* No pagination.

Tanner, C., 1994. GIS and Photogrammetry Trends in Africa. *Geodetical Info Magazine,* vol. 8(8), pp. 37-39.

Tchobanoglous, G., H. Theisen and S. Vigil, 1993. *Integrated Solid Waste Management - Engineering Principles and Management Issues.* Mcgraw-Hill International Editions. 978 pages.

Technical Section, Local Government Division. Ministry of Housing And Local Government, 1988. *Action Plan for a Beautiful and Clean Malaysia.* No pagination.

Thapa, K. and J. Bossler, 1992. The Accuracy of Spatial Data Used in Geographical Information Systems. *Photogrammetric Engineering and Remote Sensing*, vol. 58(6), pp. 835-841.

Theodossiou, E. I. and I. J. Dowman, 1990. Height Accuracy of SPOT. *Photogrammetric Engineering and Remote Sensing*, vol. 56(5), pp. 623-625.

Thiel, P. J. and J. F., Zumwald, 1995. Are Digital Orthophotos for You? *GIS World,* vol. 8(12), pp. 58-61.

Thomas, P. R., J. P. Mills, and I. Newton, 1995. An Investigation into the Use of Kodak Photo CD for Digital Photogrammetry. *Photogrammetric Record*, vol. 15(86), pp. 301-314.

Thorpe, J., 1989. The Need for Photogrammetry in Building an Urban GIS. *Geodetical Info Magazine,* vol. 3(6), pp. 19.

Thorpe, J., 1993. Aerial Photogrammetry: State of the Industry in the US. *Photogrammetric Engineering and Remote Sensing,* vol. 59(11), pp. 1599-1607.

Toth, C. K. and T. Schenk, 1992. Feature-based Matching for Automatic Image Registration. *ITC Journal,* vol. 1, pp. 40-46.

Tragheim, D. and K. Westhead, 1996. Seeing The Lie of The Land: Digital Photogrammetry Aids Geological Mapping. *Mapping Awareness*, vol. 10(2), pp. 34-37.

Treitz, P. M., P. J. Howarth and P. Gong, 1992. Application of Satellite and GIS Technologies for Land-Cover and Land-Use Mapping at the Rural-Urban Fringes: A Case Study. *Photogrammetric Engineering and Remote Sensing*, vol. 58(4), pp. 439-448.

Tudor, S. G. and L. J. Sugarbaker, 1993, GIS Orthographic Digitising of Aerial Photographs by Terrain Modelling. *Photogrammetric Engineering and Remote Sensing,* vol. 59(4), pp. 499-503.

Tyler, W. A., C. Cheisa and L. E. Reed, 1992. Satellite Mapping Comes of Age. *Geodetical Info Magazine*, vol. 6(12), pp. 56-58.

Uren, J., 1991. The Application of Surveying Techniques to the Measurement of Landfill Volumes. *Proceeding of the Planning and Engineering of Landfills Conference*, pp. 221-224.

Uren, J. and C. T. Yong, 1990. The Development of an Air Photo Based Land Information System. *Mapping Awareness,* vol. 4(3), pp. 22-26.

USEPA (United States Environmental Protection Agency), 1991. *Solid Waste Disposal Facility Criteria; Final Rule. 40 CFR Parts 257 and 258.* Federal Register - United States Environmental Protection Agency.

Usery, E. L., 1989. A Raster Approach to Topographic Map Revision. *Photogrammetric Engineering and Remote Sensing*, vol. 55(1), pp. 55-59.

Van Westen, C. J., 1994. GIS in Landslide Hazard Zonation: A Review, with Examples from the Andes of Colombia. *In Mountain Environments and Geographic Information Systems* edited by Price M. F. and D. I. Heywood. Taylor and Francis Limited. pp. 135-165.

Vargo, R, 1991. Development of an Image Management System for the Air Photo User. *Geodetical Info Magazine*, vol. 5(6), pp. 35-36.

Vesilind, P. A., J. J. Peirce and R. Weiner, 1988. *Environmental Engineering.* Second Edition, Butterworths. 545 pages.

Vincent, R. K., 1994. Remote Sensing for Solid Waste Landfills and Hazardous Waste Sites. *Photogrammetric Engineering and Remote Sensing*, vol. 60(8), pp. 979-982.

Walker, A. S., 1987. Input of Photogrammetric Data to Geographical Information Systems. *Photogrammetric Record,* vol. 12(10), pp 459-471.

Waltham, A. C., 1994. *Foundations of Engineering Geology*. Blackie Academic and Professional; an imprint of Chapman and Hall. 88 pages.

Warner, W. S., 1994. Evaluation of Low-Cost, Non-Metric Aerial Mapping System for Waste Site Investigators. *Photogrammetric Engineering and Remote Sensing*, vol. 60(8), pp. 983-988.

Weber, C., and D. E. J. Hirsch, 1992. Remotely Sensed Indices for Urban Growth using Low and High Resolution Sensors: Comparison in an Urban Growth Study with ARC/INFO. *European Conference on Geographical Information Systems (EGIS),* pp. 940-943.

Weber, R. S. and W. E. Ware, 1990. Effective Use of Geographic Information System Technology in Municipal Scale Environmental Management. *Proceedings of the 1990 Annual Conference of the Urban and Regional Information Systems Association,* vol. 1, pp. 125-139.

Welch, R. A., 1987. Integration of Photogrammetry, Remote Sensing and Database Technologies for Mapping Applications. *Photogrammetric Record*, vol 12(70). pp. 409-428.

Welch, R. A., 1989. Desktop Mapping with Personal Computers, *Photogrammetric Engineering and Remote Sensing,* vol. 55(11), pp. 1651-1662.

Welch, R. A., 1992. Photogrammetry in Transition - Analytical to Digital. *Geodetical Info Magazine*, vol. 6(7), pp. 39-41.

Welch, R. A., 1993. Low-cost Softcopy Photogrammetry. *Geodetical Info Magazine*, vol. 7(12), pp. 55-59.

Wilkinson, G. G., 1996. A Review of the Current Issues in the Integration of GIS and Remote Sensing Data. *International Journal Geographical Information Systems*, vol. 10(1), pp. 85-101.

Wolf, D. R. and E. T. Slonecker, 1989. Testing Large-Scale Digital Line Graphs and Digital Elevation Models in a Geographic Information System. *AutoCarto'89*, pp. 397-405.

Wood, J. 1994. Visualisation Contour Interpolation Accuracy in Digital Elevation Models *in Visualisation in Geographical Information Systems* edited by Hearnshaw H. M. and D. J. Unwin. John Wiley and Sons Limited. pp. 168-180.

Worall, L., 1990. Issues in the Application of GIS in Urban and Regional Policy Making Environments. *European Conference on Geographical Information Systems (EGIS),* pp. 1173-1182.

Yaakub, A. B., 1991. The Application of Geographic Information Systems for Urban Land Use Planning and Monitoring: A Case Study of Low -Cost Housing Development in Kuala Lumpur, Malaysia. *Ph.D. Thesis (unpublished)*. University of Edinburgh.

Yeh, A. G., 1991. The Development and Applications of Geographic Information Systems for Urban and Regional Planning in the Developing Countries. *International Journal Geographical Information Systems*, vol. 5(1), pp. 5-27.

Zee, C. V. and J. E. Lee, 1989. Hazardous Waste Disposal Site Selection Using Interactive GIS Technology. *AutoCarto'89*, pp. 391-396.

Zhang, J. and X. Wu, 1993. Development of Digital Photogrammetry in WTUSM. *Geodetical Info Magazine*, vol. 7(8), pp. 41-43.

Zheng, Y-J., 1993. Digital Photogrammetric Inversion: Theory and Application to Surface Reconstruction. *Photogrammetric Engineering and Remote Sensing*, vol. 59(4), pp. 489-498.

Appendix A Government agencies involved in solid waste management

Federal agencies and their intended responsibilities

Federal authorities	Responsibility
Prime Minister's department	
• Economic Planning Unit	• central planning agency responsible for socio-economic development programme. The Social Services section is responsible for solid waste management.
• Klang Valley Planning Secretariat	• to plan, coordinate, and monitor development in the Klang Valley region.
Ministry of Finance	• responsible for the allocation of funds for all development projects in the country, including projects mandated under the Five-year Malaysia Development Plan
Ministry of Housing and Local Government	
Local Government Division	• to formulate policies for the development of a uniform system of Local Government. The Technical Section role is to give technical advise to the local authorities in all public health engineering and other engineering functions in urban areas, including the solid waste management.
Department of Town and Country Planning	• to give technical advice and assistance on planning policies.
Ministry of Health	
• Engineering Services Division	• responsible for the implementation and monitoring of the National Environmental Sanitation Programme which only applies for rural areas and concerns four major aspects: 1) water supply, 2) excreta disposal, 3) sludge disposal and 4) solid waste disposal. Note:- only the first two are given attention
Ministry of Science, Technology and Environment	
• Department of Environment	• responsible for the prevention, abatement, control of pollution and enhancement of the quality of environment in accordance with the provisions of the Environmental Quality Act of 1974. As for municipal solid waste, DOE is especially concerned with the final disposal because of its environmental implications.
Ministry of Works	
• Public Works Department	• this department is responsible for the planning, construction, supervision and maintenance of public works such as roads, bridges, buildings and water supply.

State agencies and their intended responsibilities

State authorities	Responsibility
State Economic Planning Unit (SEPU)	• The SEPU of each state is an extension of the Federal Economic Planning Unit and is in charge of the actual planning of socio-economic development programme in the respective states.
State Economic Development Cooperation (SEDC)	• The SEDC is responsible for the implementation of commercial and industrial development projects of the states, including those in local authorities. It also undertakes comprehensive development of infrastructure for new local authorities, such as drains, sewers and other utilities.
State Division of Local Government	• All state governments have a division responsible for local governments. This division is responsible for the coordination of state government affairs such as allocation of land for solid waste disposal.
State Medical and Health Services Department	• This department is responsible for the public health programmes in the states. The Health Section is responsible for the rural water supply and environmental sanitation matters. Officers in this section advise and assist local authorities in matters regarding to sewerage, drainage and solid waste management.
State Town and Country Planning	• This department acts as an advisor to the state government on matters pertaining to land development so as to coincide with the overall planning policies and land use plan of the state.

Appendix B – Typical questions asked during informal discussions with officers from various organisations

[A] APPLICATIONS OF GIS AND MAPPING TECHNOLOGY - GENERAL

1. The use of GIS within municipality

- Yes
- No
- In future. when?

2. Applications of GIS

- Analysis tools
- Inventory tools
- others..

Specific applications...

3. GIS unit under which section

- planning
- engineering
- others..

4. Mapping unit

- Yes
- No
- Future planning

[B] DATA AND ACQUISITION METHODS

1. Data acquisition

- within organisation
- contracted to other

2. Future data acquisition methods

- satellite remote sensing
- digital photogrammetric method
- others…….. specify

3. Current data sources

- existing maps/plan
- existing digital data
- aerial photographs
- satellite imagery

4. Currency of data (maps or digital data)

- less than 5 years
- more than five years but less than 10 years
- more than 10 years

4. Types of maps used

- Types of maps available/used
- Problem with existing maps

5. Possibility of acquiring data in-house

- **Yes**
- **No................ Why?**

[C] SOFTWARE AND HARDWARE USED

1. Available software

- GIS
    - Workstation base
    - PC-based
- Mapping
- CAD
- Database/Spread sheets

2. Number of licences

- GIS
- Mapping
- CAD

3. Hardware platform/Numbers

- Workstations
- PCs

4. Other hardware

- digitisers
- scanners
- others

[D] SKILL PERSONNEL WITHIN ORGANISATION

1. No of skill personnel

- GIS
- Mapping

2. level of expertise

[E] LANDFILL SITE SELECTION

1. Location of existing sites

- surrounding landuse
- area
- site capacity
- problems at the site
- start operation
- expected closure

2. Methods used to select these sites

- based on social, environmental and socio-economic considerations?
- others

3. Important site selection criteria

- Geology
- Environmental considerations
- Economics
- Others …… specify.

4. Selection of future sites. Will it be a problem?

- Yes
- No

Give explanation………

5. If a regional and a stage-by-stage approach is to be implemented

- Indicate the problem that will be faced

Appendix B2 List of organisations involved

Name of organisations	Landfill	Technology	Data
Local authority			
• Petaling District Office (currently known as Subang Jaya Municipality)	✓	✓	✓
• Shah Alam Municipality	✓	✓	✓
• Petaling Jaya Municipality	✓	✓	✓
• Gombak District Council (currently known as Selayang Municipality)	✓	–	–
• Klang Municipality	✓	✓	✓
• Hulu Langat District Council	✓	–	–
• Kuala Lumpur City Council	✓	–	–
Planning authority			
• Selangor State Town and Rural Planning	✓	✓	✓
• Planning Department (Shah Alam Municipality)	✓	✓	✓
• State Economic Planning Unit (Selangor)	✓	✓	✓
• Klang Valley Planning Secretariat	–	✓	✓
Other government organisations			
• Selangor State Land Office	✓	–	✓
• Department of Environment (Head Quarters)	✓	✓	✓
• Department of Agriculture	✓	✓	✓
• Department of Geology	✓	✓	✓
• Technical Section, Ministry Housing and Local Government	✓	–	–
• Trengganu State Department of Environment	✓	–	–
• Federal Department of Survey and Mapping	–	✓	✓
• Malaysian Centre for Remote Sensing (MACRES)	–	✓	✓
• Forestry Department	✓	✓	✓
• Forestry Research Institute of Malaysia (FRIM)	–	✓	✓
• Public Works Department		✓	✓
Private company			
• Alam Flora	✓	–	–

Appendix C1 Site selection criteria for Melbourne and Metropolitan Board of Works, Australia

Exclusionary criteria	• Preference criteria characteristics
Topography • Not on slope greater than 10%	• Slopes of less than 5%
Surface soils • Not within areas where subsidence in evident or areas of unstable soils/geology where movement is a recurring event	• Stable gradational soil/rock structure
Atmospheric conditions • (no common exclusionary criteria)	• Areas where local wind systems are capable of readily dispersing emissions/odours • Areas downwind from populated areas or ecological sensitive areas
Recreational value • Not within local or regional parkland or areas declared as recreational reserves, camping reserves or sporting reserves	• Outside areas with potential as future parkland or reserves
Population density • Not within intensive and semi-intensive living areas - areas zoned for residential development, township or village development, or rural residential development	• Low residential population density • Not within labour-intensive industrial areas • Areas in small number of ownerships
Water supply • Not within water supply catchment or in areas with significance as future water catchment or resources • Not within identified aquifer recharge zones where aquifers are used for irrigation or potable supply	• Low to medium water table • Poor quality ground water

(Source: Melbourne and Metropolitan Board of Works, 1985)

Appendix C2 Criteria in essential rules

Factors	Criteria	Description
Environmental	Groundwater	• Landfill should be kept away from drinking water resources, groundwater recharge and recharge well areas
	Surface water	• Landfill should not be located within drinking water resources area or reservoir • Landfill should not be located within certain specified distance upstream and downstream of the water intake point
	Ecological critical areas	• Landfill should not be located within natural ecological conservation district
	Physiographic condition	• Landfill should not be located within a 100-year floodplain, catchment area or possible flooded area.
	Geological condition	• Landfill should not be constructed within areas subject to landslide • Landfill should be kept away from fault, underground tunnel (due to mining activities) and erosion areas.
Social/cultural	Population density	• Landfill should be at least 100 metres away from residential area
	Cultural and scene critical areas	• Landfill should not be located near school, hospital, historical sites or national park
	Regional planning	• Landfill should not be located within woodland • Land allocated for special industry can be used for landfill • Landfill can be constructed within agriculture land provided authorised by administration.

(Source: Miaoli Perfecture, 1997)

Appendix C3 Sanitary lanfill design and siting criteria as suggested by the Transportion, Water and Urban Development Department of the World Bank

Criteria	Description
Land area	• Adequate land area and volume for at least 10 years
Haul distance	• less than 30 minutes travel time from collection centres • hours travel time if transfer stations are used
Accessibility	• Accessible distance from competent paved public road that has an adequate width, slope, visibility and construction to accommodate the projected truck traffic. New access road should be less than 10 km for large landfill serving metropolitan areas and less than 3 km for small landfill serving secondary cities.
Groundwater	• Seasonal high level (i.e. 10 year high) is at least 1.5 below the proposed base of any excavation. If this criterion is not met, the use of impermeable plastic linear is required.
Soil	• Soil above groundwater must be relatively impermeable (preferably less than 10^{-9} m/s
Surfacewater	• No private of drinking, irrigation, or livestock water supply wells within 500 metres down-gradient
Cover material	• Available on-site cover materials to meet the need for immediate and final cover.
Wetland	• No environmentally significant wetlands within potential landfill site
Endangered species	• No known rare or endangered species or significant protected forests are within 500 metres of the landfill
Wind pattern	• No open area of high winds
Powerline	• No major lines of electrical transmission or other infrastructure (i.e. gas, sewer or waterlines) are crossing the landfill.
Underground mines	• No underlying underground mines
Residential areas	• No residential development within 250 metres from the perimeter of the proposed landfill,
Visibility	• No visibility of the proposed landfill area from residential neighbourhoods within 1 km.
Stream	• No perennial stream within 300 metres down-gradient of the proposed landfill.
Geology	• No significant seismic risk within the region of the landfill which could cause destruction of berms, drains or other civil engineering works • No fault lines or significantly fractured geologic structure within 500 metres of the perimeter of the proposed landfill
Floodplain	• No siting within a floodplain subject to 10-year floods
Cultural sensitive	• Avoid siting within 1 km of culturally sensitive sites where public acceptance might be unlikely (i.e. memorial sites, churches, schools) and avoid access roads which would pass by such sites
Airport	• No siting within 3 km of a turbojet engine airport and 1.6 km of a piston-type airport. Sites located more than 3 km and less than 8 km from the nearest turbo-jet airport (or more than 1.6 km and less than 8 km from the nearest piston-engine airport) should not be considered unless the aviation authority has provided written permission stating that it considers the location as not threatening the air safety.

(Source: Adopted from Cointreau-Lavine, 1996)

Appendix C4 Recommended site selection criteria (DoE of Malaysia)

Criteria	Explanation
1. Land characteristics	• low-lying land, swampy area and mud flats, disused mining area (excavated and ponds/pools), disused canals, disused ravines and foreshore estuarial land
2. Geological and hydro-geological Considerations	• avoid sites near aquifers and rivers, high water table and avoid land with potential flooding
3. Cover material	• availability of suitable cover material on or close to the site. Ideal soil for cover material should contain 50 to 60 per cents sand, plus clay and silt is roughly equal parts.
4. Accessibility	• Site selected should have good roads and must be easily accessible via highways or major roads in any kind of weather to all vehicles expected to be used.
5. Proximity to the airports	• sites should be at a safe distance from the airport. The safe distance should be determined in consultation with the Department of Civil Aviation.
6. Proximity to residential and Industrial areas	• there must be no incompatible development within, or adjacent to the site during its life span. According to the Department of Environment the recommended distance of the site to the residential or industrial areas is 1.5 km.
7. Ultimate use of site after closure	• compatible with future land use
8. Effective life expectancy of site	• minimum of 5 years
9. Other criteria	• Prevailing wind and topographic features must also be considered. No further detail is given.

(Source: Adopted from DoE of Malaysia, 1985)

Appendix C5 Proposed siting criteria (Klang Valley Environmental Improvement Project)

Criteria	Ideal condition
Environmental factors • groundwater • surface water • surrounding areas	 • Select area where groundwater is not used or planned to be used • select area not subject to flooding or major surface water supply • include upper portion of drainage area so that runoff can be redirected • Select area naturally isolated and screened to avoid noise, wind blown debris and odour
Economic factors	• reasonable land acquisition cost • reasonable life expectancy of disposal site • economical distance from collection area • availability of cover material on-site • site can be access from major transportation corridors
Social and political acceptability factors	• isolated from public by distance and screening • vehicle can be access without extensive travel through the residential areas • conformity with land use plans • suitability of completed site for subsequent use

(Source: Adopted from Environmental Science Inc., SEATEC International and DoE of Malaysia, 1987)

Appendix C6 Suitability score evaluation

Matrix Criteria	Score 1 (Not Suitable)	Score 5 (Medium Suitability)	Score 10 (Very Suitable)
Social/Political			
Adjacent Land use	Primary Conflict exist	Some conflict - can be manage	No conflicting adjacent uses
Haul Route Suitability	Route through major residential neighbourhood	Some residence on route	No residence
Offside Visibility	Highly Visible from public area	Some portion visible - can screen	Well screened - not visible
Downstream Sensitivity	Highly sensitive, needs detention	Moderate sensitivity - can be manage	No sensitivity
Current Zoning	Residential or conservation	Agricultural Zone	Industrial Zone
Physical			
Water body and Wetland impact	Extensive encroachment – restriction	Some encroachment - can manage	No encroachment
Subsurface Conditions	Restrictive – rock and water	Some restrictive -some cover soil	No restrictive - cover soil available
Acreage of Suitable Land	10 acres or less	Approximately 20 acres	more than 50 acres
Configuration of Suitable Land	Narrow and constricted	Some restriction- can manage	Square - suitable land in bulk
Existing Slope	Highly restrictive - more than 25% prevalent	Some steep area -can manage	All land 1-10%
Flood Zone Impact	Extensive encroachment – restrictive	Some encroachment - can manage	No encroachment
Water Supply Proximity	Major encroachment - from 500ft setback	Some encroachment - can manage	No encroachment
Economic			
Site Development Cost	High Cost	Medium Cost	Low Cost
Cover Material Availability	Small Quantity	Medium Quantity	Large Quantity
Haul Route Improvement	High Cost	Medium Cost	Low Cost
Haul Cost	High Cost	Medium Cost	Low Cost
Land Cost	High Cost	Medium Cost	Low Cost

(Source: Engineering and Environmental Consultant Limited, 1991)

Appendix C7 Sample of site suitability assessment score

Matrix Criteria		Best site possible		Worst possible site			
Social/Political Criteria	Wt.	Suit Score	Wt.x Score	Suit. Score	Wt.x Score	Hypothetical. Score	Wt.x Score
Adjacent Land use	100	10	100	1	100	9	900
Haul Route Suitability	90	10	900	1	90	10	900
Offside Visibility	30	10	300	1	30	6	180
Downstream Sensitivity	20	10	200	1	20	5	100
Current Zoning	10	10	100	1	10	10	100
			2500		250		2,180
Physical Criteria							
Waterbody and Wetland impact	80	10	800	1	80	2	180
Subsurface Conditions	80	10	800	1	80	3	240
Acreage of Suitable Land	70	10	700	1	70	6	420
Configuration of Suitable Land	60	10	600	1	60	3	180
Existing Slope	50	10	500	1	50	2	100
Flood Zone Impact	40	10	400	1	40	10	400
Water Supply Proximity	30	10	300	1	30	10	300
			4100		**410**		**1,800**
Economic Criteria							
Site Development Cost	100	10	1000	1	100	10	1000
Cover Material Availability	90	10	900	1	90	10	900
Haul Route Improvement	80	10	800	1	80	5	400
Haul Cost	70	10	700	1	70	1	70
Land Cost	60	10	600	1	60	5	300
			4000		**400**		**2,670**
			10,600		**1,060**		**6,650**

(Source: Engineering and Environmental Consultant Limited, 1991)

Appendix D Desktop Mapping System Menu Options

SYSTEM	VIEW	ENHANCE

On-line manual
List
  DMS files
Directories
  File Manager
  Change Dir
  c:\data
Install
  Digitiser
DOS
  Dos Shell
Quit
	File
	  Image
	  GIS
	  DEM
	  Vector
	  Browse
	3-D
	  Perspective
		Equalise
		  Global
		  Local
		  Linear Stretch
		  Disk
		I-H-S
		Ratios
		Filter
		Kernel

GEOCODE	**MAP**	**SPM**

Type GCPs
Digitise
  GCPs from Tablet
  GCPs from screen
  Image CPs
Coefficients
  Polynomial
  Local
Rectify
  Interactive
  Batch Setup
  Rotate Image
Register
  General
	Planimetric
	Thematic
	Stereo
	  Plotting
	  Correlation
	Ortho Products
	  Image
	  Map
		Digitise
		  Image CPs
		  Point Transfer
		Orientate
		  Compute
		Register/Rectify
		  Stereo Model
		  Single Photo
		Stereo
		  Plot
		  Correlate
		Ortho Products
		  Photo
		  Map

<table>
<tr>
<td>GIS

Functions
Aggregate
Recode Dns
Rasterise
Overlay
Scale DNs</td>
<td>MANAGE

Mosaic
Subset
Image Coords
Ground Coords
Bands
Extract
Merge
Blend</td>
<td>UTILITY

Hardcopy
Raster
Statistics
Raster
Vector
DEM
Slope/Aspect
Profiles
Utilities
Misc
Burn Vectors
Vector Utilities
Superimpose</td>
</tr>
<tr>
<td>DATA

Capture
Digitise
Convert
Raster
Targa
Import Vectors
Export Vectors</td>
<td>EDIT

Header
File
Text
LGD
DEF
VESA CNF
DMS Menu
SPOT DEM
Vectors</td>
<td></td>
</tr>
</table>

Appendix E1 LINCON - Linear conformal coordinate transformation program

```
DECLARE SUB CalChkPts (totalpoints#, counterchkpts#, coord#(), xscan#(), yscan#(), coeffX#(),
Xgrid#(), Ygrid#(), ChkerrX#(), ChkerrY#(), Chkerrvect#())
DECLARE SUB CtrlResidual (nopts#, coord#(), errX#(), errY#(), errvect#(), Xcontrol#(), Ycontrol#(),
L#())
DECLARE SUB CalConPts (nopts#, coord#(), coeffX#(), Xcontrol#(), Ycontrol#())
DECLARE SUB CoeffMat (coord#(), nopts#, MatA#(), L#())
DECLARE SUB MatInv (MatAtA#(), InvMat#())
DECLARE SUB MatTransp (nopts#, MatA#(), MatTrans#())
DECLARE SUB Multiply (nopts#, MatA#(), MatTrans#(), MatAtA#())
DECLARE SUB readata (datafile$, totalpoints#, coord#())
DECLARE SUB AtL (nopts#, L#(), MatTrans#(), MatrapLx#())
DECLARE SUB CalCoeff (InvMat#(), MatrapLx#(), coeffX#())
DEFDBL A-Z
SCREEN 12
COLOR 2
'
==========================================================================
==
' Program to determine the magnitude and pattern of image distortion in DTP scanners
' using LINEAR CONFORMAL transformation
' By : Wan Mohd Naim
'     Department of Geography
'     University of Edinburgh
'
==========================================================================
=



' Main Program
CLS
INPUT " Enter name of data file          :-"; datafile$


INPUT " Enter  no. of pts. in data file :-"; totalpts
INPUT " Number of control points in file :-"; nopts
INPUT " Number of check points in file   :-"; chkpts

totalpoints = nopts + chkpts
counterchkpts = nopts + 1


' --------------------------------Dimension Arrays ---------------------------------------------------------------------
DIM MatA(nopts * 2, 4), coord(totalpoints, 5), L(nopts * 2), MatTrans(4, nopts * 2)
DIM MatAtA(4, 4), InvMat(4, 4), MatrapLx(4)
DIM coeffX(4, 1), coeffY(4, 1)
DIM xscan(50), yscan(50), Xgrid(50), Ygrid(50)
```

```
DIM errX(nopts, 1), errY(nopts, 1), errvect(nopts, 1)
DIM Xcontrol(nopts), Ycontrol(nopts)
DIM ChkerrX(totalpoints, 1), ChkerrY(totalpoints, 1), Chkerrvect(totalpoints, 1)


' ------------- call matrix subroutine--------------------------
CALL readata(datafile$, totalpoints, coord())
CALL CoeffMat(coord(), nopts, MatA(), L())
CALL MatTransp(nopts, MatA(), MatTrans())
CALL Multiply(nopts, MatA(), MatTrans(), MatAtA())
CALL MatInv(MatAtA(), InvMat())
CALL AtL(nopts, L(), MatTrans(), MatrapLx())
CALL CalCoeff(InvMat(), MatrapLx(), coeffX())
CALL CalConPts(nopts, coord(), coeffX(), Xcontrol(), Ycontrol())
CALL CtrlResidual(nopts, coord(), errX(), errY(), errvect(), Xcontrol(), Ycontrol(), L())
CALL CalChkPts(totalpoints, counterchkpts, coord(), xscan(), yscan(), coeffX(), Xgrid(), Ygrid(),
ChkerrX(), ChkerrY(), Chkerrvect())


SUB AtL (nopts, L(), MatTrans(), MatrapLx())

'====== Subroutine to multiply matrix=======

   FOR i = 1 TO 4
     MatrapLx(i) = 0!
          FOR k = 1 TO nopts * 2
             MatrapLx(i) = MatrapLx(i) + MatTrans(i, k) * L(k)

          NEXT
   NEXT
  NEXT

END SUB


SUB CalChkPts (totalpoints, counterchkpts, coord(), xscan(), yscan(), coeffX(), Xgrid(), Ygrid(),
ChkerrX(), ChkerrY(), Chkerrvect())

'============== Subroutine to calculate coordinates  of check points==================

FOR i = counterchkpts TO totalpoints
   xscan(i) = coord(i, 2)
   yscan(i) = coord(i, 3)
         Xgrid(i) = coeffX(1, 1) * xscan(i) - coeffX(2, 1) * yscan(i) + coeffX(3, 1)
         Ygrid(i) = coeffX(2, 1) * xscan(i) + coeffX(1, 1) * yscan(i) + coeffX(4, 1)
   PRINT USING "###"; coord(i, 1);
   PRINT USING "#######.###"; xscan(i); yscan(i); Xgrid(i); Ygrid(i)

 NEXT

FOR i = counterchkpts TO totalpoints
```

```
    ChkerrX(i, 1) = 0#
         ChkerrY(i, 1) = 0#
    Chkerrvect(i, 1) = 0#
  NEXT
  PRINT "Residual Error of Check points"
  PRINT "pt. No .  Obs. Coord      Comp. Coord          Residual      "
  PRINT "________________________________________________________________________________"
  PRINT "      xO(m)   yO(m)  xC(m)   yC(m)   x(m)   y(m)  Vector(m)"
  PRINT "________________________________________________________________________________"
            'coord coord Xgrid Ygrid

FOR i = counterchkpts TO totalpoints
ChkerrX(i, 1) = Xgrid(i) - coord(i, 4)
        ChkerrY(i, 1) = Ygrid(i) - coord(i, 5)
      Chkerrvect(i, 1) = SQR(ChkerrX(i, 1) ^ 2 + ChkerrY(i, 1) ^ 2)
      PRINT USING "###"; coord(i, 1);
      PRINT USING "######.###"; coord(i, 4); coord(i, 5); Xgrid(i); Ygrid(i);
      PRINT USING "####.######"; ChkerrX(i, 1); ChkerrY(i, 1); Chkerrvect(i, 1)
NEXT
    ' sum of error in x,y, vector
         'initialise sum
         sumx = 0#: sumy = 0#: sumvect = 0#
         rsumX = 0#: rsumY = 0#
  FOR i = counterchkpts TO totalpoints

           sumx = sumx + ABS(ChkerrX(i, 1))
              sumy = sumy + ABS(ChkerrY(i, 1))
                 rsumX = rsumX + ABS(ChkerrX(i, 1) ^ 2)
              rsumY = rsumY + ABS(ChkerrY(i, 1) ^ 2)
           sumvect = sumvect + ABS(Chkerrvect(i, 1))
         NEXT

     nochk = totalpoints - counterchkpts + 1
    ' Mean Error and R.M.S.E in x,y,vect
     minX = sumx / nochk
      minY = sumy / nochk
      Vect = SQR((minX ^ 2) + (minY ^ 2))
         rootminX = SQR((rsumX) / (nochk - 1))
         rootminY = SQR((rsumY) / (nochk - 1))
         PRINT

         rootvect = SQR((rootminX ^ 2) + (rootminY ^ 2))

     PRINT "Mean error in x(m)   ="; USING "#####.#######"; minX
     PRINT "Mean error in y(m)   ="; USING "#####.#######"; minY
     PRINT "Mean vector error(m) ="; USING "#####.#######"; Vect
     PRINT
     PRINT "R.M.S.E in x(m)      ="; USING "#####.#######"; rootminX
     PRINT "R.M.S.E in y(m)      ="; USING "#####.#######"; rootminY
     PRINT "R.M.S.E Vector(m)    ="; USING "#####.#######"; rootvect
```

```
END SUB


SUB CalCoeff (InvMat(), MatrapLx(), coeffX())
'============== Subroutine to calculate coefficient matrix ==================
FOR i = 1 TO 4
     coeffX(i, 1) = 0#
       FOR k = 1 TO 4
         coeffX(i, 1) = coeffX(i, 1) + InvMat(i, k) * MatrapLx(k)
       NEXT
NEXT

END SUB


SUB CalConPts (nopts, coord(), coeffX(), Xcontrol(), Ycontrol())
'============== Subroutine to calculate coordinates  of control points==================

OPEN "c:\scanner\epsneOUT.DAT" FOR OUTPUT AS #10
 FOR i = 1 TO nopts

 Xcontrol(i) = coeffX(1, 1) * coord(i, 2) - coeffX(2, 1) * coord(i, 3) + coeffX(3, 1)
 Ycontrol(i) = coeffX(2, 1) * coord(i, 2) + coeffX(1, 1) * coord(i, 3) + coeffX(4, 1)
  NEXT
   FOR i = 1 TO nopts
         PRINT USING "#######.###"; coord(i, 4); coord(i, 5); Xcontrol(i); Ycontrol(i)
   NEXT

END SUB


SUB CoeffMat (coord(), nopts, MatA(), L())

'============== Subroutine to form coefficient matrix==================
      count = 1
    FOR i = 1 TO (nopts * 2 - 1) STEP 2
      MatA(i, 1) = coord(count, 2)
         MatA(i, 2) = -coord(count, 3)
      MatA(i, 3) = 1!
      MatA(i, 4) = 0
      count = count + 1
    NEXT

    FOR i = 2 TO (nopts * 2) STEP 2
    count = i / 2
      MatA(i, 1) = coord(count, 3)
         MatA(i, 2) = coord(count, 2)
      MatA(i, 3) = 0
```

```
      MatA(i, 4) = 1!
    NEXT

' Form  left hand side matrix Lx(i),Ly(i)
    count = 1
    FOR i = 1 TO (nopts * 2 - 1) STEP 2
       L(i) = coord(count, 4)
       count = count + 1
    NEXT
    count = 1
    FOR i = 2 TO (nopts * 2) STEP 2
       L(i) = coord(count, 5)
       count = count + 1
    NEXT
END SUB


SUB CtrlResidual (nopts, coord(), errX(), errY(), errvect(), Xcontrol(), Ycontrol(), L())
'============== Subroutine to calculate residuals at  control  points==================

  OPEN "C:\SCANNER\hp4clib.err" FOR APPEND AS #10
  FOR i = 1 TO nopts
    errX(i, 1) = 0#
       errY(i, 1) = 0#
    errvect(i, 1) = 0#
  NEXT
 PRINT "Residual Error"
 PRINT "pt. No .  Obs. Coord       Comp. Coord         Residual     "
 PRINT "____________________________________________________________________________"
 PRINT "      xO(m)    yO(m)  xC(m)   yC(m)   x(m)   y(m)  Vector(m)"
 PRINT "____________________________________________________________________________"
 ct = 1
    FOR i = 1 TO (nopts * 2) STEP 2

      errX(ct, 1) = Xcontrol(ct) - L(i)
        errY(ct, 1) = Ycontrol(ct) - L(i + 1)
      errvect(ct, 1) = SQR(errX(ct, 1) ^ 2 + errY(ct, 1) ^ 2)
      PRINT USING "###"; coord(ct, 1);
      PRINT USING "######.###"; L(i); L(i + 1); Xcontrol(ct); Ycontrol(ct);
      PRINT USING "####.######"; errX(ct, 1); errY(ct, 1); errvect(ct, 1)
      PRINT #10, USING "###"; coord(ct, 1);
      PRINT #10, USING "######.###"; L(i); L(i + 1); Xcontrol(ct); Ycontrol(ct);
      PRINT #10, 2; USING "####.######"; errX(ct, 1); errY(ct, 1); errvect(ct, 1)

    ct = ct + 1
    NEXT
    ' sum of error in x,y, vector
         'initialise sum
         sumx = 0#: sumy = 0#: sumvect = 0#
         rsumX = 0#: rsumY = 0#
```

```
        FOR i = 1 TO nopts
          sumx = sumx + ABS(errX(i, 1))
              sumy = sumy + ABS(errY(i, 1))
                  rsumX = rsumX + ABS(errX(i, 1) ^ 2)
              rsumY = rsumY + ABS(errY(i, 1) ^ 2)
          sumvect = sumvect + ABS(errvect(i, 1))
        NEXT

    ' Mean Error and R.M.S.E in x,y,vect
      minX = sumx / nopts
      minY = sumy / nopts
      Vect = SQR((minX ^ 2) + (minY ^ 2))
          rootminX = SQR((rsumX) / (nopts - 2))
          rootminY = SQR((rsumY) / (nopts - 2))
          PRINT
          PRINT rsumX, rsumY
          rootvect = SQR((rootminX ^ 2) + (rootminY ^ 2))

      PRINT "Mean error in x(m)   ="; USING "#####.#######"; minX
      PRINT "Mean error in y(m)   ="; USING "#####.#######"; minY
      PRINT "Mean vector error(m) ="; USING "#####.#######"; Vect
      PRINT
      PRINT "R.M.S.E in x(m)      ="; USING "#####.#######"; rootminX
      PRINT "R.M.S.E in y(m)      ="; USING "#####.#######"; rootminY
      PRINT "R.M.S.E Vector(m)    ="; USING "#####.#######"; rootvect
any$ = INPUT$(1)

CLOSE 10
END SUB



SUB MatInv (MatAtA(), InvMat())
'============= Subroutine to calculate matrix conversion==================
FOR i = 1 TO 4
  FOR j = 1 TO 4
    InvMat(i, j) = 1 - ABS(SGN(i - j))
  NEXT
NEXT
    FOR i = 1 TO 3
        FOR j = i + 1 TO 4
            x = MatAtA(j, i) / MatAtA(i, i)

              FOR k = 1 TO 4
                MatAtA(j, k) = MatAtA(j, k) - x * MatAtA(i, k)
                InvMat(j, k) = InvMat(j, k) - x * InvMat(i, k)
              NEXT
          NEXT
      NEXT
       FOR i = 4 TO 1 STEP -1
```

```
          FOR k = 1 TO 4
            FOR j = i + 1 TO 4
              InvMat(i, k) = InvMat(i, k) - MatAtA(i, j) * InvMat(j, k)
            NEXT
              InvMat(i, k) = InvMat(i, k) / MatAtA(i, i)
          NEXT
        NEXT
END SUB


SUB MatTransp (nopts, MatA(), MatTrans())

'============== Subroutine to form matrix transpose ==================

  FOR i = 1 TO nopts * 2
    FOR j = 1 TO 4
      MatTrans(j, i) = MatA(i, j)
    NEXT
  NEXT

END SUB

SUB Multiply (nopts, MatA(), MatTrans(), MatAtA())
'============== Subroutine to multiply matrix ==================

  FOR i = 1 TO 4
     FOR j = 1 TO 4
       MatAtA(i, j) = 0
         FOR k = 1 TO nopts * 2
           MatAtA(i, j) = MatAtA(i, j) + MatTrans(i, k) * MatA(k, j)
NEXT
     NEXT
  NEXT

END SUB


SUB readata (datafile$, totalpoints, coord())

'============== Subroutine to read data from data file ==================
OPEN datafile$ FOR INPUT AS #1
     ' read control points
     PRINT " Input data "
     FOR i = 1 TO totalpoints
      INPUT #1, coord(i, 1), coord(i, 2), coord(i, 3), coord(i, 4), coord(i, 5)
       PRINT coord(i, 1); coord(i, 2); coord(i, 3); coord(i, 4); coord(i, 5)
     NEXT
any$ = INPUT$(1)
END SUB
```

Appendix E2 AFFINE - Affine coordinate transformation program

```
DECLARE SUB CalConPts (out$, nopts#, coord#(), coeffX#(), coeffY#(), Xcontrol#(), Ycontrol#())
DECLARE SUB CalChkPts (out$, totalpoints#, counterchkpts#, coord#(), xscan#(), yscan#(), coeffX#(),
coeffY#(), Xgrid#(), Ygrid#(), ChkerrX#(), ChkerrY#(), Chkerrvect#())
DECLARE SUB CtrlResidual (nopts#, coord#(), errX#(), errY#(), errvect#(), Xcontrol#(), Ycontrol#(),
Lx#(), Ly#())
DECLARE SUB CoeffMat (coord#(), nopts#, MatA#(), Lx#(), Ly#())
DECLARE SUB MatInv (MatAtA#(), InvMat#())
DECLARE SUB MatTransp (nopts#, MatA#(), MatTrans#())
DECLARE SUB Multiply (nopts#, MatA#(), MatTrans#(), MatAtA#())
DECLARE SUB readata (datafile$, totalpoints#, coord#())
DECLARE SUB AtL (nopts#, Lx#(), Ly#(), MatTrans#(), MatrapLx#(), MatrapLy#())
DECLARE SUB CalCoeff (InvMat#(), MatrapLx#(), MatrapLy#(), coeffX#(), coeffY#())
DEFDBL A-Z

'=====================================================================
' Program to determine the magnitude and pattern of image distortion in DTP scanners
' using AFFINE transformation
' By : Wan Mohd Naim
'     Department of Geography
'     University of Edinburgh
'
=====================================================================
==

' Main Program
CLS
INPUT " Enter name of data file        :-"; datafile$
INPUT " Enter  no. of pts. in data file  :-"; totalpts
INPUT " Number of control points in file :-"; nopts
INPUT " Number of check points in file   :-"; chkpts

totalpoints = nopts + chkpts
counterchkpts = nopts + 1

' Dimension Arrays
DIM MatA(nopts, 5), coord(totalpoints, 5), Lx(nopts), Ly(nopts), MatTrans(5, nopts)
DIM MatAtA(nopts, nopts), InvMat(3, 3), MatrapLx(3), MatrapLy(3)
DIM coeffX(3, 1), coeffY(3, 1)
DIM xscan(102), yscan(102), Xgrid(102), Ygrid(102)
DIM errX(nopts, 1), errY(nopts, 1), errvect(nopts, 1)
DIM Xcontrol(nopts), Ycontrol(nopts)
DIM ChkerrX(totalpoints, 1), ChkerrY(totalpoints, 1), Chkerrvect(totalpoints, 1)

'====== Subroutine to call matrix suboutine=======

CALL readata(datafile$, totalpoints, coord())
CALL CoeffMat(coord(), nopts, MatA(), Lx(), Ly())
```

```
CALL MatTransp(nopts, MatA(), MatTrans())
CALL Multiply(nopts, MatA(), MatTrans(), MatAtA())
CALL MatInv(MatAtA(), InvMat())
CALL AtL(nopts, Lx(), Ly(), MatTrans(), MatrapLx(), MatrapLy())
CALL CalCoeff(InvMat(), MatrapLx(), MatrapLy(), coeffX(), coeffY())
CALL CalConPts(out$, nopts, coord(), coeffX(), coeffY(), Xcontrol(), Ycontrol())
CALL CtrlResidual(nopts, coord(), errX(), errY(), errvect(), Xcontrol(), Ycontrol(), Lx(), Ly())
CALL CalChkPts(out$, totalpoints, counterchkpts, coord(), xscan(), yscan(), coeffX(), coeffY(), Xgrid(),
Ygrid(), ChkerrX(), ChkerrY(), Chkerrvect())
'--------------- end of main program ------------------------------

SUB AtL (nopts, Lx(), Ly(), MatTrans(), MatrapLx(), MatrapLy())

'====== Subroutine to multiply matrix=======

   FOR i = 1 TO 3
      MatrapLx(i) = 0!
      MatrapLy(i) = 0!
            FOR k = 1 TO nopts
                MatrapLx(i) = MatrapLx(i) + MatTrans(i, k) * Lx(k)
                MatrapLy(i) = MatrapLy(i) + MatTrans(i, k) * Ly(k)
            NEXT
   NEXT
END SUB

SUB CalChkPts (out$, totalpoints, counterchkpts, coord(), xscan(), yscan(), coeffX(), coeffY(), Xgrid(),
Ygrid(), ChkerrX(), ChkerrY(), Chkerrvect())

 '====== Subroutine to calculate coordinates at the check points=======

 FOR i = counterchkpts TO totalpoints
   xscan(i) = coord(i, 2)
   yscan(i) = coord(i, 3)

   'calibrated grid coordinates

   Xgrid(i) = coeffX(1, 1) * xscan(i) + coeffX(2, 1) * yscan(i) + coeffX(3, 1)
   Ygrid(i) = coeffY(1, 1) * xscan(i) + coeffY(2, 1) * yscan(i) + coeffY(3, 1)
   Xchk = coord(i, 4) + ((Xgrid(i) - coord(i, 4)) * 50)
   Ychk = coord(i, 5) + ((Ygrid(i) - coord(i, 5)) * 50)

 NEXT

  FOR i = counterchkpts TO totalpoints
    ChkerrX(i, 1) = 0#
      ChkerrY(i, 1) = 0#
    Chkerrvect(i, 1) = 0#
  NEXT
  PRINT :   PRINT "Residual Error of Check points"
  PRINT "pt. No . Obs. Coord          Comp. Coord          Residual     "
  PRINT "____________________________________________________________________"
```

```
PRINT "    xO(mm)   yO(mm)  xC(mm)   yC(mm)    x(mm)  y(mm)  Vector(mm)"
PRINT "_____________________________________________________________________"


FOR i = counterchkpts TO totalpoints

   ChkerrX(i, 1) = Xgrid(i) - coord(i, 4)
     ChkerrY(i, 1) = Ygrid(i) - coord(i, 5)
   Chkerrvect(i, 1) = SQR(ChkerrX(i, 1) ^ 2 + ChkerrY(i, 1) ^ 2)
   PRINT USING "###"; coord(i, 1);
   PRINT USING "######.###"; coord(i, 4); coord(i, 5); Xgrid(i); Ygrid(i);
   PRINT USING "####.######"; ChkerrX(i, 1); ChkerrY(i, 1); Chkerrvect(i, 1)
  NEXT


  ' sum of error in x,y, vector
       'initialise sum
       sumx = 0#: sumy = 0#: sumvect = 0#
       rsumX = 0#: rsumY = 0#


 FOR i = counterchkpts TO totalpoints

          sumx = sumx + ABS(ChkerrX(i, 1))
             sumy = sumy + ABS(ChkerrY(i, 1))
                 rsumX = rsumX + ABS(ChkerrX(i, 1) ^ 2)
             rsumY = rsumY + ABS(ChkerrY(i, 1) ^ 2)
          sumvect = sumvect + ABS(Chkerrvect(i, 1))
        NEXT

   nochk = totalpoints - counterchkpts + 1
  ' Mean Error and R.M.S.E in x,y,vect
    minX = sumx / nochk
    minY = sumy / nochk
    Vect = SQR((minX ^ 2) + (minY ^ 2))
       rootminX = SQR((rsumX) / (nochk - 1))
       rootminY = SQR((rsumY) / (nochk - 1))

       rootvect = SQR((rootminX ^ 2) + (rootminY ^ 2))

   PRINT "   Mean error in x(mm)  ="; USING "#####.#######"; minX
   PRINT "   Mean error in y(mm)  ="; USING "#####.#######"; minY
   PRINT "   Mean vector error(mm) ="; USING "#####.#######"; Vect
   PRINT
   PRINT "   R.M.S.E in x(mm)     ="; USING "#####.#######"; rootminX
   PRINT "   R.M.S.E in y(mm)     ="; USING "#####.#######"; rootminY
   PRINT "   R.M.S.E Vector(mm)   ="; USING "#####.#######"; rootvect

END SUB
```

```
SUB CalCoeff (InvMat(), MatrapLx(), MatrapLy(), coeffX(), coeffY())

'====== Subroutine to calculate transformation coefficient=======

FOR i = 1 TO 3
      coeffX(i, 1) = 0#
      coeffY(i, 1) = 0#
         FOR k = 1 TO 3
           coeffX(i, 1) = coeffX(i, 1) + InvMat(i, k) * MatrapLx(k)
           coeffY(i, 1) = coeffY(i, 1) + InvMat(i, k) * MatrapLy(k)
         NEXT
NEXT

END SUB


SUB CalConPts (out$, nopts, coord(), coeffX(), coeffY(), Xcontrol(), Ycontrol())

'====== Subroutine to calculate coordinates at the control points=======

 FOR i = 1 TO nopts

   Xcontrol(i) = coeffX(1, 1) * coord(i, 2) + coeffX(2, 1) * coord(i, 3) + coeffX(3, 1)
   Ycontrol(i) = coeffY(1, 1) * coord(i, 2) + coeffY(2, 1) * coord(i, 3) + coeffY(3, 1)

   Xcon = coord(i, 4) + ((Xcontrol(i) - coord(i, 4)) * 50)
   Ycon = coord(i, 5) + ((Ycontrol(i) - coord(i, 5)) * 50)
   PRINT USING "#######.###"; coord(i, 4); coord(i, 5)
   PRINT USING "#######.###"; Xcontrol(i); Ycontrol(i); Xcon; Ycon


   PRINT #3, USING "#######.###"; coord(i, 4); coord(i, 5)
   PRINT #3, USING "#######.###"; Xcon; Ycon

 NEXT

END SUB


SUB CoeffMat (coord(), nopts, MatA(), Lx(), Ly())

'====== Subroutine to form matrix=======

' Form matrix A

    FOR i = 1 TO nopts
      MatA(i, 1) = coord(i, 2)
         MatA(i, 2) = coord(i, 3)
      MatA(i, 3) = 1!
    NEXT
```

```
' Form  left hand side matrix Lx(i),Ly(i)

    FOR i = 1 TO nopts
       Lx(i) = coord(i, 4)
       Ly(i) = coord(i, 5)

    NEXT
END SUB


SUB CtrlResidual (nopts, coord(), errX(), errY(), errvect(), Xcontrol(), Ycontrol(), Lx(), Ly())

 '====== Subroutine to calculate residual at control points======

  FOR i = 1 TO nopts
    errX(i, 1) = 0#
       errY(i, 1) = 0#
    errvect(i, 1) = 0#
  NEXT
  PRINT
  PRINT "Residual Error"
  PRINT "pt. No .  Obs. Coord          Comp. Coord          Residual     "
  PRINT "_______________________________________________________________________________"
  PRINT "     xO(mm)   yO(mm)   xC(mm)    yC(mm)   x(mm)    y(mm)  Vector(mm)"
  PRINT "_______________________________________________________________________________"
      FOR i = 1 TO nopts
        errX(i, 1) = Xcontrol(i) - Lx(i)
         errY(i, 1) = Ycontrol(i) - Ly(i)
      errvect(i, 1) = SQR(errX(i, 1) ^ 2 + errY(i, 1) ^ 2)
      PRINT USING "###"; coord(i, 1);
      PRINT USING "######.###"; Lx(i); Ly(i); Xcontrol(i); Ycontrol(i);
      PRINT USING "####.######"; errX(i, 1); errY(i, 1); errvect(i, 1)
    NEXT
    ' sum of error in x,y, vector
         'initialise sum
         sumx = 0#: sumy = 0#: sumvect = 0#
         rsumX = 0#: rsumY = 0#

          FOR i = 1 TO nopts
            sumx = sumx + ABS(errX(i, 1))
                sumy = sumy + ABS(errY(i, 1))
                    rsumX = rsumX + ABS(errX(i, 1) ^ 2)
                rsumY = rsumY + ABS(errY(i, 1) ^ 2)
            sumvect = sumvect + ABS(errvect(i, 1))
          NEXT

     ' Mean Error and R.M.S.E in x,y,vect
       minX = sumx / nopts
       minY = sumy / nopts
       Vect = SQR((minX ^ 2) + (minY ^ 2))
```

```
        rootminX = SQR((rsumX) / (nopts - 3))
        rootminY = SQR((rsumY) / (nopts - 3))
        rootvect = SQR((rootminX ^ 2) + (rootminY ^ 2))

    PRINT "  Mean error in x(mm)  ="; USING "#####.#######"; minX
    PRINT "  Mean error in y(mm)  ="; USING "#####.#######"; minY
    PRINT "  Mean vector error(mm) ="; USING "#####.#######"; Vect
    PRINT
    PRINT "  R.M.S.E in x(mm)     ="; USING "#####.#######"; rootminX
    PRINT "  R.M.S.E in y(mm)     ="; USING "#####.#######"; rootminY
    PRINT "  R.M.S.E Vector(mm)   ="; USING "#####.#######"; rootvect
any$ = INPUT$(1)

END SUB


SUB MatInv (MatAtA(), InvMat())

'====== Subroutine to calculate matrix inversion=======
FOR i = 1 TO 3
  FOR j = 1 TO 3
   InvMat(i, j) = 1 - ABS(SGN(i - j))
  NEXT
NEXT
   FOR i = 1 TO 2
      FOR j = i + 1 TO 3
         x = MatAtA(j, i) / MatAtA(i, i)

          FOR k = 1 TO 3
            MatAtA(j, k) = MatAtA(j, k) - x * MatAtA(i, k)
            InvMat(j, k) = InvMat(j, k) - x * InvMat(i, k)
          NEXT
      NEXT
   NEXT
      FOR i = 3 TO 1 STEP -1
        FOR k = 1 TO 3
          FOR j = i + 1 TO 3
            InvMat(i, k) = InvMat(i, k) - MatAtA(i, j) * InvMat(j, k)
          NEXT
            InvMat(i, k) = InvMat(i, k) / MatAtA(i, i)
        NEXT
      NEXT


END SUB


SUB MatTransp (nopts, MatA(), MatTrans())
'====== Subroutine to calculate matrix transpose=======

  FOR i = 1 TO nopts
```

```
    FOR j = 1 TO 3
      MatTrans(j, i) = MatA(i, j)
    NEXT
  NEXT

END SUB


SUB Multiply (nopts, MatA(), MatTrans(), MatAtA())
'====== Subroutine to calculate matrix multiplication=======

  FOR i = 1 TO 3
    FOR j = 1 TO 3
      MatAtA(i, j) = 0
        FOR k = 1 TO nopts
          MatAtA(i, j) = MatAtA(i, j) + MatTrans(i, k) * MatA(k, j)
        NEXT
    NEXT
  NEXT
END SUB


SUB readata (datafile$, totalpoints, coord())
'====== Subroutine to Read Scanner and Grid Coordinates from data file=======


OPEN datafile$ FOR INPUT AS #1
      ' read control points

     FOR i = 1 TO totalpoints
      INPUT #1, coord(i, 1), coord(i, 2), coord(i, 3), coord(i, 4), coord(i, 5)
       PRINT coord(i, 1); coord(i, 2); coord(i, 3); coord(i, 4); coord(i, 5)
     NEXT
END SUB
```

Appendix E3 POLY15 - Polynomial coordinate transformation program

```
DECLARE SUB CoeffMat (pterms#, coord#(), nopts#, MatA#(), Lx#(), Ly#())
DECLARE SUB CalChkPts (out$, pterms#, totalpoints#, counterchkpts#, coord#(), xscan#(), yscan#(),
coeffX#(), coeffY#(), Xgrid#(), Ygrid#(), ChkerrX#(), ChkerrY#(), Chkerrvect#())
DECLARE SUB CtrlResidual (pterms#, nopts#, coord#(), errX#(), errY#(), errvect#(), Xcontrol#(),
Ycontrol#(), Lx#(), Ly#())
DECLARE SUB CalConPts (out$, pterms#, nopts#, coord#(), coeffX#(), coeffY#(), Xcontrol#(),
Ycontrol#())
DECLARE SUB MatInv (pterms#, MatAtA#(), InvMat#())
DECLARE SUB MatTransp (pterms#, nopts#, MatA#(), MatTrans#())
DECLARE SUB Multiply (pterms#, nopts#, MatA#(), MatTrans#(), MatAtA#())
DECLARE SUB readata (datafile$, totalpoints#, coord#())
DECLARE SUB AtL (pterms#, nopts#, Lx#(), Ly#(), MatTrans#(), MatrapLx#(), MatrapLy#())
DECLARE SUB CalCoeff (pterms#, InvMat#(), MatrapLx#(), MatrapLy#(), coeffX#(), coeffY#())

DEFDBL A-Z
'
'=========================================================================
=
' Program to :-
'  1. determine the magnitude and pattern of image distortion in DTP scanners
'  2. compute longitude/latitude (geodetic) to MRSO (Malaysian National Grid) coordinates
'  using Least Squares Adjustment
' NOTE : USING 4 TERMS POLYNOMIAL AND UP TO 15 TERMS
' By : Wan Mohd Naim
'    Department of Geography
'    University of Edinburgh
'
'=========================================================================
=


' Main Program

CLS
INPUT " Enter name of data file       :-"; datafile$
INPUT " Enter  no. of pts. in data file :-"; totalpts
labelb:
INPUT " Number of control points in file :-"; nopts
INPUT " Number of check points in file  :-"; chkpts
INPUT " Number of polynomial terms      :-"; pterms

' Error message
IF nopts <= pterms THEN
   PRINT "Not enough control points to perform transformation"
   GOTO labelb
END IF
```

```
totalpoints = nopts + chkpts
counterchkpts = nopts + 1


' Dimension Arrays
DIM MatA(nopts, pterms), coord(totalpoints, 5), Lx(nopts), Ly(nopts), MatTrans(pterms, nopts)
DIM MatAtA(nopts, nopts), InvMat(pterms, pterms), MatrapLx(pterms), MatrapLy(pterms)
DIM coeffX(pterms, 1), coeffY(pterms, 1)
DIM xscan(102), yscan(102), Xgrid(102), Ygrid(102)
DIM errX(nopts, 1), errY(nopts, 1), errvect(nopts, 1)
DIM Xcontrol(nopts), Ycontrol(nopts)
DIM ChkerrX(totalpoints, 1), ChkerrY(totalpoints, 1), Chkerrvect(totalpoints, 1)


' ------------- call matrix subroutine--------------------------
CALL readata(datafile$, totalpoints, coord())
ANY$ = INPUT$(1)
CALL CoeffMat(pterms, coord(), nopts, MatA(), Lx(), Ly())
CALL MatTransp(pterms, nopts, MatA(), MatTrans())
CALL Multiply(pterms, nopts, MatA(), MatTrans(), MatAtA())
CALL MatInv(pterms, MatAtA(), InvMat())
CALL AtL(pterms, nopts, Lx(), Ly(), MatTrans(), MatrapLx(), MatrapLy())
CALL CalCoeff(pterms, InvMat(), MatrapLx(), MatrapLy(), coeffX(), coeffY())
CALL CalConPts(out$, pterms, nopts, coord(), coeffX(), coeffY(), Xcontrol(), Ycontrol())
CALL CtrlResidual(pterms, nopts, coord(), errX(), errY(), errvect(), Xcontrol(), Ycontrol(), Lx(), Ly())
CALL CalChkPts(out$, pterms, totalpoints, counterchkpts, coord(), xscan(), yscan(), coeffX(), coeffY(),
Xgrid(), Ygrid(), ChkerrX(), ChkerrY(), Chkerrvect())

' ------------- End of main program-------------------------


SUB AtL (pterms, nopts, Lx(), Ly(), MatTrans(), MatrapLx(), MatrapLy())

'====== Subroutine to multiply matrix=======

   FOR i = 1 TO pterms
      MatrapLx(i) = 0!
      MatrapLy(i) = 0!
           FOR k = 1 TO nopts
               MatrapLx(i) = MatrapLx(i) + MatTrans(i, k) * Lx(k)
               MatrapLy(i) = MatrapLy(i) + MatTrans(i, k) * Ly(k)
           NEXT
   NEXT
END SUB
```

```
SUB CalChkPts (out$, pterms, totalpoints, counterchkpts, coord(), xscan(), yscan(), coeffX(), coeffY(),
Xgrid(), Ygrid(), ChkerrX(), ChkerrY(), Chkerrvect())

'====== Subroutine to calculate coordinates at check points =======

 FOR i = counterchkpts TO totalpoints
   xscan(i) = coord(i, 2)
   yscan(i) = coord(i, 3)



 fourtmX = coeffX(1, 1) + coeffX(2, 1) * xscan(i) + coeffX(3, 1) * yscan(i) + coeffX(4, 1) * xscan(i) *
yscan(i)
 fourtmY = coeffY(1, 1) + coeffY(2, 1) * xscan(i) + coeffY(3, 1) * yscan(i) + coeffY(4, 1) * xscan(i) *
yscan(i)

 IF pterms = 4 THEN
    Xgrid(i) = fourtmX
    Ygrid(i) = fourtmY

 ELSEIF pterms = 5 THEN
  fthX = coeffX(5, 1) * coord(i, 2) ^ 2
  fthY = coeffY(5, 1) * coord(i, 2) ^ 2

    Xgrid(i) = fourtmX + fthX
    Ygrid(i) = fourtmY + fthY

 ELSEIF pterms = 6 THEN   '-----------six terms-------------
 fthX = coeffX(5, 1) * coord(i, 2) ^ 2
  fthY = coeffY(5, 1) * coord(i, 2) ^ 2
   sixX = coeffX(6, 1) * coord(i, 3) ^ 2
     sixY = coeffY(6; 1) * coord(i, 3) ^ 2
    Xgrid(i) = fourtmX + fthX + sixX
    Ygrid(i) = fourtmY + fthY + sixY

 ELSEIF pterms = 7 THEN   '---------seven terms----------------
 fthX = coeffX(5, 1) * coord(i, 2) ^ 2
  fthY = coeffY(5, 1) * coord(i, 2) ^ 2
   sixX = coeffX(6, 1) * coord(i, 3) ^ 2
     sixY = coeffY(6, 1) * coord(i, 3) ^ 2
       sevX = coeffX(7, 1) * coord(i, 2) ^ 2 * coord(i, 3)
         sevY = coeffY(7, 1) * coord(i, 2) ^ 2 * coord(i, 3)
    Xgrid(i) = fourtmX + fthX + sixX + sevX
    Ygrid(i) = fourtmY + fthY + sixY + sevY

 ELSEIF pterms = 8 THEN   '-------------eight terms-------------
 fthX = coeffX(5, 1) * coord(i, 2) ^ 2
  fthY = coeffY(5, 1) * coord(i, 2) ^ 2
   sixX = coeffX(6, 1) * coord(i, 3) ^ 2
     sixY = coeffY(6, 1) * coord(i, 3) ^ 2
```

```
sevX = coeffX(7, 1) * coord(i, 2) ^ 2 * coord(i, 3)
 sevY = coeffY(7, 1) * coord(i, 2) ^ 2 * coord(i, 3)
  eigX = coeffX(8, 1) * coord(i, 2) * coord(i, 3) ^ 2
   eigY = coeffY(8, 1) * coord(i, 2) * coord(i, 3) ^ 2
Xgrid(i) = fourtmX + fthX + sixX + sevX + eigX
Ygrid(i) = fourtmY + fthY + sixY + sevY + eigY



ELSEIF pterms = 9 THEN    ' -------------nine terms-------------
fthX = coeffX(5, 1) * coord(i, 2) ^ 2
 fthY = coeffY(5, 1) * coord(i, 2) ^ 2
  sixX = coeffX(6, 1) * coord(i, 3) ^ 2
   sixY = coeffY(6, 1) * coord(i, 3) ^ 2
    sevX = coeffX(7, 1) * coord(i, 2) ^ 2 * coord(i, 3)
     sevY = coeffY(7, 1) * coord(i, 2) ^ 2 * coord(i, 3)
      eigX = coeffX(8, 1) * coord(i, 2) * coord(i, 3) ^ 2
       eigY = coeffY(8, 1) * coord(i, 2) * coord(i, 3) ^ 2
        ninX = coeffX(9, 1) * coord(i, 2) ^ 3
         ninY = coeffY(9, 1) * coord(i, 2) ^ 3
  Xgrid(i) = fourtmX + fthX + sixX + sevX + eigX + ninX
  Ygrid(i) = fourtmY + fthY + sixY + sevY + eigY + ninY
ELSEIF pterms = 10 THEN    '------------ten terms-----------------
fthX = coeffX(5, 1) * coord(i, 2) ^ 2
 fthY = coeffY(5, 1) * coord(i, 2) ^ 2
  sixX = coeffX(6, 1) * coord(i, 3) ^ 2
   sixY = coeffY(6, 1) * coord(i, 3) ^ 2
    sevX = coeffX(7, 1) * coord(i, 2) ^ 2 * coord(i, 3)
     sevY = coeffY(7, 1) * coord(i, 2) ^ 2 * coord(i, 3)
      eigX = coeffX(8, 1) * coord(i, 2) * coord(i, 3) ^ 2
       eigY = coeffY(8, 1) * coord(i, 2) * coord(i, 3) ^ 2
        ninX = coeffX(9, 1) * coord(i, 2) ^ 3
         ninY = coeffY(9, 1) * coord(i, 2) ^ 3
        tenX = coeffX(10, 1) * coord(i, 3) ^ 3
       tenY = coeffY(10, 1) * coord(i, 3) ^ 3
  Xgrid(i) = fourtmX + fthX + sixX + sevX + eigX + ninX + tenX
  Ygrid(i) = fourtmY + fthY + sixY + sevY + eigY + ninY + tenY
ELSEIF pterms = 11 THEN    ' ---------eleven terms-----------------
fthX = coeffX(5, 1) * coord(i, 2) ^ 2
 fthY = coeffY(5, 1) * coord(i, 2) ^ 2
  sixX = coeffX(6, 1) * coord(i, 3) ^ 2
   sixY = coeffY(6, 1) * coord(i, 3) ^ 2
    sevX = coeffX(7, 1) * coord(i, 2) ^ 2 * coord(i, 3)
     sevY = coeffY(7, 1) * coord(i, 2) ^ 2 * coord(i, 3)
      eigX = coeffX(8, 1) * coord(i, 2) * coord(i, 3) ^ 2
       eigY = coeffY(8, 1) * coord(i, 2) * coord(i, 3) ^ 2
        ninX = coeffX(9, 1) * coord(i, 2) ^ 3
         ninY = coeffY(9, 1) * coord(i, 2) ^ 3
        tenX = coeffX(10, 1) * coord(i, 3) ^ 3
       tenY = coeffY(10, 1) * coord(i, 3) ^ 3
      eleX = coeffX(11, 1) * coord(i, 2) ^ 3 * coord(i, 3)
```

```
eleY = coeffY(11, 1) * coord(i, 2) ^ 3 * coord(i, 3)
Xgrid(i) = fourtmX + fthX + sixX + sevX + eigX + ninX + tenX + eleX
Ygrid(i) = fourtmY + fthY + sixY + sevY + eigY + ninY + tenY + eleY
ELSEIF pterms = 12 THEN  ' --------------twelve terms--------------------
fthX = coeffX(5, 1) * coord(i, 2) ^ 2
fthY = coeffY(5, 1) * coord(i, 2) ^ 2
sixX = coeffX(6, 1) * coord(i, 3) ^ 2
sixY = coeffY(6, 1) * coord(i, 3) ^ 2
sevX = coeffX(7, 1) * coord(i, 2) ^ 2 * coord(i, 3)
sevY = coeffY(7, 1) * coord(i, 2) ^ 2 * coord(i, 3)
eigX = coeffX(8, 1) * coord(i, 2) * coord(i, 3) ^ 2
eigY = coeffY(8, 1) * coord(i, 2) * coord(i, 3) ^ 2
ninX = coeffX(9, 1) * coord(i, 2) ^ 3
ninY = coeffY(9, 1) * coord(i, 2) ^ 3
tenX = coeffX(10, 1) * coord(i, 3) ^ 3
tenY = coeffY(10, 1) * coord(i, 3) ^ 3
eleX = coeffX(11, 1) * coord(i, 2) ^ 3 * coord(i, 3)
eleY = coeffY(11, 1) * coord(i, 2) ^ 3 * coord(i, 3)
twlX = coeffX(12, 1) * coord(i, 2) * coord(i, 3) ^ 3
twlY = coeffY(12, 1) * coord(i, 2) * coord(i, 3) ^ 3
Xgrid(i) = fourtmX + fthX + sixX + sevX + eigX + ninX + tenX + eleX + twlX
Ygrid(i) = fourtmY + fthY + sixY + sevY + eigY + ninY + tenY + eleY + twlY
ELSEIF pterms = 13 THEN      ' ----------------thirteen terms------------------
fthX = coeffX(5, 1) * coord(i, 2) ^ 2
fthY = coeffY(5, 1) * coord(i, 2) ^ 2
sixX = coeffX(6, 1) * coord(i, 3) ^ 2
sixY = coeffY(6, 1) * coord(i, 3) ^ 2
sevX = coeffX(7, 1) * coord(i, 2) ^ 2 * coord(i, 3)
sevY = coeffY(7, 1) * coord(i, 2) ^ 2 * coord(i, 3)
eigX = coeffX(8, 1) * coord(i, 2) * coord(i, 3) ^ 2
eigY = coeffY(8, 1) * coord(i, 2) * coord(i, 3) ^ 2
ninX = coeffX(9, 1) * coord(i, 2) ^ 3
ninY = coeffY(9, 1) * coord(i, 2) ^ 3
tenX = coeffX(10, 1) * coord(i, 3) ^ 3
tenY = coeffY(10, 1) * coord(i, 3) ^ 3
eleX = coeffX(11, 1) * coord(i, 2) ^ 3 * coord(i, 3)
eleY = coeffY(11, 1) * coord(i, 2) ^ 3 * coord(i, 3)
twlX = coeffX(12, 1) * coord(i, 2) * coord(i, 3) ^ 3
twlY = coeffY(12, 1) * coord(i, 2) * coord(i, 3) ^ 3
thrX = coeffX(13, 1) * coord(i, 2) ^ 4
thrY = coeffY(13, 1) * coord(i, 2) ^ 4
Xgrid(i) = fourtmX + fthX + sixX + sevX + eigX + ninX + tenX + eleX + twlX + thrX
Ygrid(i) = fourtmY + fthY + sixY + sevY + eigY + ninY + tenY + eleY + twlY + thrY
ELSEIF pterms = 14 THEN      '----------------------- fourteen terms-----------------------
fthX = coeffX(5, 1) * coord(i, 2) ^ 2
fthY = coeffY(5, 1) * coord(i, 2) ^ 2
sixX = coeffX(6, 1) * coord(i, 3) ^ 2
sixY = coeffY(6, 1) * coord(i, 3) ^ 2
sevX = coeffX(7, 1) * coord(i, 2) ^ 2 * coord(i, 3)
sevY = coeffY(7, 1) * coord(i, 2) ^ 2 * coord(i, 3)
eigX = coeffX(8, 1) * coord(i, 2) * coord(i, 3) ^ 2
```

```
eigY = coeffY(8, 1) * coord(i, 2) * coord(i, 3) ^ 2
ninX = coeffX(9, 1) * coord(i, 2) ^ 3
ninY = coeffY(9, 1) * coord(i, 2) ^ 3
tenX = coeffX(10, 1) * coord(i, 3) ^ 3
tenY = coeffY(10, 1) * coord(i, 3) ^ 3
eleX = coeffX(11, 1) * coord(i, 2) ^ 3 * coord(i, 3)
eleY = coeffY(11, 1) * coord(i, 2) ^ 3 * coord(i, 3)
twlX = coeffX(12, 1) * coord(i, 2) * coord(i, 3) ^ 3
twlY = coeffY(12, 1) * coord(i, 2) * coord(i, 3) ^ 3
thrX = coeffX(13, 1) * coord(i, 2) ^ 4
thrY = coeffY(13, 1) * coord(i, 2) ^ 4
fteX = coeffX(14, 1) * coord(i, 2) ^ 2 * coord(i, 3) ^ 2
fteY = coeffY(14, 1) * coord(i, 2) ^ 2 * coord(i, 3) ^ 2
Xgrid(i) = fourtmX + fthX + sixX + sevX + eigX + ninX + tenX + eleX + twlX + thrX + fteX
Ygrid(i) = fourtmY + fthY + sixY + sevY + eigY + ninY + tenY + eleY + twlY + thrY + fteY
ELSEIF pterms = 15 THEN
fthX = coeffX(5, 1) * coord(i, 2) ^ 2
fthY = coeffY(5, 1) * coord(i, 2) ^ 2
sixX = coeffX(6, 1) * coord(i, 3) ^ 2
sixY = coeffY(6, 1) * coord(i, 3) ^ 2
sevX = coeffX(7, 1) * coord(i, 2) ^ 2 * coord(i, 3)
sevY = coeffY(7, 1) * coord(i, 2) ^ 2 * coord(i, 3)
eigX = coeffX(8, 1) * coord(i, 2) * coord(i, 3) ^ 2
eigY = coeffY(8, 1) * coord(i, 2) * coord(i, 3) ^ 2
ninX = coeffX(9, 1) * coord(i, 2) ^ 3
ninY = coeffY(9, 1) * coord(i, 2) ^ 3
tenX = coeffX(10, 1) * coord(i, 3) ^ 3
tenY = coeffY(10, 1) * coord(i, 3) ^ 3
eleX = coeffX(11, 1) * coord(i, 2) ^ 3 * coord(i, 3)
eleY = coeffY(11, 1) * coord(i, 2) ^ 3 * coord(i, 3)
twlX = coeffX(12, 1) * coord(i, 2) * coord(i, 3) ^ 3
twlY = coeffY(12, 1) * coord(i, 2) * coord(i, 3) ^ 3
thrX = coeffX(13, 1) * coord(i, 2) ^ 4
thrY = coeffY(13, 1) * coord(i, 2) ^ 4
fteX = coeffX(14, 1) * coord(i, 2) ^ 2 * coord(i, 3) ^ 2
fteY = coeffY(14, 1) * coord(i, 2) ^ 2 * coord(i, 3) ^ 2
fthnX = coeffX(15, 1) * coord(i, 3) ^ 4
fthnY = coeffY(15, 1) * coord(i, 3) ^ 4

Xgrid(i) = fourtmX + fthX + sixX + sevX + eigX + ninX + tenX + eleX + twlX + thrX + fteX + fthnX
Ygrid(i) = fourtmY + fthY + sixY + sevY + eigY + ninY + tenY + eleY + twlY + thrY + fteY + fthnY

END IF

Xchk = coord(i, 4) + ((Xgrid(i) - coord(i, 4)) * 100)
Ychk = coord(i, 5) + ((Ygrid(i) - coord(i, 5)) * 100)

PRINT USING "###"; coord(i, 1);
PRINT USING "#######.###"; xscan(i) ; yscan(i); Xgrid(i) ; Ygrid(i)
```

```
NEXT

FOR i = counterchkpts TO totalpoints
  ChkerrX(i, 1) = 0#
    ChkerrY(i, 1) = 0#
  Chkerrvect(i, 1) = 0#
NEXT

PRINT "Residual Error of Check points"
PRINT "pt. No . Obs. Coord      Comp. Coord            Residual    "
PRINT "____________________________________________________________________________"
PRINT "    xO(m)    yO(m)  xC(m)    yC(m)   x(m)    y(m)  Vector(m)"
PRINT "____________________________________________________________________________"



FOR i = counterchkpts TO totalpoints

    ChkerrX(i, 1) = Xgrid(i) - coord(i, 4)
      ChkerrY(i, 1) = Ygrid(i) - coord(i, 5)
    Chkerrvect(i, 1) = SQR(ChkerrX(i, 1) ^ 2 + ChkerrY(i, 1) ^ 2)
 PRINT USING "###"; coord(i, 1);
 PRINT USING "########.###"; coord(i, 4) ; coord(i, 5) ; Xgrid(i); Ygrid(i);
 PRINT USING "####.###"; ChkerrX(i, 1); ChkerrY(i, 1); Chkerrvect(i, 1)
  IF i = 12 THEN ANY$ = INPUT$(1)
  NEXT

  ' sum of error in x,y, vector
       'initialise sum
       sumx = 0#: sumy = 0#: sumvect = 0#
       rsumX = 0#: rsumY = 0#


FOR i = counterchkpts TO totalpoints

          sumx = sumx + ABS(ChkerrX(i, 1))
              sumy = sumy + ABS(ChkerrY(i, 1))
                  rsumX = rsumX + ABS(ChkerrX(i, 1) ^ 2)
              rsumY = rsumY + ABS(ChkerrY(i, 1) ^ 2)
          sumvect = sumvect + ABS(Chkerrvect(i, 1))
        NEXT

    nochk = totalpoints - counterchkpts + 1
  ' Mean Error and R.M.S.E in x,y,vect
    minX = sumx / nochk
    minY = sumy / nochk
    Vect = SQR((minX ^ 2) + (minY ^ 2))

       rootminX = SQR((rsumX) / (nochk - 1))
```

```
        rootminY = SQR((rsumY) / (nochk - 1))
        PRINT

        rootvect = SQR((rootminX ^ 2) + (rootminY ^ 2))

   PRINT "Mean error in x(m)  ="; USING "#####.###"; minX
   PRINT "Mean error in y(m)  ="; USING "#####.###"; minY
   PRINT "Mean vector error(m) ="; USING "#####.###"; Vect
     PRINT
   PRINT "R.M.S.E in x(m)     ="; USING "#####.###"; rootminX
   PRINT "R.M.S.E in y(m)     ="; USING "#####.###"; rootminY
   PRINT "R.M.S.E Vector(m)   ="; USING "#####.###"; rootvect

LABELQQQ:
END SUB


SUB CalCoeff (pterms, InvMat(), MatrapLx(), MatrapLy(), coeffX(), coeffY())

'====== Subroutine to calculate transformation coefficients=======

FOR i = 1 TO pterms
     coeffX(i, 1) = 0#
     coeffY(i, 1) = 0#
        FOR k = 1 TO pterms
          coeffX(i, 1) = coeffX(i, 1) + InvMat(i, k) * MatrapLx(k)
          coeffY(i, 1) = coeffY(i, 1) + InvMat(i, k) * MatrapLy(k)
        NEXT
NEXT

END SUB


SUB CalConPts (out$, pterms, nopts, coord(), coeffX(), coeffY(), Xcontrol(), Ycontrol())

'====== Subroutine to calculate control points coordinates=======

 FOR i = 1 TO nopts

fourtmX = coeffX(1, 1) + coeffX(2, 1) * coord(i, 2) + coeffX(3, 1) * coord(i, 3) + coeffX(4, 1) * coord(i,
2) * coord(i, 3)
 fourtmY = coeffY(1, 1) + coeffY(2, 1) * coord(i, 2) + coeffY(3, 1) * coord(i, 3) + coeffY(4, 1) * coord(i,
2) * coord(i, 3)

' Choice of different polynomial terms

 IF pterms = 4 THEN
    Xcontrol(i) = fourtmX
    Ycontrol(i) = fourtmY
```

```
ELSEIF pterms = 5 THEN
 fthX = coeffX(5, 1) * coord(i, 2) ^ 2
 fthY = coeffY(5, 1) * coord(i, 2) ^ 2

   Xcontrol(i) = fourtmX + fthX
   Ycontrol(i) = fourtmY + fthY
 ELSEIF pterms = 6 THEN
fthX = coeffX(5, 1) * coord(i, 2) ^ 2
 fthY = coeffY(5, 1) * coord(i, 2) ^ 2
  sixX = coeffX(6, 1) * coord(i, 3) ^ 2
    sixY = coeffY(6, 1) * coord(i, 3) ^ 2
   Xcontrol(i) = fourtmX + fthX + sixX
   Ycontrol(i) = fourtmY + fthY + sixY
 ELSEIF pterms = 7 THEN
fthX = coeffX(5, 1) * coord(i, 2) ^ 2
 fthY = coeffY(5, 1) * coord(i, 2) ^ 2
  sixX = coeffX(6, 1) * coord(i, 3) ^ 2
    sixY = coeffY(6, 1) * coord(i, 3) ^ 2
      sevX = coeffX(7, 1) * coord(i, 2) ^ 2 * coord(i, 3)
       sevY = coeffY(7, 1) * coord(i, 2) ^ 2 * coord(i, 3)
   Xcontrol(i) = fourtmX + fthX + sixX + sevX
   Ycontrol(i) = fourtmY + fthY + sixY + sevY
 ELSEIF pterms = 8 THEN
fthX = coeffX(5, 1) * coord(i, 2) ^ 2
 fthY = coeffY(5, 1) * coord(i, 2) ^ 2
  sixX = coeffX(6, 1) * coord(i, 3) ^ 2
    sixY = coeffY(6, 1) * coord(i, 3) ^ 2
      sevX = coeffX(7, 1) * coord(i, 2) ^ 2 * coord(i, 3)
       sevY = coeffY(7, 1) * coord(i, 2) ^ 2 * coord(i, 3)
         eigX = coeffX(8, 1) * coord(i, 2) * coord(i, 3) ^ 2
           eigY = coeffY(8, 1) * coord(i, 2) * coord(i, 3) ^ 2
   Xcontrol(i) = fourtmX + fthX + sixX + sevX + eigX
   Ycontrol(i) = fourtmY + fthY + sixY + sevY + eigY
 ELSEIF pterms = 9 THEN
fthX = coeffX(5, 1) * coord(i, 2) ^ 2
 fthY = coeffY(5, 1) * coord(i, 2) ^ 2
  sixX = coeffX(6, 1) * coord(i, 3) ^ 2
    sixY = coeffY(6, 1) * coord(i, 3) ^ 2
      sevX = coeffX(7, 1) * coord(i, 2) ^ 2 * coord(i, 3)
       sevY = coeffY(7, 1) * coord(i, 2) ^ 2 * coord(i, 3)
         eigX = coeffX(8, 1) * coord(i, 2) * coord(i, 3) ^ 2
           eigY = coeffY(8, 1) * coord(i, 2) * coord(i, 3) ^ 2
             ninX = coeffX(9, 1) * coord(i, 2) ^ 3
               ninY = coeffY(9, 1) * coord(i, 2) ^ 3
   Xcontrol(i) = fourtmX + fthX + sixX + sevX + eigX + ninX
   Ycontrol(i) = fourtmY + fthY + sixY + sevY + eigY + ninY
 ELSEIF pterms = 10 THEN
fthX = coeffX(5, 1) * coord(i, 2) ^ 2
 fthY = coeffY(5, 1) * coord(i, 2) ^ 2
  sixX = coeffX(6, 1) * coord(i, 3) ^ 2
    sixY = coeffY(6, 1) * coord(i, 3) ^ 2
```

```
sevX = coeffX(7, 1) * coord(i, 2) ^ 2 * coord(i, 3)
sevY = coeffY(7, 1) * coord(i, 2) ^ 2 * coord(i, 3)
eigX = coeffX(8, 1) * coord(i, 2) * coord(i, 3) ^ 2
eigY = coeffY(8, 1) * coord(i, 2) * coord(i, 3) ^ 2
ninX = coeffX(9, 1) * coord(i, 2) ^ 3
ninY = coeffY(9, 1) * coord(i, 2) ^ 3
tenX = coeffX(10, 1) * coord(i, 3) ^ 3
tenY = coeffY(10, 1) * coord(i, 3) ^ 3
Xcontrol(i) = fourtmX + fthX + sixX + sevX + eigX + ninX + tenX
Ycontrol(i) = fourtmY + fthY + sixY + sevY + eigY + ninY + tenY
ELSEIF pterms = 11 THEN
fthX = coeffX(5, 1) * coord(i, 2) ^ 2
fthY = coeffY(5, 1) * coord(i, 2) ^ 2
sixX = coeffX(6, 1) * coord(i, 3) ^ 2
sixY = coeffY(6, 1) * coord(i, 3) ^ 2
sevX = coeffX(7, 1) * coord(i, 2) ^ 2 * coord(i, 3)
sevY = coeffY(7, 1) * coord(i, 2) ^ 2 * coord(i, 3)
eigX = coeffX(8, 1) * coord(i, 2) * coord(i, 3) ^ 2
eigY = coeffY(8, 1) * coord(i, 2) * coord(i, 3) ^ 2
ninX = coeffX(9, 1) * coord(i, 2) ^ 3
ninY = coeffY(9, 1) * coord(i, 2) ^ 3
tenX = coeffX(10, 1) * coord(i, 3) ^ 3
tenY = coeffY(10, 1) * coord(i, 3) ^ 3
eleX = coeffX(11, 1) * coord(i, 2) ^ 3 * coord(i, 3)
eleY = coeffY(11, 1) * coord(i, 2) ^ 3 * coord(i, 3)
Xcontrol(i) = fourtmX + fthX + sixX + sevX + eigX + ninX + tenX + eleX
Ycontrol(i) = fourtmY + fthY + sixY + sevY + eigY + ninY + tenY + eleY
ELSEIF pterms = 12 THEN
fthX = coeffX(5, 1) * coord(i, 2) ^ 2
fthY = coeffY(5, 1) * coord(i, 2) ^ 2
sixX = coeffX(6, 1) * coord(i, 3) ^ 2
sixY = coeffY(6, 1) * coord(i, 3) ^ 2
sevX = coeffX(7, 1) * coord(i, 2) ^ 2 * coord(i, 3)
sevY = coeffY(7, 1) * coord(i, 2) ^ 2 * coord(i, 3)
eigX = coeffX(8, 1) * coord(i, 2) * coord(i, 3) ^ 2
eigY = coeffY(8, 1) * coord(i, 2) * coord(i, 3) ^ 2
ninX = coeffX(9, 1) * coord(i, 2) ^ 3
ninY = coeffY(9, 1) * coord(i, 2) ^ 3
tenX = coeffX(10, 1) * coord(i, 3) ^ 3
tenY = coeffY(10, 1) * coord(i, 3) ^ 3
eleX = coeffX(11, 1) * coord(i, 2) ^ 3 * coord(i, 3)
eleY = coeffY(11, 1) * coord(i, 2) ^ 3 * coord(i, 3)
twlX = coeffX(12, 1) * coord(i, 2) * coord(i, 3) ^ 3
twlY = coeffY(12, 1) * coord(i, 2) * coord(i, 3) ^ 3
Xcontrol(i) = fourtmX + fthX + sixX + sevX + eigX + ninX + tenX + eleX + twlX
Ycontrol(i) = fourtmY + fthY + sixY + sevY + eigY + ninY + tenY + eleY + twlY
ELSEIF pterms = 13 THEN
fthX = coeffX(5, 1) * coord(i, 2) ^ 2
fthY = coeffY(5, 1) * coord(i, 2) ^ 2
sixX = coeffX(6, 1) * coord(i, 3) ^ 2
sixY = coeffY(6, 1) * coord(i, 3) ^ 2
```

```
      sevX = coeffX(7, 1) * coord(i, 2) ^ 2 * coord(i, 3)
       sevY = coeffY(7, 1) * coord(i, 2) ^ 2 * coord(i, 3)
        eigX = coeffX(8, 1) * coord(i, 2) * coord(i, 3) ^ 2
         eigY = coeffY(8, 1) * coord(i, 2) * coord(i, 3) ^ 2
          ninX = coeffX(9, 1) * coord(i, 2) ^ 3
           ninY = coeffY(9, 1) * coord(i, 2) ^ 3
          tenX = coeffX(10, 1) * coord(i, 3) ^ 3
         tenY = coeffY(10, 1) * coord(i, 3) ^ 3
        eleX = coeffX(11, 1) * coord(i, 2) ^ 3 * coord(i, 3)
       eleY = coeffY(11, 1) * coord(i, 2) ^ 3 * coord(i, 3)
      twlX = coeffX(12, 1) * coord(i, 2) * coord(i, 3) ^ 3
     twlY = coeffY(12, 1) * coord(i, 2) * coord(i, 3) ^ 3
   thrX = coeffX(13, 1) * coord(i, 2) ^ 4
  thrY = coeffY(13, 1) * coord(i, 2) ^ 4
    Xcontrol(i) = fourtmX + fthX + sixX + sevX + eigX + ninX + tenX + eleX + twlX + thrX
    Ycontrol(i) = fourtmY + fthY + sixY + sevY + eigY + ninY + tenY + eleY + twlY + thrY

 ELSEIF pterms = 14 THEN
  fthX = coeffX(5, 1) * coord(i, 2) ^ 2
   fthY = coeffY(5, 1) * coord(i, 2) ^ 2
    sixX = coeffX(6, 1) * coord(i, 3) ^ 2
     sixY = coeffY(6, 1) * coord(i, 3) ^ 2
      sevX = coeffX(7, 1) * coord(i, 2) ^ 2 * coord(i, 3)
       sevY = coeffY(7, 1) * coord(i, 2) ^ 2 * coord(i, 3)
        eigX = coeffX(8, 1) * coord(i, 2) * coord(i, 3) ^ 2
         eigY = coeffY(8, 1) * coord(i, 2) * coord(i, 3) ^ 2
          ninX = coeffX(9, 1) * coord(i, 2) ^ 3
           ninY = coeffY(9, 1) * coord(i, 2) ^ 3
          tenX = coeffX(10, 1) * coord(i, 3) ^ 3
         tenY = coeffY(10, 1) * coord(i, 3) ^ 3
        eleX = coeffX(11, 1) * coord(i, 2) ^ 3 * coord(i, 3)
       eleY = coeffY(11, 1) * coord(i, 2) ^ 3 * coord(i, 3)
      twlX = coeffX(12, 1) * coord(i, 2) * coord(i, 3) ^ 3
     twlY = coeffY(12, 1) * coord(i, 2) * coord(i, 3) ^ 3
   thrX = coeffX(13, 1) * coord(i, 2) ^ 4
  thrY = coeffY(13, 1) * coord(i, 2) ^ 4
  fteX = coeffX(14, 1) * coord(i, 2) ^ 2 * coord(i, 3) ^ 2
  fteY = coeffY(14, 1) * coord(i, 2) ^ 2 * coord(i, 3) ^ 2
    Xcontrol(i) = fourtmX + fthX + sixX + sevX + eigX + ninX + tenX + eleX + twlX + thrX + fteX
    Ycontrol(i) = fourtmY + fthY + sixY + sevY + eigY + ninY + tenY + eleY + twlY + thrY + fteY

 ELSEIF pterms = 15 THEN

'====================
  fthX = coeffX(5, 1) * coord(i, 2) ^ 2
   fthY = coeffY(5, 1) * coord(i, 2) ^ 2
    sixX = coeffX(6, 1) * coord(i, 3) ^ 2
     sixY = coeffY(6, 1) * coord(i, 3) ^ 2
      sevX = coeffX(7, 1) * coord(i, 2) ^ 2 * coord(i, 3)
       sevY = coeffY(7, 1) * coord(i, 2) ^ 2 * coord(i, 3)
        eigX = coeffX(8, 1) * coord(i, 2) * coord(i, 3) ^ 2
```

```
            eigY = coeffY(8, 1) * coord(i, 2) * coord(i, 3) ^ 2
              ninX = coeffX(9, 1) * coord(i, 2) ^ 3
                ninY = coeffY(9, 1) * coord(i, 2) ^ 3
              tenX = coeffX(10, 1) * coord(i, 3) ^ 3
            tenY = coeffY(10, 1) * coord(i, 3) ^ 3
          eleX = coeffX(11, 1) * coord(i, 2) ^ 3 * coord(i, 3)
        eleY = coeffY(11, 1) * coord(i, 2) ^ 3 * coord(i, 3)
      twlX = coeffX(12, 1) * coord(i, 2) * coord(i, 3) ^ 3
    twlY = coeffY(12, 1) * coord(i, 2) * coord(i, 3) ^ 3
  thrX = coeffX(13, 1) * coord(i, 2) ^ 4
thrY = coeffY(13, 1) * coord(i, 2) ^ 4
fteX = coeffX(14, 1) * coord(i, 2) ^ 2 * coord(i, 3) ^ 2
fteY = coeffY(14, 1) * coord(i, 2) ^ 2 * coord(i, 3) ^ 2
fthnX = coeffX(15, 1) * coord(i, 3) ^ 4
fthnY = coeffY(15, 1) * coord(i, 3) ^ 4


    Xcontrol(i) = fourtmX + fthX + sixX + sevX + eigX + ninX + tenX + eleX + twlX + thrX + fteX +
fthnX
    Ycontrol(i) = fourtmY + fthY + sixY + sevY + eigY + ninY + tenY + eleY + twlY + thrY + fteY +
fthnY

END IF

   Xcon = coord(i, 4) + ((Xcontrol(i) - coord(i, 4)) * 100)
   Ycon = coord(i, 5) + ((Ycontrol(i) - coord(i, 5)) * 100)
  NEXT
END SUB



SUB CoeffMat (pterms, coord(), nopts, MatA(), Lx(), Ly())

'====== Subroutine to form matrix  A=======

FOR i = 1 TO nopts
   MatA(i, 1) = 1!
     MatA(i, 2) = coord(i, 2)
       MatA(i, 3) = coord(i, 3)
         IF pterms = 3 GOTO labela
         MatA(i, 4) = coord(i, 2) * coord(i, 3)
         IF pterms = 4 GOTO labela
           MatA(i, 5) = coord(i, 2) ^ 2
           IF pterms = 5 GOTO labela

             MatA(i, 6) = coord(i, 3) ^ 2
           IF pterms = 6 GOTO labela
               MatA(i, 7) = coord(i, 2) ^ 2 * coord(i, 3)
           IF pterms = 7 GOTO labela
                 MatA(i, 8) = coord(i, 2) * coord(i, 3) ^ 2
           IF pterms = 8 GOTO labela
```

```
            MatA(i, 9) = coord(i, 2) ^ 3
        IF pterms = 9 GOTO labela
          MatA(i, 10) = coord(i, 3) ^ 3
        IF pterms = 10 GOTO labela
        MatA(i, 11) = MatA(i, 9) * coord(i, 3)
        IF pterms = 11 GOTO labela
      MatA(i, 12) = coord(i, 2) * MatA(i, 10)
        IF pterms = 12 GOTO labela
    MatA(i, 13) = coord(i, 2) ^ 4
        IF pterms = 13 GOTO labela
   MatA(i, 14) = coord(i, 2) ^ 2 * coord(i, 3) ^ 2
        IF pterms = 14 GOTO labela
   MatA(i, 15) = coord(i, 3) ^ 4

labela:
    NEXT

' Form  left hand side matrix Lx(i),Ly(i)

    FOR i = 1 TO nopts
       Lx(i) = coord(i, 4)
       Ly(i) = coord(i, 5)

    NEXT
END SUB
SUB CtrlResidual (pterms, nopts, coord(), errX(), errY(), errvect(), Xcontrol(), Ycontrol(), Lx(), Ly())

'====== Subroutine to residual at the control points=======

  FOR i = 1 TO nopts
    errX(i, 1) = 0#
      errY(i, 1) = 0#
    errvect(i, 1) = 0#
  NEXT
  PRINT "Residual Error"
  PRINT "pt. No . Obs. Coord      Comp. Coord         Residual     "
  PRINT "____________________________________________________________________________"
  PRINT "      xO(m)   yO(m)  xC(m)   yC(m)   x(m)   y(m)  Vector(m)"
  PRINT "____________________________________________________________________________"

    FOR i = 1 TO nopts
      errX(i, 1) = Xcontrol(i) - Lx(i)
        errY(i, 1) = Ycontrol(i) - Ly(i)
      errvect(i, 1) = SQR(errX(i, 1) ^ 2 + errY(i, 1) ^ 2)
      PRINT USING "###"; coord(i, 1);
      PRINT USING "########.###"; Lx(i) ; Ly(i) ; Xcontrol(i) ; Ycontrol(i) ;
     PRINT USING "####.###"; errX(i, 1); errY(i, 1); errvect(i, 1)
   NEXT
   ' sum of error in x,y, vector
        'initialise sum
        sumx = 0#: sumy = 0#: sumvect = 0#
```

```
        rsumX = 0#: rsumY = 0#

         FOR i = 1 TO nopts
           sumx = sumx + ABS(errX(i, 1))
               sumy = sumy + ABS(errY(i, 1))
                   rsumX = rsumX + ABS(errX(i, 1) ^ 2)
               rsumY = rsumY + ABS(errY(i, 1) ^ 2)
           sumvect = sumvect + ABS(errvect(i, 1))
         NEXT
    ' Mean Error and R.M.S.E in x,y,vect
      minX = sumx / nopts
      minY = sumy / nopts
      Vect = SQR((minX ^ 2) + (minY ^ 2))
         rootminX = SQR((rsumX) / (nopts - pterms))
         rootminY = SQR((rsumY) / (nopts - pterms))
         PRINT
         PRINT rsumX, rsumY
         rootvect = SQR((rootminX ^ 2) + (rootminY ^ 2))
     PRINT "Mean error in x(m)   ="; USING "#####.###"; minX
     PRINT "Mean error in y(m)   ="; USING "#####.###"; minY
     PRINT "Mean vector error(m) ="; USING "#####.###"; Vect
     PRINT
     PRINT "R.M.S.E in x(m)      ="; USING "#####.###"; rootminX
     PRINT "R.M.S.E in y(m)      ="; USING "#####.###"; rootminY
     PRINT "R.M.S.E Vector(m)    ="; USING "#####.###"; rootvect
ANY$ = INPUT$(1)

END SUB



SUB MatInv (pterms, MatAtA(), InvMat())

'====== Subroutine to calculate matrix inversion=======

FOR i = 1 TO pterms
   FOR j = 1 TO pterms
     InvMat(i, j) = 1 - ABS(SGN(i - j))
   NEXT
NEXT
    FOR i = 1 TO pterms - 1
        FOR j = i + 1 TO pterms
            x = MatAtA(j, i) / MatAtA(i, i)

              FOR k = 1 TO pterms
                MatAtA(j, k) = MatAtA(j, k) - x * MatAtA(i, k)
                InvMat(j, k) = InvMat(j, k) - x * InvMat(i, k)
              NEXT
         NEXT
     NEXT
       FOR i = pterms TO 1 STEP -1
```

```
        FOR k = 1 TO pterms
          FOR j = i + 1 TO pterms
            InvMat(i, k) = InvMat(i, k) - MatAtA(i, j) * InvMat(j, k)
          NEXT
            InvMat(i, k) = InvMat(i, k) / MatAtA(i, i)
        NEXT
      NEXT

END SUB


SUB MatTransp (pterms, nopts, MatA(), MatTrans())

'====== Subroutine to calculate matrix transpose=======

  FOR i = 1 TO nopts
    FOR j = 1 TO pterms
      MatTrans(j, i) = MatA(i, j)
    NEXT
  NEXT
END SUB

SUB Multiply (pterms, nopts, MatA(), MatTrans(), MatAtA())

'====== Subroutine to calculate matrix multiplication=======
  FOR i = 1 TO pterms
    FOR j = 1 TO pterms
      MatAtA(i, j) = 0
        FOR k = 1 TO nopts
          MatAtA(i, j) = MatAtA(i, j) + MatTrans(i, k) * MatA(k, j)
        NEXT
    NEXT
  NEXT
END SUB



SUB readata (datafile$, totalpoints, coord())

 '====== Subroutine to read data from data file=======

OPEN datafile$ FOR INPUT AS #1
     ' read control points

     FOR i = 1 TO totalpoints
      INPUT #1, coord(i, 1), coord(i, 2), coord(i, 3), coord(i, 4), coord(i, 5)
      PRINT coord(i, 1); coord(i, 2); coord(i, 3); coord(i, 4); coord(i, 5)
     NEXT

END SUB
```

Appendix E4 LLATRSO – perogram to convert coordinates in Longitude and Latitude inti Eastings and Northings (m) of the Malaysian Rectified Skew Orthomorphic coordinate system

```
DECLARE SUB CoeffMat (pterms#, coord#(), nopts#, MatA#(), Lx#(), Ly#())
DECLARE SUB CalChkPts (out$, pterms#, totalpoints#, counterchkpts#, coord#(), xscan#(), yscan#(),
coeffX#(), coeffY#(), Xgrid#(), Ygrid#(), ChkerrX#(), ChkerrY#(), Chkerrvect#())
DECLARE SUB CtrlResidual (pterms#, nopts#, coord#(), errX#(), errY#(), errvect#(), Xcontrol#(),
Ycontrol#(), Lx#(), Ly#())
DECLARE SUB CalConPts (out$, pterms#, nopts#, coord#(), coeffX#(), coeffY#(), Xcontrol#(),
Ycontrol#())
DECLARE SUB MatInv (pterms#, MatAtA#(), InvMat#())
DECLARE SUB MatTransp (pterms#, nopts#, MatA#(), MatTrans#())
DECLARE SUB Multiply (pterms#, nopts#, MatA#(), MatTrans#(), MatAtA#())
DECLARE SUB readata (datafile$, totalpoints#, coord#())
DECLARE SUB AtL (pterms#, nopts#, Lx#(), Ly#(), MatTrans#(), MatrapLx#(), MatrapLy#())
DECLARE SUB CalCoeff (pterms#, InvMat#(), MatrapLx#(), MatrapLy#(), coeffX#(), coeffY#())

DEFDBL A-Z
SCREEN 12
COLOR 2
'================================
' Program to convert long/lat  to MRSO coordinates
' using Least Squares Adjustment
' NOTE: USING 10 TERMS POLYNOMIAL
' By : Wan Mohd Naim
'    Department of Geography
'    University of Edinburgh
'================================


' Main Program

CLS
INPUT " Enter name of data file        :-"; datafile$
PRINT " Enter name of data file        :- "; totalpts
labelb:
INPUT " Number of control points in file :-"; nopts
INPUT " Number of check points in file  :-"; chkpts
INPUT " Number of polynomial terms      :-"; pterms

' error message
IF nopts <= pterms THEN
   PRINT "Not enough control points to perform transformation"
   GOTO labelb
END IF

' Dimension Arrays
DIM MatA(nopts, pterms), coord(totalpoints, 5), Lx(nopts), Ly(nopts), MatTrans(pterms, nopts)
```

```
DIM MatAtA(nopts, nopts), InvMat(pterms, pterms), MatrapLx(pterms), MatrapLy(pterms)
DIM coeffX(pterms, 1), coeffY(pterms, 1)
DIM xscan(102), yscan(102), Xgrid(102), Ygrid(102)
DIM errX(nopts, 1), errY(nopts, 1), errvect(nopts, 1)
DIM Xcontrol(nopts), Ycontrol(nopts)
DIM ChkerrX(totalpoints, 1), ChkerrY(totalpoints, 1), Chkerrvect(totalpoints, 1)


' ------------- call matrix subroutine--------------------------
CALL readata(datafile$, totalpoints, coord())
ANY$ = INPUT$(1)
CALL CoeffMat(pterms, coord(), nopts, MatA(), Lx(), Ly())
CALL MatTransp(pterms, nopts, MatA(), MatTrans())
CALL Multiply(pterms, nopts, MatA(), MatTrans(), MatAtA())
CALL MatInv(pterms, MatAtA(), InvMat())
CALL AtL(pterms, nopts, Lx(), Ly(), MatTrans(), MatrapLx(), MatrapLy())
CALL CalCoeff(pterms, InvMat(), MatrapLx(), MatrapLy(), coeffX(), coeffY())
CALL CalConPts(out$, pterms, nopts, coord(), coeffX(), coeffY(), Xcontrol(), Ycontrol())
CALL CtrlResidual(pterms, nopts, coord(), errX(), errY(), errvect(), Xcontrol(), Ycontrol(), Lx(), Ly())
CALL CalChkPts(out$, pterms, totalpoints, counterchkpts, coord(), xscan(), yscan(), coeffX(), coeffY(),
Xgrid(), Ygrid(), ChkerrX(), ChkerrY(), Chkerrvect())

SUB AtL (pterms, nopts, Lx(), Ly(), MatTrans(), MatrapLx(), MatrapLy())

'====== Subroutine to multiply matrix=======

  FOR i = 1 TO pterms
    MatrapLx(i) = 0!
    MatrapLy(i) = 0!
        FOR k = 1 TO nopts
           MatrapLx(i) = MatrapLx(i) + MatTrans(i, k) * Lx(k)
           MatrapLy(i) = MatrapLy(i) + MatTrans(i, k) * Ly(k)
        NEXT
  NEXT
END SUB

SUB CalChkPts (out$, pterms, totalpoints, counterchkpts, coord(), xscan(), yscan(), coeffX(), coeffY(),
Xgrid(), Ygrid(), ChkerrX(), ChkerrY(), Chkerrvect())

'======== Subroutine to calculate coordinate of TIC points ============


 FOR i = 1 TO totalpoints
   xscan(i) = coord(i, 2)
   yscan(i) = coord(i, 3)

 fourtmX = coeffX(1, 1) + coeffX(2, 1) * xscan(i) + coeffX(3, 1) * yscan(i) + coeffX(4, 1) * xscan(i) *
yscan(i)
 fourtmY = coeffY(1, 1) + coeffY(2, 1) * xscan(i) + coeffY(3, 1) * yscan(i) + coeffY(4, 1) * xscan(i) *
yscan(i)
```

```
fthX = coeffX(5, 1) * coord(i, 2) ^ 2
  fthY = coeffY(5, 1) * coord(i, 2) ^ 2
    sixX = coeffX(6, 1) * coord(i, 3) ^ 2
      sixY = coeffY(6, 1) * coord(i, 3) ^ 2
        sevX = coeffX(7, 1) * coord(i, 2) ^ 2 * coord(i, 3)
          sevY = coeffY(7, 1) * coord(i, 2) ^ 2 * coord(i, 3)
            eigX = coeffX(8, 1) * coord(i, 2) * coord(i, 3) ^ 2
              eigY = coeffY(8, 1) * coord(i, 2) * coord(i, 3) ^ 2
                ninX = coeffX(9, 1) * coord(i, 2) ^ 3
                  ninY = coeffY(9, 1) * coord(i, 2) ^ 3
                tenX = coeffX(10, 1) * coord(i, 3) ^ 3
              tenY = coeffY(10, 1) * coord(i, 3) ^ 3
    Xgrid(i) = fourtmX + fthX + sixX + sevX + eigX + ninX + tenX
    Ygrid(i) = fourtmY + fthY + sixY + sevY + eigY + ninY + tenY
Xchk = coord(i, 4) + ((Xgrid(i) - coord(i, 4)) * 100)
Ychk = coord(i, 5) + ((Ygrid(i) - coord(i, 5)) * 100)

    PRINT USING "###"; coord(i, 1);
   PRINT USING "#######.###"; xscan(i); yscan(i); Xgrid(i); Ygrid(i)


 NEXT

LABRLQQQ:

END SUB

SUB CalCoeff (pterms, InvMat(), MatrapLx(), MatrapLy(), coeffX(), coeffY())

'====== Subroutine to calculate transformation coefficient ===========

FOR i = 1 TO pterms
      coeffX(i, 1) = 0#
      coeffY(i, 1) = 0#
         FOR k = 1 TO pterms
           coeffX(i, 1) = coeffX(i, 1) + InvMat(i, k) * MatrapLx(k)
           coeffY(i, 1) = coeffY(i, 1) + InvMat(i, k) * MatrapLy(k)
         NEXT
NEXT

END SUB



SUB CalConPts (out$, pterms, nopts, coord(), coeffX(), coeffY(), Xcontrol(), Ycontrol())
  FOR i = 1 TO nopts

'====== Subroutine to calculate control point coordinates ===========

 fourtmX = coeffX(1, 1) + coeffX(2, 1) * coord(i, 2) + coeffX(3, 1) * coord(i, 3) + coeffX(4, 1) * coord(i,
2) * coord(i, 3)
```

```
fourtmY = coeffY(1, 1) + coeffY(2, 1) * coord(i, 2) + coeffY(3, 1) * coord(i, 3) + coeffY(4, 1) * coord(i,
2) * coord(i, 3)

fthX = coeffX(5, 1) * coord(i, 2) ^ 2
  fthY = coeffY(5, 1) * coord(i, 2) ^ 2
   sixX = coeffX(6, 1) * coord(i, 3) ^ 2
     sixY = coeffY(6, 1) * coord(i, 3) ^ 2
       sevX = coeffX(7, 1) * coord(i, 2) ^ 2 * coord(i, 3)
         sevY = coeffY(7, 1) * coord(i, 2) ^ 2 * coord(i, 3)
           eigX = coeffX(8, 1) * coord(i, 2) * coord(i, 3) ^ 2
             eigY = coeffY(8, 1) * coord(i, 2) * coord(i, 3) ^ 2
               ninX = coeffX(9, 1) * coord(i, 2) ^ 3
                 ninY = coeffY(9, 1) * coord(i, 2) ^ 3
               tenX = coeffX(10, 1) * coord(i, 3) ^ 3
             tenY = coeffY(10, 1) * coord(i, 3) ^ 3
    Xcontrol(i) = fourtmX + fthX + sixX + sevX + eigX + ninX + tenX
    Ycontrol(i) = fourtmY + fthY + sixY + sevY + eigY + ninY + tenY

END SUB

SUB CoeffMat (pterms, coord(), nopts, MatA(), Lx(), Ly())

'====== Subroutine to form matrix A ============

FOR i = 1 TO nopts
   MatA(i, 1) = 1!
     MatA(i, 2) = coord(i, 2)
       MatA(i, 3) = coord(i, 3)
         IF pterms = 3 GOTO labela
         MatA(i, 4) = coord(i, 2) * coord(i, 3)
         IF pterms = 4 GOTO labela
           MatA(i, 5) = coord(i, 2) ^ 2
           IF pterms = 5 GOTO labela

             MatA(i, 6) = coord(i, 3) ^ 2
           IF pterms = 6 GOTO labela
               MatA(i, 7) = coord(i, 2) ^ 2 * coord(i, 3)
           IF pterms = 7 GOTO labela
                 MatA(i, 8) = coord(i, 2) * coord(i, 3) ^ 2
           IF pterms = 8 GOTO labela
               MatA(i, 9) = coord(i, 2) ^ 3
           IF pterms = 9 GOTO labela
             MatA(i, 10) = coord(i, 3) ^ 3
           IF pterms = 10 GOTO labela
           MatA(i, 11) = MatA(i, 9) * coord(i, 3)
           IF pterms = 11 GOTO labela
         MatA(i, 12) = coord(i, 2) * MatA(i, 10)
           IF pterms = 12 GOTO labela
       MatA(i, 13) = coord(i, 2) ^ 4
           IF pterms = 13 GOTO labela
      MatA(i, 14) = coord(i, 2) ^ 2 * coord(i, 3) ^ 2
```

```
        IF pterms = 14 GOTO labela
     MatA(i, 15) = coord(i, 3) ^ 4

labela:
    NEXT

' Form  left hand side matrix Lx(i),Ly(i)

    FOR i = 1 TO nopts
      Lx(i) = coord(i, 4)
      Ly(i) = coord(i, 5)

    NEXT
END SUB

SUB CtrlResidual (pterms, nopts, coord(), errX(), errY(), errvect(), Xcontrol(), Ycontrol(), Lx(), Ly())

'====== Subroutine to calculate the residual at the control points ============


  FOR i = 1 TO nopts
    errX(i, 1) = 0#
      errY(i, 1) = 0#
    errvect(i, 1) = 0#
  NEXT
  PRINT "Residual Error"
  PRINT "pt. No . Obs. Coord      Comp. Coord        Residual    "
  PRINT "_________________________________________________________________"
  PRINT "     xO(m)   yO(m)  xC(m)   yC(m)   x(m)   y(m)  Vector(m)"
  PRINT "_________________________________________________________________"

    FOR i = 1 TO nopts

      errX(i, 1) = Xcontrol(i) - Lx(i)
        errY(i, 1) = Ycontrol(i) - Ly(i)
      errvect(i, 1) = SQR(errX(i, 1) ^ 2 + errY(i, 1) ^ 2)
      PRINT USING "###"; coord(i, 1);
      PRINT USING "#########.###"; Lx(i); Ly(i); Xcontrol(i); Ycontrol(i);
      PRINT USING "########.######"; errX(i, 1); errY(i, 1); errvect(i, 1)
    NEXT
    ' sum of error in x,y, vector
         'initialise sum
         sumx = 0#: sumy = 0#: sumvect = 0#
         rsumX = 0#: rsumY = 0#

          FOR i = 1 TO nopts
            sumx = sumx + ABS(errX(i, 1))
                sumy = sumy + ABS(errY(i, 1))
                    rsumX = rsumX + ABS(errX(i, 1) ^ 2)
                rsumY = rsumY + ABS(errY(i, 1) ^ 2)
            sumvect = sumvect + ABS(errvect(i, 1))
```

```
        NEXT

    ' Mean Error and R.M.S.E in x,y,vect
      minX = sumx / nopts
      minY = sumy / nopts
      Vect = SQR((minX ^ 2) + (minY ^ 2))
         rootminX = SQR((rsumX) / (nopts - pterms))
         rootminY = SQR((rsumY) / (nopts - pterms))
         PRINT
         PRINT rsumX, rsumY
         rootvect = SQR((rootminX ^ 2) + (rootminY ^ 2))

    PRINT "Mean error in x(m)  ="; USING "#####.#######"; minX
    PRINT "Mean error in y(m)  ="; USING "#####.#######"; minY
    PRINT "Mean vector error(m) ="; USING "#####.#######"; Vect
    PRINT
    PRINT "R.M.S.E in x(m)     ="; USING "#####.#######"; rootminX
    PRINT "R.M.S.E in y(m)     ="; USING "#####.#######"; rootminY
    PRINT "R.M.S.E Vector(m)   ="; USING "#####.#######"; rootvect
ANY$ = INPUT$(1)

END SUB



SUB MatInv (pterms, MatAtA(), InvMat())


'====== Subroutine to calculate matrix inversion ============

FOR i = 1 TO pterms
  FOR j = 1 TO pterms
    InvMat(i, j) = 1 - ABS(SGN(i - j))
  NEXT
NEXT
    FOR i = 1 TO pterms - 1
        FOR j = i + 1 TO pterms
            x = MatAtA(j, i) / MatAtA(i, i)

              FOR k = 1 TO pterms
                MatAtA(j, k) = MatAtA(j, k) - x * MatAtA(i, k)
                InvMat(j, k) = InvMat(j, k) - x * InvMat(i, k)
              NEXT
          NEXT
     NEXT
        FOR i = pterms TO 1 STEP -1
          FOR k = 1 TO pterms
            FOR j = i + 1 TO pterms
              InvMat(i, k) = InvMat(i, k) - MatAtA(i, j) * InvMat(j, k)
            NEXT
              InvMat(i, k) = InvMat(i, k) / MatAtA(i, i)
```

```
        NEXT
      NEXT


END SUB


SUB MatTransp (pterms, nopts, MatA(), MatTrans())

"====== Subroutine to calculate matrix transpose ============

  FOR i = 1 TO nopts
    FOR j = 1 TO pterms
      MatTrans(j, i) = MatA(i, j)
    NEXT
  NEXT
   FOR i = 1 TO pterms
    PRINT MatTrans(i, 1); MatTrans(i, 2); MatTrans(i, 3); MatTrans(i, 3)
   NEXT
 END SUB

SUB Multiply (pterms, nopts, MatA(), MatTrans(), MatAtA())

"====== Subroutine to calculate multiply matrix ============
  FOR i = 1 TO pterms
     FOR j = 1 TO pterms
       MatAtA(i, j) = 0
         FOR k = 1 TO nopts
            MatAtA(i, j) = MatAtA(i, j) + MatTrans(i, k) * MatA(k, j)
          NEXT
     NEXT
  NEXT
 END SUB


SUB readata (datafile$, totalpoints, coord())

"====== Subroutine to read data from data file ============


OPEN datafile$ FOR INPUT AS #1
      ' read control points

     FOR i = 1 TO totalpoints
      INPUT #1, coord(i, 1), coord(i, 2), coord(i, 3), coord(i, 4), coord(i, 5)
PRINT coord(i, 1); coord(i, 2); coord(i, 3); coord(i, 4); coord(i, 5)
     NEXT
END SUB
```

Appendix E5 – Sample of input and output data file

Sample of input data

1	28.375	2734.875	1000	1220
2	617.375	2737.125	1050	1220
3	1209.875	2739.125	1100	1220
4	1803.125	2740.375	1150	1220
5	2396.125	2742.125	1200	1220
6	2397.875	2151.625	1200	1170
7	1804.125	2150.125	1150	1170
8	1210.875	2148.375	1100	1170
9	618.875	2146.625	1050	1170
10	30.125	2144.625	1000	1170
11	31.625	1435.375	1000	1110
12	620.125	1437.625	1050	1110
13	1212.375	1439.625	1100	1110
14	1806.125	1441.125	1150	1110
15	2399.625	1442.625	1200	1110
16	2400.875	734.125	1200	1050
17	1807.125	732.875	1150	1050
18	1213.875	730.875	1100	1050
19	621.875	729.125	1050	1050
20	33.125	727.125	1000	1050
21	34.875	136.375	1000	1000
22	622.875	138.625	1050	1000
23	1214.875	140.375	1100	1000
24	1807.875	142.125	1150	1000
25	2401.875	143.625	1200	1000
26	263.375	2735.875	1020	1220
27	1446.875	2739.625	1120	1220
28	2158.875	2741.375	1180	1220
29	28.625	2498.375	1000	1200
30	973.125	2501.875	1080	1200
31	1684.875	2503.875	1140	1200
32	2396.875	2505.625	1200	1200
33	30.875	1790.125	1000	1140
34	974.625	1793.125	1080	1140
35	1686.125	1795.125	1140	1140
36	2398.625	1797.375	1200	1140
37	32.375	1081.375	1000	1080
38	976.125	1084.875	1080	1080
39	1687.625	1086.625	1140	1080
40	2400.375	1088.375	1200	1080
41	34.125	372.875	1000	1020
42	977.375	376.375	1080	1020
43	1688.875	378.375	1140	1020
44	2401.625	379.875	1200	1020
45	269.875	137.375	1020	1000
46	1451.875	141.125	1120	1000
47	2164.125	143.125	1180	1000

Note:
Column No. 1 is point number
Column No. 2 is x image coordinate
Column No. 3 is y image coordinate
Column No. 4 is x grid plate coordinate (in mm)
Column No. 5 is y grid plate coordinate (in mm)
Total number of control points – 25
Total number of check points – 22

Sample of output

For control points

Pt.No	Grid coord		Computed coord.		Errors		
	x(mm)	y(mm)	x(mm)	y(mm)	x(mm)	y(mm)	Vector(mm)
1	1000.000	1220.000	999.976	1219.994	-0.024	-0.006	0.024
2	1050.000	220.000	1050.032	1220.011	0.032	0.011	0.034
3	1100.000	1220.000	1099.985	1220.013	-0.015	0.013	0.019
4	1150.000	1220.000	1150.000	1219.988	0.000	-0.012	0.012
5	1200.000	1220.000	1200.009	1219.990	0.009	-0.010	0.013
6	1200.000	1170.000	1199.971	1170.017	-0.029	0.017	0.034
7	1150.000	1170.000	1150.013	1170.011	0.013	0.011	0.017
8	1100.000	1170.000	1099.992	1170.001	-0.008	0.001	0.008
9	1050.000	1170.000	1050.006	1169.984	0.006	-0.016	0.017
10	1000.000	1170.000	1000.007	1170.003	0.007	0.003	0.008
11	1000.000	1110.000	1000.030	1110.012	0.030	0.012	0.032
12	1050.000	1110.000	1049.949	1109.974	-0.051	-0.026	0.057
13	1100.000	1110.000	1100.024	1110.002	0.024	0.002	0.024
14	1150.000	1110.000	1150.002	1109.981	0.002	-0.019	0.019
15	1200.000	1110.000	1200.010	1110.008	0.010	0.008	0.013
16	1200.000	1050.000	1200.025	1049.981	0.025	-0.019	0.032
17	1150.000	1050.000	1149.998	1050.003	-0.002	0.003	0.004
18	1100.000	1050.000	1099.966	1050.019	-0.034	0.019	0.039
19	1050.000	1050.000	1050.000	1050.007	-0.000	0.007	0.007
20	1000.000	1050.000	1000.001	1050.006	0.001	0.006	0.007
21	1000.000	1000.000	999.981	999.990	-0.019	-0.010	0.021
22	1050.000	1000.000	1050.030	1000.004	0.030	0.004	0.030
23	1100.000	1000.000	1100.008	999.994	0.008	-0.006	0.010
24	1150.000	1000.000	1150.004	999.998	0.004	-0.002	0.004
25	1200.000	1000.000	1199.981	1000.008	-0.019	0.008	0.021

Mean error in x(mm) = 0.016
Mean error in y(mm) = 0.010
Mean vector error(mm) = 0.019
R.M.S.E in x(mm) = 0.028
R.M.S.E in y(mm) = 0.016
R.M.S.E Vector(mm) = 0.032

Sample of output file - continued

For check points

Pt.No	Grid coord		Computed coord.		Errors		
	x(mm)	y(mm)	x(mm)	y(mm)	x(mm)	y(mm)	Vector (mm)
26	1020.000	1220.000	1019.969	1220.011	-0.031	0.011	0.033
27	1120.000	1220.000	1120.017	1219.964	0.017	-0.036	0.040
28	1180.000	1220.000	1179.995	1219.980	-0.005	-0.020	0.021
29	1000.000	1200.000	999.998	1200.013	-0.002	0.013	0.013
30	1080.000	1200.000	1080.026	1199.981	0.026	-0.019	0.032
31	1140.000	1200.000	1139.999	1199.950	-0.001	-0.050	0.050
32	1200.000	1200.000	1200.015	1199.985	0.015	-0.015	0.021
33	1000.000	1140.000	1000.038	1140.008	0.038	0.008	0.039
34	1080.000	1140.000	1079.997	1140.011	-0.003	0.011	0.012
35	1140.000	1140.000	1139.996	1139.977	-0.004	-0.023	0.024
36	1200.000	1140.000	1200.025	1140.017	0.025	0.017	0.030
37	1000.000	1080.000	1000.010	1079.953	0.010	-0.047	0.048
38	1080.000	1080.000	1079.992	1079.981	-0.008	-0.019	0.020
39	1140.000	1080.000	1139.986	1079.999	-0.014	-0.001	0.014
40	1200.000	1080.000	1200.037	1080.016	0.037	0.016	0.040
41	1000.000	1020.000	999.987	1019.984	-0.013	-0.016	0.021
42	1080.000	1020.000	1080.042	1020.027	0.042	0.027	0.050
43	1140.000	1020.000	1140.041	1020.027	0.041	0.027	0.049
44	1200.000	1020.000	1199.999	1020.012	-0.001	0.012	0.012
45	1020.000	1000.000	1019.932	999.979	-0.068	-0.021	0.071
46	1120.000	1000.000	1120.052	1000.002	0.052	0.002	0.052
47	1180.000	1000.000	1179.998	1000.032	-0.002	0.032	0.032

Mean error in x(mm) = 0.021
Mean error in y(mm) = 0.020
Mean vector error(mm) = 0.029
R.M.S.E in x(mm) = 0.028
R.M.S.E in y(mm) = 0.024
R.M.S.E Vector(mm) = 0.037

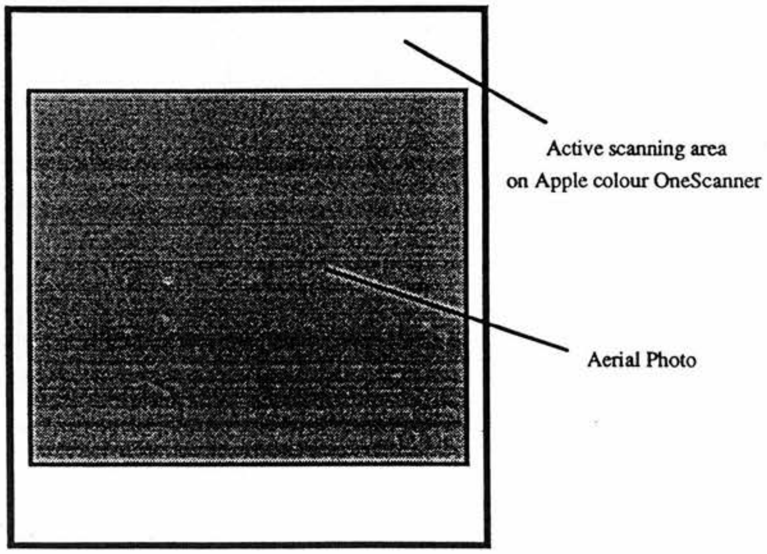
Appendix F Image rectification procedure for images scanned in DTP scanners (using ERDAS 7.5 image processing software)

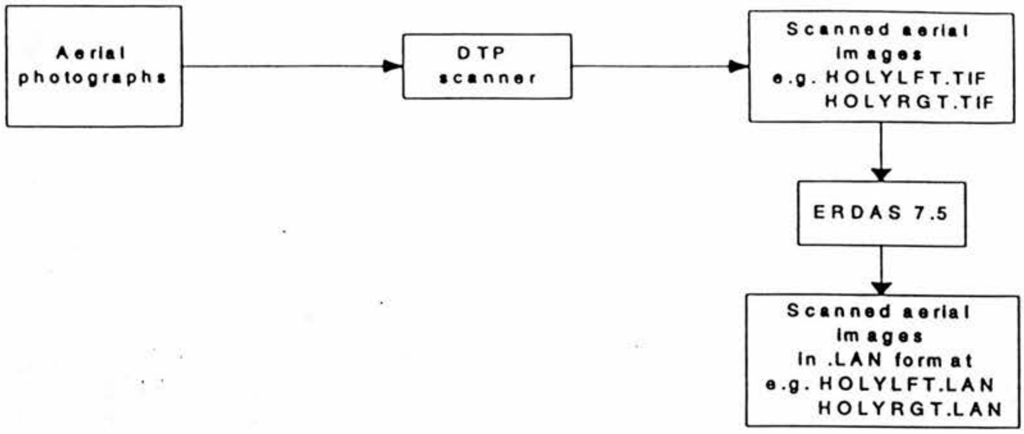
a) Scan aerial photos and calibrated grid plate

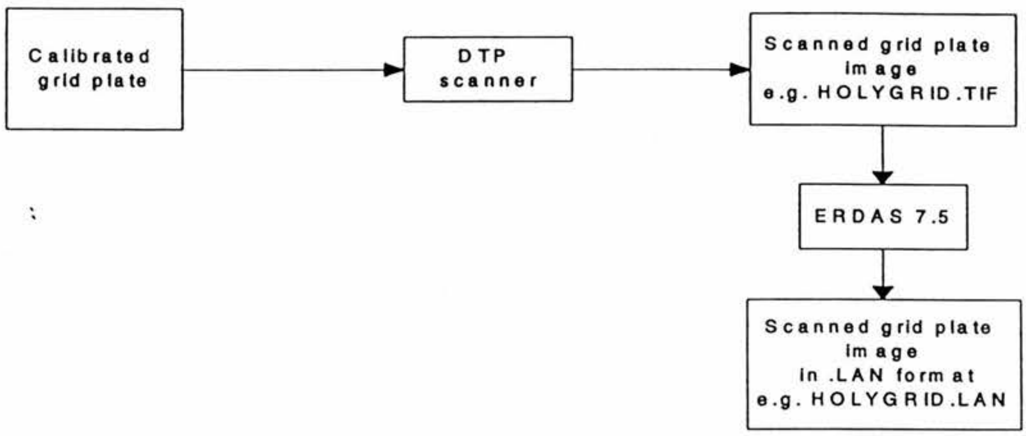
Procedures

1. Place aerial photo such that the four side fiducial marks are within the active area
2. Scan the aerial photo at the required resolution.
3. Place calibrated grid plate within the scanner active area and scan at the same scanning resolution as the aerial photo.

[Note:- make sure that the scanning for both the aerial photos and grid plate is at same area on the scanner. This can be easily be achieved in most DTP scanners]



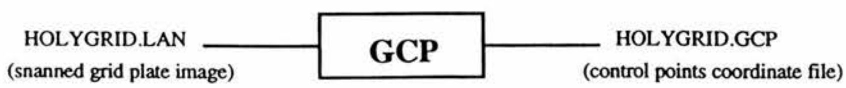




b) Measure image control points

Using GCP program in ERDAS image processing software, measure the image coordinates of the control points (refer chapter 5 for more detailed explanation) and also input the grid plate coordinates of the selected control points.

example



c) **Calculate image transformation coefficients**

The main purpose of this process is to calculate the transformation coefficient from scanned grid image coordinates to calibrated grid plate coordinates. This coefficient will later be used to correct the scanned aerial images. Program COORDN in ERDAS can be used to perform this process.

[Note:- for each scanner setup there should be only one CFN file]

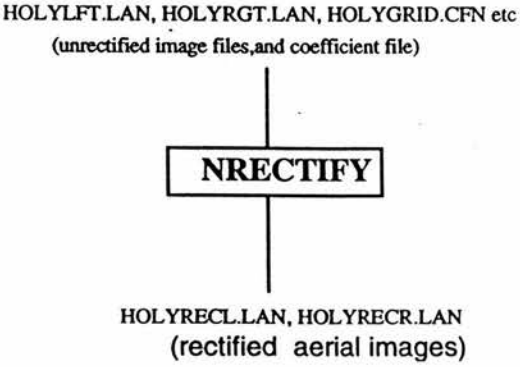
d) **Rectify the scanned image**

The purpose of this process is to minimise the distortion of image scanned in Apple desktop scanner.

Use NRECTIFY program in ERDAS to perform image rectification.

Note:-
When running NRECTIFY make sure that the followings are followed:-

- use the same coefficient file determined earlier (i.e. HOLYGRID.CFN)
- output pixel size must be 1
- use the defaults to rectify the entire image
- use cubic convolution resampling to maintain the best image detail



Appendix G1 R.m.s.e. and maximum errors (distortion) of Apple Colour OneScanner at the control and check points

Transformation	Control Points R.m.s.e. in pixel			Control Points Max. Error in pixel			Check Points R.m.s.e. in pixel			Check Points Max. Error in pixel		
	Mx	My	Mv	Ex	Ey	Ev	Mx	My	Mv	Ex	Ey	Ev
Linear Conformal	1.90	1.29	2.29	3.51	2.63	3.65	1.88	1.36	2.32	3.35	2.33	3.59
Affine	1.35	0.27	1.38	2.98	0.63	3.03	1.29	0.33	1.33	2.73	0.60	2.74
Polynomial												
4 terms (xy)	1.36	0.27	1.38	2.82	0.68	2.87	1.29	0.33	1.33	2.63	0.61	2.68
5 terms (x^2)	0.62	0.19	0.65	1.44	0.48	1.46	0.56	0.25	0.61	0.88	0.51	0.93
6 terms (y^2)	0.62	0.19	0.65	1.32	0.49	1.34	0.56	0.26	0.62	0.95	0.49	0.95
7 terms (x^2y)	0.61	0.19	0.64	1.03	0.40	1.04	0.54	0.25	0.60	1.01	0.46	1.06
8 terms (xy^2)	0.61	0.19	0.64	0.95	0.47	0.96	0.55	0.25	0.61	1.02	0.47	1.06
9 terms (x^3)	0.16	0.19	0.25	0.34	0.44	0.45	0.19	0.26	0.32	0.35	0.48	0.52
10 terms (y^3)	0.16	0.15	0.22	0.36	0.36	0.36	0.19	0.22	0.29	0.32	0.45	0.49
11 terms (x^3y)	0.16	0.15	0.22	0.34	0.36	0.36	0.18	0.22	0.28	0.34	0.46	0.49
12 terms (xy^3)	0.15	0.15	0.22	0.37	0.32	0.40	0.18	0.22	0.27	0.33	0.44	0.46
13 terms (x^4)	0.15	0.15	0.21	0.34	0.35	0.36	0.16	0.22	0.27	0.30	0.45	0.46
14 terms(x^2y^2)	0.14	0.15	0.21	0.33	0.34	0.34	0.15	0.22	0.27	0.27	0.44	0.44
15 terms (y4)	0.14	0.15	0.21	0.35	0.32	0.38	0.15	0.21	0.26	0.27	0.43	0.45

Note:
Number of control points - 72
Number of check points - 29

Appendix G2 R.m.s.e at the control and check points of the Apple, HPScanjet IIc and Epson scanners

	Apple Colour One Scanner									HP Scanjet IIc Scanner						Epson Scanner GT-9000					
	rmse at control (pixel)			rmse at control (pixel) **			rmse at check (pixel)			rmse at control (pixel)			rmse at check (pixel)			rmse at control (pixel)			rmse at check (pixel)		
Transformation	x	Y	vec	x	y	vec	x	y	vec	x	y	vec	x	y	vec	x	y	vec	x	y	vec
Linear conformal	1.97	1.21	2.32	3.41	2.27	4.01	1.80	1.34	2.24	0.83	0.50	0.97	0.79	0.45	0.91	0.80	0.75	1.09	0.71	0.71	1.00
Affine	1.52	0.25	1.54	2.58	0.78	2.70	1.37	0.29	1.39	0.69	0.24	0.73	0.67	0.24	0.72	0.60	0.54	0.81	0.53	0.36	0.64
4 terms poly (xy)	1.56	0.25	1.58	2.64	0.59	2.68	1.35	0.29	1.38	0.71	0.22	0.74	0.68	0.28	0.73	0.55	0.38	0.67	0.41	0.24	0.48
5 terms poly (x^2)	0.59	0.16	0.61	0.99	0.54	1.11	0.37	0.21	0.42	0.39	0.21	0.45	0.45	0.27	0.52	0.56	0.38	0.68	0.42	0.24	0.48
6 terms poly (y^2)	0.59	0.16	0.61	1.01	0.47	1.11	0.35	0.21	0.41	0.38	0.21	0.43	0.43	0.26	0.50	0.59	0.36	0.69	0.42	0.28	0.50
7 terms poly (x^2y)	0.59	0.16	0.61	0.96	0.49	1.08	0.31	0.21	0.38	0.37	0.22	0.43	0.44	0.27	0.51	0.60	0.38	0.70	0.42	0.28	0.51
8 terms poly (xy^2)	0.59	0.17	0.62	0.99	0.49	1.11	0.34	0.21	0.40	0.36	0.21	0.42	0.39	0.27	0.48	0.59	0.39	0.71	0.49	0.26	0.55
9 terms poly (x^3)	0.20	0.17	0.26	0.40	0.52	0.64	0.19	0.21	0.29	0.33	0.21	0.39	0.36	0.27	0.46	0.32	0.39	0.51	0.25	0.25	0.35
10 terms poly (y^3)	0.21	0.17	0.27	0.40	0.47	0.60	0.19	0.22	0.29	0.33	0.19	0.38	0.35	0.27	0.45	0.31	0.40	0.51	0.25	0.26	0.35
11 terms poly (x^3y)	0.21	0.18	0.27	0.40	0.45	0.59	0.19	0.21	0.29	0.33	0.19	0.38	0.34	0.29	0.44	0.31	0.41	0.52	0.25	0.25	0.34
12 terms poly (xy^3)	0.21	0.18	0.28	0.42	0.42	0.59	0.18	0.21	0.28	0.33	0.17	0.37	0.34	0.30	0.35	0.31	0.44	0.53	0.24	0.26	0.35
13 terms poly (x^4)	0.18	0.19	0.26	0.33	0.42	0.54	0.18	0.21	0.28	0.34	0.17	0.38	0.36	0.31	0.48	0.32	0.44	0.54	0.25	0.25	0.34
14 terms poly(x^2y^2)	0.18	0.20	0.27	0.33	0.45	0.54	0.18	0.21	0.28	0.32	0.16	0.36	0.32	0.31	0.45	0.33	0.46	0.56	0.24	0.25	0.34
15 terms poly (y4)	0.19	0.15	0.24	0.33	0.40	0.54	0.18	0.24	0.29	0.34	0.16	0.37	0.37	0.32	0.46	0.34	0.40	0.53	0.25	0.25	0.34

Appendix G3 R.m.s.e. at the control and check points of the two HP Scanjet 4c scanners

	HP Scanjet 4c (Scanner 1)						HP Scanjet II4c (Scanner 2)					
	rmse at control (pixel)			rmse at check (pixel)			rmse at control (pixel)			rmse at check (pixel)		
Transformation	x	y	vec	x	y	vec	x	y	vec	x	y	vec
Linear conformal	0.84	0.73	1.11	0.68	0.78	1.04	1.89	1.82	2.62	1.87	1.93	2.67
Affine	0.48	0.32	0.58	0.35	0.35	0.50	0.58	0.33	0.67	0.42	0.35	0.64
4 terms poly (xy)	0.48	0.33	0.59	0.33	0.35	0.48	0.44	0.34	0.55	0.39	0.34	0.52
5 terms poly (x^2)	0.45	0.31	0.54	0.29	0.32	0.44	0.44	0.35	0.56	0.40	0.34	0.53
6 terms poly (y^2)	0.45	0.29	0.53	0.39	0.32	0.32	0.44	0.33	0.54	0.39	0.36	0.53
7 terms poly (x^2y)	0.46	0.29	0.54	0.31	0.32	0.44	0.39	0..33	0.51	0.34	0.38	0.51
8 terms poly (xy^2)	0.46	0.31	0.55	0.33	0.32	0.46	0.38	0.33	0.49	0.38	0.38	0.53
9 terms poly (x^3)	0.41	0.31	0.52	035	0.32	0.47	0.29	0.33	0.45	0.34	0.40	0.53
10 terms poly (y^3)	0.34	0.32	0.46	0.42	0.32	0.53	0.31	0.33	0.45	0.34	0.40	0.53
11 terms poly (x^3y)	0.34	0.31	0.46	0.42	0.35	0.55	0.31	0.34	0.46	0.34	0.40	0.53
12 terms poly (xy^3)	0.34	0.32	0.47	0.42	0.35	0.55	0.31	0.35	0.47	0.35	0.40	0.53
13 terms poly (x^4)	0.35	0.33	0.48	0.42	0.36	0.56	0.32	0.36	0.48	0.36	0.40	0.53
14 terms poly (x^2y^2)	0.36	0.34	0.51	0.42	0.36	0.55	0.33	0.39	0.51	0.36	0.40	0.54
15 terms poly (y4)	0.36	0.32	0.48	0.40	0.40	0.56	0.33	0.33	0.47	0.36	0.46	059

Note : scanning at 600 dpi

Appendix G4 Maximum error (in pixels) at the control and check points

	Apple Colour One Scanner			**HP Scanjet IIc Scanner**		**Epson Scanner GT-.9000**		**HP Scanjet 4c (Scanner 1)**		**HP Scanjet 4c (Scanner 2)**	
Transformation	Max error. at control pts	Max error. at control pts ***	Max error at check pts	Max error at control pts	Max error at check pts	Max error at control pts	Max error at check pts	Max error at control pts	Max error at check pts	Max error at control pts	Max error at check pts
Affine	2.45	4.59	2.18	1.49	1.34	1.63	1.29	0.98	0.91	1.55	1.21
Polynomial											
4 terms (xy)	2.26	4.07	2.04	1.47	1.32	1.18	0.87	0.98	0.79	0.93	0.98
5 terms (x^2)	1.04	1.81	0.69	0.82	1,32	1.18	0.87	0.99	0.74	0.94	0.91
6 terms (y^2)	0.96	1.79	0.61	0.78	1.20	1.16	0.82	0.96	0.73	0.84	0.91
7 terms (x^2y)	0.96	1.67	0.60	0.78	1.24	1.16	0.81	0.99	0.74	0.79	0.91
8 terms (xy^2)	0.89	1.60	0.64	0.88	1.08	1.14	0.98	0.96	0.86	0.80	1.04
9 terms (x^3)	0.36	0.99	0.54	0.67	0.96	0.76	0.65	0.72	0.74	0.69	1.04
10 terms (y^3)	0.34	0.92	0.55	0.67	0.89	0.74	0.65	0.51	0.87	0.58	1.08
11 terms (x^3y)	0.28	0.92	0.55	0.67	0.84	0.74	0.66	0.51	0.88	0.58	1.08
12 terms (xy^3)	0.28	0.92	0.60	0.67	0.88	0.74	0.69	0.51	0.94	0.58	1.08
13 terms (x^4)	0.29	0.92	0.61	0.69	0.94	0.65	0.60	0.49	0.88	0.56	1.07
14 terms (x^2y^2)	0.31	0.80	0.60	0.61	0.91	0.65	0.60	0.51	0.89	0.55	1.08
15 terms (y4)	0.25	0.61	0.69	0.63	0.91	0.69	0.67	0.52	0.96	0.53	1.04

Note : *** - scanning at 600 dpi

Appendix G5 Distortion pattern after image calibration

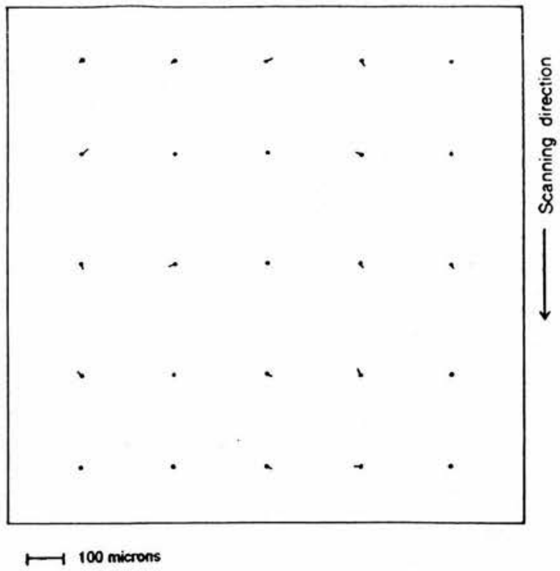


Figure a) Distortion pattern of the Apple scanner image after applying third order polynomial transformation

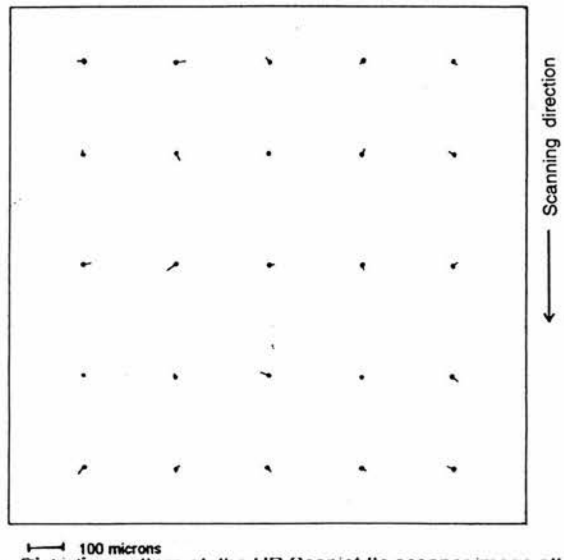


Figure b) Distortion pattern of the HP Scanjet IIc scanner image after applying third order polynomial transformation

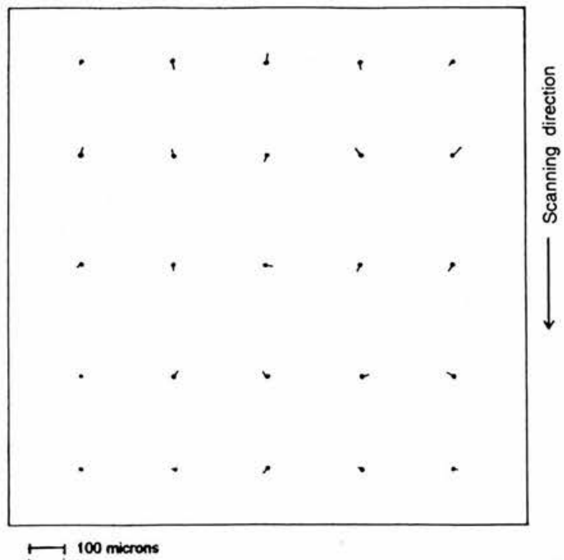


Figure c) Distortion pattern of the Epson GT-9000 scanner image after applying third order polynomial transformation

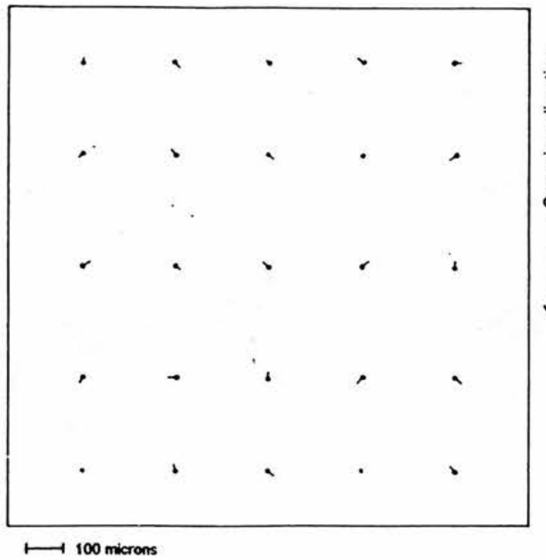


Figure d) Distortion pattern of the HP Scanjet 4c (Scanner 1) scanner image after applying second order polynomial transformation

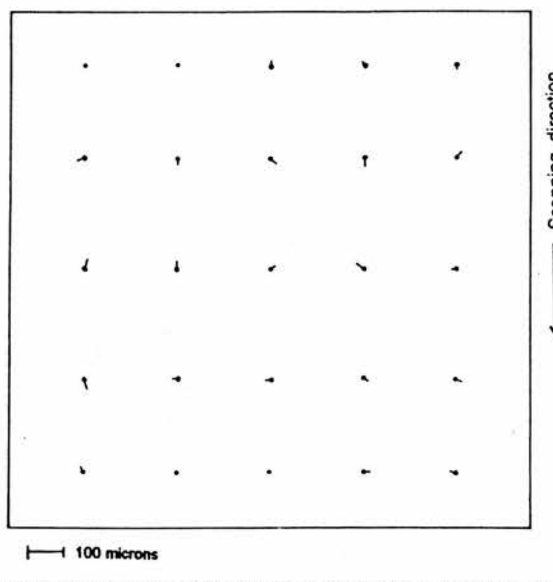


Figure e) Distortion pattern of the HP Scanjet 4c (Scanner 2) scanner image after applying second order polynomial transformation

Appendix H1 - List of GCPs used

Table 1 Set 1 GCPs for Test Site 1

GCP No.	Eastings (m)	Northings (m)	Height (m)
2934	327077.800	674445.987	37.744
2914	327480.194	674431.046	30.251
2114	327612.416	673945.573	38.012
2932	327107.500	673897.000	35.551
2936	327013.470	673553.295	110.566
2906	327502.374	673538.662	94.944
3334	327336.129	673635.761	59.62
2908	327149.486	673743.263	36.506

Table 2 Set 2 GCPs for Test Site 1

GCP No.	Eastings (m)	Northings (m)	Height (m)
1001	327072.102	674431.375	37.730
1002	327553.510	674416.647	30.789
1003	327504.407	674146.833	27.822
1004	327283.777	674130.270	32.999
1005	327067.036	673954.428	36.268
1006	327572.076	673883.065	38.486
2936	327013.470	673553.295	110.566
1008	327502.637	673538.441	95.944
2932	327107.500	673897.000	35.551

Table 3 GCPs for Test Site 2

GCP No.	Eastings (m)	Northings (m)	Height (m)
1	387587.802	341296.790	5.079
2	384958.977	343521.716	5.484
3	384140.364	341570.198	5.755
4	385909.699	342979.094	86.589
5	387670.821	342396.039	9.806
6	384782.473	342354.636	5.488
7	386338.265	341592.296	12.507
8	385914.556	341055.612	20.199
9	387769.878	340943.734	4.685
10	388250.130	342354.549	7.250

Appendix H2 - Accuracy of model orientation set-up

Table 1 Accuracy of model orientation set-up using image scanned in different scanners and at different scanning resolution using Set 1 GCPs

	Desktop Scanner (Apple Colour OneScanner)				**Zeiss PS1 Scanner**	
GCP No.	Left image -rectified 300 dpi (in pixel)	Right image -rectified 300 dpi (in pixel)	Left image - unrectified 300 dpi (in pixel)	Right image -unrectified 300dpi (in pixel)	Left image 850 dpi (in pixel)	Right image 850 dpi (in pixel)
2934	0.565	1.039	1.334	1.226	1.016	1.496
2914	0.492	1.018	1.728	1.267	0.864	1.270
2114	0.785	0.799	0.684	1.180	1.283	1.079
2932	0.877	0.847	1.053	0.655	1.344	1.759
2908	0.147	1.162	1.205	0.943	0.763	1.519
2906	1.175	0.870	1.237	0.868	1.922	1.176
2936	1.097	0.856	1.152	0.932	1.634	1.488
3334	1.200	1.054	1.246	1.330	1.803	1.546
R.M.S.E. xy (pixel)	**0.640**	**0.680**	**1.180**	**0.870**	**1.570**	**1.510**
R.M.S.E. xy (m)	**0.280**	**0.290**	**0.520**	**0.380**	**0.240**	**0.230**

Table 2 Accuracy of model orientation set-up using image scanned in Zeiss PS1 scanner using Set 2 GCPs

GCP No.	Left image- 850 dpi (in pixel)	Right image-850 dpi (in pixel)
1001	0.721	1.289
1002	1.184	0.850
1003	0.918	0.975
1004	1.369	0.460
1005	1.352	0.959
1006	1.021	1.435
1007	1.591	1.215
1008	1.379	1.501
1009	0.500	1.245
R.M.S.E. xy (pixel)	**1.080**	**1.030**
R.M.S.E. xy (m)	**0.170**	**0.160**

Appendix H3 - Coordinates of the check points measured in both the AP190 stereoplotter and DMS based on image scanned at different resolution for both the test sites

Table a) Test Site 1 - Coordinates measured in both AP190 stereoplotter and DMS. (Scanning resolution - 300 dpi)

	AP190		DMS			
			Rectified Image		Unrectified image	
Check Point No.	E(m)	N(m)	E(m)	N(m)	E(m)	N(m)
1	327070.74	674430.15	327070.76	674429.84	327070.70	674429.65
2	327222.35	674415.63	327222.35	674415.40	327222.26	674415.30
3	327379.19	674375.93	327379.35	674375.67	327379.56	674375.15
4	327335.21	674265.79	327335.14	674265.83	327335.25	674265.90
5	327366.15	674187.49	327366.09	674187.81	327366.76	674186.97
6	327263.40	674126.42	327263.91	674126.11	327263.75	674126.08
7	327146.72	674276.94	327146.87	674276.81	327146.69	674276.77
8	327059.96	674264.99	327060.05	674264.93	327059.47	674265.18
9	327052.62	673969.14	327052.79	673968.83	327052.62	673968.41
10	327571.98	673882.99	327572.27	673882.83	327573.02	673882.87
11	327374.44	673759.65	327375.08	673759.61	327375.51	673760.51
12	327246.80	673806.18	327247.07	673805.55	327246.89	673805.72
13	327102.84	673731.15	327103.22	673730.99	327103.03	673730.53
14	327023.12	673677.01	327023.68	673676.86	327024.03	673676.53
15	327120.91	673659.37	327121.36	673658.84	327120.74	673658.34
16	327311.37	674706.95	327311.72	674707.14	327311.72	674707.60
17	327350.16	673641.29	327350.60	673640.79	327350.39	673641.53
18	327491.64	673676.48	327492.16	673676.01	327492.67	673675.80
19	327499.18	673584.41	327499.05	673584.68	327499.06	673585.44
20	327368.56	673521.94	327368.83	673521.97	327368.12	673520.89

Table 2 Test Site 1 - Coordinates measured in both AP190 stereoplotter and DMS. (Scanning resolution - 850 dpi)

	AP190		**DMS**	
Point No.	E(m)	N(m)	E(m)	N(m)
1	327070.74	674430.15	327070.77	674429.93
2	327222.35	674415.63	327222.46	674415.44
3	327379.19	674375.93	327379.21	674375.80
4	327549.32	674408.62	327549.50	674408.25
5	327335.21	674265.74	327335.23	674265.86
6	327366.15	674187.49	327366.43	674187.58
7	327263.40	674126.42	327263.61	674126.48
8	327146.72	674276.94	327146.97	674276.65
9	327059.95	674264.93	327060.15	674264.77
10	327052.62	673969.14	327052.59	673969.04
11	327287.90	674026.96	327288.02	674026.95
12	327374.44	673759.65	327374.70	673759.58
13	327246.80	673806.18	327246.88	673806.13
14	327120.91	673659.37	327120.94	673659.36
15	327311.37	674706.95	327311.42	674707.07
16	327350.16	673641.29	327350.27	673641.32
17	327491.64	673676.48	327491.75	673676.57
18	327499.18	673584.41	327499.16	673584.45
19	327368.56	673521.94	327368.73	673521.86

Table 3 Test Site 2 - Coordinates measured in both AP190 stereoplotter and DMS

	AP190		DMS	
Point No.	E(m)	N(m)	E(m)	N(m)
1	387770.77	340943.36	387769.78	340943.53
2	387440.52	341324.47	387440.82	341323.13
3	387329.36	341113.79	387328.03	341113.04
4	384783.60	342353.45	384782.81	342353.59
5	384526.73	314866.59	384526.79	314865.99
6	386039.13	341138.82	386038.84	341138.57
7	386337.75	341591.88	386336.57	341593.09
8	385646.93	341665.94	385645.35	341665.54
9	386759.87	342287.57	386759.34	342286.94
10	386488.56	342590.83	386489.14	342590.88
11	388956.21	341720.01	388954.60	341719.80
12	386431.84	340850.29	386430.37	340849.05
13	384924.30	341500.67	384923.72	341500.17

Appendix H4 - Coordinates of check points measured in the AP190 and from orthoimage generated in DMS

Table 1 Test site 1 - Coordinates of check points measured in the AP190 and from the orthoimage generated in DMS

AP190		DMS	
Eastings (m)	Northings (m)	Eastings (m)	Northings(m)
327263.401	674126.421	327263.600	674126.600
327199.739	674013.137	327199.700	674013.000
327287.897	674026.963	327288.100	674027.100
327571.976	673882.992	327572.200	673883.000
327374.435	673759.649	327374.600	673759.900
327246.800	673806.178	327246.600	673806.000
327102.842	673731.148	327102.900	673731.100
327120.908	673659.369	327120.500	673659.600
327311.368	674706.950	327311.400	674707.000
327350.164	673641.292	327350.000	673641.200
327491.639	673676.484	327491.800	673676.200
327368.563	673521.942	327368.500	673521.600

Table 2 Test site 2 - Coordinates of check points measured in the AP190 and from orthoimage (small area) generated in DMS

AP190		DMS	
Eastings (m)	Northings (m)	Eastings (m)	Northings(m)
387441.0	341325.3	387440.9	341324.4
387424.3	341293.7	387423.2	341293.3
387357.3	341166.3	387357.4	3411667.7
387331.3	341113.3	387330.2	341113.4
387558.6	341268.2	387559.6	341267.2
387625.5	341241.4	387626.5	341240.7
387776.5	341155.4	387776.3	341156.0
387582.4	341129.5	387581.1	341127.0
387370.5	340912.7	387372.2	340913.4
387770.5	340944.1	387771.8	340945.5
387265.1	340976.1	387265.2	340976.5
387244.5	340860.7	387244.8	340861.8

APPENDIX H5 - Comparison between manually measured heights in the AP190 and automatically generated heights in DMS along cross-section 1- relatively flat area (Site 1)

N(m)	E(m)	DMS Ht(m)	AP190 Ht(m)	Remarks
673974.916	327009.704	55.24	35.24	Uncorrelated - Edge
673974.406	327018.384	55.24	35.45	Uncorrelated - Shadow
673973.897	327027.064	55.24	36.40	Uncorrelated - Trees
673973.387	327035.744	47.68	35.45	Uncorrelated
673972.877	327044.424	34.66	34.82	good contrast of surrounding features
673972.367	327053.104	34.24	34.50	"
673971.857	327061.784	34.24	34.34	"
673971.347	327070.464	35.08	34.34	"
673970.837	327079.144	34.66	34.34	"
673970.327	327087.824	34.66	34.81	"
673969.817	327096.503	34.24	34.17	"
673969.308	327105.183	34.24	34.17	"
673968.798	327113.863	32.98	34.49	
673968.288	327122.543	34.24	34.70	good contrast of surrounding features
673967.778	327131.223	33.40	34.59	
673967.268	327139.903	34.24	34.90	good contrast of surrounding features
673966.248	327157.263	34.24	34.05	"
673965.738	327165.943	32.98	34.16	open field
673965.228	327174.623	32.98	34.89	"
673964.719	327183.303	32.98	34.45	"
673964.209	327191.983	32.98	34.40	"
673963.699	327200.663	32.98	34.29	"
673963.189	327209.343	32.98	34.39	"
673962.679	327218.023	32.98	34.28	"
673962.169	327226.703	34.24	34.49	"
673961.659	327235.383	32.98	34.91	"
673961.149	327244.063	32.98	34.91	"
673960.640	327252.743	34.24	35.01	"
673960.130	327261.423	34.24	35.33	"
673959.620	327270.103	34.24	35.11	"
673959.110	327278.783	34.24	35.22	"
673958.600	327287.463	34.66	35.63	"
673958.090	327296.143	34.24	35.84	"
673957.580	327304.823	34.66	36.05	"
673957.070	327313.503	34.66	36.40	"
673956.560	327322.183	35.92	36.57	"
673956.051	327330.863	35.92	36.68	"
673955.541	327339.543	35.92	36.68	'
673955.031	327348.223	35.92	36.98	"
673954.521	327356.903	35.92	37.30	"
673954.011	327365.583	35.92	37.72	"
673953.501	327374.263	37.18	38.56	"

continued......

673952.991	327382.943	37.18	38.56	good contrast of surrounding features
673952.481	327391.623	37.18	38.98	"
673951.971	327400.303	37.18	38.66	"
673951.462	327408.983	35.92	38.98	"
673951.971	327400.303	37.18	38.66	good contrast of surrounding features
673951.462	327408.983	35.92	38.98	"
673950.952	327417.663	38.86	39.61	good contrast of surrounding features
673950.442	327426.343	40.12	40.87	good contrast of surrounding features
673949.932	327435.023	40.54	41.19	"
673949.422	327443.703	40.54	41.19	"
673948.912	327452.383	40.12	41.01	"
673948.402	327461.063	40.54	41.01	"
673947.892	327469.743	40.54	41.19	"
673947.383	327478.423	40.54	41.39	"
673946.873	327487.103	40.54	41.91	"
673946.363	327495.783	41.38	42.13	"
673945.853	327504.463	41.80	42.55	"
673945.343	327513.143	41.80	42.55	"
673944.833	327521.823	41.80	42.65	
673944.323	327530.503	41.80	43.18	
673943.813	327539.183	42.22	43.92	
673943.303	327547.863	53.14	44.13	poor contrast
673942.794	327556.543	53.56	44.65	"
673942.284	327565.222	56.92	44.33	"
673941.774	327573.902	55.24		
673941.264	327582.582	49.36		
673940.754	327591.262	41.80	41.59	
673940.244	327599.942	55.24	40.21	Uncorrelated
673939.734	327608.622	55.24	38.04	Uncorrelated

APPENDIX H6 - Comparison between manually measured heights in the AP190 and and automatically generated heights in DMS along cross-section 2- Hilly area (Site 1)

N(m)	E(m)	DMS Ht(m)	AP190Ht(m)	Remarks
673523.557	326983.190	55.24	-	uncorrelated
673523.047	326991.870	55.24	119.16	"
673522.537	327000.550	55.24	117.78	"
673522.028	327009.230	116.56	116.09	Good constrast of surrounding features
673521.518	327017.910	112.36	112.39	"
673521.008	327026.590	112.36	108.16	
673520.498	327035.270	114.04	110.17	
673519.988	327043.950	115.30	112.49	
673519.478	327052.630	114.04	111.75	
673518.968	327061.310	111.10	111.33	good contrast of surrounding features
673518.458	327069.990	110.26	108.47	
673517.949	327078.669	106.90	106.77	good contrast of surrounding features
673517.439	327087.349	105.64	104.45	
673516.929	327096.029	103.96	102.76	
673516.419	327104.709	101.44	101.38	good contrast of surrounding features
673515.909	327113.389	100.18	99.16	
673515.399	327122.069	97.24	97.57	good contrast of surrounding features
673514.889	327130.749	95.98	96.09	"
673514.379	327139.429	93.04	93.45	"
673513.869	327148.109	90.10	90.59	"
673513.360	327156.789	87.16	89.32	
673512.850	327165.469	85.90	85.41	good contrast of surrounding features
673512.340	327174.149	81.70	82.03	good contrast of surrounding features
673511.830	327182.829	77.08	79.38	poor contrast of surrounding features
673511.320	327191.509	74.56	77.54	"
673510.810	327200.189	72.88	75.05	"
673510.300	327208.869	71.62	74.52	"
673509.790	327217.549	69.94	71.98	"
673509.280	327226.229	68.68	71.24	"
673508.771	327234.909	67.42	70.07	"
673508.261	327243.589	66.16	69.44	"
673507.751	327252.269	65.74	67.43	"
673507.241	327260.949	64.06	67.74	"
673506.731	327269.629	64.06	66.47	"
673506.221	327278.309	62.80	64.89	"
673505.711	327286.989	61.54	64.36	"
673505.201	327295.669	61.12	62.98	"
673504.692	327304.349	59.86	62.98	"
673504.182	327313.029	58.60	61.61	"
673503.672	327321.709	59.86	62.56	"
673503.162	327330.389	58.18	60.86	"

continued........

673502.652	327339.069	56.92	61.92	poor contrast of surrounding features
673502.142	327347.749	58.60	60.23	"
673501.632	327356.429	56.92	60.55	"
673501.122	327365.109	56.92	60.97	"
673500.612	327373.789	58.60	60.67	"
673500.103	327382.469	59.86	62.34	"
673499.593	327391.149	61.54	64.56	"
673499.083	327399.829	67.42	68.04	"
673498.573	327408.509	67.00	69.10	"
673498.063	327417.189	67.00	69.10	"
673497.553	327425.869	68.68	69.20	"
673497.043	327434.549	72.88	70.68	poor contrast of surrounding features
673496.533	327443.229	75.82	73.53	"
673496.023	327451.909	78.76	78.40	good contrast of surrounding features
673495.514	327460.589	81.70	82.09	good contrast of surrounding features
673495.004	327469.269	84.64	86.21	poor contract of surrounding features
673494.494	327477.949	88.84	90.44	"
673493.984	327486.629	93.04	96.36	"
673493.474	327495.309	105.64	102.11	"
673492.964	327503.989	106.90	106.92	good contrast of surrounding features
673492.454	327512.669	106.90	106.50	good contrast of surrounding features
673491.944	327521.349	104.38	104.70	good contrast of surrounding features
673491.435	327530.029	102.70	103.12	good contrast of surrounding features
673490.925	327538.709	88.84	101.85	poor contrast of surrounding features
673490.415	327547.388	88.84	100.37	"
673489.905	327556.068	90.10	98.25	"
673489.395	327564.748	77.50	95.93	"
673488.885	327573.428	58.18	96.98	"

APPENDIX H7 - Comparison between manually measured heights in the AP190 and and automatically generated heights in DMS along cross-section for Site 2

Distance along cross-section	DMS height in metres (No smoothing function applied)	DMS height in metres (smoothing function applied)	AP190 height in metres
73.63	40.81	38.46	42.89
92.03	56.49	52.57	42.75
110.44	61.58	58.06	47.09
128.85	61.58	61.19	52.5
147.26	61.58	62.76	52.36
165.66	63.54	63.15	53.3
184.07	61.58	61.98	54.8
202.48	56.49	59.23	57.24
220.88	54.92	55.7	52.9
239.29	49.82	50.61	48.02
257.7	44.34	47.08	46.54
276.11	45.9	43.55	45.59
294.51	40.42	41.59	43.15
312.92	39.24	39.24	39.63
331.33	38.46	38.06	39.22
349.73	37.28	37.67	37.73
368.14	39.24	39.24	37.6
386.55	42.77	40.81	42.2
404.95	44.73	42.38	43.15
423.36	42.77	44.34	42.61
441.77	47.86	46.3	48.3
460.18	47.86	48.26	48.84
478.58	49.82	48.26	48.98
496.99	47.86	49.04	49.52
515.4	51.39	49.82	52.64
533.8	51.39	50.22	43.02
552.21	47.86	49.04	43.29
570.62	47.86	47.47	42.07
589.02	47.47	46.3	41.94
607.43	45.9	45.51	42.21
625.84	46.3	44.73	43.02
644.25	44.73	43.55	44.1
662.65	40.81	41.98	42.34
681.06	40.81	40.81	41.67
699.47	40.81	38.85	37.74
717.87	37.67	38.06	38.42
736.28	37.28	38.46	37.95
754.69	40.81	39.24	40.46
773.09	40.81	39.24	37.74

1656.63	35.71	31.01	15.79
1675.04	26.7	25.52	14.30
1693.44	19.64	21.21	19.30
1711.85	21.6	19.25	18.48
1730.26	16.5	19.64	18.23
1748.66	18.07	23.17	17.82
1767.07	26.7	31.01	19.59

Appendix I Data dictionary used for the study area

Layer	Feature	Class	Attributes	Value	Description
Existing land use	LANDUSE	Polygons	LU-CODE	101	Residential
				102	Industrial
				103	Agricultural
				104	Government Institution
				105	Commercial
				106	Recreational
				107	Forest reserve
				108	Agriculture research area
				109	Abandon tin mining area
				110	Existing dumping site
				111	Special reserve
				112	Water catchment area
				113	Nature reserve
Geology	GEOLOGY	Polygons	GEOLOGY-CODE	301	Alluvium
				302	Granitic rock
				303	Quartzite and Phyllite
				304	Phyllite and Schist
				305	Vein Quartz
				306	Schist with minor intercalation of phyllite
				307	Limestone (marble) with minor intercalation of phyllite
Water bodies	WATER_BODY	Polygons	WATER-CODE	401	Lakes
				402	Reservoir
				403	Ex-mining pond
Rivers	RIVERS	Lines	RIV-CODE	501	Major river more than 100 m wide
				502	Smaller river less than 100 m wide
				503	Minor stream
				504	Canal
Transportation	TRANSPORT	Lines	TRANSP-CODE	601	Federal highway
				602	State road
				603	Minor road
				610	Railway
Boundaries	BOUNDARY	Polygons	BDY-CODE	701	State boundary
				702	District boundary
				703	Local Authority boundary
Water intake point	WATERIN	Point	-	-	Location of water intake point
Slope	SLOPE	Polygons	SLOPE-CODE	1	0 - 5 % slope
				2	> 5 to 10 % slope
				3	> 10 to 25 % slope
				4	> 25 % slope
Sensitive area	AIRPORT	Polygon	SEN-CODE	801	Airport

Appendix J1 EXTCS - program to extract heights along a cross-section

```
CLS
DEFDBL A-Z

' --------------Open input DEM file and output cross-section file ----------------------------

input "Enter DEM file";DEMfile1$
input "Enter output cross-section file";Crossfile1$


OPEN  DEMfile1$ FOR INPUT AS #1
OPEN Crossfile$ FOR OUTPUT AS #2


INPUT "Enter no. of rows";row
INPUT "Enter no. of column";column
INPUT "Enter which row  to select";rowselect

     FOR i = 1 TO row
     FOR j = 1 TO pixel

        LOCATE 15, 20: PRINT "Row = "; i; "  Pixel = "; j
         INPUT #1, x, y, z

          IF j = rowselect THEN

          '---------print output to file------------------
             PRINT #2, USING "#######.###"; y; x;
             PRINT #2, USING "####.##"; z
          END IF
     NEXT
     NEXT

CLOSE #1
CLOSE #2
```

APPENDIX J2 DEMCONV- program to convert X Y Z ASCII formated DEM generated in DMS into ARC/INFO ASCII file format

```
DEFDBL A-Z

INPUT "Enter name of DEM file (generated in DMS)";DEMDMS$
INPUT "Enter name of ARC/INFO ASCII output file";ARCINFO$

OPEN DEMDMS$ FOR INPUT AS #1
OPEN ARCINFO$ FOR OUTPUT AS #2

CLS

INPUT "Number of rows";row
INPUT "Number of column";column
FOR lineno = 1 TO row
  FOR pixelno = 1 TO column
     INPUT #1, X, Y, Z
     id = 1

'print to screen
     LOCATE 10, 30: PRINT lineno, pixelno
     PRINT USING "#"; id;
     PRINT USING "#########.##"; X; Y;
     PRINT USING "####.#"; Z

' print to data file
     PRINT #2, USING "#"; id;
     PRINT #2, USING "#########.##"; X; Y;
     PRINT #2, USING "####.#"; Z

  NEXT
NEXT

PRINT #2, "END"

END
```

APPENDIX J3 WASTEDIS - program to calculate linear distance from all candidate sites to waste generation center and number of waste generation centers within certain specified distance

```
DEFDBL A-Z
CLS
DIM waste(70, 4), dist(70), distkm(70)

INPUT "Enter no. of candidate sites"; candsite
INPUT "Enter no. of waste generation centres";wastecenter
REDIM Site(candsite, 4), totaldist(candsite), totcount1(candsite)
REDIM totcount2(candsite), totcount3(candsite), totcount4(candsite)

OPEN "a:siteopt4.dat" FOR INPUT AS #1
OPEN "a:wastece1.dat" FOR INPUT AS #2

  FOR i = 1 TO candsite
     FOR j = 1 TO 4
       INPUT #1, Site(i, j)
      ' PRINT site(i, j)
     NEXT

  NEXT

    FOR i = 1 TO wastecenter
         FOR j = 1 TO 4
            INPUT #2, waste(i, j)
         NEXT
    NEXT


FOR i = 1 TO candsite

 'initialise distance and count
 totaldist(i) = 0
 totcount1(i) = 0
 totcount2(i) = 0
 totcount3(i) = 0
 totcount4(i) = 0


 FOR j = 1 TO wastecenter

   dist(j) = SQR((Site(i, 3) - waste(j, 3)) ^ 2 + SQR((Site(i, 4) - waste(j, 4)) ^ 2))
   distkm(j) = dist(j) / 1000

   IF distkm(j) < 4.999999 THEN
    totcount1(i) = totcount1(i) + 1
   ELSEIF distkm(j) >= 5! AND distkm(j) < 9.999999 THEN
    totcount2(i) = totcount2(i) + 1
   ELSEIF distkm(j) >= 10! AND distkm(j) < 14.999999# THEN
    totcount3(i) = totcount3(i) + 1
   ELSE
    totcount4(i) = totcount4(i) + 1
   END IF


   totaldist(i) = totaldist(i) + distkm(j)
  NEXT

NEXT
```

```
' DISPLAY ON THE SCREEN

  PRINT "TOTAL  HAUL  DISTANCE TO CANDIDATE SITE"
  PRINT "-----------------------------------------"
  PRINT
  PRINT "  SITE-ID    TOTAL DISTANCE"

FOR i = 1 TO candsite
  PRINT USING "##############"; Site(i, 2);
  PRINT USING "##############"; totaldist(i)
NEXT

PRINT
PRINT
PRINT


PRINT "     NUMBER OF WASTE GENERATION CENTRE FROM CANDIDATE SITES"
PRINT "     ----------------------------------------------------"
PRINT
PRINT "                    DISTANCE (KM) "
PRINT "  Site-ID      < 5    5 - 9.99    10 - 14.99   > 15 "

FOR i = 1 TO candsite
  PRINT USING "##############"; Site(i, 2); totcount1(i); totcount2(i); totcount3(i); totcount4(i)
NEXT

FOR i = 1 TO candsite
   wt1 = totcount1(i) * 40
        wt2 = totcount2(i) * 30
              wt3 = totcount3(i) * 20
                   wt4 = totcount4(i) * 10
                    totwt = wt1 + wt2 + wt3 + wt4
                    weighting = totwt / 100
  PRINT USING "##############"; Site(i, 2); wt1; totwt;
  PRINT USING "######.##"; weighting
NEXT

' PRINT TO PRINTER

  LPRINT "TOTAL  HAUL  DISTANCE TO CANDIDATE SITE"
  LPRINT "-----------------------------------------"
  LPRINT
  LPRINT "  SITE-ID    TOTAL DISTANCE"

FOR i = 1 TO candsite
  LPRINT USING "##############"; Site(i, 2);
  LPRINT USING "##############"; totaldist(i)
NEXT

LPRINT
LPRINT
LPRINT


LPRINT "     NUMBER OF WASTE GENERATION CENTRE FROM CANDIDATE SITES"
LPRINT "     ----------------------------------------------------"
LPRINT
LPRINT "                    DISTANCE (KM) "
LPRINT "  Site-ID      < 5    5 - 9.99    10 - 14.99   > 15 "
FOR i = 1 TO candsite
  LPRINT USING "##############"; Site(i, 2); totcount1(i); totcount2(i); totcount3(i); totcount4(i)
NEXT
```

```
labelxx:
FOR I = 1 TO candsite
wt1 = totcount1(I) * 40
wt2 = totcount2(I) * 30
wt3 = totcount3(I) * 20
wt4 = totcount4(i) * 10
totwt = wt1 + wt2 + wt3 + wt4
weighting = totwt / 100
   LPRINT USING "################"; Site(I, 2); wt1; totwt;
   LPRINT USING "#######.###"; weighting
NEXT
```

APPENDIX J4 WASTEGEN - program to estimate the yearly and cummulative amount of waste generated in the Petaling District.

```
DEFDBL A-Z
DIM petpopul(20, 4), totpopul(20), waste(20), wastevolume(20), comwastevol(20)


' Specify input and output file
INPUT "Enter name of population file"; populationfile$
INPUT "Enter output file name"; outfile$

OPEN populationfile$ FOR INPUT AS #1
OPEN "a:" + outfile$ FOR OUTPUT AS #2

CLS
'define  variables

 compaction = 711    ' compaction rate  kg/cu metres
 soilcover = .2      ' soil to cover material ratio

INPUT " enter start operation year"; year

PRINT " Waste from which municipality"
PRINT " Enter choice:-"
PRINT "    < 1 > Petaling Jaya Municipality only"
PRINT "    < 2 > Shah Alam Municipality only"
PRINT "    < 3 > Petaling District Council only "
PRINT "    < 4 > All municipality"
INPUT choiceno

PRINT "Enter output device"
PRINT "    <1> Screen"
PRINT "    <2> Data file"
INPUT outoption

noyearleft = 16 - (year - 1995)
datano = (year - 1995) + 1

'--------read population  data---------------

    FOR i = 1 TO 16
      FOR j = 1 TO 4
        INPUT #1, petpopul(i, j)
      NEXT
    NEXT
PRINT

IF outoption = 2 THEN GOTO labela
' ------calculate total population ----------------------
 FOR i = datano TO 16
```

```
    IF choiceno = 1 THEN
     totpopul(i) = petpopul(i, 2)
      ELSEIF choiceno = 2 THEN
       totpopul(i) = petpopul(i, 3)
        ELSEIF choiceno = 3 THEN
         totpopul(i) = petpopul(i, 4)
          ELSEIF choiceno = 4 THEN
            totpopul(i) = petpopul(i, 2) + petpopul(i, 3) + petpopul(i, 4)
    END IF

'------------calculate the amount of waste generated and volume occupied
    waste(i) = totpopul(i) * .843 * 365 ' waste generated in kilogram/year
    wastevolume(i) = waste(i) / compaction
    comwastevol = comwastevol + wastevolume(i)
    wastesoilvol = (comwastevol * 1.25)

    PRINT petpopul(i, 1);
    PRINT USING "########"; totpopul(i);
    PRINT USING "###########"; waste(i);
    PRINT USING "#########"; wastevolume(i);
    PRINT USING "#########"; comwastevol;
    PRINT USING "##########"; wastesoilvol

NEXT
END

'-----------output to data file-----------------

labela:
 FOR i = datano TO 16

    IF choiceno = 1 THEN
        totpopul(i) = petpopul(i, 2)
          ELSEIF choiceno = 2 THEN
              totpopul(i) = petpopul(i, 3)
                  ELSEIF choiceno = 3 THEN
                       totpopul(i) = petpopul(i, 4)
          ELSEIF choiceno = 4 THEN
             totpopul(i) = petpopul(i, 2) + petpopul(i, 3) + petpopul(i, 4)
    END IF

    waste(i) = totpopul(i) * .843 * 365 ' waste generated in kilogram/year
    wastevolume(i) = waste(i) / compaction
    comwastevol = comwastevol + wastevolume(i)
    wastesoilvol = (comwastevol * 1.25)

    PRINT #2, petpopul(i, 1);
    PRINT #2, USING "########"; totpopul(i);
    PRINT #2, USING "###########"; waste(i);
    PRINT #2, USING "#########"; wastevolume(i);
    PRINT #2, USING "#########"; comwastevol;
    PRINT #2, USING "##########"; wastesoilvol
NEXT
```

Appendix K List of control and check points

Table 1 List of control points

	Malaysian Revised Triangulation (MRT) 93 Coordinates		Rectified Skew Orthomorphic (RSO) coordinates	
Point No.	Longitude	Latitude	Eastings (m)	Northings(m)
1	100.8371814	3.786426172	315911.354	419233.121
2	101.1423112	3.525751811	349709.666	390293.925
3	101.7807835	3.041333014	420515.43	336540.897
4	101.3068053	3.225984333	367888.804	357092.169
5	101.4576971	2.722797992	384513.627	301404.855
6	101.6143828	3.538939933	402157.681	391602.967
7	102.1915048	3.178249319	466191.361	351585.216
8	102.1866562	3.553580381	465729.754	393081.021
9	101.7825406	4.019065992	420963.82	444638.667
10	102.0656141	4.0184043	452389.398	444495.534
11	101.9763858	2.682509114	442175.969	296820.957
12	101.865374	2.423684028	429774.819	268226.632
13	101.042058	4.001510203	338746.903	442935.825
14	101.3116596	3.992227217	368677.541	441813.313
15	100.7905574	3.903023328	310780.508	432145.301

Table 2 List of the check points

	Malaysian Revised Triangulation (MRT) 93 Coordinates		Rectified Skew Orthomorphic (RSO) coordinates	
Point No.	Longitude(^{o})	Latitude(^{o})	Eastings (m)	Northings(m)
16	101.5342617	3.151964589	393145.718	348839.193
17	101.3905173	3.684887761	377334.622	407806.818
18	101.4472115	3.024939011	383433.785	334818.586
19	101.0569917	3.750018967	340311.951	415122.650
20	101.2484142	3.462184736	361476.530	383228.925
21	101.5974408	3.309167631	400210.892	366203.084
22	102.0329298	3.492238347	448640.400	386332.870
23	101.8625398	2.740803453	429531.498	303292.159
24	101.3261166	3.782259417	370213.338	418593.598
25	101.5224809	3.799298611	392025.987	420415.587