DEVELOPING A SYSTEM FOR THE INTEGRATED MANAGEMENT OF FOREST ROADS AND TRANSPORT

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STATEMENT OF ORIGINALITY

I dclare that the work submitted is my own except where acknowledged otherwise.

Signed: ______________________________

Andrew Winter, January 1999.

ABSTRACT

The efficiency of roading and log transport has a major impact on the forest environment and on the cost of delivering wood to the mill. Sound management aims to minimise the environmental impacts, such as degradation of water quality, of forest roads and transport systems while providing for efficient log transport. A system was developed to help forestry organisations achieve these aims.

A pilot-scale forest road management system (FRMS) was developed to allow the collection, storage, display and analysis of a wide range of forest road and transport data. The FRMS utilises spatial analysis capabilities of a Geographical Information Systems (GIS). Data collection procedures were developed that used Global Positioning System (GPS) units with integrated electronic data loggers. A non-computer based pen and paper method was also developed as a backup for circumstances where GPS was not available. These techniques were trialled and a complete dataset for the roads of a section of Bago State Forest (in southern NSW) was collected. This dataset was used as an example during development of the FRMS.

The dataset included attributes of road sections as well information about the location and condition of associated assets (eg. bridges, culverts) and defect areas (eg. potholes, eroded areas). The FRMS was designed to include information on log truck travel times, related to route segments, which can be used in the management of haulage operations. Collection and addition of log truck travel time data to the FRMS was trialled.

The FRMS was developed to a pilot-scale to prove the concept. The application of the system in supporting the achievement and demonstration of environmental compliance, systematic road inspection, log transport management and road works planning was successfully tested with the pilot-scale version of the FRMS showing the potential to be a useful management tool.

Collecting the initial dataset required to implement the FRMS was recognised as the major cost for forestry organisations adopting such a system. A study to determine the likely cost of collecting the initial dataset required for the FRMS showed that it will cost around $0.92/ha of forest and $15.10/km of forest road.

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- *Photograph on the title page taken from "Kinsey Photographer- Volume One and Two", produced by D. Bohn and R. Petschek. Chronicle Books, 1982. San Fransisco, USA.*

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ADT – Average Daily Traffic

CTI – Central Tyre Inflation

DEM – Digital Elevation Model

DNRE – Department of Natural Resources and Environment

FRMS – Forest Road Management System

EPA – Environmental Protection Authority (New South Wales)

GIS – Geographical Information System

GPS – Global Positioning System

ha - hectares

IRI – International Roughness Index (developed by World Bank)

km – kilometres

m - metres

PCL – Pollution Control Licence

PMS – Pavement Management System

RMS – Road Management System

SFNSW - State Forests of New South Wales

Tonne.km's – Tonne kilometres i.e. the equivalent of one tonne of wood travelling one kilometre

TQM – Total Quality Management

USDAFS – United States Department of Agriculture Forest Service

1 INTRODUCTION

Chapter Objectives:

1. Provide background and motives for the study

2. Outline the study procedure

1.1 FOREST ROADS

Roads are an essential element of any production forest. They provide access to the forest for management operations, fire suppression, timber harvesting and haulage and, in some forests, recreational activities. Construction and maintenance of roads account for a considerable part of the cost of forestry operations. Together with transport costs, they account for around one third to one half of the total cost of logs delivered to the mill door (Douglas, 1992). Forest roads are usually unsealed, as they rarely warrant the high cost of bitumen sealing, but require regular maintenance to prevent deterioration. Forest roads also impact heavily on log transport costs because they are generally of a lower standard and cause trucks to travel more slowly, use more fuel and incur greater mechanical wear. There is a tradeoff between road expenditure and transport efficiency. Decreasing log transport cost often requires an increase in road construction/maintenance costs. Road construction and maintenance is usually paid for by the forest owner while costs associated with log transport are often paid by the mill or contractor. Recent moves, especially in NSW, towards mill door delivery, in both native and softwood plantation forest areas, will provide an opportunity for more integrated management of roads and trucks thus capitalising on the potential to minimise both haulage and roading costs.

Forestry is an intensive user of roads. As an example, State Forest of New South Wales manage approximately 3,520,000 ha of forest and use a road network of about 20,000 to 25,000 kilometres (this figure includes roads of all standards) (P. Weeden[1], pers comm., May 18th, 1998). This equates to an average road network intensity of 6.4 m/ha. Forest road network densities, however, can be as intensive as 40 m/ha in some plantation forests (Tan, 1992; Morkel, 1994). Forestry, in all Australian states, is pursuing a policy of continued expansion of its softwood and eucalypt plantation resource. Plantations are management intensive and require high density road networks, so the number of forest roads will continue to climb, making the bigger forestry organisations amongst the largest road managers in their respective states.

A number of factors distinguish forest roads from other road types (summarised in Figure 1.1). Forests roads are often described as low volume, meaning that they receive small amounts of traffic (typically less than 100 vehicles per day). However, the average axle loads supported by forest roads are generally much higher than those experienced by other low volume roads (e.g. rural shire roads).

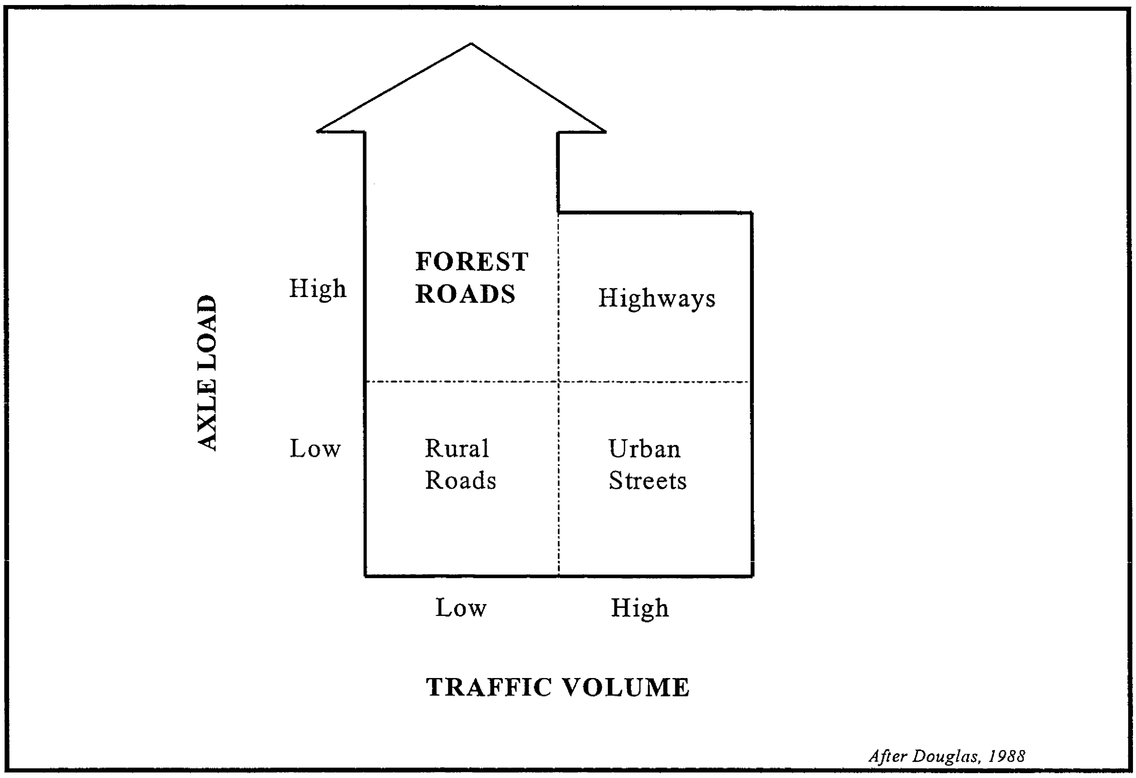
1.2 FOREST ROAD MANAGEMENT ISSUES

A variety of factors make the management of forest roads complex:

1. The need to minimise the impact of forest roads on the surrounding environment, especially stream water quality, has become an important priority for forest managers.
2. The standard of forests roads, and therefore the cost, is rising to meet the requirements of log haulage contractors who are using heavier trucks
3. There is often a need to meet the demands of the public who require access to forests for recreational pursuits. This need sometimes conflicts with the main aim of providing access for log haulage

[1] Manager, Civil Engineering Branch, State Forests of New South Wales

Figure 1.1 Comparison of Forest Road Characteristics with Those of Other Road Types (after Douglas, 1988)



Forested catchments are often the source of high quality water for community supply. Forest operations are a primary cause of sediment production. Therefore, the need to harvest timber from within these catchments conflicts with water production requirements. Researchers have identified that the bulk of sediment produced by forest operations originates from roads (Haydon *et al.,* 1991; Elliot *et al.,* 1995), and this issue is receiving the attention of monitoring bodies.

The rising cost of running log trucks has seen a move towards bigger trucks, capable of carting heavier payloads, in order to increase efficiency. For example, a B-Triple log jinker has recently been introduced in Victoria, Australia. The jinker is 31.6 metres in length and can carry 20 tons more than a B-double trailer, which has a payload of approximately 40 tons (Forest Logger and Sawmiller, 1998). Trucks of this size place great demands on forest roads due to increased axle loadings and the wide curve radius they require. Therefore, if log trucks of this size become more common, major road upgrades will be required in many forests.

Some emerging log truck technology may benefit the forest road manager. Automatic Slip Regulation (ASR) and tridem drives allow log trucks to operate on increased road gradients (Amlin, 1998). Central Tyre Inflation (CTI), already being used by some log haulage contractors in Australia, allows drivers to reduce or increase the pressures of a truck's tyres during operation. This ability has direct benefits for the haulage contractor as it provides a better ride, decreased mechanical wear and greater traction on unsealed roads. Lower tyre pressures are also less damaging to the pavement of forest roads (Bradley, 1996). Systematic road management is required, before the benefits of these new technologies can be properly assessed.

1.3 Forest Road Management Systems

Successful management of assets and infrastructure requires a sound knowledge of condition. This premise underlies the road management system concept, with the road management system combining inventories of road network components and descriptions of their condition. Computerised road management systems have been developed over the last 20 years and are now in common use by shires and highway managers, largely for pavement management. They can then make information available to the road manager for use in deciding management priorities such as maintenance or upgrading.

A number of road management systems are already in existence but these are generally aimed at the needs of shires and highway managers. Their primary focus is sealed pavement maintenance. Forest roads have very different characteristics to shire roads and highways. Forest road managers have a need to meet strict environmental compliance rules. The suite of road management systems currently available do not specifically address forestry needs.

Rummer *et al.* (1997) observe that there is a requirement by forest managers for practical, cost effective tools to manipulate the forest and achieve desired ecological conditions. They state that developing management tools for ecosystem management is the new challenge for forest operations. A computer based forest road management system that addresses both environmental and commercial objectives is an example of such a tool.

The practicality and utility of road management systems is increasing rapidly due to recent advances in Geographical Information System (GIS) and Global Positioning System (GPS) technology. GIS's provide an excellent database for storing road information. They allow data to be viewed at various scales, from the individual road section up to the regional network. Modern GIS's allow sophisticated querying based on the spatial relationship between data. GPS is being used to dramatically increase the efficiency of spatial data collection. Some types of GPS are integrated with electronic data loggers that allow the user to enter information about the point of interest at the same time as the GPS measures and records its location. Information recorded in this way can then be electronically transferred and stored within a GIS for display and analysis.

One benefit of a Forest Road Management System (FRMS) would be to provide support in environmental performance objectives. It could do this by providing a platform to systematically monitor key road features (such as drainage and crossing structures) and report their condition and to identify road sections that present high environmental risk. In the longer term, a FRMS has the potential to provide major benefit in managing transport, planning road upgrades and determining maintenance schedules. Detailed road condition information will be available for harvest managers to use in assessing the optimum haulage routes for logging operations. Impediments to haulage operations (e.g. unsound bridge decking) can be identified and repaired well in advance. Records of the locations of loading bays, truck turnarounds and landings would be stored within the FRMS to facilitate their reuse in future harvesting operations.

1.4 STUDY APPROACH

The goal of this project was to develop and test a pilot-scale FRMS designed to meet the specific requirements of Australian forestry. These requirements are to maintain and demonstrate environmental compliance as well as to support road and transport planning. Development and testing of the system involved:

1. Defining what road data need to be collected and rules for classification
2. Designing data collection procedures
3. Developing the FRMS as extension to the widely used ArcView™ GIS
4. Investigating the addition of road user cost to the FRMS
5. Demonstrating potential applications of the FRMS
6. Designing methods to support road condition auditing and updating FRMS
7. Evaluating the likely cost of implementing FRMS

Systematic asset management requires collection of data in the field, classifying, recording and structuring data in a way that allows efficient analysis. Methods for collecting data for the FRMS were designed and trialled. Conventions for systematically classifying and describing road segments, assets and defects were then developed.

Forestry organisations are realising that gains in efficiency are possible through controlling harvesting and transport operations. This presents the opportunity to better integrate roading and transport operations. For this to occur, road managers need information on how their roads are influencing the operation of log trucks. This influence is best measured through log truck travel times and these data need to be stored and made available to managers in the same context as road maintenance and construction costs. The collection and addition of these data to the FRMS was investigated.

The FRMS was developed within the ArcView GIS (ESRI, 1996) framework around datasets collected in the field. Many of its operations use the functions provided by this GIS program. Customisation of the GIS allowed several management related enquiry functions to be developed as examples. Their use in supporting forest road management was then demonstrated.

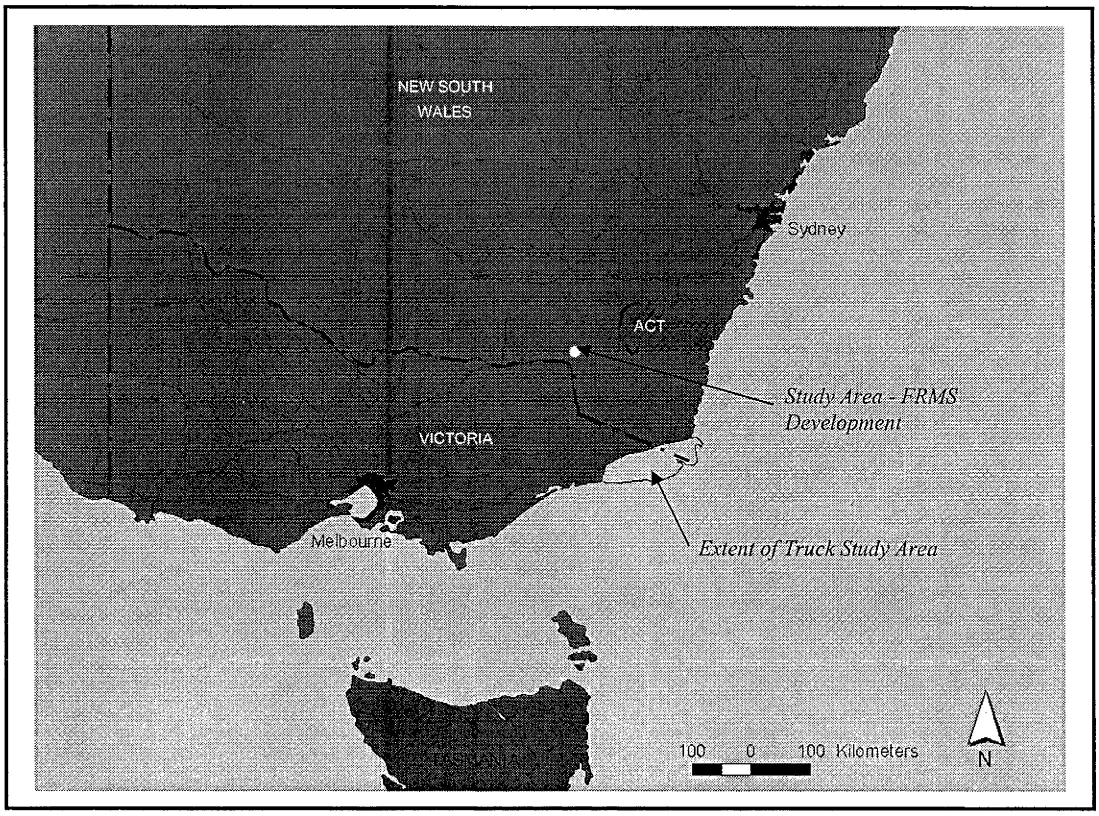
Forest roads should be inspected on a regular basis and the FRMS was designed to support and improve the inspection process. This is one of its major benefits. The FRMS was used to produce condition reports and assessment sheets to assist in regular road assessment. These were trialled in the field to relocate features in the field and to note any changes in their condition.

Collection of road data for an extensive forest management area will be a large task. Many road management systems are abandoned at the implementation phase because collecting the initial dataset is too costly and time consuming. These costs are a function of the collection efficiency and the numbers of features requiring mapping. A study was made to determine the likely FRMS data collection cost for a large plantation forest.

1.5 DATA COLLECTION AREAS

The data set around which the pilot-scale FRMS was developed was collected from Bago State Forest near Tumbarumba in Southern NSW. Data for the implementation cost study were collected in Bago and in the adjacent Green Hills State Forest (both part of State Forests of NSW's Hume Region). Log truck travel times were collected from the East Gippsland Region of Northern Victoria. A locality map showing these areas is presented in Figure 1.2.

Figure 1.2 Locality Map of Study Areas - South Eastern Australia



1.6 OBJECTIVES AND OUTLINE

The objectives of this research were twofold:

1. To develop a pilot-scale forest road and transport management system, including development of efficient data collection techniques, that operates in a GIS database allowing querying and analysis based on spatial relationships
2. To estimate the time and money costs of implementing such a system for a large forest management area

The thesis outline is as follows:

Chapter 1	Introduction of study describing its justification and scope
Chapter 2	Review of literature to identify the needs of forest road managers, identify components of road and pavement management systems and review existing systems
Chapter 3	Design and trial of data collection methods suitable for capturing road segment and road feature information; Development of a road management system within GIS environment
Chapter 4	Investigation of the addition of road user cost (in the form of log truck travel times) to the system's database
Chapter 5	Demonstration of proof-of-concept by using the system to perform a range of functions
Chapter 6	Investigation of the feasibility of implementing such a system
Chapter 7	Discussion of further development of the FRMS and possibilities for further research and summary the findings of this research.

2 FOREST ROAD MANAGEMENT

Chapter Objectives:

- ***Describe what management of forest roads involves and discuss issues and factors affecting it***
- ***Discuss the concept of Road Management Systems that have been developed for use by Highway and shire road managers***
- ***Review the application of Road Management Systems to forestry***

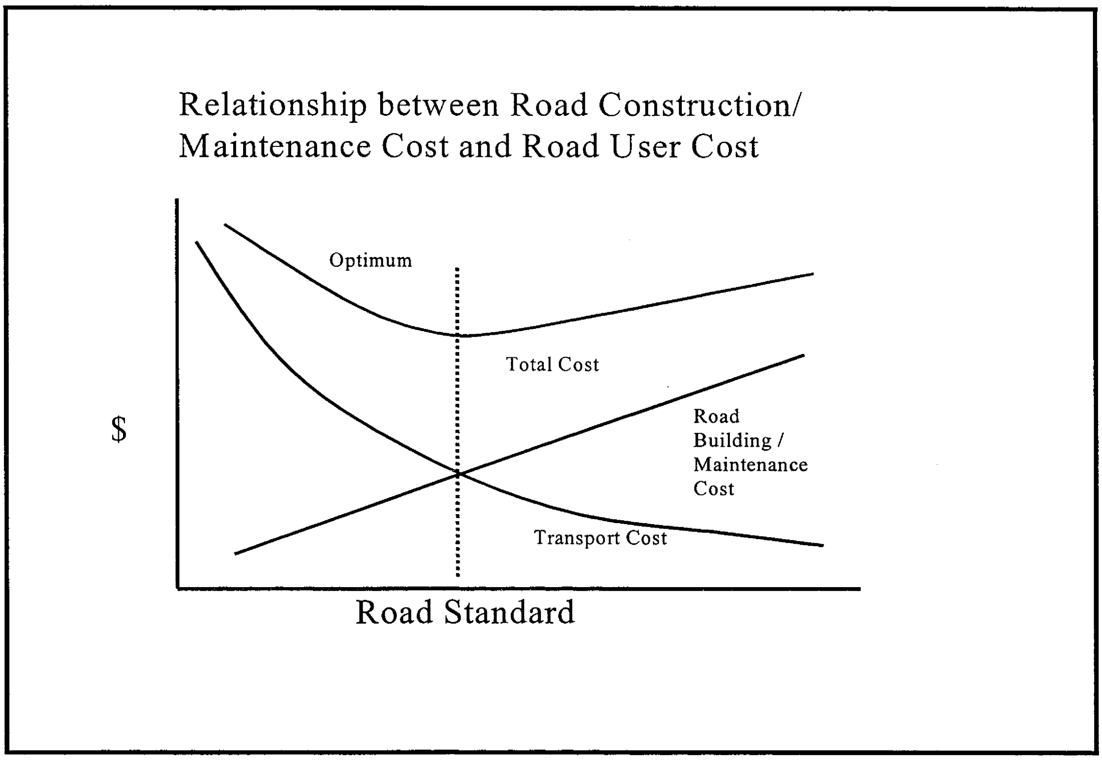
2.1 INTRODUCTION

Forestry activities require a suitable road network. Roads, in turn, require management. Proper management of forest roads requires knowledge of the condition of the road network and its associated structures and an understanding of how effectively it is serving the needs of the road users. This chapter reviews forest road management and the concept of road management systems, and their applicability to forestry, is discussed.

2.2 FOREST ROAD MANAGEMENT

The major objective of this research project was to develop a forest road management system for use in Australia and, in particular, New South Wales. Sound forest road management aims to minimise the overall cost of transporting logs to the mill. This involves striking a balance between providing a certain level of access for the forest user (referred to as serviceability) while keeping construction and maintenance costs as low as possible. This problem is illustrated in Figure 2.1.

Figure 2.1 **Relationship between Road Construction/Maintenance Cost and Road User Cost**



This aim is becoming more complex in areas such as NSW due to the need to meet strict environmental regulations. The environmental risk posed by unsealed forest roads has been recognised since at least 1917 (Reid and Dunne, 1984). Until recently however, water users downstream of the forest met the cost of water body sedimentation. The responsibility of ensuring that the amount of sediment that reaches water bodies is minimised now rests with forest owners. Their success in doing so is monitored by various agencies. In New South Wales, the monitoring agency is the Environmental Protection Authority (EPA). The Environmental Protection Authority issues State Forests of New South Wales a 'Pollution Control Licence' (PCL). Heavy fines punish breaches of the conditions attached to the PCL.

Historically, log haulage costs in Australia have been directly accrued by mills rather than forest owners, as timber was sold on the stump. This is changing to a system that involves the forest owner selling logs at the mill door. Therefore, forest owners will have increasing interest in minimising all costs associated with roads.

Poor management of forest roads can result in three costs: the cost associated with environmental degradation; increased cost to the user and high maintenance cost. Sound forest management can reduce the environmental impact of roads through a number of means. Field staff and contractors working in the forest should understand the causes of erosion and sedimentation, as well as techniques for their mitigation. New mitigation techniques should be developed and trialled. Roads constructed before such tight environmental requirements existed must now be upgraded to meet these requirements. The next step for forest management is to implement systematic monitoring of the functionality of road drainage structures and the early detection of erosion risks.

Separated management of forest roads and transport has often meant that the role of forest owners in ensuring road serviceability was often limited to maintaining regular contact with haulage contractors and reacting to problems as they occurred. The introduction of mill door log sales may see the potential for lower haulage rates to be negotiated in exchange for guarantees of increased road network serviceability.

High maintenance costs sometimes result from poor construction practices, which are beyond the scope of this study (which is aimed at managing the existing asset). In some cases, the remedy may be relatively cheap (eg. install extra drainage) but in other cases, upgrading the road alignment may be the only solution. Most forest road networks will have segments that fail periodically, such as during wetter winter months. A common response to such failures is the 'quick fix'. A simple example of this may be dumping several loads of gravel on a troublesome spot every winter. However, at some point, the cost of this annual patch gravelling operation is going to exceed the cost of a permanent repair job (eg. dig up the road, install subsoil drainage and recompact road surface). Sound management is required to determine whether the 'quick fix' or the 'permanent fix' is ultimately the cheaper option.

Successful forest road management requires an understanding of the environmental impacts of roads and knowledge of the factors influencing the road user. The environmental impacts of forest roads are described and discussed in Section 2.3. Factors affecting serviceability levels, or road user costs, are addressed in Section 2.4. The importance of road drainage in maintaining serviceability while minimising environmental impact is discussed in Section 2.5.

2.3 ENVIRONMENTAL IMPACTS

The heavy environmental cost associated with unsealed forest roads is widely acknowledged. The primary cost is the amount of sediment, removed from roads by rainfall runoff, that ultimately enters creeks and streams. Sedimentation of creeks and streams has a detrimental effect on aquatic life; (Cambell and Doeg, 1989) and decreases the quality of water for end users (Wallis and McMahon, 1994; Rothwell, 1983; Beschta, 1978). Ensuring that their roads are environmentally compliant has become a major concern for forest managers world wide (FAO, 1996). This level of concern is highlighted in a study performed by Egan *et al.* (1996). They conducted a survey in which 10 resource professionals (from the USA) with extensive experience in forest road management were asked to comment on a range of management issues. Water and drainage management was identified as being the major consideration for forest road engineering and as forming the biggest challenge to forest road construction and maintenance.

The surfaces of forest roads generally have low permeability, with infiltration rates as low as 1 to 4 mm/hr (Mockler and Croke, 1998). This results in runoff occurring even after relatively small amounts of rainfall. Runoff, travelling at sufficient velocity, can suspend and carry sediment.

There are several important sediment sources associated with forest road construction and use:

1. Movement of soil and debris directly into permanent water courses during construction/maintenance of roads, snig tracks and landings
2. Movement of soil and debris placed near permanent water-courses or temporary water courses
3. Surface erosion from road and landing surfaces and table drains
4. Surface erosion of fill material
5. Mass movement of batters
6. Mass movement of up-slope materials caused by reactivating old erosion features
7. Failure due to removal of batter slope toe (Wallis and McMahon, 1994).

Much research had been dedicated to measuring the amount of sedimentation produced by forest roads (Burroughs Jr. *et al.*, 1983; Reid and Dunne, 1984; Haydon *et al.*, 1991; Brown, 1994). Efforts have also been made to model the sedimentation process in order to predict future production levels (Leaf, 1974; Elliot *et al.*, 1994; Elliot *et al.*, 1995; Macdonald *et al.*, 1997; Anderson and Macdonald, 1998). Other research has been directed at developing and evaluating structures (Eriksson, 1983) and techniques (Rothwell, 1983; Swift Jr., 1984; Grace III *et al.*, 1998) that reduce the environmental impact of forest roads.

The level of sediment production from unsealed roads varies with slope, soil type and traffic levels. Researchers have reported a large range of production rates (see Table 2.1), varying from 0.2 tonnes/hectare/year up to 1250 tonnes/hectare/year (Haydon *et al.*, 1991). The lower rates were reported by Fahey and Coker (1989) in Wallis and McMahon (1994) on predominantly granitic and schist soil and rock types. They estimated that these levels would increase to 1 to 2 tonnes/ha/yr if the roads were used, but acknowledged that these figures were very low in comparison with other findings (Haydon *et al.*, 1991). Reid and Dunne (1984) studied the effect

Table 2.1 Forest Road Sediment Production Rates - Literature Comparison

SOURCE	SEDIMENTATION RATE (tonnes/km^2/yr)	COMMENTS
Mosley in McMahon	710	SW Nelson, NZ
Fahey & Coker (1989) in McMahon (1994)	37	SW Nelson, NZ – Granite soil
Fahey & Coker (1989) in McMahon	320	SW Nelson, NZ - Granite soil during harvest operations
Fahey & Coker (1989) in McMahon (1994)	67	SW Nelson, NZ – Schist soil
Fahey & Coker (1989) in McMahon (1994)	200	SW Nelson, NZ - Schist soil during harvest operations
Fahey & Coker (1992) in McMahon (1994)	62	Marlborough Sounds, NZ
Fahey & Coker (1992) in McMahon (1994)	100	Marlborough Sounds, NZ
O'Loughlin in McMahon (1994)	176	Westland, NZ
Haydon et al. (1991)	30	Melbourne (Victoria) water catchment area
Reid & Dunne (1984)	500	Heavily used road, Washington State, USA
Reid & Dunne (1984)	66	Road temporarily in nonuse, Washington State, USA
Reid & Dunne (1984)	42	Moderately used road, Washington State, USA
Reid & Dunne (1984)	3.8	Lightly used road, Washington State, USA
Reid & Dunne (1984)	2	Paved road, Washington State, USA
Reid & Dunne (1984)	0.51	Abandoned road, Washington State, USA
Beschta (1978)	98	Average across study watersheds, Western Oregon, USA

of traffic density on sediment yields and report a production rate of 1250 tonnes/ha/year for roads receiving a minimum of 4 loaded trucks per day. They found sediment production dropped significantly, to 9 tonnes/ha/year, on roads that were only used occasionally by light vehicles.

One mitigation measure is to ensure that the road is drained at intervals that are frequent enough to prevent runoff gaining enough velocity to cause erosion. The ideal drainage interval must counter two effects. Firstly, the interval must prevent erosion of the road surface or table drain (State Forests of NSW, 1996c). Secondly, the interval must be such that discharge from the structure's outlet doesn't form channellised flow from the structures outlet to a drainage feature (creek or stream) (Montgomery, 1994; Wemple *et al.*, 1996; Bowling *et al.*, 1996, Mockler, 1998; Mockler and Croke, 1998).

2.4 Maintaining Serviceability

Forest roads have two functions. The major function is to provide access to the forest for management and silvicultural purposes and for transporting forest products (Morkel, 1994). Their minor function is to act as firebreaks. The level of access provided by forest roads is referred to as serviceability. A road with zero serviceability is impassable. Poor forest road management results in a decrease in the level of serviceability. Road serviceability is reflected in six ways:

1. Driver comfort
2. Safety
3. Fuel consumption
4. Mechanical wear
5. Driver fatigue
6. Travel speed

Any characteristic of a road that prevents transport from being 100% efficient is known as a 'resistance factor' (Douglas, 1988). Resistance factors are classified either as direct, present in a road from its construction, or indirect, which accumulate due to lack of road maintenance. The impacts of these resistance factors are described below.

2.4.1 Direct Resistance Factors

Direct resistance factors are present in the road as soon as it is built. Performing a major upgrade on the road itself is the only way of reducing the effect that these factors have on increasing transport cost. These factors include road pavement flexibility, vertical alignment, horizontal alignment and road profile.

Forest roads exhibit flexibility, to varying degrees, under the downward pressure exerted by vehicle tyres. This flexibility creates a depression under each tyre that moves continuously with the wheels. The depression creates a resistance to the travel of the vehicle and is referred to as rolling resistance. Rolling resistance affects fuel consumption, mechanical wear and travel speed (Douglas, 1988).

Grade, or vertical alignment, is widely acknowledged to have a significant effect on log truck travel speed and hence, log transport cost (Byrne *et al.*, 1960; Beath, 1976; Jackson and Sessions, 1987; Winter, 1995). Road gradient affects travel speed, fuel consumption and mechanical wear.

The horizontal alignment, or 'twistiness', of a road has a significant impact on travel speeds. The tighter a corner is, the slower the vehicle must travel to negotiate it. Corner tightness is referred to in terms of curve radius. The twistiness of a section of road is established by measuring the number of curves per kilometre and the average curve radii. These factors were used by Massey-

Reed (1978) in the formulation of a log truck travel time prediction model for forest roads in New South Wales.

As a truck negotiates a corner, centrifugal forces tend to move the truck to the outside of the corner. The power expended by the truck in countering this tendency, in order to stay on the road, is known as centrifugal resistance (Morkel, 1994). Centrifugal resistance affects truck travel speed and for this reason, corners of high standard roads are tilted or bermed (known as super-elevation). Super-elevated corners reduce the amount of centrifugal resistance to the truck and allow it to corner at a higher speed.

2.4.2 Indirect Resistance Factors

Indirect resistance factors are aspects of the road that can affect transport efficiency but change over time or with level of maintenance. Indirect resistance factors include surface condition, sight distance and road width.

Surface condition has a major influence on transport cost. Lui and O'Reilly (1987) in Morkel (1994) developed simulation models showing that, by grading an unsealed road, the achievable speed of a loaded log truck increased by 90% and fuel consumption decreased by 11.6%. For unloaded log trucks, they determined that achievable speed increased by 60% and that fuel consumption decreased by 60%. Liautaud and Faiz (1994) estimate that neglect of maintenance of unsealed road surfaces can result in vehicle operating costs doubling or even tripling.

Sight distance, the length of road visible to the driver at a given point, affects travel speed and safety (Yamamoto, 1981). Vegetation regularly encroaches onto the road right-of-way, reducing sight distance, so slashing/clearing of the verges of major roads should be a routine maintenance operation. Yamamoto (1981) examined how sight distance on mountainous forest roads in Japan affected vehicle speed. A high correlation was established between vehicle speed and sight distance. However, the limiting effects of grade may override those of sight distance (Jackson and Sessions, 1987). McCormack (1992) considered that the limiting factor on log truck speed and engine power for road sections with poor sight distance was the driver's willingness to avoid a collision.

Narrow roads inherently have poor sight distance, affecting travel speed (Douglas, 1988). Travel speed can be further reduced when vehicles meet, though this is usually catered for by the provision of passing bays (Byrne *et al.*, 1960).

2.4.3 Interaction between road and vehicle

The interaction between road and vehicle is complex. Road roughness generates dynamic forces in the vehicle which, in turn, exacerbate the roughness of the road (Mamlouk, 1997).

Forest roads are characterised by low traffic volumes but high average axle loads. This means that a 'typical interaction' between forest road and vehicle results in a greater impact to the forest road than for other road types. Sedlak (1988) illustrates this point by noting that one 20 ton truck with a single axle load of 14 tons may cause stresses on the pavement equal to that of 12 trucks with single axle loads of 8.2 tons. However, the pavement stresses applied by the 8.2 ton single axle truck are equivalent to those generated by 5,000 light vehicles. Martin *et al.* (1998) evaluated the pavement damage caused by a 6 axle log truck (40 ton gross vehicle weight, 27 ton payload). They noted that this type of truck represented 3 times the load of a standard axle (8.2 tons) and determined that raising the payload by 10% would increase the potential road pavement damage by 20%. Their conclusion was that the serviceability of forest roads is significantly reduced by incidences of overloading. This research also suggests that road serviceability is compromised considerably whenever truck configurations with greater axle loadings are introduced to forest operations.

Vehicle speed also affects pavement condition. This is especially true of gravel surfaced roads. High cornering speeds result in gravel particles being swept off the road (Sedlak, 1988). The result is the 'windrows' of gravel commonly seen on forest roads. These gravel windrows then exacerbate pavement deterioration by preventing water from leaving the road surface. They also represent a hazard to traffic.

2.5 Influence of road drainage on Environmental Impact and Road Serviceability

It is clear that a functioning road drainage system is necessary to maintain a high level of service as well as to minimise the impact of forest roads on the environment. Poor road drainage causes increased environmental degradation and maintenance costs and reduces road serviceability. The majority of forest road problems are caused by poor drainage (Morkel, 1994). Martin *et al.* (1998) explored the relationship between road drainage and surface condition. They found that pavement quality was largely dependent upon drainage conditions and that number of potholes was strongly influenced by level of road drainage.

In some circumstances, road serviceability level is also linked to environmental degradation. For example, water can pool on the surface of poorly formed unsealed roads. When vehicles pass through the standing water, rutting can occur (Figure 2.2). The rutted surface provides an obstacle to further road use and increases the potential for sediment to be produced from the road surface.

Figure 2.2 Example of Rutting on a Forest Road (Bago State Forest, 19/5/98)

Burroughs Jr. and King (1989) describe a comparison between the sediment production of a smooth forest road with that of a road that had been rutted by the passage of a heavy logging truck. Simulated rainfall experiments were used to show that sediment production from the rutted road surface was 2.08 times greater than the amount produced by the smooth surface.

Three types of road drainage are required: drainage to keep the road out of water; drainage to keep water out of the road and drainage to get water away from the road (Hoffman (1993) in Morkel, 1994).

Ensuring that the road is kept out of water is mainly a planning or construction issue. Obviously roads should be routed away from swampy areas, but sometimes construction must traverse areas such as bogs and springs. These areas require subsoil drainage, which allows movement of water beneath the road subgrade without penetrating it. In flat or low-lying areas, roads are usually elevated.

If water is allowed to reach the subgrade of a road, the integrity of the road itself is lost. This means that the road will be unable to support traffic (especially heavy vehicles). Common problem areas are where roads traverse or pass springs and swampy areas.

Water penetrating the road surface can cause the pavement to breakup, producing potholing and cracking. Proper grading and compaction techniques aim to seal the road surface so that water tends to run off it rather than penetrate it. A good forest road is constructed with a slight fall (crossfall) to its surface to prevent water pooling. In flatter areas, roads generally have a crowned profile in which the surface of the road slopes away form the road centre at each side. Side cut roads should have either infall to direct water to culvert inlets, or outfall to turn water onto the fill batter.

Erosion potential of runoff increases in proportion to its volume and velocity (State Forests of NSW, 1996c). Therefore, major problems result if the road surface and table drains aren't drained at regular intervals. The spacing between drainage points becomes more critical as the gradient of the road increases. Water flowing across a road surface with high velocity causes rilling and gullying which increases surface roughness dramatically. In some circumstances, it may make roads impassable.

A fully functional drainage structure extends to the area onto which the runoff is released. This area must be stable and runoff velocity should be minimised. If the outlet area is a batter slope, armoured structures (known as dropdowns) should be used to direct the flow down the batter face. Roads should also be drained prior to crossings to prevent turbid water entering the drainage feature (EPA, 1998).

Effective road drainage plays an important role in maintaining levels of forest access and minimising environmental impact. Road drainage management should include provision of sufficient drainage and then systematic checking and maintenance of drainage structures. The adoption of such a strategy is an example of 'Best Practice'. This concept, and its application to forest road operations, is described in the next section.

2.6 BEST PRACTICE AND TOTAL QUALITY MANAGEMENT

The forest industry (like other sectors) is recognising the need to demonstrate to customers and the public that its operations are conducted thoroughly, using the most appropriate methods. This is known as 'best practice' and they have been devised for a variety of forestry operations with more being initiated. Best practice is often formulated via a process called 'Total Quality Management'.

Total Quality Management (TQM) is a concept that is being used by many businesses to increase the efficiency of common operations and procedures. TQM is being applied to the forest industry in a variety of ways. For example, State Forests of New South Wales are pursuing TQM objectives for tasks such as harvest planning in softwood plantations, administrative processes, land purchase for eucalypt plantation and waste disposal (H. Wall[1], pers. comm, 4th August 1998).

The aim of TQM is to ensure that the output or result of a process is at an optimal level, or at least within a set of predefined, acceptable limits. Tarte (1992) provides an example that is of direct relevance to road managers:

> "Consider an asphalt road pavement. The optimum thickness of the asphalt pavement may be determined and will depend on the underlying soil conditions,

[1] Harold Wall, General Manager of Operational Services, State Forests of New South Wales

> the amount and type of traffic, the economic design life of the road and the type of asphalt to be used. If the pavement is thicker than the optimum design then clearly we are paying for too much expensive asphalt. If the pavement is thinner than the optimum design we will pay for increased and earlier maintenance. Each of these types of cost increases as we move away from the target or optimum thickness values."

TQM works by minimising 'Cost of Quality' which is comprised of three aggregate costs (Tarte, 1992):

1. 'Cost of Failure' – Eg. cost associated with log trucks hauling on a sub- standard road
2. 'Cost of Appraisal' – Eg. cost to collect information on the impact of having log trucks hauling on a sub- standard road
3. 'Cost of prevention' – Eg. cost of building a higher standard road.

Road management can benefit from using a TQM approach. Before costs of failure and prevention can be determined for a road network, its current condition must be ascertained. Priorities for the reduction of these costs can then be set. The need for road managers to set these priorities saw the development of specialised management systems that incorporate low appraisal costs. These management systems are described in Section 2.7.

2.7 Road Management Systems

Systems have been developed to help organisations manage their roads. These have been termed Road or Pavement Management Systems. Pavement Management Systems, as their name suggests, focus specifically on the road pavement. Road management systems include road verges, drainage and other associated structures. The term 'road management systems' is used here to refer to both types of system. All systems address at least one component of serviceability cost. The problem for forest road managers is that few systems, even those developed specifically for forestry, address the environmental costs as well. A road management system can be defined as any system that increases the ability of an organisation to manage the network of roads under their administration.

Road maintenance is an expensive, ongoing task and the major application for most road management systems lies in prioritising maintenance operations. Various systems use a combination of current road condition information and road use data to assign priorities. The road manager then matches the allocated budget to the highest priority jobs (McCullough, 1985; Visser and Curtayne, 1987; Ayers, 1987; Hallet and Jacobsen, 1994).

The use of current road condition information can be extended to the prediction of future road condition (Ullidtz, 1985). Systems that perform this function utilise road deterioration models and use assumptions made about future traffic volumes (Haas *et al.*, 1994).

Road management systems can also have an historical database application. Hallet and Jacobsen (1994) suggest the addition of maintenance details and expenditure information to a system in order to more accurately predict the cost of future maintenance operations.

2.7.1 Applying Road Management Systems to Forestry

Douglas and McCormack (1995) identified the need for forest road managers to adopt the principles used in road management systems. They observed that the emphasis of forest roading activities is shifting from the construction of new roads to the maintenance of existing ones. The approach advocated by Douglas and McCormack is to recognise the differences between highway (for which most road management systems are designed) and forest road pavements and then modify the practices used in road management systems to accommodate them.

The majority of road management systems have been designed for sealed roads, particularly highways. Australian forest road networks, however, are characterised by being mostly unsealed. For example, State Forests of New South Wales manage less than 200km of sealed road compared with approximately 25,000 km of unsealed road (P. Weeden [2], pers. comm., 18th May 1998).

The amount of justifiable expenditure on the management of an asset is directly proportional to the value of that asset. The level of investment, per average kilometre, made in forest roads is vastly less than that made for highways. Therefore, the likelihood of a forest agency deciding to invest heavily in a road management system is low. As well as generally being of low standard, forest roads typically receive low traffic volumes hence any road management system adopted by a forestry organisation will have to be low in cost since there isn't the traffic volume against which its cost can be amortised (Douglas and McCormack, 1995).

Table 2.2 provides a general comparison of the differences in styles of management adopted by road management agencies in Australia. The comparison suggests that forest management agencies (who are often amongst the largest road managers) are the least likely to adopt sophisticated road management systems.

[2] Peter Weeden, Manager, Civil Engineers Branch, State Forests of New South Wales

Table 2.2 Differences in road management approach in Australia – Forestry, Shires and Highway Authorities

FEATURE	FOREST ROADS	SHIRE ROADS	HIGHWAYS
Pavement	Generally Unsealed	Majority Sealed	Virtually all Sealed
Management Focus of Responsible Agency	Forest Management	Infrastructure Management	Highway Management
Traffic Characteristics	Low Volume, High average axle loading	Medium Volume, Moderate average axle loading	High Volume, low average axle loading
Professional Training	Usually Forestry trained, reliance on staff with experience	Engineers	Engineers
Environmental Risk (after roads are built)	High	Moderate	Low

The task of developing a system for the management of forest roads is being undertaken in several countries. Many of these systems are designed to perform complex functions such as prediction of road life or selection of appropriate truck configurations for specified conditions (Provencher, 1997). These systems have been mainly designed for forest companies in North America and Canada that operate in highly industrialised forests. The immediate needs of the Australian forest road manager are more likely to be to know “what’s out there?” and “what condition is it in?”. Once this information is at the manager’s fingertips, a higher level of decision making can take place.

2.7.2 Levels of Operation

Road Management Systems usually operate on at least two levels, network and project:

- Network – Road Management System functions at this level are confined to prioritising / scheduling roadwork and budget management
- Project – Operations at a project level deal with individual sections within the network. Eg. Selecting maintenance alternatives

Haas *et al.* (1994) differentiate between road management systems that operate at two levels and those that operate at three. Three level systems have an extra level that concerns decisions involving a group of projects and so fall between the scope of network and project levels. A forest road management system should be designed to operate at three levels in order to handle the wide variety of forest road and forest road user types. For example, the forest road manager may wish to consider the network of fire trails as a distinct entity within the whole network.

2.7.3 Road Section Definition and Referencing

For the purpose of road management systems, the road network should be divided into sections. The road sections should then be referenced in a logical way. Section definition can be either by uniform characteristics or by fixed lengths. The use of the fixed length approach is simple as data is collected at each milepost. However, changes in road standard and other features of interest are more likely to occur between mileposts.

Section definition through the use of uniform characteristics means that section boundaries are selected to correspond with features such as maintenance district boundaries, change in pavement type or geometry, traffic levels or intersections with other structures (Haas *et al.*, 1994).

In the forestry environment, it is preferable to define sections as links between intersections as they are generally built to a consistent standard along the entire length of each link. This also makes section definition via the use of a GIS straightforward. Points of significant change in road standard not occurring at an intersection are relatively rare.

Haas *et al.* (1994) describe four systems for referencing road links:

1. Route Milestone System: Each route is assigned a unique identifier and the starting point of the route is defined. Mileposts are then sequentially numbered, along the route, commencing at the starting point
2. Node-Link Method: Key points within the road network are defined as nodes and the sections between these points are defined as links. Nodes usually equate to intersections, boundaries or abrupt changes in road standard (especially pavement change)
3. Branch – Section Method: Developed for use in airfield pavement management. Has been extended for use in road management in which individual roads or routes are defined as branches and homogeneous portions of these roads or routes are defined as sections.
4. GIS: The major disadvantage with the use of a GIS supported road management system is that the initial definition of the road network can be time-consuming and expensive. However, advantages include the ability to produce maps showing selected road features and the easy addition of new features to the database.

Diggens *et al.* (1994) describe a linear referencing method used in the Road Information Management System (RIMS) developed for the Northern Territory (Australia) Government.

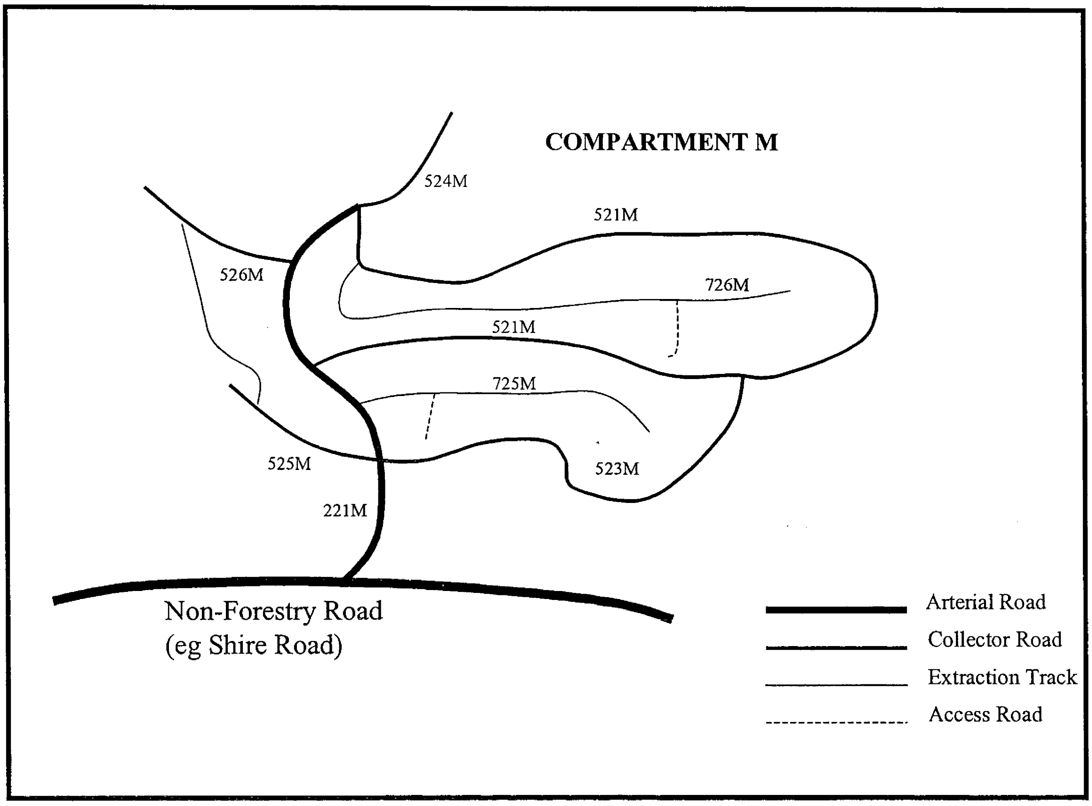
RIMS uses a network reference key consisting of three components:

1. Unique Road Number (4 digits)
2. Permanent Reference Point (PRP) – usually located at a permanent physical feature such as a bridge (4 digits)
3. Distance from the PRP (5 digits, 2 decimal places)

These components provide an identifier for any unique point in the road network. A segment is named by listing the identifiers for the start and end points of the segment. Using this reference key, a road segment could be named 0001:0001:000.00 – 0001:0001:009.00 for a nine km section of road no.1 (with PRP #1 located at the start of the road segment). A point along that road would be referenced as 0001:0001:008.99 (ie. the point 1 m before the road segments end). Though logical, this method produces segments numbers that are unwieldy and they would be difficult to use in numeric operations.

Stewart Scott Inc. (1995a) describe the road referencing method used in the forest road management system developed by them in South Africa. They propose a method in which road numbers have four characters. The first three can be any combination of numeric or alphabetic characters that describes a particular route or the road section's class. The fourth character is used to indicate the locality of the road. An example of how this method might work is shown in Figure 2.3. In this example, the first three characters correspond to road classes with 0-299 being class A, 300-599 being Class B and 600 – 999 being Class C.

Figure 2.3 Example of Road Numbering Method proposed by Stewart Scott Inc., (after Stewart Scott Inc., 1995)



2.7.4 Data Considerations

A road management system will only be useful if the information within it is of high quality. The data used in a Road Management System should have the following attributes (Haas *et al.*, 1994):

1. Integrity – 2 pieces of data that represent the same fact must be equal
2. Accuracy – Values in the data base must represent the actual situation at the indicated location and time, as closely as possible
3. Validity – Values must be correct, logical and fall within reasonable limits (eg. culverts shouldn't have diameters less than 375 mm)
4. Security – Primarily to prevent loss of data
5. Documentation – Each field in the database should be accurate with respect to meaning, unit of measure, format, source, use, relationships etc. eg. It is important that road

features be termed in a way end users would recognise, for example "Mitre-drains" (Australia) vs. "Turnouts"(USA, Canada) or "Rollovers" (NSW) vs "Whoa-boys" (Qld)

The variety of data that could potentially be collected for a road network is extensive. It is important the road manager decides what data will be most useful and concentrate on those items. Some data used in a road management system relates largely to asset existence and location and usually remains unchanged. However, other data relates to asset condition and requires frequent updating.

Efficient data collection methods are needed for an economical system. Many road management systems rely on visual estimates of road condition, generally made from a moving vehicle (for example, the systems described by Kullas (1985) and Stewart Scott Inc. (1995a) and a number of the systems available in Australia described by Koniditsiotis (1992). This method has been extended in some systems by mounting still-photo cameras or video cameras to the vehicle. This enables a visual record to be stored and redisplayed at a later date (Hopwood II *et al.*, 1987; Wang *et al.*, 1997).

Cairney (1984) warns of the dangers of subjectivity in road data collection. He acknowledges that for some data requirements, no appropriate physical measurements can be made and that, for some other data types, the cost of physical measurement may be prohibitive. Cairney recommends that if subjective judgements are to be used as part of road condition assessment, empirical work should be undertaken to determine how reliable and valid the judgements are likely to be.

2.7.5 GPS Road Data Collection

Efficient collection of spatial data has been greatly enhanced by the use of Global Positioning System (GPS) technology. It can be used to map the location of individual road features as well as to map the actual road sections. GPS is a satellite based navigation system developed and operated by the US Department of Defence. Each GPS satellite regularly emits a time signal that is provided by on board atomic clocks. Receivers on the ground collect these signals and are capable of decoding them and then computing the distance to that satellite. If this process is conducted with four satellites simultaneously, the three dimensional location of the receiver on the earth's surface can be computed. GPS utilises a constellation of 24 satellites orbiting the earth at a nominal altitude of 20,183 km (Brice, 1993). This number of satellites is required to ensure that signals from at least four satellites can be received at any point at all times.

GPS Satellites actually emit two types of signal. The US Department of Defence encrypts the first type of signal in order to limit usage to US Military forces only. This type of signal forms the Precise Positioning Service (PPS) and allows an accuracy of about 10 metres (Roberts and Panyin, 1995). The second type of signal is used to provide the Standard Positioning System (SPS) that is available to non-US military users. The US Department of Defence deliberately distorts the SPS signals to deny non-US military users the level of accuracy available with PPS. This deliberate distortion of the SPS signal is known as Selective Availability (SA). The SPS provides an accuracy of approximately 100 m. Other errors can be caused by atomic clock malfunctions and delays incurred as the signal passes through the upper atmosphere.

If greater accuracy than that offered by SPS is required, differential processing must be used. Differential Processing (also known as post-processing) uses a receiver positioned at a point of known geographic location. This receiver can measure the error applied by SA and other sources. The GPS unit at the known location is called a base (or reference) station. Units used in the field are called rover units. The rover unit/s and the base station are set to record simultaneously. The data collected by the rover can then be corrected using specialised software provided with the GPS. The correction software uses the base station data to obtain the measured error at a particular time. This error is then subtracted from any point recorded by a rover unit at that same time. This is known as post processing and allows an accuracy of approximately 5 m. Differential corrections are also transmitted on radio frequencies. Some GPS receivers have the ability to apply these corrections to the positions that they collect, as they are received. This process is called real time correction.

Jalinier and Courteau (1993) investigated the rate at which forest road section profiles could be obtained using GPS. They reported that data collection could occur at speeds approaching 100 km/h and that a saving of approximately 20 person-days was achieved in surveying the profile of 234 km of forest road by using GPS instead of conventional survey methods (compass and clinometer in a vehicle). Fawcett (1995) used GPS to survey road signs during the development of a GIS based pavement asset management system. He found that GPS data collection was actually 35% slower than a manual method but noted that the real benefit was in the transfer of the information into the GIS which, on average, was approximately 80% quicker. He notes that slowness of the GPS data collection was due partially to the GPS unit used and partially due to the collection environment, which contained a lot of tall buildings that interfered with the satellite signal necessary for the units to operate.

Forest canopy can act in a similar way, blocking the satellite signals as they attempt to pass through it. This generally results in the receiver having difficulty registering enough satellites (minimum requirement is 4) to obtain a 3-dimensional positional fix. Fixes that are obtained under the canopy are likely to be 2 to 3 times less accurate compared with those made in the open (Kennedy, 1997). Various forest characteristics, such as age and stocking rate, can affect signal reception. Older stands have larger basal areas and are generally taller so they present a greater barrier to the GPS signal. A forest with a high stocking density has the same effect (Kennedy 1997). Deckert and Bolstad (1996) found that points recorded in hardwood forests in Northern America were, on average more accurate than points recorded in coniferous forests. Kennedy (1997) singles out *Pinus radiata* (D. Don) stands as being a particularly difficult environment for GPS recording. Roberts and Panyin (1995) found that the percentage of failed observations due to inadequate view of satellites decreased dramatically as consecutive thinning operations 'opened up' pine plantations in the Tumut (New South Wales) area.

Application of GPS to forest transport management has occurred in three ways. GPS is being used by forestry organisations to map forest roads (Jalinier and Courteau, 1993; Kruczynsky *et al.*(1993) in Deckert and Bolstad, 1996; Lawrence *et al.*, 1995; Kennedy, 1997). Researchers are using GPS to track logging machinery in order to better understand factors affecting machine productivity and impact on the environment (Plamondon, 1995; Roberts and Panyin, 1995; McMahon, 1996; Thompson *et al.*, 1998). GPS has also been used to track log truck movements (Steve, 1994).

2.7.6 Road Segment Attribute Data

Road segment attribute data describes those features of a road segment that don't change with time or maintenance intensity. This type of data only changes when a road segment is upgraded by realignment or by application of new pavement material. Principal examples of road segment attribute data collected for a road management system include:

- Length
- Segment Classification
- Horizontal Alignment
- Grade
- Pavement Type

The length of each segment should be available to the system as well as the segment classification. Most forestry organisations have at least one classification system for their roads, often based on service or function. The similarity between the classes used by State Forests of New South Wales and the Department of Natural Resources and Environment (Victoria) are illustrated in Table 2.3.

The width of forest roads can be referred to in various terms. Pavement width describes the width of pavement applied to a gravel or sealed road. For a natural surfaced road, pavement width refers to the width of the road available to the vehicle to travel safely. Formation width is another commonly used term and applies to the distance from the outside edge on the road shoulder on one side to the outside of the road shoulder on the other.

Horizontal alignment refers to the twistiness of a road segment. It is usually measured in terms of number of curves per kilometre or average curve radius. Grade (or vertical alignment) describes the slope or gradient of road segments. It is usually referred to in terms of average gradient or maximum grade (degrees or percent). Maximum grade is useful, as grade may be the limiting factor affecting a vehicle's ability to negotiate a certain road segment.

Forest roads usually have a gravel pavement or a natural surfaced pavement. A small percentage of Australian forest roads have a sealed pavement. Further definition of the type of pavement may be useful. Pavement types for gravel roads can be classified on the basis of gravel size and type (eg. Crushed, uncrushed, basalt, shale etc.); natural surfaced roads on the basis of soil type and sealed roads on the basis of seal type (eg. Chip seal, hot mix, macadam etc.).

Table 2.3 Similarity between the Classification system used by DNRE (formerly DCNR) (DCNR (Vic.), 1995) and State Forests of New South Wales (State Forests of NSW, 1991)

CLASS	DCNR CLASSIFICATION	SFNSW CLASSIFICATION
Class One	All weather, surfaced, 2 lane primary road, speed not unduly affected by grades and curves	All weather, 2 lane road with minimum pavement width of 7.3 m and meeting the requirements of a 50km/h design speed
Class Two	All weather, surfaced 1 lane secondary road, speed is reduced by grades and curves	All weather road with a minimum pavement width of 3.7m, formation width 5.5m and meeting the requirements of a 30km/h design speed
Class Three	Single lane substantially all weather minor road, road may or may not be surfaced, speed is considerably reduced by grades and curves	Single lane substantially all weather with a minimum pavement width of 3m, minimum formation width of 4.2 m, with passing places and meeting the requirements of at least a 20km/h design speed
Class Four	Single lane unsurfaced vehicular track. Speed is severely restricted by grades and curves, may or may not be all weather	A road which doesn't meet the criteria of Class 3 road but is trafficable under normal conditions to a conventional 2 wheel drive vehicle
Class Five	Vehicular Track, generally a 4 Wheel Drive OR Any road or track which does not meet Class 4 standards, may or may not be all weather	A 'road' or way which is not normally trafficable to a conventional 2-wheel drive vehicle or, regardless of effective standard, is required for short term service only

Detailed information on pavement type is essential if the road management system is for use in the prediction of future pavement performance or life. As an example, information on gravel type, particle size distribution and gravel thickness is required for equations used to predict gravel loss and regravelling period (USDAFS, 1983; Visser *et al.*, 1995) and road roughness (Ferry, 1994).

2.7.7 Road Asset Data

Structures that are associated with roads but don't form part of the actual road pavement can be classified as 'road assets'. Road asset may not include the condition of the structures as this will change with time and maintenance. Forest road assets include:

- Bridges
- Culverts
- Signs
- Road related harvesting structures such as log dumps and loading bays
- Guardrail
- Cattle grids

Road assets are of interest to forest road managers because of the investment they represent. This time and cost investment has been studied by several researchers who have established rates for the construction or installation of a variety of road assets including rollovers (known aswaterbars in the US; Hewitt *et al.*, 1998), culverts (Pulkki, 1996); and culverts, causeways and bridges (Thompson, 1996).

Drainage structure records are likely to be among the most frequently used classes of data held in a forest road management system as these require regular inspection and maintenance. Relief drainage structure spacing information is also useful from an environmental perspective. Structures spanning drainage features, such as bridges and large diameter culverts, have the potential to become limiting factors for road sections (eg. an unstable bridge). Crossings represent the intersections of the road network with the drainage network and so are points at which the environmental aspects of road management are focused.

There are a variety of other structures associated with road networks that don't actually form part of the individual road sections. These have been described as 'road furniture' (Diggens *et al.* 1994). The term 'ancillaries' has been used for these structures in this study. Inclusion of these structures in a forest road management system may be warranted on safety grounds (guideposts, advisory signs, guardrail), harvest planning (truck loading bay/turnaround locations and condition), road maintenance (quarries and gravel pits) or for specific forest road users (eg. signs for recreational forest users).

2.7.8 Road Condition Data

Road condition changes with time and maintenance. This is especially true for unsealed roads (Morkel, 1994). Unsealed roads that receive no maintenance deteriorate very quickly. Therefore, road condition data should be updated frequently.

Eaton and Beaucham (1995) listed the seven distress items they considered to affect the performance of unpaved roads. Hallet and Jacobsen (1994) also listed seven distress items for unpaved roads.

Six items are common to both lists:

1. Improper Cross section
2. Corrugations
3. Potholing
4. Rutting
5. Loose Aggregate
6. Inadequate roadside drainage / water scour

Therefore, a useful forest road management system might include condition information such as:

- Pavement structure inventory
- Road roughness
- Structural integrity measurements
- Dusting potential

A pavement structure inventory is a record of the construction history of a road section. Data may include pavement thickness, type of material and year of construction. It may also include quality control data such as densities of compacted layers, compressive strength of concrete etc. The PSI should also include records of major maintenance or reconstruction (Haas *et al.*, 1994). In an Australian forestry context, a PSI would be limited to a record ofpavements treatments that have been carried out on the major roads of the subject network.

Road roughness is widely acknowledged as being a key indicator of the performance of both sealed (Queiroz, 1983; Divinsky *et al.*, 1997) and unsealed roads (Jamsa, 1983; Riverson *et al.*, 1987; Ferry, 1994; Douglas and McCormack, 1995). Haas *et al.* (1994) describe a number of devices used to measure road roughness. The devices can be divided into three types. The first type is Pavement Profile Measurement Devices, also known as profilometers. Profilometers measure the profile of a pavement at predetermined intervals along a road segment. The second type is the profilograph. Profilographs are towed behind a vehicle and have a set of bogie wheels at the front and at the rear, with a recording wheel in the centre. The recording wheel is free to move up and down with the bumps in the pavement and a strip chart recorder measures its vertical travel relative to the two sets of bogie wheels. Both types of road roughness measurement systems are generally unsuitable for forestry use, as they are expensive, in terms of both time and money, and not intended for unsealed roads (Provencher, 1997).

The third type is Response Type Road Roughness Measuring Systems (shortened to RTRRMS). These devices hold the most potential for forestry use. RTRRMS's measure the effect of a road's roughness on the vehicle they are mounted to. They do this either by measuring the displacement between the vehicle body and axle as it traverses the road, or by using an accelerometer to record the response of the vehicle body or axle to the bumps in the road.

Once a device has been selected, it is important to calibrate it so that subjective criteria can be established to determine the levels of roughness that correspond to various levels of vehicle ride quality (Haas *et al.*, 1994).

Ferry (1994) presents a model for estimating the mean annual roughness of gravel roads using indicators that are readily available to the road manager. The model was developed by recording information for a number of sites on unsealed New Zealand roads. Data collected included road geometry, traffic volumes and types, climatic variables, maintenance details, measurements of surface conditions, pavement materials testing and road roughness. Statistical analysis of this data was performed and an equation produced. The independent variables used in the equation are indicators that should be able to be easily obtained by the road manager.

Provencher and Méthot (1994) describe the 'International Roughness Index' (IRI) developed by the World Bank to estimate road user comfort as a function of road surface condition. The IRI represents the sum of the vertical displacements of a vehicles suspension (in metres) divided by the km driven. This is equivalent to millimetres per metre (mm/m). Provencher and Méthot state that a good gravel road should achieve an IRI of approximately 4mm/m with 14mm/m representing a road on which travel speed would have to be considerably reduced. This seems a sensible way of quantifying unsealed road roughness but the drawback is in the expense of purchasing a machine that can record the IRI measurements.

The structural integrity of a road can be measured by destructive evaluation or by non-destructive measurement. Destructive evaluation involves digging up the road surface to remove samples of each pavement layer for laboratory analysis (Haas *et al.*, 1994). Destructive evaluation techniques are not described further as their use in the ongoing management of forest roads is unlikely, with any use confined to a preliminary step in the repair of a major pavement fault to ascertain the cause of the fault.

Non-destructive measurement of a pavement's structural integrity focuses on recording pavement deflection. Deflection is curvature of the pavement surface under load. The amount of deflection reflects the structural integrity of the pavement and subgrade.

A commonly used instrument for deflection measurement is the Benkelmann Beam that consists of a lever arm attached to a lightweight aluminium or wooden frame. The beam is placed on the road surface with the tip of the arm being placed underneath the axle of a truck of specified axle load (usually 80 kiloNewtons). The loaded truck than drives away from the test point and a gauge on the beam measures the amount of rebound or upward movement of the pavement once the load has dissipated, at regular intervals (Haas *et al.*, 1994). This method is described as being simple and inexpensive by Haas *et al.* however, they also mention it as being slow and labour intensive. It has been described specifically here as it has been used by State Forests of New South Wales for deflection testing of its sealed roads (P.Weeden[3] pers. comm., 1998).

Dusting of forest roads is undesirable for a number of reasons. Thick clouds of dust obscure driver vision, cause driver discomfort and dust particles can affect a vehicles mechanical performance (Paige Green (1990) *in* Morkel, 1994). Significant dusting could also increase the potential for watercourse sedimentation to occur. Kramer (1991) *in* Morkel (1994) developed a system for rating dust severity (outlined in Table 2.4) and recommended that dust suppressants be used if dusting reached the 'high severity' stage.

Table 2.4 Dust Severity Test - after Kramer (1991) *in* Morkel (1994)

SEVERITY	HEIGHT OF DUST CLOUD PRODUCED BY VEHICLE TRAVELLING AT AVERAGE SPEED
Low Severity	< 3 feet
Medium Severity	3 - 5 feet
High Severity	> 5 feet

The condition of structures associated with the road can affect the performance of the road itself and these usually receive regular inspection.

Queensland Department of Primary Industries (QDPI) Forestry (1997) outlines a set of procedures for rating the condition of bridges, concrete box culverts and similar structures. Inspection techniques for the superstructure and substructure of bridges consist of either visual inspection combined with drilling, probing and sounding of bridge members or the preferred method of measuring deflection under specified traffic loads.

[3] Peter Weeden, Manager, Civil Engineers Branch, State Forests of New South Wales

A technique using radiographic (x-ray) methods to analyse bridge members is dismissed as being too expensive. Overall appraisal is made of the superstructure, substructure, stream stability, road approaches and load capacity. Following assessment, the bridge is given one of the five condition ratings listed in Table 2.5.

Table 2.5 Bridge rating system used by Queensland DPI Forestry (QDPI Forestry, 1997)

RATING	DEFINITION	ACTION
0	Critical Condition	Bridge closed pending major rehabilitation or replacement
1	Poor Condition	Load limit required (eg. light traffic 3 tonne GVM max. until rehabilitation or replacement)
2	Fair Condition	Potential exists for major maintenance within next 12 months or before logging operation
3	Fair to Good Condition	Potential exists for major maintenance within next 5 years
4	Good Condition	Minor, non-urgent maintenance required
5	As New Condition	Nil maintenance required

The rating of the condition of relief culverts, mitre drains and table drains is less complex than bridges. These structures have to be checked regularly to ensure that they are functioning properly and that no associated erosion is occurring.

The forest road manager may also decide to monitor the state of road furniture such as cattle grids, guideposts, guardrail, gates and even road line markings.

Traffic data is required for the prediction of pavement performance and is used in some road management systems to assign upgrading priorities. Traffic data can be obtained through the measurement of actual traffic volumes or through the use of performance modelling. Performance modelling requires an estimate of the heavy vehicle traffic that generates the majority of the distress (Haas *et al.*, 1994).

Eaton and Beaucham (1995) advocate the establishment of maintenance priorities with priority increasing proportionally to average daily traffic (ADT) volumes. A similar approach is adopted by the system described by Jamsa (1983). Weighting maintenance priority by ADT has mixed suitability to the forest road situation. Forest roads are generally characterised by infrequent periods of high use (at time of harvesting) and so it would be difficult to assign maintenance priorities for these roads according to average daily traffic volume. Major access roads are the only in-forest roads for which this technique might be suited. Forest road management systems may need facilities to record expected usage levels for upcoming periods.

2.7.9 Road Cost Data

A forest road management system should have the ability to maintain records of construction, maintenance and rehabilitation costs. These records then allow the road manager to understand how money is being spent across the road network, identify trends in spending and better anticipate future costs. Road cost data should be updated either annually or as costs are incurred. Items typically recorded are (Haas *et al.*, 1994):

- Construction cost
- Maintenance cost
- Road user cost

Construction cost information should be added to the database upon completion of a new road section. This information can be used in determining the present value of a road and, hence, the present value of the entire forest road network. Any further capital expenditure incurred for that road section can be added.

The purpose of adding maintenance costs to the database is to allow analysis of expenditure. Once a history of maintenance expenditure has been acquired, predictions can be made about likely future expenditure. Predictions of future maintenance costs for an area made from prior management experience are likely to be more accurate than those based on costs accrued in other areas. This is because a wide range of site specific factors heavily influence the frequency and cost of maintenance operations (Liautaud and Faiz, 1994). Liautaud and Faiz identify grading and gravelling costs as being particularly susceptible to influence by local factors such as rainfall, traffic volumes, pavement material properties and material resources.

User costs should be estimated on the basis of traffic volumes, pavement condition and/or models of vehicle operating costs (Haas *et al.* 1994). The user cost for forest roads is often measured in terms of log truck travel times. The influence of various road characteristics on log truck travel times has been the subject of a number of studies (Byrne *et al.*, 1960; Beath, 1976; Massey-Reed, 1978; Groves *et al.*, 1983; Winter, 1995). Other costs are undoubtedly caused by road roughness, although these are very difficult to measure.

2.7.10 Databases

The choice of database type is critical to the success of a computerised road management system. The database should be easy to use, capable of handling disparate data sources and powerful enough to perform complex analysis. It is important that they be able to accommodate the changing nature of road networks as well as that of computer technology without the capital invested in data acquisitions being lost (OECD, 1995).

The first road management systems developed by highway agencies in the late 1970's and early 1980's used mainframe computers. These were necessary, at the time, to handle the large data sets used by these systems (Ullidtz, 1985).

The advent of powerful personal computers has made database platforms, capable of storing and analysing large amounts of information, available to road managers of all levels. Spreadsheet programs can be used to store road inventory data. Specialist road management programs have been developed to run on personal computers. The widespread use of personal computers has also given road managers access to Geographical Information Systems.

Effective management of roads requires information on a variety of features, eg. road pavement characteristics, drainage structures, watercourse crossings and road signs. The common element present in these disparate data sources is geographic location. This has allowed GIS to emerge as the integrated support environment for road management systems (Fawcett, 1995). The advantages of GIS for use with road management systems are widely recognised (Paredes *et al.*, 1990; Finniear and Aik Lim, 1994; Johnson and Demetsky, 1994; Caroff *et al.*, 1994; Oluwoye, 1996). A major advantage for forestry organisations in using GIS as the platform for a road management system is that many already use GIS in day to day management of their forests. Finniear and Aik Lim (1994) point out that with the availability of user friendly GIS applications off the shelf and an increasing number of GIS literate personnel, a more proactive and holistic method of managing roads is now feasible.

Johnson and Demetsky (1994) point out that, like any automated decision support system, few if any benefits are realised as a result of one application of the technology. Major benefits in using GIS as the database for a road management system will be realised as usage continues.

Photologs provide another method for storing road network condition information. Photologs are photos of the features of the road network that can be stored in a computer. The user can retrieve the photo in order to gain an idea of the feature's condition at time of last survey. The advantage of photologs is that the user is presented with a picture that can be more descriptive of the features condition than lines of text. Spear and Cottrill (1993) describe the development and use of photologs in a management system designed for use on the roads of the Grand Teton and Yellowstone National Parks in the USA. The system is supported by the TIGER GIS. The photologs are 35-mm photographs that are taken with a camera mounted on the front of a specially equipped vehicle. The camera was set to take photographs every 1/100 mile (16 m). The Photolog software was interfaced with the GIS so that the user can point to a specific location on the network and the nearest photolog to that point will be displayed.

2.7.11 Implementation

Implementation is a crucial stage in the development of a road management system. It can be viewed as either putting a new system (or some components of it) into practice or the execution of decisions resulting from use of the system (Haas *et al.*, 1994). In this instance, the term 'implementation' is used to mean the adoption of a new system by an organisation.

OECD (1995) lists a number of problems that can occur during implementation. Those of particular relevance to forestry are:

1. Competing funding needs - Frequently, funds are directed towards the most visible purpose. Staff who have spent much time and energy in adopting developing and implementing a system may become discouraged when they see their results ignored because other, more immediate needs are deemed to have priority
2. Resistance to change – many forestry organisations are bureaucratic in nature and implementation may be hampered by an organisation being unsuited to rapid change
3. "Not invented here" syndrome – a road management system developed for an organisation by another group is sometimes perceived as not having the target organisation's best interests in mind
4. Long time frame – implementation of a road management system may take several years. Staff usually require time to learn the system and to gain confidence in it. Through this process, the road management system should evolve to suit the needs of the user organisation.
5. One person show – some road management systems are developed or adopted due to the specific interest of one person. If that person moves on, or perceives a lack of interest in the idea, the system will rarely be implemented.
6. Complexity – This is possibly the major cause of implementation problems. In some situations, the software used by the road management system is so complex or is accompanied by such inadequate documentation that the user has difficulty in understanding the concepts used in the system or is unable to explain them to others
7. Organisational level - It is imperative that the staff most likely to benefit from the use of a road management system will actually have access to the system. If this is not the case, implementation is likely to be hindered.

Implementation is often the stage at which carefully designed functions of a road management system are discovered to be impractical. The Yarrowlumla Shire (in New South Wales), for example, began using a management system called TAMS (Total Asset Management System).

This system required the shire to undertake an extensive survey of the pavements of their entire road network for distress indicators such as rutting, heaving, cracking and shoulder deformation. The shire quickly realised that this level of survey intensity was going to be too expensive and complex. Road roughness was selected as the indicator they would use for road performance and they arranged to have the entire road network surveyed at the one time. This decision proved to be inexpensive and satisfactory (G. Cunningham[4], pers comm. 17th April 1998)

This experience is similar to the one described by Friedrichs *et al.* (1997) who were involved in the implementation of one of the first comprehensive PMS to be used in the US. The PMS was a GIS based one that fell into disuse only months after it had been introduced. Friedrichs *et al.* concluded that the PMS should concentrate on providing users with more information than on determining a single solution, ie. the system development should focus on simplicity and flexibility. They also stress that addressing the user's attitudes and ideals is just as important in developing a PMS as the development of technology, data and models.

2.8 Road Management Systems Applicable to Forestry

The majority of the world's roads are unsealed and carry low traffic volumes. Forest roads also share these characteristics. A number of non-forestry road management systems have been developed for unsealed, low volume roads. Eck (1987) defines a low volume road as one that receives traffic volumes of 400 vehicles per day or less.

Development of management systems that address the needs of these type of roads (as opposed to sealed, high volume roads such as highways) is seen by many experts as a priority. Roohanirad (1994) observes that many agencies use management systems designed for high volume roads for low volume roads. He concludes that such systems fail to meet the needs of many of these

[4] Gordon Cunningham, Works Engineer, Yarrowlumla Shire

agencies because low volume roads have different classifications, characteristics, distresses and pavement types.

Douglas and McCormack (1995), writing specifically from a forestry viewpoint, consider that forest roads are often wrongly assigned to the same category as low volume roads. They argue that forest roads are distinct due to the heavy average axle loads they support. However, systems developed for unsealed / low volume roads are still likely to be much more applicable to forestry than the majority of systems which are developed for high-use, sealed road networks. Three systems with some potential for forestry use are described below.

2.8.1 Systems Designed for Unsealed and/or Low Volume Roads

Visser *et al.* (1995) describe the features and implementation of an unpaved road management system for the 51,750 km of unsealed roads in the Cape Province area of South Africa. The system's primary use is to calculate the volume of gravel lost annually (with gravel loss assumed to be a function of traffic volume and gravel parent material type) and determine an optimum regravelling strategy. This strategy is designed to accommodate a policy of a minimum time period between regravelling operations of 6 years.

In the early 1990's, a management system for the unsealed roads of northern New Zealand was developed for the local council (Hallet and Jacobsen, 1994). The system required a survey of road roughness and another to record road condition. The system employs an interesting reporting mechanism whereby the user defines 'trigger' values to select roads with specific distress features. One of the examples used by Hallet and Jacobsen was to select road sections in which over 25% had deficient drainage, more than 3 m of pavement deformation and over 3 m^2 of scouring. This reporting technique is useful because it allows the user to match road sections in need of repair with current resources.

Eaton and Beaucham (1992) designed a useful system intended to support the management of unsealed military roads. Data collection was conducted on 2 levels. The first level occurs on sample areas of the road network that have been chosen as being representative and detailed condition rating is conducted for these areas annually. The second level involves driving all roads in the network at approximately 30km/h. This is a quick survey, conducted four times per year, in which any surface or drainage problems are detected. The results of the 2 collection activities are combined to determine a condition index, used to prioritise works.

2.8.2 Systems Designed Specifically for Forestry

Six systems developed specifically for forestry use are reviewed below. Each of these systems has been developed to at least the prototype stage.

One of the first computerised road management systems designed specifically for forestry use is described by Nieuwenhuis *et al.* (1984). The system was developed in recognition of the increasing need for more detailed information for forest road management. The system was map-based and its primary function was the production of network status reports. Such a system is outmoded today as a modern GIS using a sophisticated road network representation could easily obtain the reports it was designed to produce.

Nieuwenhuis *et al.*, however, designed the system with further applications in mind including:

- Travel time estimation
- Route optimisation
- New road location planning

Utterback (1992) describes the testing of an urban pavement management system, developed by the Metropolitan Transportation Commission (MTC-PMS), on the sealed roads of the US Forest Service. Unfortunately, this work is not of direct relevance to Australian forest roads as the vast proportion are unsealed. Utterback concluded that this PMS was effective on such roads but recognised that it shouldn't be used in a "stand-alone" capacity. A key recommendation from the study was that the MTC-PMS be integrated into a comprehensive transportation management system.

Provencher and Méthot (1994) argue that significant gains are available to forest road managers by managing grading operations more intensively. They compare the cost of orthodox grading operations (in which roads are graded in their entirety based on a fixed schedule) with spot grading (in which only road segments that have deteriorated beyond a certain level are graded). Deterioration level is rated using the 'International Roughness Index' (IRI) (see Section 2.7.8). Provencher and Méthot developed equations to predict the IRI rating for given road section using variables describing traffic volume and topography. The predicted section IRI ratings are then used to schedule future spot grading operations.

The technique outlined by Provencher and Méthot was developed for harvesting operations involving a high degree of interaction between grading and timber haulage operations. For example, Provencher and Méthot quote a grading frequency of one pass every 60 truck trips. In Australia, grading tends to occur prior to haulage commencing. Grading is usually only employed during haulage operations at the request of the haulage contractor. Therefore, the technique of intensive spot-grading management may not be as beneficial in Australia. The actual technique of spot grading, however, should be considered by Australian forest road managers as a way to maximise grader utilisation.

The models of grading frequency developed by Provencher and Méthot are being used in a forest road management system being developed at FERIC and described by Provencher (1997). This system has three modules:

- Maintenance module – utilises the grading frequency models mentioned above to minimise combined grading and trucking costs. If these costs are predicted to exceed a certain level, reconstruction work or major rehabilitation is suggested.
- Road Construction module –will use information such as distribution of wood along the road network, volumes to be hauled and delivery schedule to determine a proposed roads functional class, geometric design and structural capability.
- Trucking module – relies on truck cost prediction software developed previously by FERIC to calculate haul costs and select the most appropriate truck/trailer configuration for a given haulage task.

The Stewart-Scott firm, in South Africa, designed a road management system to form part of an overall forest management system. The broad aim of the system is to determine the optimum road maintenance and upgrading levels for current and projected forestry activities (Stewart Scott Inc., 1995b). The specific purpose of the system is stated as being to provide the following information:

- Detailed definition of the forest road network including information on dimensions, layout and inventory items
- Traffic information
- Gravel information
- Information regarding the current condition of the road network with specific reference to road surface and drainage

- Maintenance and upgrading needs of the entire road network in summarised format and detailed descriptions of the needs of major haulage routes
- Comparative costs between alternative haul routes; and
- Works programs and corresponding annual budgets

The Stewart-Scott FRMS provides a useful decision making tool for the forest road manager. However, it doesn't provide any support for environmental objectives. The system has no provision for interaction with a GIS database. The data collection procedures described are thorough (especially from an engineering perspective) but are complicated and data collection for a large forest management area may prove expensive. No indication as to the anticipated cost of the data collection is provided.

A number of forest management agencies in Australia have recognised the need for a formal system to manage their road infrastructure. Possibly the most advanced system developed by an Australian forest management agency is the ROADS System devised by the then Department of Conservation and Natural Resources, Victoria, now the Department of Natural Resources and Environment.

ROADS is a PC based DOS system. It was designed for use by staff involved in the construction and maintenance of the road network serving not only Victoria's state forests but also its national parks, reserves and other forested crown land (DCNR (Vic.), 1995).

Data necessary for the operation of the system are collected via the use of 'input forms' that cover:

1. Road Inventory – conducted on a road section basis: eg. road section distance, road status, construction year, class, purpose, carriage width, surface type, pavement width

and depth, number of culverts, estimate of traffic flow, constraints (eg passes through flora reserve), occurrence of drainage feature crossings and type, intersection information, water points (for fire suppression) and proximity to gravel pits/quarries

2. Maintenance Frequency – a frequency is stipulated for each road section for the following maintenance operations: clean culverts, install relief culverts, creek crossing work, drainage work, erosion work, full grade, patrol grade, hand clear road verge, machine clear road verge, poison road verge, clear obstructions by hand, clear obstructions by machine, patch gravel, repair potholes, resurface base course, patrol road, remove rocks and gravel wearing course
3. Roadworks required – same options as for Maintenance Frequency.

These data are then entered into the program where they can be used by roading staff to maintain road records, plan future road works, track present and past road works and present road information as hard-copy reports (DCNR (Vic.), 1995).

Examples of queries able to be submitted to the system include:

- How many water points are located on Road X?
- What constraints are imposed on Road X and at what distance along that road do they occur?
- How many roads are located in areas of water production value?
- How many kilometres of road in Region X receive high levels of truck use?

The ROADS system is a useful one but a GIS can easily do many of the functions it performs. The GIS also has the immediate advantage of being able to produce a hard copy map resulting from a query.

The system developed for Forestry Tasmania by Neve is similar and also lacks the spatial analysis capabilities of ROADS (R. Neve[5], pers. comm, 22nd April, 1998). Neve's system is based around the Microsoft Access data management program and has registers of roads, road structures (eg. culverts and bridges) and quarries. It also incorporates a road network condition reporting system. Collection of data for the system is via visual survey using a laptop or paper forms. The intention is to integrate the system with a GIS in the future.

2.9 CONCLUSION

A review of relevant literature indicated the necessary components and functions of a successful forest road management system and the types of data that may be incorporated into them.

It was seen that, for a road management system to be effective, it must be able to offer support to the manager in achieving:

- Reduction of the impact of forest roads on the surrounding environment, especially water quality
- An increase in the efficiency and effectiveness of maintenance operations
- An increase in the efficiency of forest transport operations

The system must have an efficient data collection process and the database it uses must be user friendly with powerful analysis capabilities that are able to deal with large amounts and varieties of information. Implementation must occur relatively quickly and with minimum disruption to the user organisation.

[5] Ron Neve, Chief Engineer, Forestry Tasmania.

A system using a GIS as its database meets these requirements. GIS's are designed to deal with data as points, lines or shapes (polygons) in addition to non-spatial attributes such as condition descriptions. Most forestry organisations already use GIS so the implementation of a GIS based road management system would be much more streamlined than for specialised software systems. Global Positioning System units equipped with integrated electronic data loggers can complement a GIS based road management system by providing an efficient method for collecting road data. Data collected by most off-the-shelf GPS / electronic data logger units available currently can be easily redisplayed in a GIS.

A diverse range of data can be collected from forest roads including road surface type, pavement integrity, grade, sight distance, vertical and horizontal alignment, location and condition of assets, location and description of defects, traffic volumes and road user costs. All of these data can be used to manage different aspects of forest roads and transport systems. Time and money constraints imposed on this study however, meant that not all data types could be collected for the development of the pilot-scale FRMS. For example, collection of pavement integrity information and traffic volume data requires specialist equipment and large amounts of time.

Development of the pilot-scale FRMS concentrated on capturing general road segment information (such as pavement type and width) as well as the location and description of specific points of interest (eg. assets such as culverts and bridges; areas and points of defect; road related harvesting structures such as loading bays). It was also decided to incorporate a measure of road user cost. Successful capture of such data then allows support for the management of the road network in order to achieve environmental, maintenance scheduling, road planning and transport optimisation objectives. The development of the pilot-scale FRMS is described in Chapter 3, the addition of road user cost is described in Chapter 4 and testing various applications of the system are described in Chapter 5.

3 DEVELOPMENT OF A PILOT SCALE FOREST ROAD MANAGEMENT SYSTEM

Chapter Objectives:

1. ***Develop a data collection procedure and test it in the field***
2. ***Construct a GIS database to store, manage and analyse the data collected***
3. ***Develop techniques for the maintenance of the information held in the database***

3.1 INTRODUCTION

The pilot-scale Forest Road Management System (FRMS) development process can be summarised as follows:

- Define data types and naming/numbering conventions
- Develop data collection procedures:
    - Use of GPS with integrated electronic data logger
    - Manual paper and pencil collection method
- Trial collection procedures and obtain data for the roads of a discrete forest unit
- Load the data into a GIS to allow its display in easy to interpret maps and reports
- Develop GIS database to allow data to be queried using both the built in functions of the GIS and customised ones to be developed
- Design techniques to allow reporting on the current condition of the road network or individual road sections and to support reassessment of roads and road features
- Develop procedures for use in updating the FRMS data on a regular basis

3.2 DATA DEFINITION

3.2.1 Road Segment Definition and Numbering

Road segments were defined as homogeneous sections of the road network delineated by either intersections or changes of road standard (eg. gravelled surface changes to natural surface).

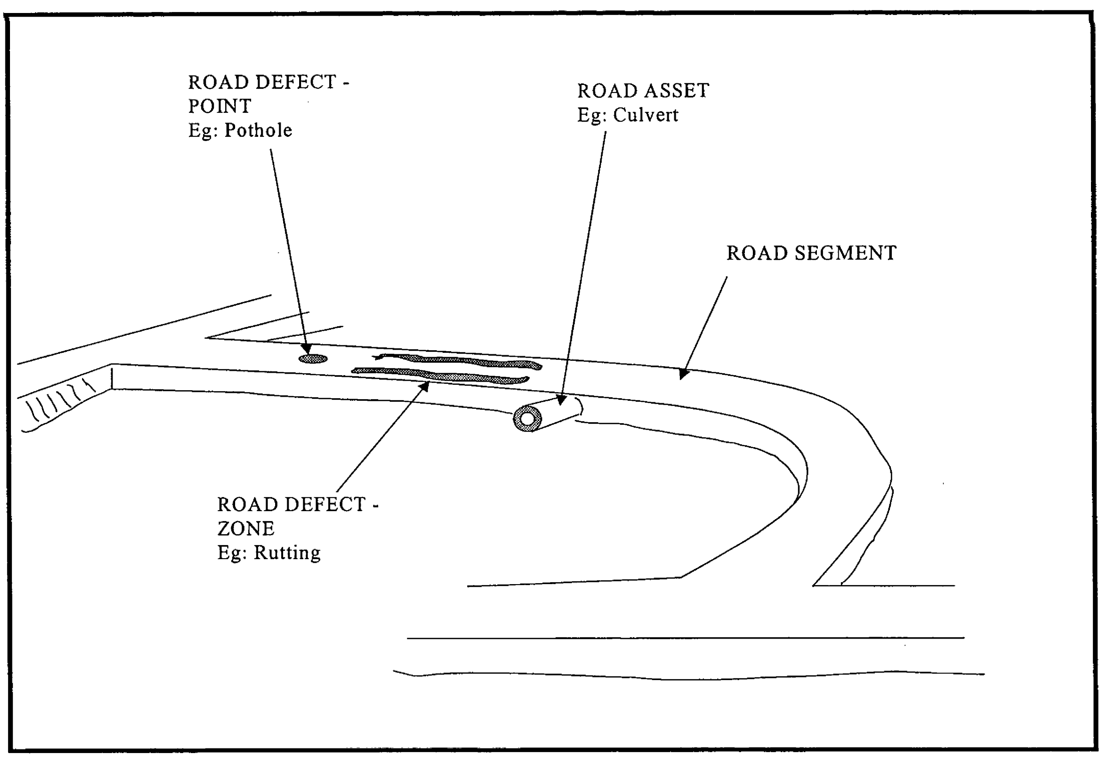
The road segment numbering method was designed to be simple and logical. Road segments were numbered in order of distance from a reference point located at the most south-westerly point of the forest road network. The segments were numbered to one decimal place to allow for the numbering of any newly constructed roads without having to renumber all the roads located further away from the reference point. For example, if the newly constructed road is built between two existing roads which are the 53rd and 54th road segments from the reference point respectively (ie. road segments 53.0 and 54.0), the new construction will be numbered 53.1. If a second road was constructed, further away from reference point but still between the two original roads, it would be numbered 53.2. If the road manager thought that there was a chance that another road could be constructed in the future between road 53.0 and the newly constructed road, a higher number such as 53.5 might be assigned to the new road.

3.2.2 Road Feature Classification

The term 'road feature' is used in this study to describe a specific point or area on or adjacent to a road that is of interest to the road manager. Road features were divided into two categories: assets and defects. A road asset was defined as a deliberate, permanent structure that benefits the road or road user. A road defect was considered to be any non-deliberate road feature that degrades the performance of the road in any way. The spatial nature of a GIS database dictated that road features be further segregated into lineal (zone) features and point features. The three types of road feature classification are illustrated in Figure 3.1. The classification is based on whether the feature is considered an asset or a liability and whether the feature forms a zone or is located at a single point.

Some information concerning road assets (ie. location) is typically more permanent while other information, such as condition and specifications, is more likely to change over time (eg. blocked culvert is cleared; culvert may have a set of headwalls added). Information on defect features will be transferred once the defect is repaired. This data will either move from the current dataset to a historical database (eg pavement failure history dataset) or be discarded altogether. The process of assigning identification numbers to road features reflects these differences. Each road asset requires a unique number that can be used to identify that asset for the life of the road. Distress features should also be numbered, but in a way that indicates the temporary nature of the feature.

Figure 3.1 Illustration of different classes of road feature



3.2.3 Road Feature Naming Convention

A naming convention was chosen to convey the following information:

• Forest in which it was located	(4 alpha characters)
• Road segment on which it is located	(3 numeric characters – to one decimal place)
• Type of road feature	(string, up to 12 characters)
• Fetaure number along road segment	(2 numeric characters)
• Month and year of data collection	(YYMM format)

The naming convention is described by way of example:

(i) Point Asset:

AMBP97.0-Culvert08

(iii) Point Distress Item:

D-AMBP97.0-ErosionPoint08-9805

(iv) Zone Distress Item:

D-AMBP97.0- ErosionPoint 08a-9805 (start)

D-AMBP97.0- ErosionPoint 08b-9805 (end)

Where:

AMBP	= 3 letter code assigned to each State Forest (AMB = Bago State Forest No. 560). The fourth letter is assigned to each section of the State Forest (P= Pound Creek section)
D	= Prefix assigned to defects features
97	= Road ID number – Road numbers are assigned by the GIS, based on the distance of any part of the road from the most south-westerly point of the forest

08	= Feature number.
a	= Zone commencement point (in direction of survey)
b	= Zone completion point (in direction of survey)
9805	= Month and year of initial detection for defect features (YYMM format)

The feature type is included in the id-number for clarity but makes it bulky and uses a lot of characters. This could be replaced by having a number represent each feature type or an abbreviated feature type name, eg. "*Culv*" for culverts.

3.3 DEVELOPMENT OF COLLECTION PROCEDURES

Forest road network segments often vary widely in standard. Therefore, any data collection techniques used for a forest road management system must be versatile enough to accommodate features confined to high quality sealed roads as well as those found on low standard unsealed roads.

Two data collection procedures were developed, one based on the use of an integrated GPS/electronic data capture unit (data logger) and a second based on estimation of field position and pencil and paper recording of data

3.3.1 Data Collection Using GPS and Data Logger

The type of GPS units most commonly used by land management agencies incorporates both a GPS receiver and a hand held electronic data logger to record position and attributes. Any GPS / Data Logger used for data collection for the FRMS should have the following features:

- Differential correction – either real time or post processing

- Robust data logger
- Ability to collect attribute data and design a custom attribute library
- Ability to collect data in both point and stream mode (i.e. can track a moving object such as a vehicle)
- Can be powered from a vehicle cigarette lighter or by rechargeable battery

The Sokkia Spectrum GPS used in this study has these capabilities. It has three major features:

1. The ability to record data either as individual points (eg. locating individual culverts along a road) or as a stream of points. The stream mode can be used to track an object through space and time.
2. It allows the user to enter attribute information about the point location being measured.
3. The points collected can be processed to provide a reasonable level of accuracy and then displayed and analysed in a GIS.

The GPS used in the study was selected by CSIRO Division of Forestry and Forest Products for use in a harvest machinery tracking study. This study demanded GPS units capable of withstanding dust, physical shock caused by vehicles negotiating rough terrain and temperature extremes (-10 to 40 degrees Celsius) (Roberts and Panyin, 1995). The ability of the units to function in either stream or point mode make them ideal for a variety of forest research activities.

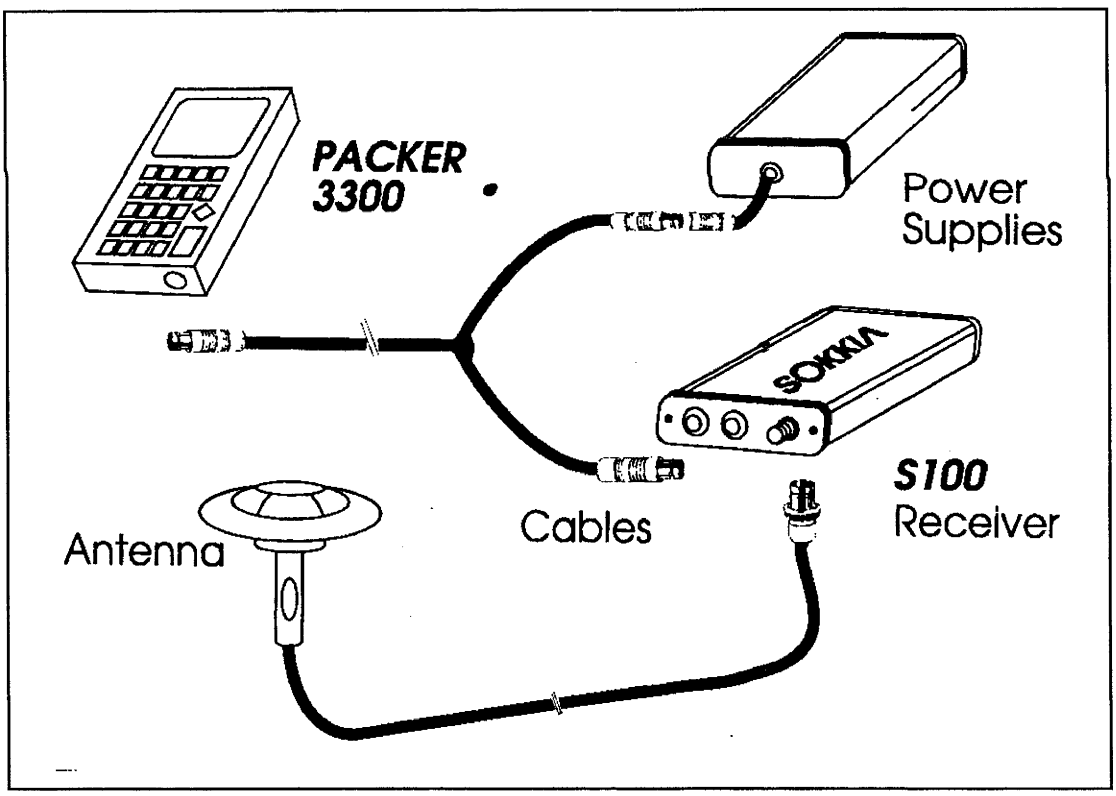
The field units used consisted of:

- Packer 3300 data logger
- Sokkia S100 GPS 6 channel receiver
- Satellite receiving antenna with magnetic mounting bracket

- Rechargeable gel cell battery (12Volt, 6.5 Ampère-hour)
- Connecting cable (Wye cable)
- Plastic carry case with foam lined interior
- Car cigarette lighter plug-in power supply (for use when tracking vehicles)

The 3-way Wye cable connects the receiver to the data logger and both items to the power source (12 V battery). The magnetic aerial mount is used to attach the aerial to a vehicle with a cable connecting the aerial to the receiver. The field unit componentry and order of assembly is shown in Figure 3.2.

Figure 3.2 Sokkia Field GPS Unit Componentry and Order of Assembly (SOKKIA, 1996)



The base station, required for differential post processing, was located at Yarralumla, in the ACT. It comprised:

- Sokkia S100 GPS 6 channel receiver
- Satellite antenna mounted on an 1.25m high tower mounted on top of a building
- Uninterruptible power supply
- PC for running base station Sokkia Spectrum® software and logging observations
- A programmable backup tape system

The GPS recording unit (Packer) is preloaded with a file containing the allowable feature types, attributes and choices, which forces the recorder to use only 'correct' codes. As the unit records the location of the point, the user can simultaneously enter the type of feature that the point coordinate represents, followed by a list of the feature's attributes.

The file, called a 'Feature Library', is written in a software application called Spectrum Attribute Manager® which is produced by the manufacturer of the GPS used in the study. Feature libraries contain entries for all features of interest, have a sufficient number of attributes to unambiguously identify the feature and have maximum and minimum acceptable values for numerical attributes, where possible, to help trap erroneous entries (Sokkia, 1994). The FRMS data collection feature library is described in Appendix C.

The standard data collection procedure is:

1. Drive slowly (approximately 20 km/h) to feature location
2. Position vehicle so that the front left hand corner (where the GPS aerial was mounted) is as close to the feature as safety and practicality permit
3. Commence GPS recording (GPS recording took from 0.5 to 10 minutes)

4. Inspect the feature from outside the vehicle if necessary
5. Make any measurements (eg. culvert diameter), take photos etc.
6. Record information on Road Feature Attribute form
7. Drive to next feature

3.3.2 Manual Data Collection

A non-GPS data collection method was also developed for situations where forest road managers do not have access to GPS. There are also locations under dense forest canopies or in steep terrain where GPS data collection can be inefficient or impossible (O'Connell *et al.*, 1995; Deckert and Bolstad, 1996). Three methods were developed; two were trialled in the field.

Method One – Vehicle Trip Meter (Odometer)

With this method, the data collector zeroes the vehicle odometer at the intersection closest to the reference point (i.e. the most south-westerly end of the segment) and then notes the distance along the road segment at which each road feature occurs. The accuracy of this technique is compromised by most vehicle odometers only reading to the nearest 100 metres.

Method Two – Grid Map

A grid map was used to record feature locations unable to be recorded with the GPS. This method uses maps printed from the GIS prior to the data collection trip with grids at 200m intervals (Figure 3.3). It was anticipated that the grid would act as an aid in estimating the location of a feature along a road section. A number is marked on the map where the collector estimates the feature lies, with that number corresponding to a description of the feature entered on the separate data entry form.

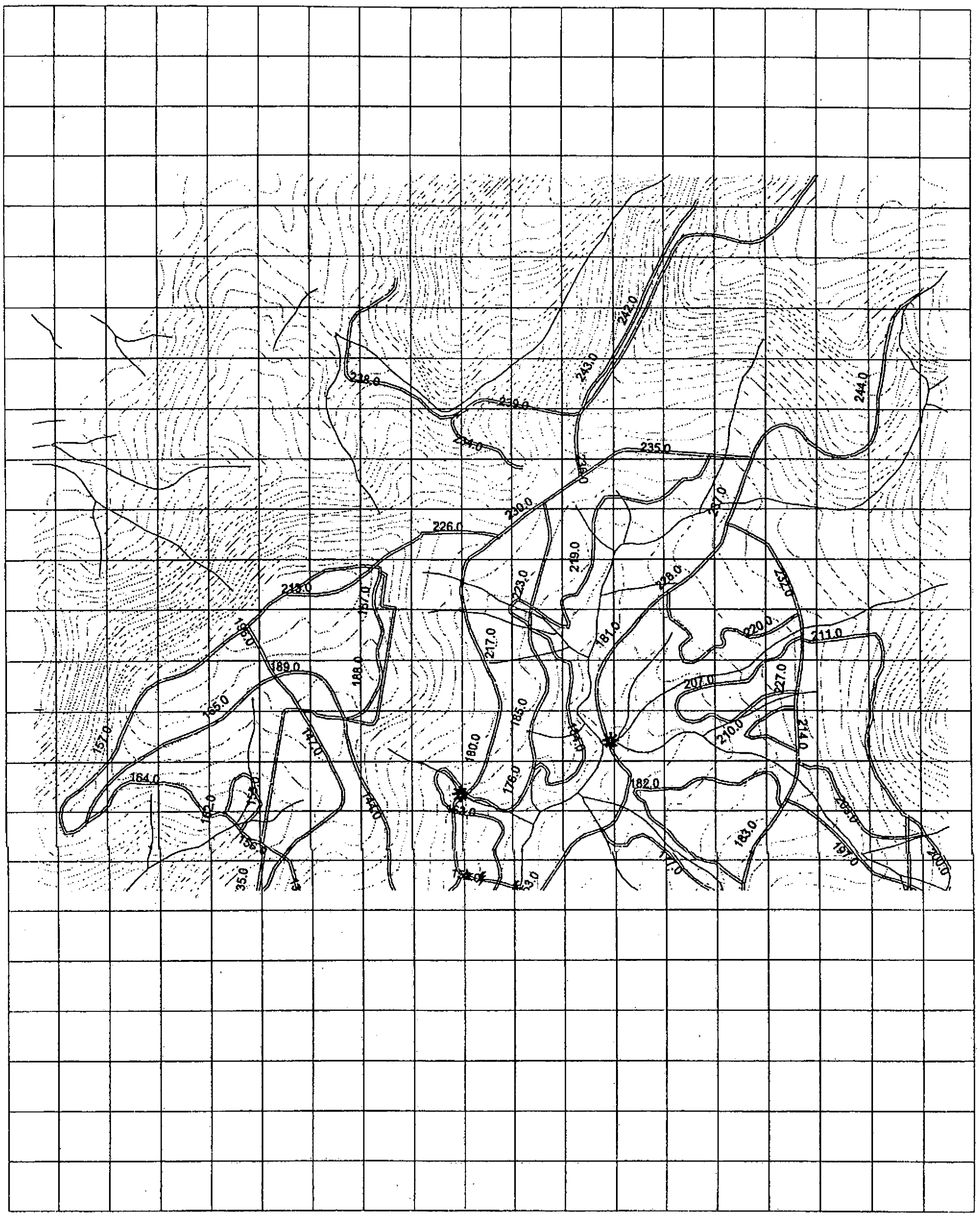
Method Three - Strip Map Data Collection Form

This method used the concept of the strip map in which a road segment is represented on paper as a straight line, with distance along the line representing distance along the road segment. An example of a completed data collection strip map is presented as Figure 3.4. The advantage of this form is that road segment attribute data (eg. pavement type and width, formation width) can be recorded as well as road feature locations. For the strip map data collection form to be effective however, a measuring wheel of robust construction and reasonable precision (ie. within 5 metres) has to be attached to the data collection vehicle. This was not available during the study and Method 3 was not trialled.

3.3.3 Data Recording Form

A data recording form was required for use in manaul data collection to capture information about the road feature. It was also envisaged as a hardcopy backup when using the GPS in case of any corruption of the data files or to remove any ambiguity caused by operator error. The form used is shown in Figure 3.5. The data shown on this form matches that on the form in Figure 3.4.

Figure 3.3 Gridded Map Used in Manual Data Collection Method 2



1:20,000

I cell = 200m x 200m

N

Figure 3.4 Example of Data Collection Strip Map (Manual Data Collection Method 2)

Road No.: 18.0

Road Name: –

Date: 18 / 6 / 98

Surveyor's Initials: AW

Pavement Type: NS

Pavement Width: 4 . 2 m

Formation Width: 3 . 7 m

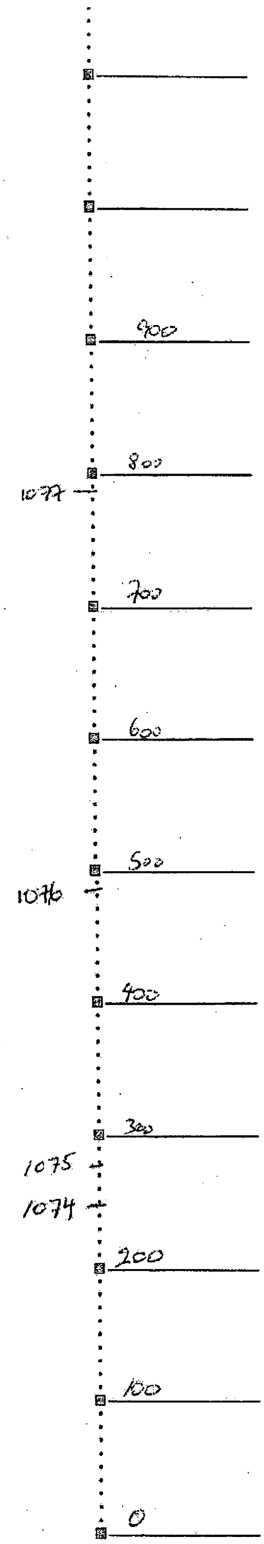


Figure 3.5 Example of Data Recording Form

Road Attribute Point Description Sheet

Form Revised: 17/06/98

GPS NO./ POINT NO.	ATTRIBUTE TYPE		ROAD FRMS ID	ZONE End1	ZONE End2	ITEM TYPE	Description/Comments
1074	D	(A)	18.0	a	b	MITRE	MEDIUM, GOOD COND.
1075	(D)	A	"	a	b	PAV. DEFECT	RUTTING, MEDIUM
1076	D	(A)	"	a	b	CULV.	375 mm, STABLE, NO HW'S
1077	D	(A)	"	a	b	"	" " "
	D	A		a	b		
	D	A		a	b		
	D	A		a	b		
	D	A		a	b		
	D	A		a	b		
	D	A		a	b		
	D	A		a	b		
	D	A		a	b		
	D	A		a	b		
	D	A		a	b		
	D	A		a	b		
	D	A		a	b		
	D	A		a	b		
	D	A		a	b		
	D	A		a	b		
	D	A		a	b		
	D	A		a	b		
	D	A		a	b		
	D	A		a	b		

STATE FOREST: BACO NO. 560 SECTION: POUND CK.

DATE: 18 / 6 / 98

SURVEYOR'S INITIALS: AW

Form stored at: C:/Andreww/Excel/Road Reporting Forms - #2/Road Attr. Pt. Form

3.3.4 Collection of Road Segment Data

Road segment data recorded in the field included:

- Pavement type
- Pavement width
- Formation width
- Inspection date

Provision was made for additional data to be added:

- Road name
- Construction cost
- Upgrade cost
- Maintenance costs
- Other information where available:
  - Year of construction or upgrade
  - Source of gravel

3.4 DATA COLLECTION TRIALS

3.4.1 Data Collection Area

The area chosen to trial FRMS data collection was a section of *Pinus radiata* plantation in Bago State Forest known as Pound Creek (also known as Blomley's Section). Bago State Forest is located between the towns of Batlow and Tumbarumba in the South-West Slopes Region of New South Wales (see Figure 3.6).

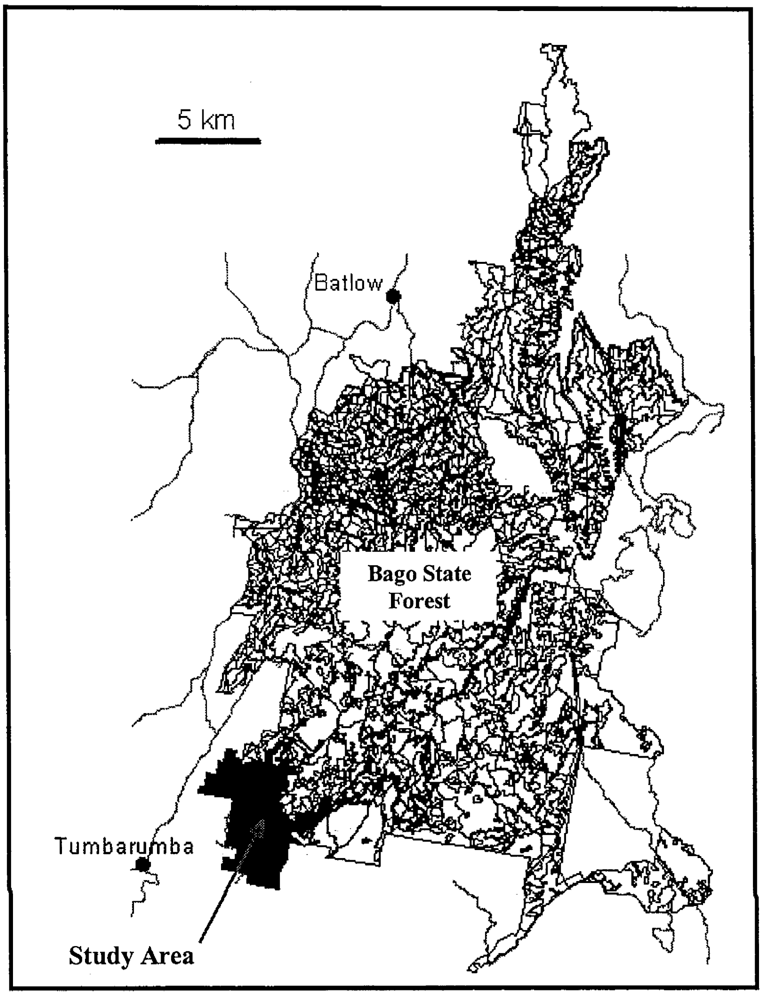
This particular area was chosen for a number of reasons:

- The plantation is a discrete unit of forest
- The plantation was being harvested at time of study
- The recent history of roadworks for that forest was known
- The roads serving the plantation area ranged widely, from standard bitumen sealed road to fire trails. The roads also varied widely in age from newly constructed through to roads that existed before plantation establishment.
- The wide variety of drainage structures used, including a set of box culverts, a bridge, single and double celled large diameter pipe crossings and causeways.
- The road network of this area receives a wide variety of road users such as: B-double log trucks, other heavy vehicle traffic associated with timber harvesting, forest managers and workers (for both the plantation and the surrounding native hardwood forest), apiarists, graziers and firewood collectors.
- GIS data, including a Digital Elevation Model (DEM), were available for the area

The plantation was undergoing first thinning, yielding pulpwood for the ANM Newsprint Mill located at Albury (New South Wales), at the time of the trial.

Data collection for the forest roads of Pound Creek occurred in two stages. An initial collection trip (Trip #1) was made to the area (6th to 8th May, 1998) to evaluate collection techniques. The techniques were then revised and improved and the bulk of the road data was collected on a second trip (Trip #2 - 19th to 21st May, 1998).

Figure 3.6 Pound Creek Study Area (Blomley's Section), Bago State Forest



3.4.2 Data Collection Using GPS and Data Logger

Approximately 140 points were collected on Trip #1. Efficiency of data collection proved highly dependent on the performance of the GPS receiver, which was affected by forest conditions and topography.

The feature library was modified prior to Trip #2 to eliminate some faults. The same technique for data collection was used as for Trip #1, with one person doing the collecting. Approximately 285 points were collected. Despite periods of heavy rainfall, data collection for all major roads and most minor roads within the Pound Creek area was completed within three days. The rainfall actually aided data collection in some instances as the effectiveness of drainage structures and road formation could be gauged by observing runoff behaviour.

Time taken for the GPS to record location seemed to increase substantially in densely stocked plantations and on certain road segments with steep side cuts. Recordings in these areas may give less precise positional values. Points collected on road segments that passed through a variety of forest types and along a road segment built mainly in steep sidecut were analysed to test this (Table 3.1). The average quality value, automatically determined by the GPS, was calculated for these points. The quality value is a theoretical indication of the reliability of a computed position. It doesn't represent the discrepancy between computed and true positions. Roberts and Panyin (1995) found that GPS accuracy improved significantly in thinned *P.radiata* stands in Tumut plantations (approximately 60 km north east of the study site) when compared with inaccuracy of GPS recordings obtained in unthinned stands. Therefore, a significantly higher average quality value was expected for points located on a road segment passing through the thinned 1983 ageclass when compared with points collected on road segments passing through the unthinned 1984/85/86 ageclasses. However, the results did not substantiate this and it is likely topography was also exerting an influence on these results. Points collected on a sealed road through open paddock for most of its length had the highest average quality value as anticipated. This is due to the receiver having uninterrupted access to satellite signals.

These results suggest that there are benefits to be gained in data collection efficiency by planning collection trips for plantation forest roads to occur at times when cover is minimised (e.g. after clearfelling or while trees are still young). This possibility is pursued further in Chapter 6.

Table 3.1 Average Quality Values Derived From GPS Recording in a Variety of Forest Conditions

ROAD SECTION	DESCRIPTION	DATE RECORDED	AVERAGE QUALITY (unitless)
Pound Creek Road Stage 1	Open paddock, scattered trees	20/5/98	2.1
Bobtail Gully Road	Native Forest Retention	19/5/98	2.2
The Boulevard	1st thinned 1983 P. radiata on one side, native forest retention on the other	20/5/98 8/5/98	5.1 4.4 Overall: 4.7
Island Road	1st thinned 1983 P. radiata on both sides	7/5/98	6.9
Wattle Ridge Road & Pound Ridge Road	1985 P. radiata Ageclass	19/5/98 20/5/98	8.4 2.2 Overall: 5.1
Wattle Ridge Road	1986 P. radiata Ageclass	19/5/98	3.4
Dog Tree Road	Paddocks with consolidated clumps of trees, road in high sidecut for majority of length	20/5/98	3.2

3.4.3 Manual Data Collection

The method tested during Trip #1 was the use of the vehicle odometer to measure locations of road features from intersections closest to the specified reference point. This method proved unsuccessful since most vehicle odometers only measure to the nearest 100 metres. However, within a 100m section of road, several road features may require recording. Another problem is that vehicle based data recording invariably involves a degree of reversing and/or turning around which can cause cumulative error. Correcting for reversing (in which the odometer records as if the vehicle was still travelling forward) or turning around added a complicating element to data collection.

The gridded map system was used on Trip #2 to record road feature location for several road segments where satellite geometry was too poor for the GPS to be used. It was still difficult to pinpoint road feature locations on the map, despite the scaled grid. The main problem was that, with only one person collecting the data, it was difficult to drive and estimate position on the map at the same time. With a two-person collection team, this might not be such a problem.

It was concluded that Method 3 (described in Section 3.3.2) would be the most desirable given the availability of a practical, robust, detachable vehicle mounted measuring wheel that could be read from within the vehicle.

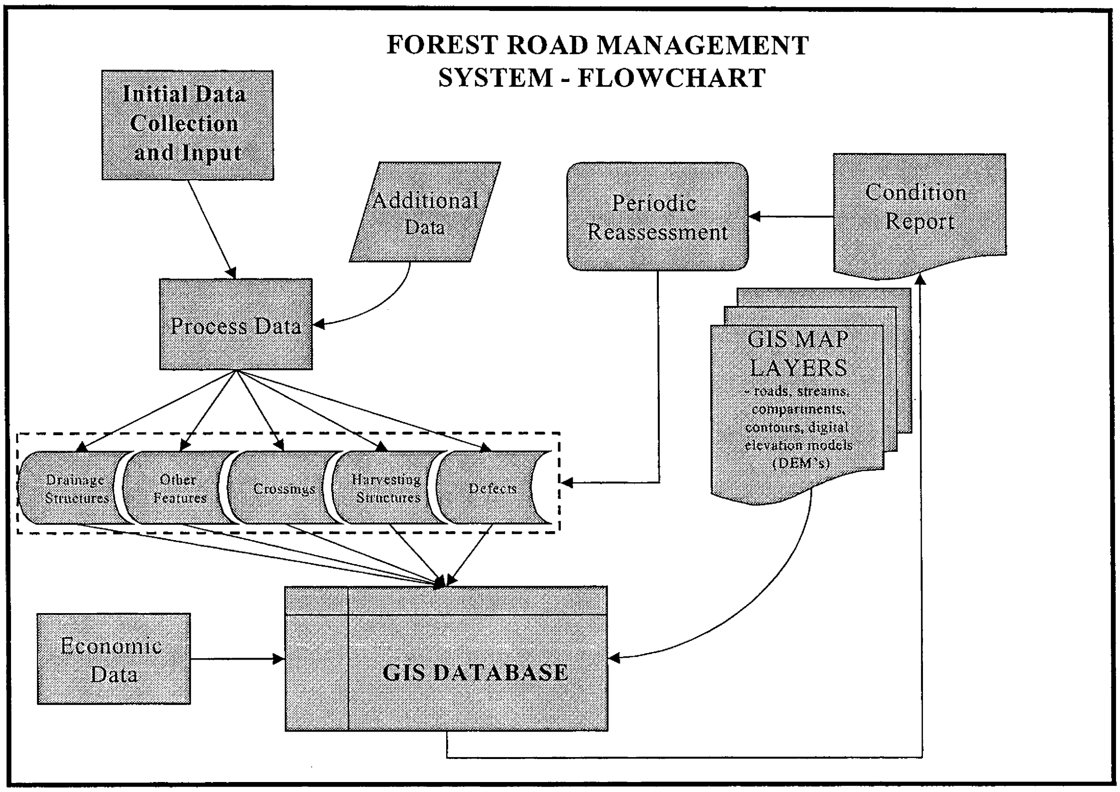
3.4.4 Collection of Road Segment Data

Information on the individual road segments was also collected during Trip #2. Data on pavement type, pavement width and formation width were collected in the field. Some construction and major maintenance cost information was obtained from the local SFNSW office in Tumbarumba.

3.5 BUILDING THE GIS APPLICATION

The ArcView GIS program forms the database of the FRMS. It allows data to be viewed at various scales, from the individual road section up to the regional network and it can summarise the data in the form of maps and reports. Modern GIS's also allow sophisticated querying based on the spatial relationship between data. For example, data within a GIS can be queried to select all road segments located within 50m of watercourses. Figure 3.7 shows how the FRMS operates around the GIS.

Figure 3.7 FRMS Operational Flow Chart



Another advantage of using GIS as a database is that road data can be shared between operational centres and organisational levels.

In ArcView GIS, spatial data is displayed as a 'theme'. A theme is a layer of geographic information eg. road network of a forest. ArcView recognises three types of themes:

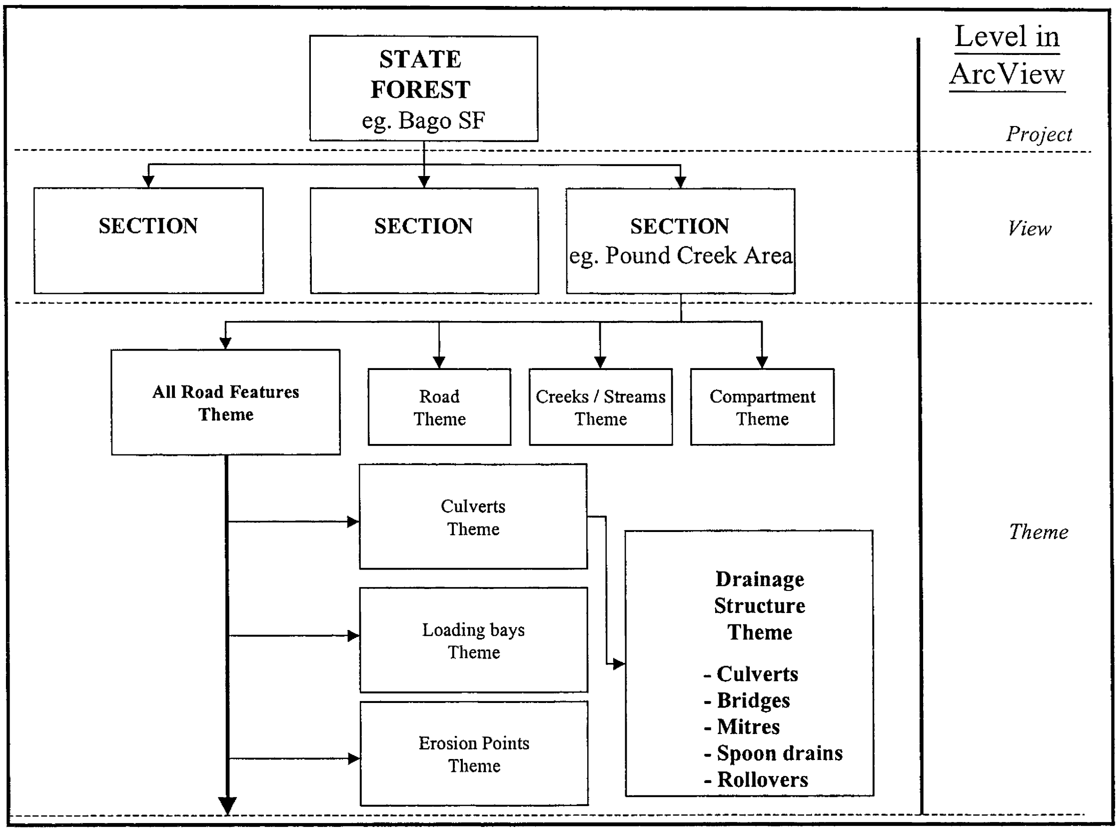
- Point themes – these represent individual locations such as culverts or quarries.
- Line Themes – line themes represent lineal features such as roads or streams
- Polygon Themes – polygon themes represent areas of homogeneity such as a forest compartment (an area of forest that has a single management boundary) or an ageclass (an area of plantation that has a common establishment date).

A 'theme table' is a dBase file (a file of a format used by the dBase database management package, widely used in industry) that lists the attributes of a theme. Theme tables have a full range of functions for obtaining summary statistics for theme attributes as well as sorting and querying. Tables are linked to themes so features can be selected either in the table or in a 'view'. A 'view' is a collection of themes (eg. roads, streams and compartments of a forest) displayed as an interactive map. ArcView stores the spatial data comprising themes as 'shapefiles'. ArcView shapefiles have a simple, non-topological format for storing the geometric location and attribute information of geographic features (ESRI, 1996). A project is a file that stores the computer disc location of all views, themes, tables and map layouts relating to a particular ArcView session or application.

The ArcView database structure intended for the FRMS is illustrated in Figure 3.8. With this structure, each forest within the management area is assigned an ArcView project. The forest can then be divided into subsections if required, each of which is given a view. Within each view are the themes that represent the actual features of the forest or forest section. The road segment numbering system (Section 3.2.1) is applied to each view. This allows the road feature numbering system, described in Section 3.2.3, to be implemented.

It is proposed that larger forests be divided into sections because smaller data sets should be more manageable. It would also be an advantage where a data set were corrupted to the extent that use of the FRMS was hindered. With the forest divided into sections, the FRMS would continue to be available for use on the majority of the forest while the fault was rectified.

Figure 3.8 FRMS Structure Within the ArcView GIS



3.5.1 Adding Information to Road Theme

The underlying road theme provides the backbone of the FRMS. The road segment data collected is added directly to the road theme table by adding new fields (columns) and typing the data in. The fields used for the pilot-scale FRMS were:

- Pavement Width
- Formation Width
- Pavement Type
- Construction Cost
- Upgrade Cost
- Maintenance Cost

- Date of last inspection
- Comments

Unnamed road segments of low standard can be named "Boundary Track" or "Internal Track", depending on their location in relation to the plantation area. The relevant data, stored in the road theme table, are shown in Figure 3.9.

Figure 3.9 Example of Data Stored in Roads Theme Table

Attributes of Frms_rds.shp

Road Name	Segment Id	Pavement Width	Formation Width	Pavement Type	Construction Cost	Upgrade Cost	Maintenance Cost	Inspected	Comments
Island Road	54.0	4.0	5.5	Natural Surface	0.00	0.00	0.00	19982105	Constructed - 1997/8
Island Road	58.0	4.0	5.5	Natural Surface	0.00	0.00	0.00	19982105	Constructed - 1997/8
Dog Tree Road	66.0	5.5	7.2	Gravel - Lubke's	0.00	1221.81	0.00	19982105	Gravelled - 1997
Dog Tree Road	72.0	5.5	7.2	Gravel - Lubke's	0.00	8386.65	0.00	19982105	Gravelled - 1997
Charcoal Gap Road	46.0	4.0	5.5	Gravel - Lubke's	0.00	3563.89	0.00	19982105	Gravelled - 1997
The Boulevarde	75.0	4.0	5.5	Gravel - Lubke's	0.00	14887.28	0.00	19982105	Gravelled - 1997
Dog Tree Road	63.0	5.5	7.2	Gravel - Lubke's	0.00	391.91	0.00	19982105	Gravelled - 1997
Bobtail Gully Road	73.0	4.0	5.5	Gravel - Lubke's	0.00	4037.32	0.00	19982105	Gravelled - 1997
Dog Tree Road	45.0	5.5	7.2	Gravel - Lubke's	0.00	36985.62	0.00	19982105	Gravelled - 1997
Charcoal Gap Road	40.0	4.0	5.5	Gravel - Lubke's	0.00	4644.38	0.00	19982105	Gravelled - 1997
Charcoal Gap Road	50.0	4.0	5.5	Gravel - Lubke's	0.00	4043.57	0.00	19982105	Gravelled - 1997
Charcoal Gap Road	56.0	4.0	5.5	Gravel - Lubke's	0.00	3463.49	0.00	19982105	Gravelled - 1997
Bobtail Gully Road	69.0	4.0	5.5	Gravel - Lubke's	0.00	4392.88	0.00	19982105	Gravelled - 1997
Bobtail Gully Road	67.0	4.0	5.5	Gravel - Lubke's	0.00	4460.48	0.00	19982105	Gravelled - 1997
Charcoal Gap Road (Ha	79.0	4.0	5.5	Natural Surface	0.00	0.00	0.00		Managed by Hardwoods secti
Pound Creek Road - Sta	47.0	8.0	10.0	Bitumen Seal	130000.00	0.00	0.00	19982105	Shire Rd. - Built by SFNSW in
Boundary Track	61.0	3.7	4.2	Natural Surface	0.00	0.00	0.00	19982105	
Boundary Track	77.0	3.7	4.2	Natural Surface	0.00	0.00	0.00	19982105	
Boundary Track	78.0	3.7	4.2	Natural Surface	0.00	0.00	0.00	19982105	
Charcoal Gap Road	68.0	4.0	5.5	Gravel	0.00	0.00	0.00	19982105	
Boundary Track	74.0	3.7	4.2	Natural Surface	0.00	0.00	0.00	19982105	

3.5.2 Adding Data Collected With GPS Data Logger to GIS

The procedure described here applies specifically to the SOKKIA GPS/ Data logger units used during this study. Data is downloaded from the Packer data logger into a portable computer at the end of each day. Sokkia Spectrum® software is used to correct and translate the point coordinates to the Australian Geodetic Datum (AGD66) Zone 56 projection matching that of SFNSW GIS data. The coordinate format is also changed from degrees-minutes-seconds to decimal degrees. The software allows the data to be stored as dBase files that can be opened in Microsoft Excel®. Each data logger file produces two dBase files. One lists point-id, latitude/longitude and eastings/northings. The other file contains the actual attribute information. Both types of dBase file are opened in ArcView where the two types of file can be joined based on the common point-id field (known as a *join-item*). The joined file is then opened in Microsoft Excel®. At this stage, the dBase files are still grouped by date of recording. All the files are grouped into one spreadsheet and an extra column showing date of data point collection is added. File format is rearranged using a simple logical operator so that attribute information appearing in rows is redisplayed in columns to make it compatible with an ArcView theme table.

The spreadsheet is then saved as a dBase file. This file can be opened in ArcView by adding it to the 'Project' as a table and then using the 'AddEvent Theme' function in the 'View' menu. This function adds a point theme to a View based on coordinates listed in the table.

3.5.3 Adding Data Collected by Paper Form

The data addition process was tested for some data (collected in the Pound Creek area) in order to assess the feasibility of adding data collected by paper form. The following procedure was used:

1. Type data into Excel spreadsheet and save as a dBase file – include a field with record number
2. Create a raster (grid) version of the roads theme using ArcView *Spatial Analyst*. This is done by selecting 'convert to grid', specifying the road theme and the desired grid size (20 m was used).
3. Overlay the original road theme (vector format) onto the grid version. This is done to provide a scale to guide the placement of points representing road features.
4. Create a new point theme
5. Digitise new point theme using the raster version of the road theme as a guide for the placement of the point along the road.

This process was quite time consuming with a large potential for error.

3.5.4 Processing Road Feature Data

Features were named using the convention described in Section 3.2.3. This process was automated to a large extent by opening the feature theme table in Microsoft Excel and using the functions of the program.

It is useful for field staff to know the relative location of features from road start points. This information isn't collected in the field (if using the GPS / Data Logger) so it was added within the FRMS. Once features have been named and their location along the road calculated, individual feature themes are created. An example of a feature theme table (crossings in this case) is shown in Figure 3.10. Some of the more pertinent data included in this table are: SFNSW permanence classification, type of crossing structure used, road segment on which the crossings are located, individual identification number and the distance (in metres) along their respective segments.

Figure 3.10 Feature Type Theme Table Showing Relevant Attributes – Crossings (Pound Creek Area, Bago State Forest)

Date Inspected	Feature Type	[illegible]	Easting	Permanence	Crossing Type	On Segment	Feature Id	Distance along Segment
19982105	Xing	6040844.467	596170.102	Drainage Line	Pipe	24.0	AMBP24-Xing1	181
19980705	Xing	6041696.671	595941.420	Depression	Nat Causeway	42.0	AMBP42-Xing1	524
19980705	Xing	6041735.087	595855.879	Depression	Nat Causeway	42.0	AMBP42-Xing2	430
19982005	Xing	6042216.019	594879.919	Drainage Line	Pipe	45.0	AMBP45-Xing1	941
19982005	Xing	6042234.230	594697.808	Drainage Line	Pipe	45.0	AMBP45-Xing2	1182
19982005	Xing	6042348.667	594517.721	Depression	Pipe	45.0	AMBP45-Xing3	2158
19982005	Xing	6042779.464	595337.363	Water Course	Pipe	45.0	AMBP45-Xing4	1384
19982005	Xing	6042399.697	593671.794	Water Course	Pipe	47.0	AMBP47-Xing1	1
19980705	Xing	6042443.328	595538.830	Depression	Nat Causeway	49.0	AMBP49-Xing1	270
19980605	Xing	6041768.185	596529.861	Drainage Line	Pipe	50.0	AMBP50-Xing1	8
19980705	Xing	6041891.106	596774.566	Drainage Line	Pipe	50.0	AMBP50-Xing2	283
19980605	Xing	6042195.135	596557.993	Drainage Line	Nat Causeway	51.0	AMBP51-Xing1	618
19980705	Xing	6042743.863	595526.774	Water Course	Pipe	54.0	AMBP54-Xing1	40
19980705	Xing	6042745.135	595680.272	Drainage Line	Nat Causeway	59.0	AMBP59-Xing1	57
19980705	Xing	6042093.682	597027.968	Water Course	Pipe	69.0	AMBP69-Xing1	100
19980705	Xing	6042197.709	596885.250	Depression	Pipe	69.0	AMBP69-Xing2	283
19980705	Xing	6043199.820	595610.909	Drainage Line	Pipe	72.0	AMBP72-Xing1	180
19980705	Xing	6043362.174	595684.197	Drainage Line	Pipe	72.0	AMBP72-Xing2	358
19980805	Xing	6043186.709	596413.954	Depression	Pipe	75.0	AMBP75-Xing1	447
19982005	Xing	6043373.682	595986.786	Water Course	Pipe	75.0	AMBP75-Xing2	918
19982005	Xing	6042357.000	597455.000	Water Course	Pipe	77.0	AMBP77-Xing1	124
19982005	Xing	6042358.000	597454.000	Water Course	Pipe	77.0	AMBP77-Xing2	125
19981905	Xing	6043662.832	595268.405	Depression	Nat Causeway	81.0	AMBP81-Xing1	292
19981905	Xing	6043625.813	595481.223	Water Course	Nat Causeway	81.0	AMBP81-Xing2	76
19980805	Xing	6043600.234	595800.373	Water Course	Pipe	85.0	AMBP85-Xing1	90
19981905	Xing	6043277.482	596740.728	Drainage Line	Pipe	91.0	AMBP91-Xing1	38
19982005	Xing	6043761.909	595800.897	Water Course	Bridge	92.0	AMBP92-Xing1	97

Road Feature themes with a common function can also be collated into new themes to allow additional analysis. For example, all drainage structures (culverts, bridges, mitre drains, rollovers and spoon drains) can be selected and then converted to a new shapefile to form a drainage structure theme. This would be done so that road managers can analyse an entire road network's drainage system, without incurring the computer overhead and delay involved in selecting out drainage structures.

Procedures for adding new data to existing themes were also developed.

3.6 THE FUNCTIONING FRMS

The result at this stage is a number of themes representing different road features overlaying a road network theme. Each item in the road feature theme has a unique identification and was related to the road segment on which it was located. The end product (for Pound Creek Plantation, Bago State Forest) is shown in Figure 3.11. In this example, data describing road assets and defects are overlaying representations of the road network, forest compartments, contours and drainage system. This provides a basic platform for supporting systematic forest road management.

3.7 SCHEDULING ROAD REASSESSMENT AND UPDATING FRMS

One of the major functions of the FRMS is to support regular reassessment of roads and associated structures. Reassessment will also ensure that the information within the FRMS is current. The production of strip maps and condition reports assists in regular road reassessment.

3.7.1 Strip Maps

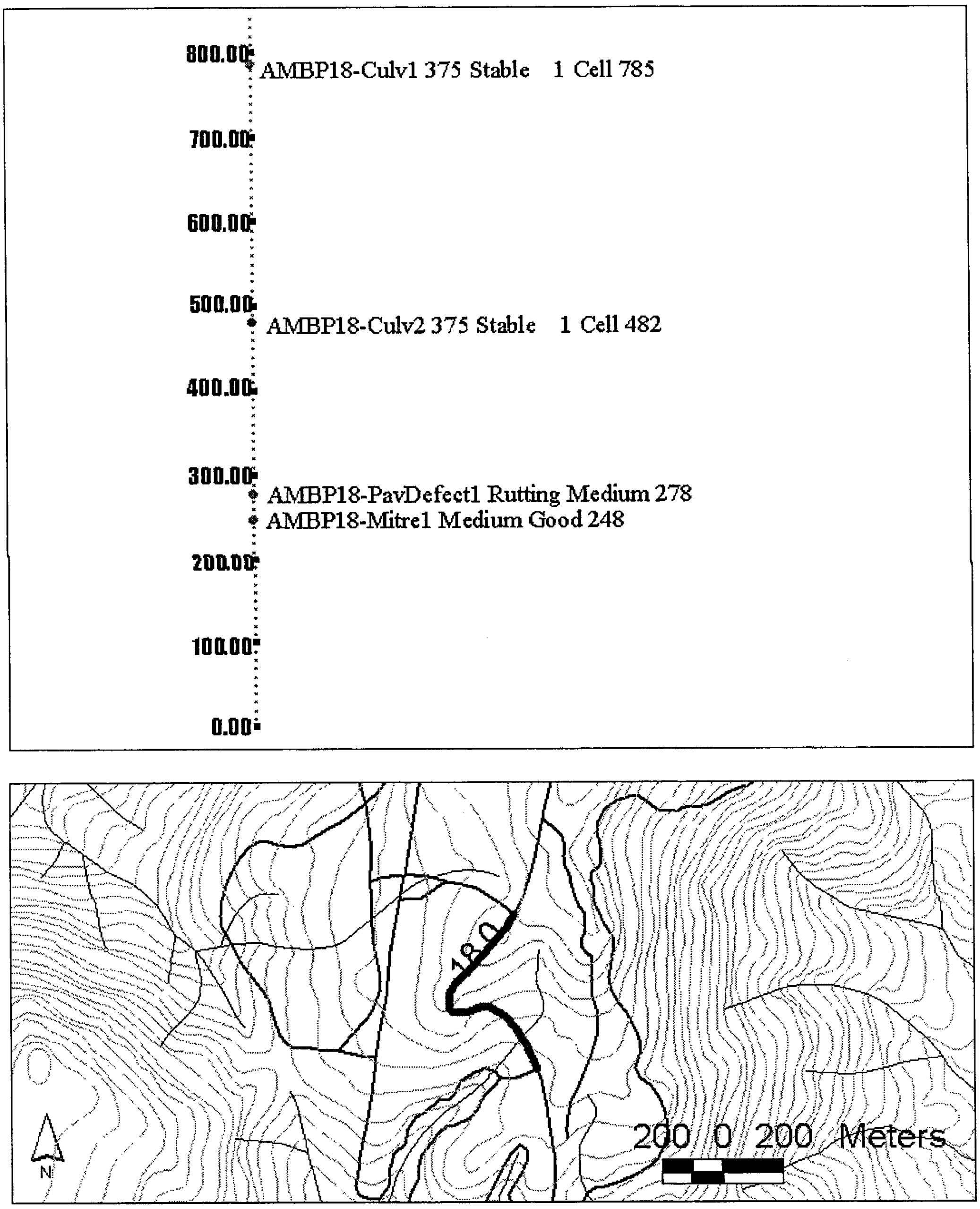
Strip maps are used by road managers to display where points of interest occur along the road. The road section is represented as a scaled down straight line and features are marked along the line proportionally to their distance along the actual road. Strip maps were chosen as one form of road condition report (Figure 3.12).

It is envisaged the strip maps would form the hard copy of the information stored in the Forest Road Management System and that they would be used for routine management of forest roads, similar to the way compartment histories are used for silvicultural management.

Figure 3.11 The Forest Road Management System at Completion of Data Addition

Figure 3.12 Example of a Strip Map Road Segment Condition Report (the number at the end of each road feature description is the distance of the feature along the road segment)

Road 18.0 , Pound Ridge Road



3.7.2 Condition Report and Reassessment Form

Prior to strip map production, the distance along the road at which each feature occurred was automatically calculated using ArcView functions. This information can be copied from the ArcView GIS theme table dBase files into the Microsoft Access® database program, which is then used to design a condition report. The reassessment form is simply a condition report with spaces provided below each item to allow updating in the field. An example is shown in Figure 3.13.

Figure 3.13 Reassessment Form designed in Microsoft Access®

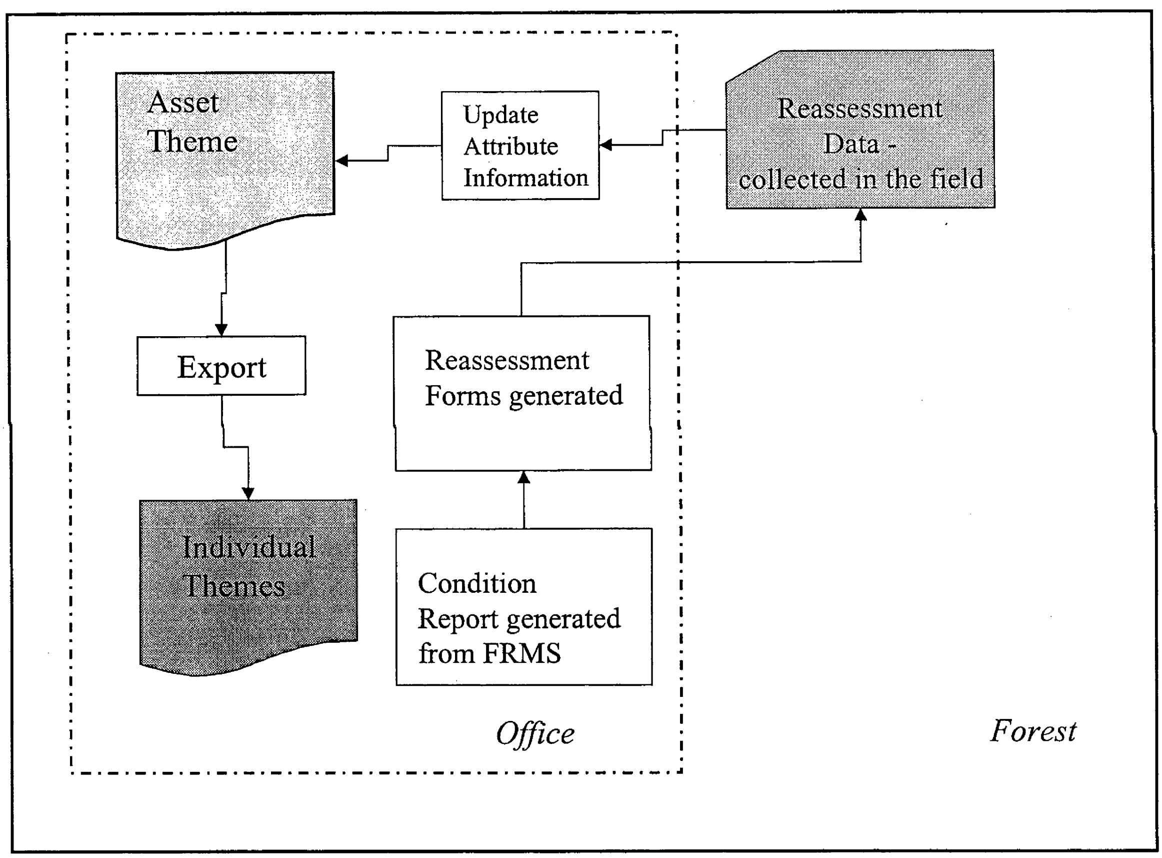
DISTANCE ON ROAD (m)	LAST INSEPCTED (YYYMMDD)	FEATURE TYPE	ATTRI-BUTE 1	ATTRI-BUTE 2	ATTRI-BUTE 3	ATTRI-BUTE 4	ATTRI-BUTE 5	ATTRI-BUTE 6	ATTRI-BUTE 7	ATTRI-BUTE 8
1790	19980722	Turnaround	Circular	Gravel						
		COMMENTS:								
Back Nacki Creek Road										
475	19980723	Culvert	375	Blocked	None	None	None	None	None	1
		COMMENTS:								
505	19980723	Culvert	375	Blocked	None	None	None	None	Inlet Eroding	1
		COMMENTS:								
570	19980723	Culvert	375	Stable	None	Sump Req.	None	None	None	1
		COMMENTS:								

FOREST: Green Hills, No. 657 **This Condition Report Printed on:** Monday, 26 October 1998 Page 14 of 106

3.7.3 Database Maintenance

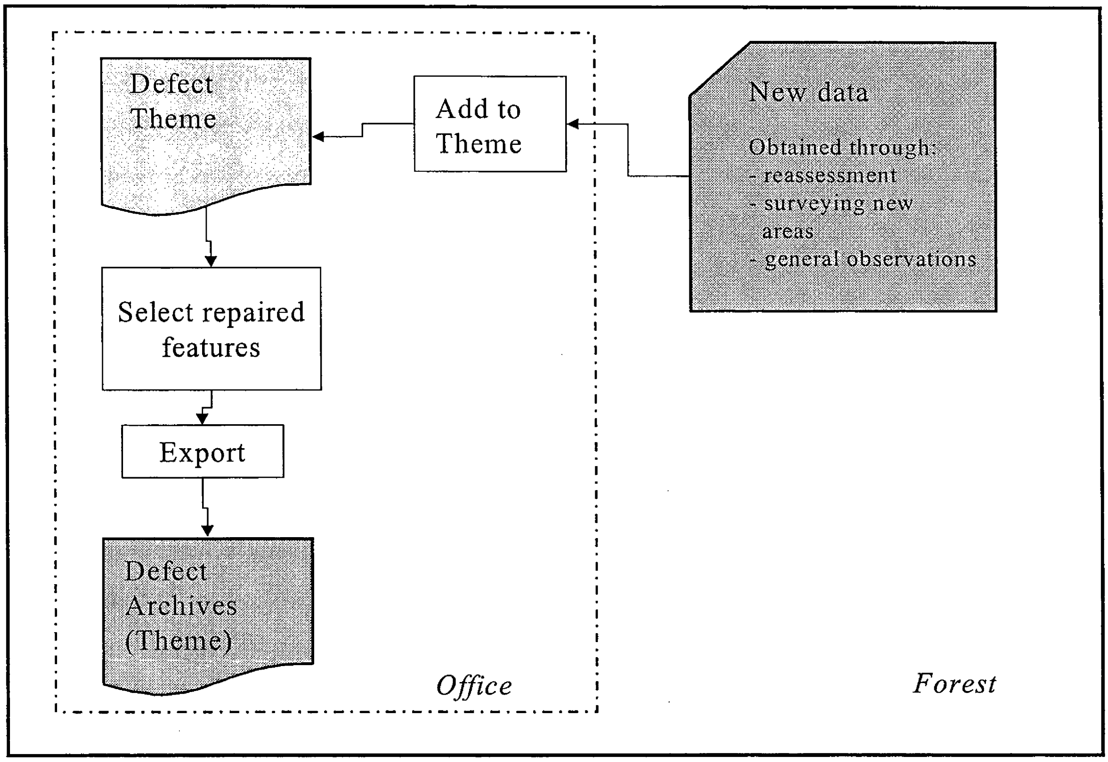
Road features should be re-visited on a regular, systematic basis. Each road feature should be appraised to check that the actual condition of the feature matches that shown in the FRMS, using the reassessment form described in Section 3.7.2. This process is illustrated by a flowchart (Figure 3.14).

Figure 3.14 Flowchart Illustrating the Procedure for Updating Asset Condition Information



Road defects are usually eliminated by maintenance operations as time and resources allow. The FRMS database needs to reflect this and defects should be removed from the current data set once they have been repaired. Rather than discarding them completely, information on repaired defects should be transferred to a historical data set that can be used to identify ongoing problems. A flowchart, illustrating this process is shown in Figure 3.15.

Figure 3.15 Flowchart Illustrating the Procedure for Updating Defect Information



Information about newly upgraded, constructed or gravelled roads must also be added to the GIS roads data. At the same time, costs associated with these operations should be added to the road themes table in the FRMS. A clerical procedure needs to be implemented to ensure the database is kept up to date.

3.8 CONCLUSION

The major objectives of this section of the study were to develop a Forest Road Management System (FRMS) and techniques to be used for the ongoing updating of data used by the system. The FRMS was designed around ArcView GIS with a GPS and data logger being used as the primary means of acquiring data for it. Another data collection system, based on paper forms was also developed for situations where GPS is unavailable.

Some of the tasks required to establish and maintain the FRMS are repetitive and/or time consuming. However, the requisite processes were identified and further development by computer programming specialists would allow significant gains in operational efficiency.

4 ADDING ROAD USER COST TO THE SYSTEM

Chapter objectives:

1. ***Introduce concept of log truck travel time as representing 'road user cost' in a forest road management system***
2. ***Describe a preliminary investigation into the potential of tracking log trucks with GPS with the view to extracting travel time data***
3. ***Describe the establishment of a travel time map in ArcView GIS that estimates log truck travel times based on a sample of measured times***

4.1 INTRODUCTION

A number of existing road management systems can accommodate expressions of road user cost (Haas *et al.*, 1994). User cost can provide a measure of road performance, and the most common expression of road user cost is travel time. Road users generally of most interest to the forest road manager are log hauliers. Travel time is the single most important factor influencing log hauling costs (Shaw, 1974; Massey-Reed, 1978; Pearn, 1983; Groves *et al.*, 1987). Log truck travel speed can also be used as an indicator of forest road performance. Slow travel speeds may indicate inefficient or substandard sections within the road network.

The interest in obtaining log truck travel times, within the context of this study, is to provide information on road user cost that could be stored and queried within the FRMS. The FRMS could then support the planning of optimal log haulage routes on both harvest unit and regional network scales. This component of FRMS development occurred as part of a larger study into the logistics of timber haulage in East Gippsland (Victoria).

Timber haulage in this region includes:

- Haulage of sawlogs to a number of different sawmills located along the Princes Highway
- Haulage of pulpwood to the Harris-Daishowa mill, near Eden, New South Wales
- Haulage of chip from sawmills in East Gippsland to the Harris-Daishowa mill

East Gippsland provides a good example of the potential application of the FRMS. The need for rationalising the wood flow in this region has been identified by (Waugh, 1996) during a study of new wood processing opportunities. Information on log truck travel times across the regional network is needed before rationalisation can occur.

Methods previously used by researchers to collect log truck travel times are described and compared in Table 4.1. Of the methods described, stopwatch studies generally provide the highest quality information but are time-consuming to conduct.

GPS might also provide a solution for collecting travel time information for the FRMS by allowing automated recording of log truck movements. This technique is already in use on a commercial basis for monitoring log haulage in Canada and is likely to be adopted in other countries in the near future (Steve, 1994).

Table 4.1 Description and Comparison of Log Truck Travel Time Collection Methods

METHOD	ADVANTAGES	DISADVANTAGES	SOURCE
Car following truck	• Data of high quality	• Labour intensive and costly	• Used by Pearn, 1983
Vibrorecorders	• Can collect large amounts of data • Doesn't require researcher to travel in truck	• Mechanically unreliable • High initial cost	• Used by McCormack, 1983
Tachographs	• Data of high quality • Reliable • Doesn't require researcher to travel in truck	• Tachographs require specialist fitting • High initial cost	• Used by McCormack, 1983
Two People Stationed at Each End of a Road Section	• Should yield high quality data	• Labour intensive and costly	• Discussed by Pearn, 1983
Truck Driver Records Times	• Cheap • Doesn't require researcher to travel in truck	• Difficult / Dangerous for truck driver • Yields poor results (Shaw (1974) used this technique and found only 1 in 13 drivers returned data of any use)	• Discussed by Pearn, 1983 • Used by Ada, 1979 • Used by Shaw, 1974
Have Truck Driver report position on radio as certain landmarks (eg. leaves highway, arrives at mill etc.)	• Doesn't require researcher to travel in truck	• Drivers often forget to report in • Doesn't provide information about individual road segments • Other radio traffic cuts over report	• Used by Pearn, 1983
Weighbridge Docket Analysis	• Large amounts of data can be collected in short time frame	• Doesn't provide information about individual road segments, delays, abnormalities (ie. Trip characteristics)	• Used by Winter, 1995 • Used by McCormack, 1983 • Used by Ada, 1979
Truck Passenger Study (Stopwatch)	• Should yield high quality data • Reasons for delays or abnormalities are known to researcher	• Labour intensive • Presence of researcher may alter driver behaviour	• Used by Pearn, 1983

4.2 GPS Evaluation

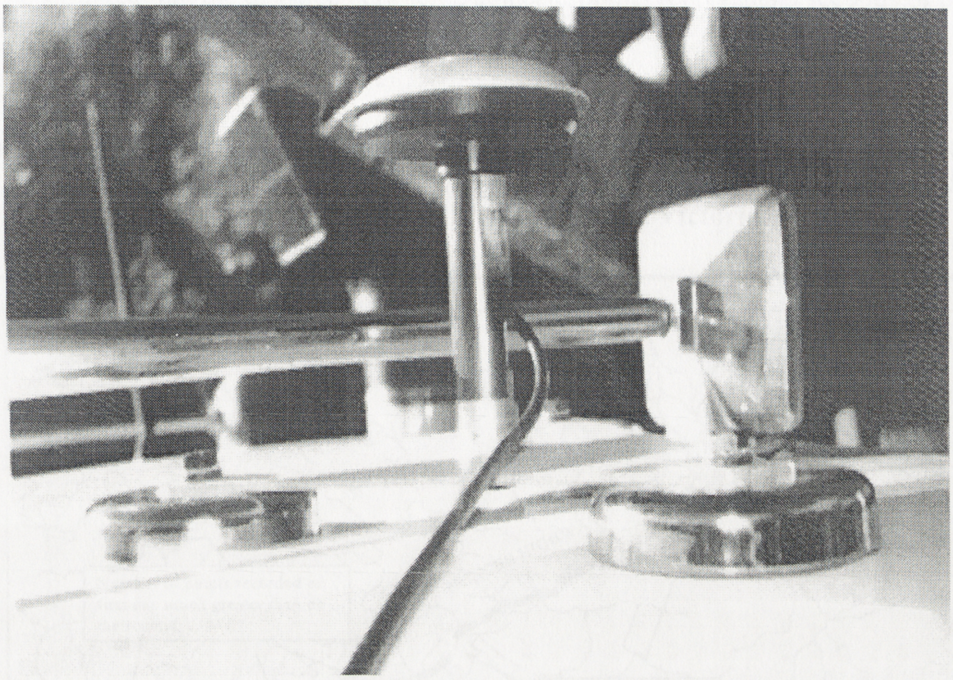
Two Sokkia GPS rover units (described in Chapter 3) were used in the evaluation. Twenty-four trips were tracked using the GPS units between 8/9/97 to 16/9/97 and between 28/9/97 to 3/10/97. These trips included hauls of sawlogs and pulpwood as well as chip being carted from mills in the Orbost area to the HDA chipmill south of Eden (NSW). The GPS units were installed in the trucks each day (Figure 4.1) and removed at night to download recorded data and recharge the battery.

Fitting the GPS units to trucks, to a stage where they were actually recording, took around 10 minutes. A large plastic carry case, holding most of the components, was usually stowed between the driver and passenger seats or in the passenger side footwell.

The GPS receiver was initially set to record truck position every 30 seconds. It was discovered that the GPS had trouble locating enough satellite signals to record its position when the truck was on a road which had a large proportion of tree cover overhead or immediately adjacent. Recording interval was decreased to 5 seconds in order to increase the number of positions recorded by the GPS on such roads. This improved the chance of the GPS recording a position when it came into a clearer section of road. Decreasing the recording interval further was not possible because it would have overextended the data logger's memory during the course of a full days recording.

A drawback in using GPS to track log trucks was that they needed to receive signals from at least four satellites before they could be set to start recording and this process took up to 30 minutes. The opportunity to record complete trips was lost on several occasions due to the driver not being able to wait for the unit to acquire enough satellites to commence recording.

Figure 4.1 GPS aerial and magnetic mount on log truck roof

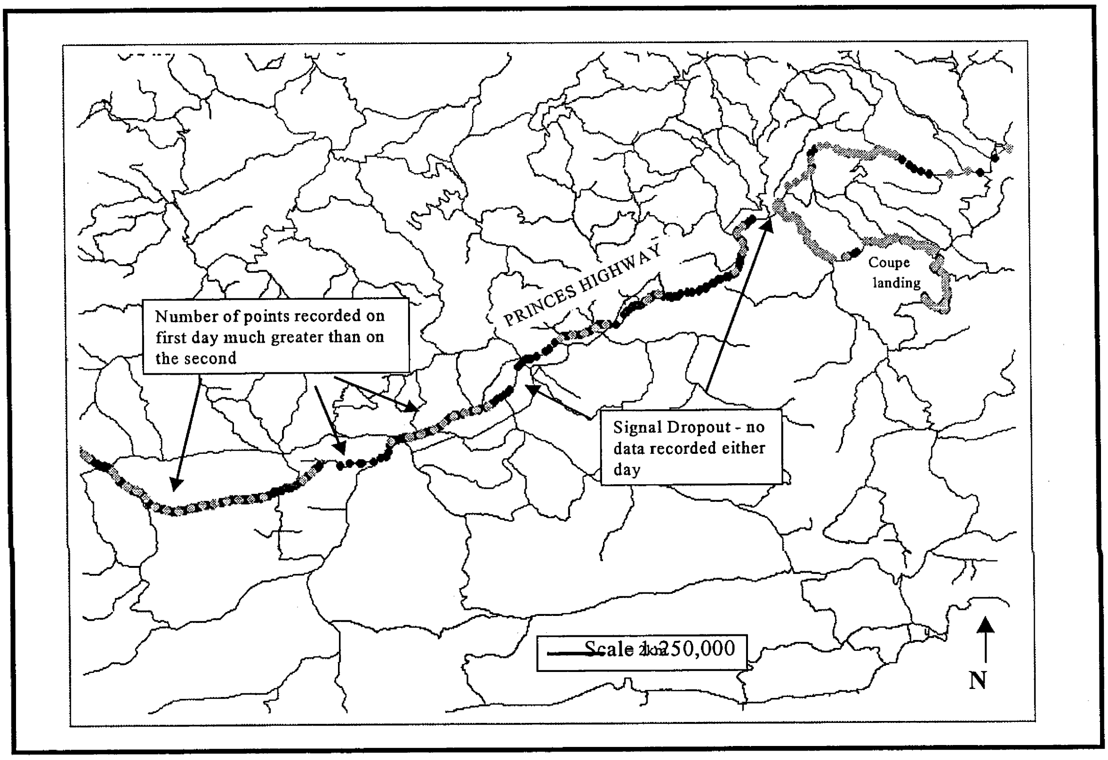


4.2.1 GPS Data Collection Results

Figure 4.2 illustrates the variability in the amount of data recorded between days. The lighter coloured points were recorded on the 9/9/97 and the darker points were recorded over the same route on the following day (10/9/97). Both days data were recorded using the same truck undertaking a similar work cycle (two loads of chiplogs to the Harris-Daishowa mill and one load of sawlogs to the Smith Bros. Mill at Brodribb River). The increase of the 'coverage' on the second day can be attributed to more favourable satellite geometry. However, it can be seen that there are certain locations for which data wasn't collected on either day. This is most likely due to features adjacent to the road blocking satellite signals. Features such as high road cuttings or dense vegetative growth on the road verge can cause such blockage.

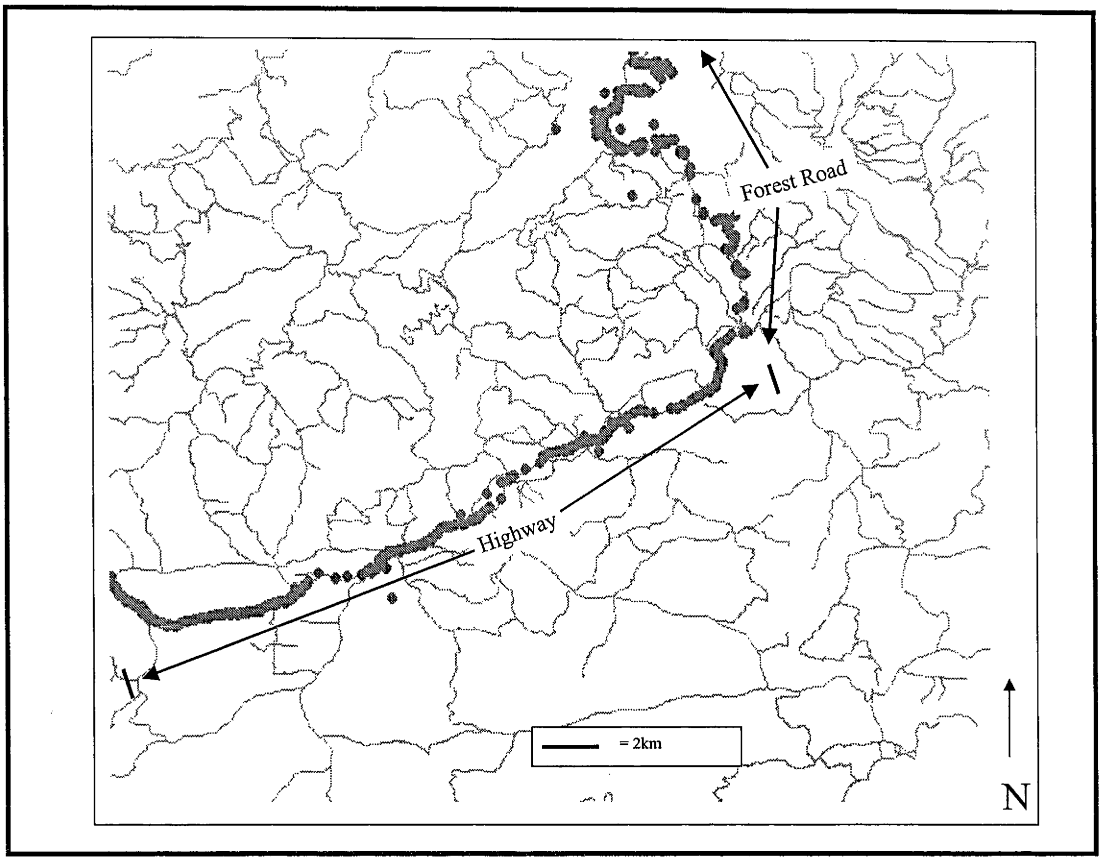
The GPS was set to record truck location every 5 seconds, however, if satellite signals were insufficient, the GPS would be delayed until enough signals were available. This means that it cannot be assumed that the distance between 2 adjacent points represents 5 seconds of truck travel.

Figure 4.2 Comparison of 2 days data showing difference in the number of points collected. Data recorded 9th & 10th September, 1997. Princes Highway and Poddy Creek Forest Road, East Gippsland, Victoria.



Differential processing is required where accuracy of one to five metres must be achieved, however, this level of accuracy is not required for log truck tracking and uncorrected signals (30-100m accuracy) may be acceptable. Figure 4.3 shows non-differentially (ie. corrections for errors affecting accuracy have not been applied to these data) processed GPS data points located in the same area as those in Figure 4.2. It can be seen that the points recorded on the Princes Highway, which generally has cleared road verges, are comparable in accuracy to the differentially processed point in Figure 4.2 at the scale of the map. The only difference is the existence of several erroneous points in the non-differentially processed data.

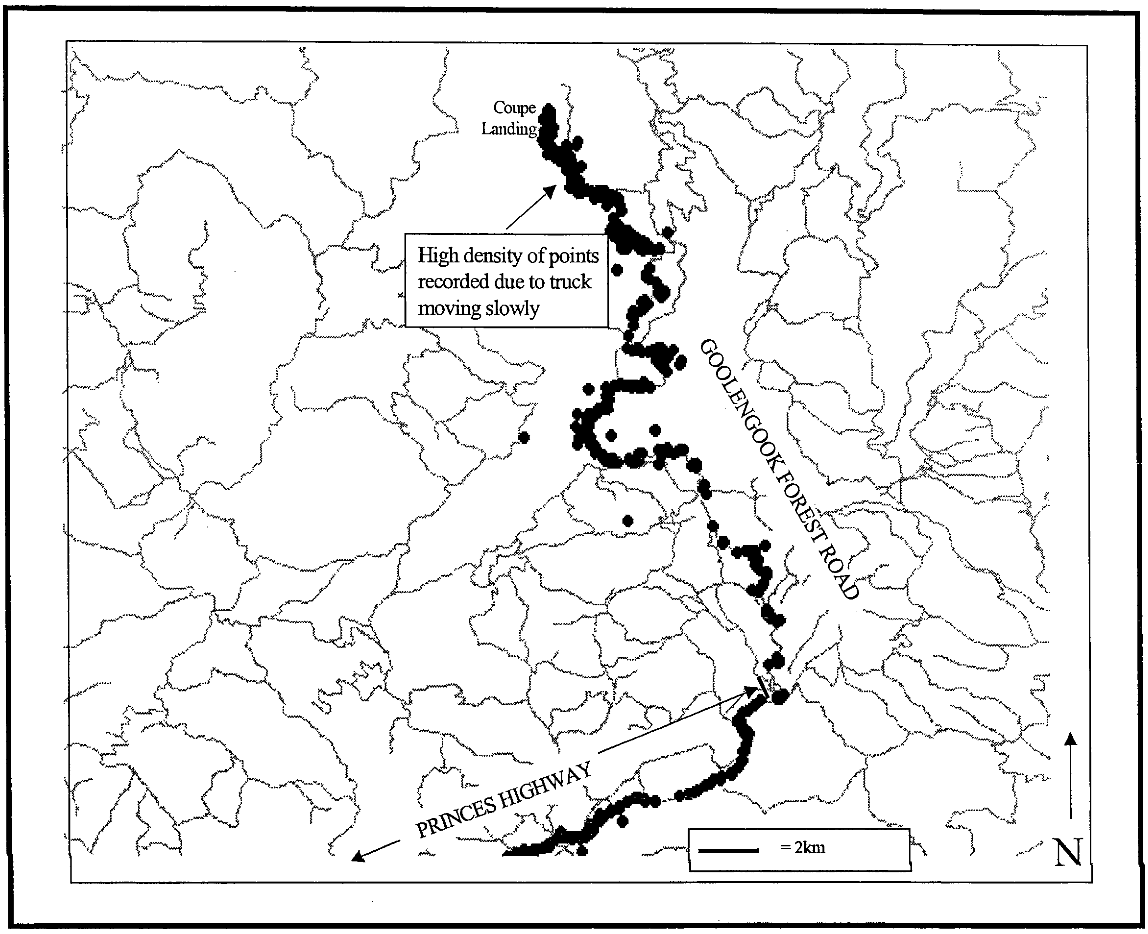
Figure 4.3 **Non-differentially processed data recorded 13/9/97. Princes Highway and Goolengook Road, East Gippsland, Victoria.**



The accuracy of the non-differentially processed points decreases on forest roads as illustrated in Figure 4.4. This drop in accuracy is almost certainly due to the forest vegetation growing directly adjacent to the roadside interfering with satellite signals.

The conclusion to be drawn from this comparison is that for some uses, going to the expense of differential processing must be questioned. Collection of some data (eg. absolute trip time, time spent at the landing or time spent at the mill) may not require differential processing.

Figure 4.4 Non-differentially processed data recorded on Goolengook Forest Road, East Gippsland, Victoria, 13/9/97.



4.2.2 Extracting Travel Times from the GPS data

Most GPS units record the time at which each point's location was recorded. This function is known as a 'time-stamp'. The Sokkia GPS equipment used in this study does this but the associated software wasn't designed to redisplay this information for analysis. This meant that actual travel time data could not be extracted from the GPS data. For the purposes of the study, dummy time-stamps were added in order to determine whether travel times for individual road segments could be extracted from the GPS data.

The data were imported into ArcView. GPS points that represented non-travel time spent by the truck (eg. time spent loading) were easily identified and selected in the GIS and were tagged either: "Mill" or "Coupe". Groups of points recorded after a mill visit were labelled as "Travel Out" (ie. Unloaded) and points recorded after a group of "Coupe" points were labelled "Travel In" (ie. Loaded). Points labelled as "Travel In" or "Travel Out" were then linked to their nearest intersection. Travel points located within 10 m of an intersection were also labeled "Intersection". These data were then exported to Microsoft Excel and a series of logical operators were used to identify legitimate road segment travel times.

The travel time extraction process highlighted a major problem with using GPS data to derive truck travel times for individual road segments (some of which may be only several hundred metres in length). A travel time can only be calculated for a segment if the GPS recorded a location close to the start and end points of the segment. Due to satellite signal blockage by forest canopy and also to chance effects, there is a probability that this condition will not be met for a proportion of road segments on any given trip. On the trip analysed, GPS points were recorded on 252 individual road segments but only 73 of these segments yielded legitimate travel times.

4.2.3 GPS Trial Outcome

GPS was found to perform adequately in tracking log truck movements though, without the development of specialist software, it relies on the analyst having knowledge of regional truck movements and requires individual processing for each trip. With time-stamping capabilities and automation of data processing, the units used in the study could provide excellent information on travel times for major sections of the road network as well as providing information on time spent by trucks at the landing and in the mill yard. However, further development is required in order to use these units to obtain log truck travel times for individual road segments for use within the FRMS.

The low yield rate of segment travel times suggests an alternative approach. A more practicable method may be to divide the GIS regional road network representation into reasonably homogeneous management sections of approximately 5 kilometre lengths. The GPS data could then be used to determine travel times for these sections which would then be split proportionally amongst the individual road segments comprising the management section.

There are a number of GPS transport applications, indicating that it will play an important role in forest transport management. Examples include the Canadian TRUCKBASE system described by Steve (1994), or the GPS being developed in Australia by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) described by McCormack and Winter (1998). The TRUCKBASE GPS is manufactured specifically for use in log trucks while the CSIRO GPS is being developed as a dedicated tracking device for forest machinery.

4.3 STOPWATCH STUDY

Travel times were also collected using passenger stopwatch studies. Data collected using this method were used to demonstrate the additions of travel times to the FRMS. Stopwatch data collection took place between 8/9/97 to 16/9/97 and between 28/9/97 to 3/10/97. Thirty-one trips were recorded on a range of truck configurations carting both chiplogs and sawlogs. Trips were chosen to cover most of the major roads within the haulage area including the Princes Highway (from Nowa Nowa, Victoria to the Harris-Daishowa chipmill at Eden, NSW), Bonang Road, Combienbar Road, Buchan/Bruthen Road and major forest roads of the Goolengook, Murangowar, Poddy Creek, Kuark, Curlip and Colquhoun areas.

4.3.1 Stopwatch Collection of Log Truck Travel Times

Collection of log truck travel times with a stopwatch involved:

- Starting the stopwatch as truck started moving
- Recording the time shown by the stopwatch (to the nearest second) as the truck passed each intersection or turned from one road onto another. Time of intersection passing was measured when the front of the truck reached the middle of the intersection.
- Noting the time shown on the stopwatch upon arrival at the destination

4.3.2 Adding Stopwatch Data to the GIS

The stopwatch times were processed and the average loaded and unloaded travel time was calculated for each segment for which at least one travel time was collected. The average travel time data were then added to the GIS database as a proposed added component of the FRMS. At this stage average travel time data were available for approximately 500 road segments in the region. The GIS representation of the East Gippsland road network contains around 10,000 segments (although at least half of these represent roads not used for log haulage). To be fully useful to road and transport managers, travel time estimates would be needed for all haulage segments. The approach used by Winter (1995) was to apply a speed-gradient relationship, previously developed for log trucks, to a GIS representation of a regional haulage network in order to estimate travel times for routes that hadn't had actual travel time data recorded.

Therefore, the next step was to try and determine the relationship between the measured segment travel times and data already stored in the GIS about the segments and their terrain. This relationship could then be applied across the region to estimate travel times for every road segment.

The road network theme contained the following pertinent segment data:

- Segment length
- Road Name (not available for every segment)
- Road Class

The road classification system used in the Victorian Department of Natural Resources and Environment (DNRE) theme was based on Australian Standard AS2482 (Standards Australia, 1989). The classes are summarised in Table 4.2.

Table 4.2 East Gippsland Road Classification System (DNRE)

AS2482 ROAD CLASS NO.	DESCRIPTION	COMMENTS
2003	Highway sealed	
2004	Highway unsealed	Only one segment likely to be used by Log Trucks
2005	Major road sealed	
2006	Major road unsealed	
2013	Vehicular track	Only four segments likely to be used by log trucks
2016	Other road sealed	No segments likely to be used by log trucks
2017	Other road unsealed	
2034	Walking track	Not used by log trucks
2501	Other track	

4.3.3 Calculating Relationship Between Road Class, Gradient and Travel Speed

Terrain information was available from themes (also supplied by DNRE) for the contours, streams and lakes of the region. This enabled a digital elevation model (DEM) of the entire East Gippsland Region to be constructed in order to obtain road gradient values. The DEM was made using the

ANUDEM program (Version 4.5) (Hutchinson, 1997). ANUDEM uses GIS contour and stream/lake data to determine a gridded surface for a landscape. The grid values are elevations in metres.

The road network theme was overlaid onto the DEM and the maximum and minimum elevations for each road segment were obtained. Segment gradient values were produced by dividing the elevation range of each road segment by length.

The majority of the travel times were collected for road classes 2003, 2005, 2006, 2013 and 2017. Linear regression was performed on the segment gradient and average travel speeds for each of these road classes. The results are shown in Table 4.3.

Table 4.3 Results of Regression Showing Correlation Between Gradient Statistics and Segment Travel Speeds

AS2482 ROAD CLASS NO.	R^2-Loaded	R^2-Unloaded
2003	0.003271	0.005823
2005	0.003817	0.019972
2006	0.136029	0.043017
2013	0.008083	0.000585
2017	0.245002	0.193487

These results indicate that only a very slight correlation exists between the gradient statistic and travel speed. The most likely explanation for this is that other factors such as sight distance and road surface properties are exerting strong influences on truck speed.

This process was repeated using a terrain statistic in place of the gradient statistic. The terrain statistic was obtained through the use of the ArcView Spatial Analyst Extension. This was used to derive a new grid from the DEM with each cell value in the grid equaling slope in degrees. The average cross slope for each segment was used as the terrain gradient statistic. It was thought that this could provide a better correlation with travel speed as many cross-slope road segments located in steeper terrain have low gradients but winding horizontal alignments imposed by the topography, that should have a limiting effect on truck travel speed. However, the regression analysis between the terrain gradient statistic and travel speed returned very similar results to the road gradient analysis.

These results indicate that a simple travel time model is unlikely to be developed and more complex approaches such as that of McCormack (1990) will be needed. For the purpose of demonstration, it was decided to model travel across the network on the basis of road class.

Average speeds were calculated from the stopwatch data for both loaded and unloaded trucks for each of four road classes:

1. Sealed Highway (AS2482 road class 2003)
2. Unsealed highway or major sealed road (AS2482 road classes 2004, 2005)
3. Major unsealed road (AS2482 road class 2006)
4. Other unsealed roads (AS2482 road classes 2013, 2017, and 2501)

The average speeds determined for each of these road classes are presented in Table 4.4. Segments of classes not used by log trucks were assigned null travel speeds.

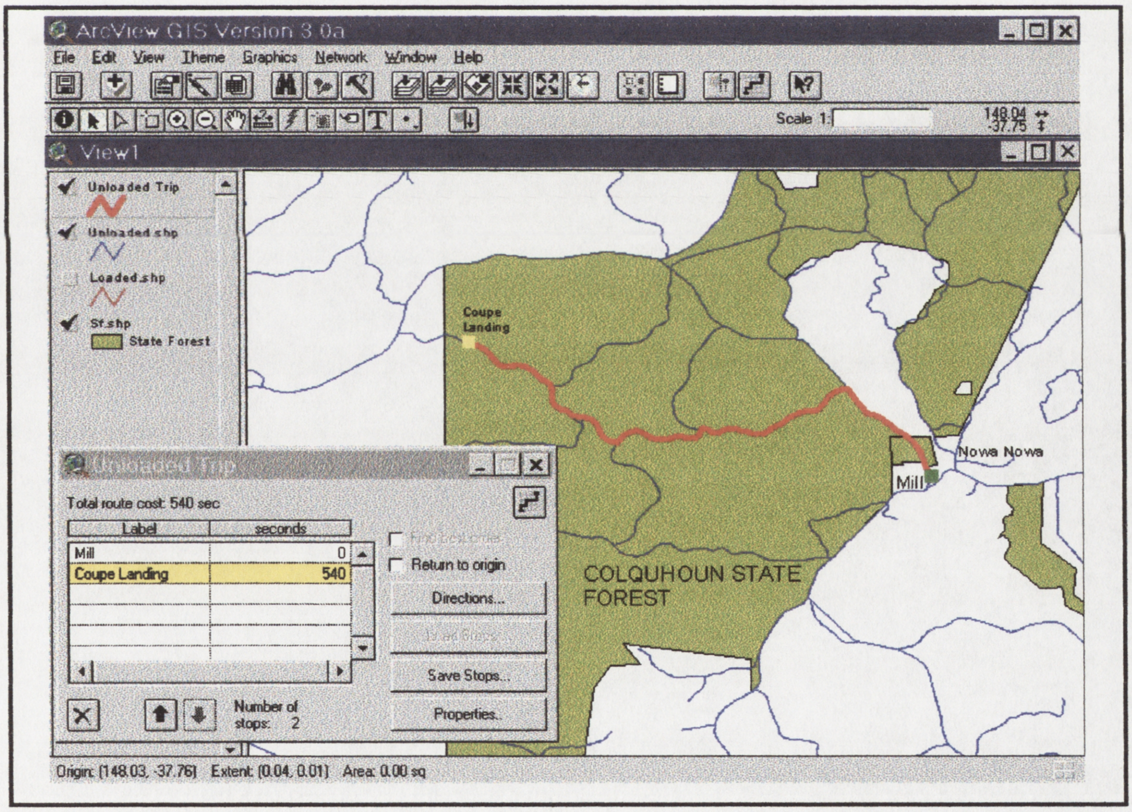
Table 4.4 Average Speeds for each Road Class in East Gippsland, Victoria. Based on Stopwatch Study, September and October, 1997.

ROAD CLASS	UNLOADED (km/h)	LOADED (km/h)
2003	85.5	77.9
2004, 2005	73.4	62.1
2006	51.4	45.0
2013, 2017, 2501	48.5	34.7

4.3.4 GIS Travel Time Map

Road class travel speeds were applied to all segments in the regional FRMS. This allowed the development of a trip time function using Network Analyst™ (an extension to ArcView GIS that allows the user to solve network algorithms). Incorporation of this extension allows the user to specify departure and destination points as well as any stops to be made along the way. The user is also prompted to select a cost for the trip. In this case, the cost selected is travel time (in seconds) for either a loaded or unloaded trip. The least cost route is then calculated and highlighted and the associated cost (total travel time) is returned (Figure 4.5).

Figure 4.5 Example of Log Truck Travel Time Map Query



4.3.5 Comparison of Estimated Trip Times With Actual Trip Times

Some examples of actual trip times are compared with estimates generated using the GIS travel time map in tables 4.5 (Unloaded) and 4.6 (Loaded). It can been seen that average speed can be used to provide a reasonable estimate for trip time. It should be noted that the trips used for the comparison provided data used in the formulation GIS travel time map.

Table 4.5 Comparison of actual times for two unloaded trips with estimates made using GIS travel time map

TRIP DETAILS	UNLOADED		COMPARISON
	GIS	ACTUAL	
Waygara Mill – Legge Road.		**NPK-697 30/9/97**	
Mill	0 secs	0 secs	
Princes Highway	140 secs	153 secs	
Orbost	778 secs	831 secs	
Legge Road	5752 secs	5653 secs	97.93%
Smith Bros Brodribb River Mill – Poddy Creek		**NIX-409 12/9/97**	
Mill	0 secs	0 secs	
Poddy Creek Rd	1610 secs	1411 secs	
Dinah Divide Tk	1875 secs	1814 secs	
Coupe Rd	2517 secs	2400 secs	95.35%

Table 4.6 Comparison of actual times for two loaded trips with estimates made using GIS travel time map

TRIP DETAILS	LOADED		COMPARISON
	GIS	ACTUAL	
Waygara Mill – Legge Road.		**NPK-697 30/9/97**	
Legge Road	0 secs	0 secs	
Orbost	5781 secs	5431 secs	
Waygara Rd	6475 secs	6105 secs	
Mill	6658 secs	6237 secs	93.67%
Smith Bros Brodribb River Mill – Poddy Creek		**NIX-409 12/9/97**	
Coupe Rd	0 secs	0 secs	
Dinah Divide Tk	897 secs	705 secs	
Poddy Creek Rd	1268 secs	1222 secs	
Mill	3039 secs	3071 secs	101.05%

4.3.6 Stopwatch Study Outcome

The major disadvantage with using stopwatch studies to provide log truck travel times is that they area time and labour intensive. However, this study demonstrated that a reasonable coverage of the East Gippsland regional haulage network could be obtained within a short space of time. This suggests that if stopwatch data collection is used to provide user costs for the FRMS, its use must be concentrated on the major haulage roads within the region, as the data for these might be collected quickly. Travel time estimates for the low standard roads that form the end of network 'branches' may best be estimated using the data provided in Table 4.4.

4.4 Conclusion

Two methods for collecting log truck travel times were trialled. Data collected by truck passengers using stopwatches were added to the FRMS where it was demonstrated that estimated travel times could be automatically returned for loaded and unloaded trips throughout a regional road network. Software limitations prevented trip data recorded using Global Positioning Systems (GPS) to be added in this manner. However, the potential to do so was shown.

The next chapter demonstrates some potential applications of the FRMS to forest road and transport management. It includes some applications thatutilise road user cost in the form of log truck travel times.

5 APPLICATIONS OF THE SYSTEM

Chapter Objectives:

1. ***Demonstrate potential uses of the Forest Road Management System***

5.1 INTRODUCTION

The FRMS is structured within ArcView and the standard functions of this GIS program are available to the FRMS user. These functions include the production of maps at any scale, labelling data, selecting data with particular attributes and selecting data based on spatial relationships with other data. The standard ArcView functions can be used with the data stored in the FRMS to support a range of management tasks and some examples are described in this chapter.

A custom application developed for use in the FRMS is also described. This provides an example of how ArcView can be customised to cater for the specific needs of the FRMS user. The commercial ArcView extensions Network Analyst and Spatial Analyst can also greatly enhance the utility of the FRMS and some examples of functions that utilise these are also provided.

The examples described in this chapter are divided into three sections. The first section shows how the FRMS can be used in routine road management. The second describes some examples of transport management applications while the third section demonstrates how the FRMS can be used to support the analysis of specific road related environmental issues.

5.2 DAY TO DAY MANAGEMENT FUNCTIONS

An important consideration in the development of the FRMS was to provide management support for achieving both commercial and environmental objectives for forest roads. Several examples follow of how the FRMS could be used in routine management operations. They include functions that make road status reporting more efficient and identify potential cost savings during road works planning.

5.2.1 Custom Built Condition Report

The power of a database is reflected in the ease with which it can be queried. Figures 5.1 and 5.2 show a query module designed for use in the Forest Road Management System. It is an extension to ArcView and was developed using the Avenue programming language (the ArcView programming language). It automates the querying process to provide the user with a summary of road attributes and a listing of assets and defects for a selected road. This information can be obtained using standard ArcView functions, however it involves selecting each individual road feature theme in turn, a task both repetitive and time consuming.

This information can then be used to prioritise works or to budget for upcoming maintenance. A more sophisticated version of the condition report module could be developed that also reports the condition of the assets located along the selected road.

Figure 5.1 Condition Report Module within the Forest Road Management System

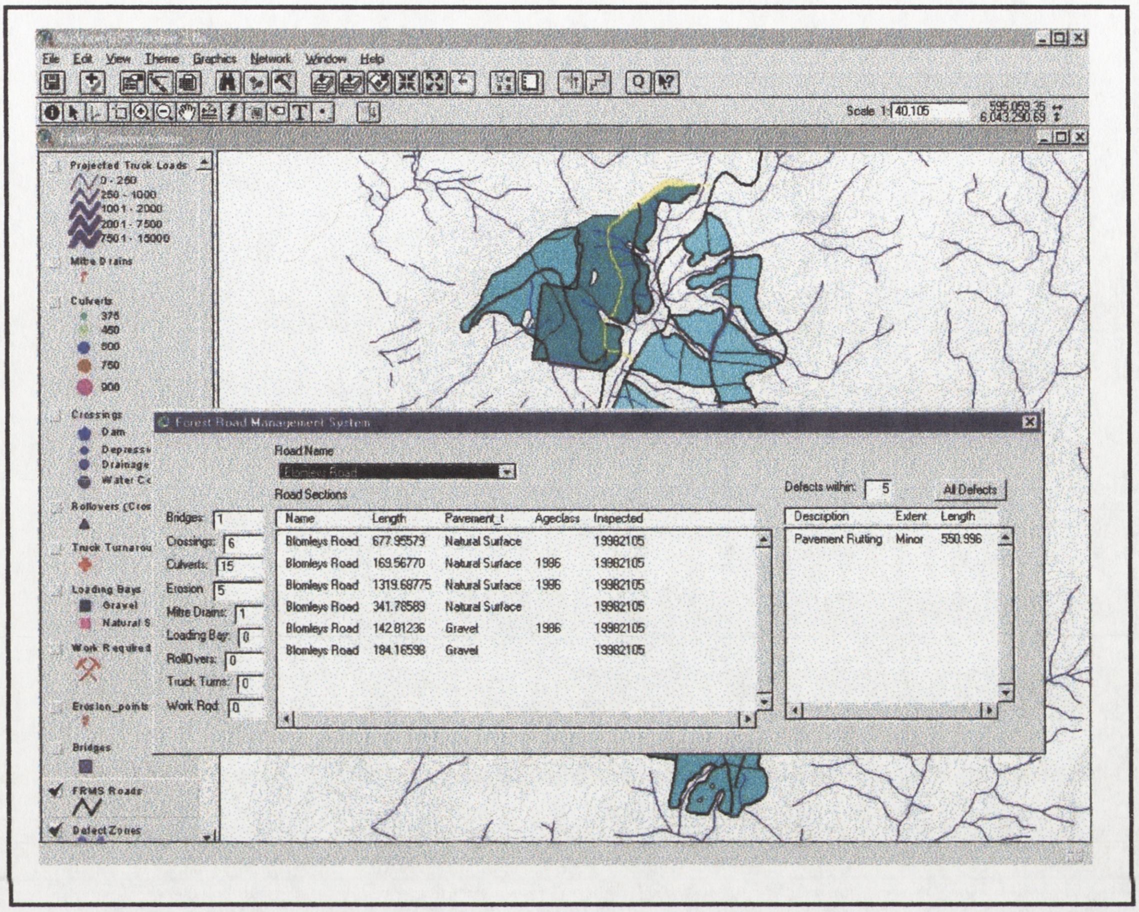
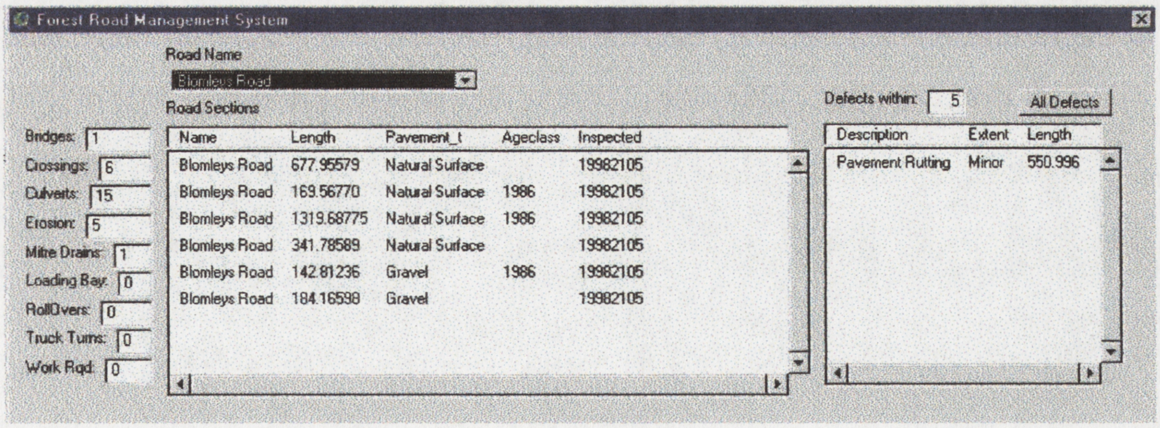


Figure 5.2 Close-up of Condition Report Module Display



In this example, 'Blomleys Road' has been selected using a pulldown menu that lists all the roads in the Pound Creek Forest area, and the following information has been displayed:

- Number of each type of feature i.e. 1 bridge, 6 crossings, 5 erosion points, 15 culverts, 1 mitre drain
- Information on the individual segments comprising Blomleys Road (length of each segment, pavement type, what plantation ageclass it serves and date of last inspection)
- Any defects occurring on the selected road are listed in the right hand section of the module – the module shows that approximately 550 metres of pavement rutting has occurred on Blomleys Road and that the extent is minor.

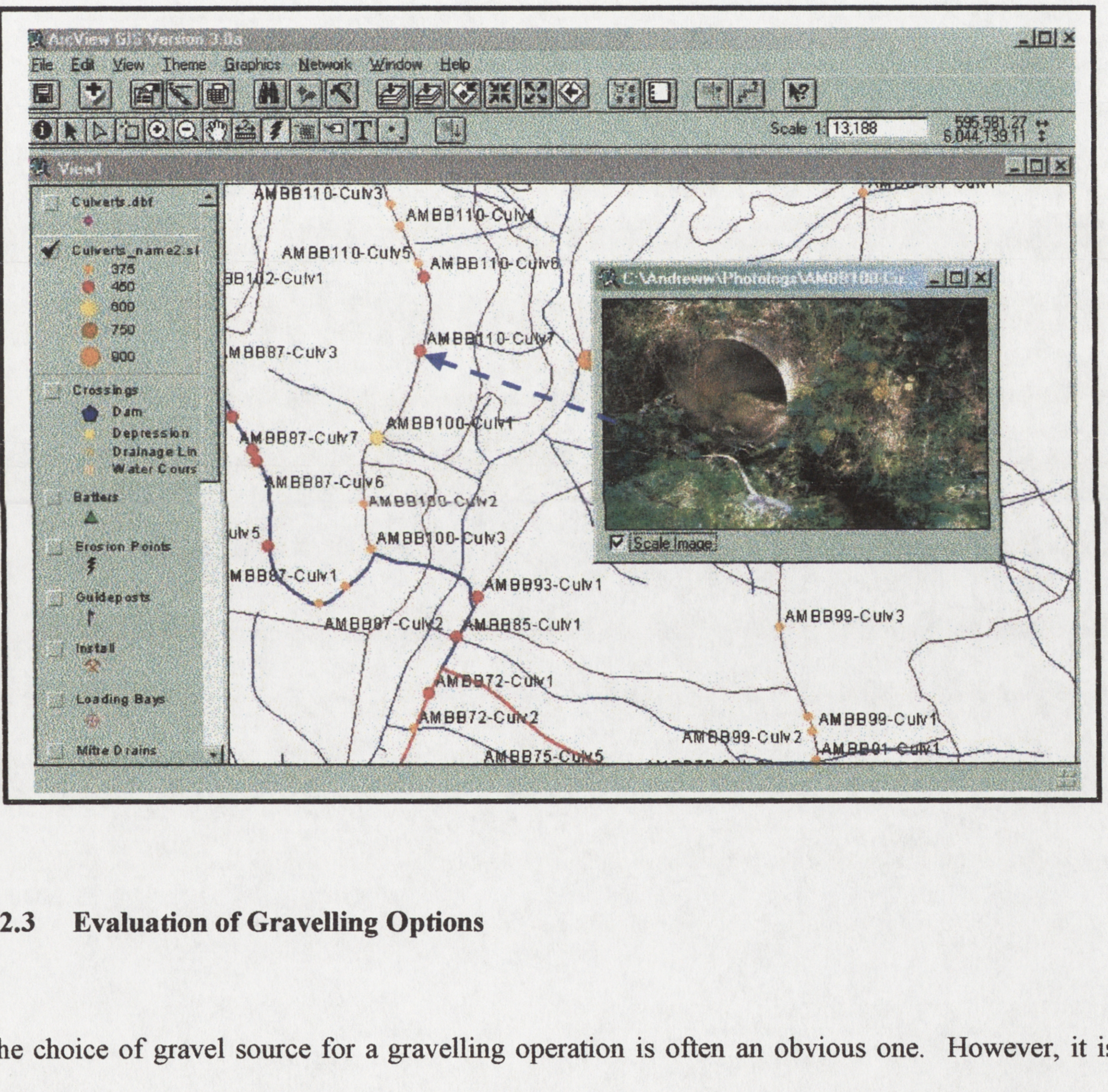
5.2.2 Photologs

A number of road management systems have the ability to display visual records of road features or sections (Ullidtz, 1985; Spear and Cottrill, 1993; CartéGraphe Systems, 1998). These records can either be a video clip or a photograph and are known as photologs.

The FRMS utilises the ArcView capability of 'hotlinking' a point in a view to aphotolog. A user can display a points image-file simply by selecting the 'hotlink' tool and clicking on or near the point. An example of a photolog is shown in Figure 5.3. In this case, the point theme is the culvert theme and the user has selected culvert number *AMBB100–Culv1*.

This illustrates another way that road condition data can be presented. Photographs of problem areas on the road network can be used to quickly convey information that would otherwise take much writing to describe. For example, photologs could be used to clearly illustrate to management why funding is required to fix a particular defect.

Figure 5.3 Example of a Photolog



5.2.3 Evaluation of Gravelling Options

The choice of gravel source for a gravelling operation is often an obvious one. However, it is also common to have to chose between several alternatives. For example, during the planning of the gravelling of logging roads in Pound Creek study area, in the summer of 1996/97, three quarries were evaluated (State Forests of NSW 1996a; State Forests of NSW 1996b). The decision is usually made on the basis of cost, given that the quarries / gravel pits being evaluated all provide material of reasonable quality.

Gravelling cost consists of three components:

1. Gravel Cost – This includes the cost of winning the gravel and any crushing costs. The calculation of the total gravel cost for a job is a simple one: Area to be gravelled × Desired depth × Gravel cost per m^3.
2. Cartage Cost – Usually involves a set rate plus a cost/km. Most contracts are calculated on the basis of the shortest practical route from the quarry or pit to the gravelling site.
3. Spreading Cost – This cost should be independent of gravel source, unless particularly hard gravel is being considered.

The cartage cost is generally the most difficult component to calculate. A procedure for calculating this component, utilising the functions of the Network Analyst extension to ArcView, was developed. The Roads and Traffic Authority's schedule of road haulage rates was expressed as an equation detailing cost per km. The set rate component of the rates schedule was ignored at this stage. This equation was used to add a gravel cartage cost field to the road theme's table. Any road section that had a quarry or gravel pit on it had the set rate component of the rate schedule added to its cost field as well. In this way, each road segment had an appropriate gravel cartage cost assigned to it and segments representing entrances to gravel quarries also had the set rate applied. The 'Find Best Route' function of Network Analyst can then used to find the shortest distance from gravel pit to job site by selecting the quarry location and the centroid of the job site. If the cartage cost field has been specified as the travel cost to be used by the 'Find Best Route' function, the gravel cartage cost per m^3 for that quarry or gravel pit will be returned automatically.

5.3 TRANSPORT MANAGEMENT APPLICATIONS

5.3.1 Projecting Road Use

The number of log trucks that will use a road segment can be determined if the following is known:

- Estimate of timber yield per unit area
- Average truck payload
- Area of forest served by road segment

An estimate of the total number of trucks that would use each segment of the Pound Creek forest road network over one rotation of the pine plantation was made. The Pound Creek area provides a relatively simple case study as all timber traffic flows in one direction. The first step was to identify segments that would actually be used for haulage. Then, the plantation areas served by each haulage segment were calculated.

The next step was to calculate how many truckloads would be provided per unit area. This process can be demonstrated by the following example in which it was assumed:

- B-doubles would be used to haul pulpwood
- B-double payload = 40 tons
- Trucks with Single Trailers (Skels) would be used to haul sawlogs
- Skel payload = 25 tons
- The yield for each operation would be as shown in Table 5.1 (Source - State Forests of NSW, 1996a; State Forests of NSW, 1996b)

Table 5.1 Yields by Harvesting Operation - Pound Creek Plantation, Bago State Forest

HARVESTING OPERATION	YIELD – PULPWOOD (tons/ha)	YIELD – SAWLOG (tons/ha)	TRUCKS – PULP (#/ha)	TRUCKS – SAWLOG (#/ha)
First Thinning	80	0	2	0
Second Thinning	45	55	1.125	2.2
Third Thining	15	65	0.375	2.6
Clearfall	20	220	0.5	10.4

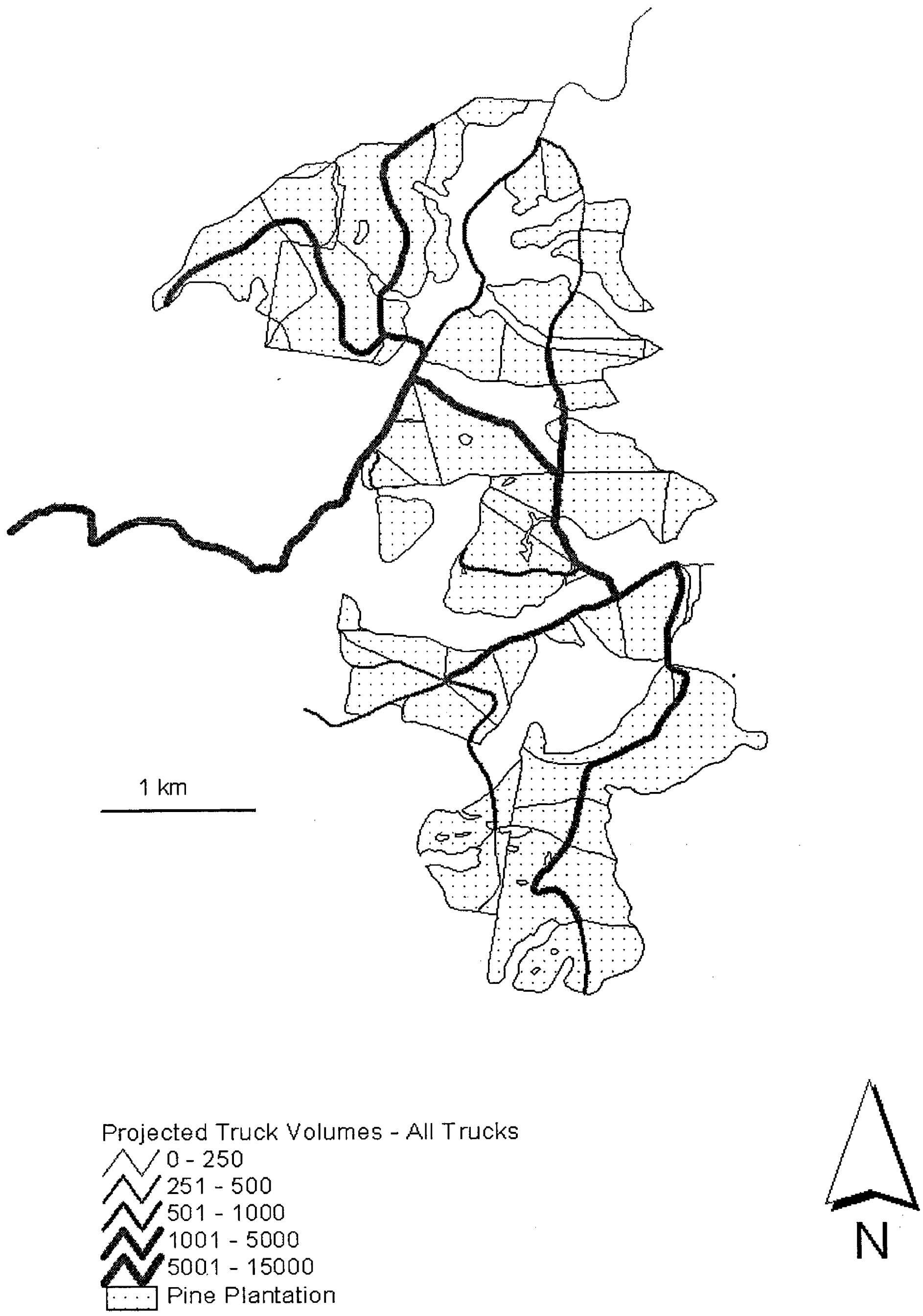
The number of contributing truckloads per segment was then calculated by:

Area served by segment (ha) × *(#. of B-doubles/ha + # Skels/ha)*

This was added as a field to the roads theme table. The cumulative number of loads was then calculated for each haulage segment, commencing at the extremities of the road network and working towards the point where the trucks exit the forest. This formed another field in the road themes table. Several of the more time consuming steps in this process, such as determining areas served by road segments and calculating cumulative load numbers have the potential to be automated by developing custom Avenue programs. This would need to occur before conducting this exercise on a large forest.

The result is shown in Figure 5.4. Projected log truck volume data are now available for use in road planning. One potential use is described in the next section.

Figure 5.4 **Projected Log Truck Loads for One Rotation - Pound Creek Area, Bago State Forest**

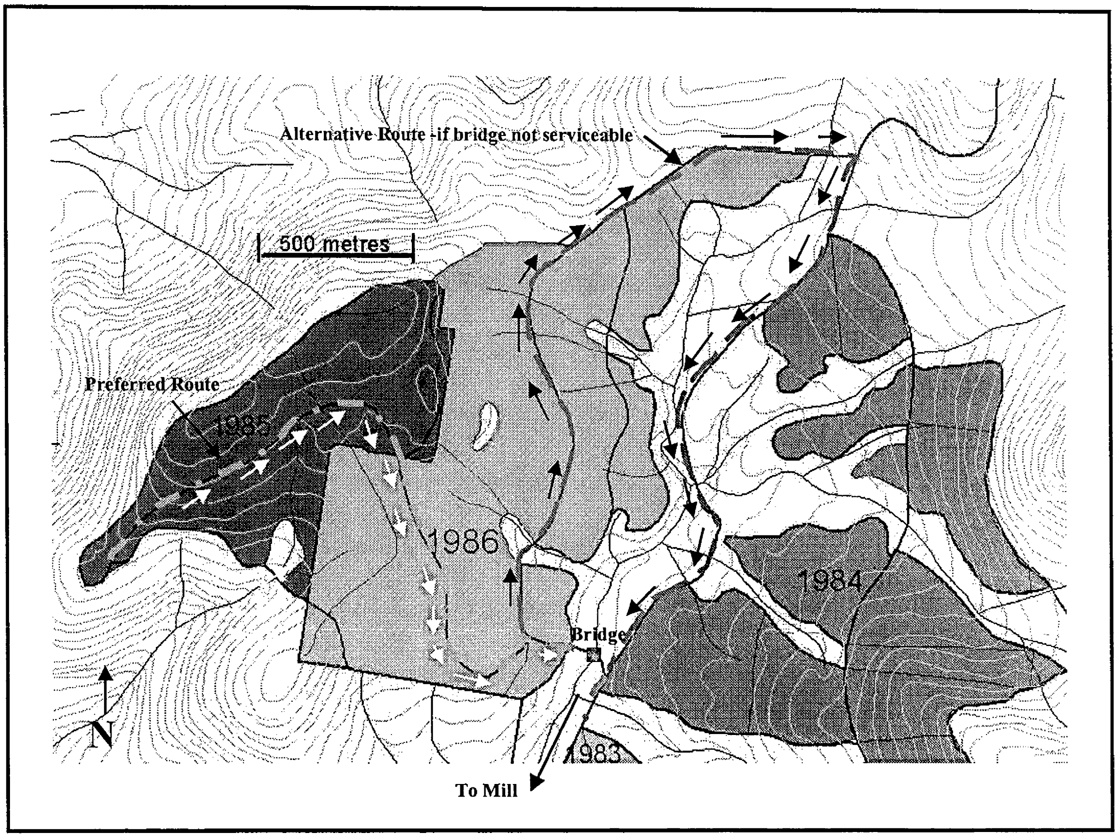


5.3.2 Estimating Additional Transport Cost Caused by Road or Crossing Closure

Australian forest managers are facing pressure to close road segments that present high environmental risk (eg. road segments running directly adjacent to watercourses). However, the impact on transport operations needs to be known before the decision to either upgrade or close the road can be made. A similar problem is addressed by Pulkki (1996), who describes the investigation of the effect of stream crossing closures on wood transport cost using network analysis in a raster type GIS.

To demonstrate how the FRMS could be used to solve such a problem, a hypothetical situation was constructed for the Pound Creek area. The bridge on Blomleys Road fording Pound Creek, that provides access to the 1985 and 1986 ageclasses in this area (see Figure 5.5), was assumed to be unsuitable for use by B-double trucks (used during first thinning operations). The cost of a new bridge installation was estimated at $75,000. Using ArcView's Network Analyst extension and the data within the Forest Road Management System, it was established that 706 B-double loads of timber would have to be re-routed an additional 4,645 m. This is equivalent to one truck (payload of 40 tons) travelling an additional 3,280 km. This equates to 131,200 ton.km's. If the rate of $0.10/ton.km is assumed, the extra cost of rerouting the trucks is $13,120 so the installation of a new bridge in this case is unwarranted.

Figure 5.5 Illustration of B-double Log Truck re-routing analysis



5.4 ENVIRONMENTAL MANAGEMENT APPLICATIONS

A major use of the FRMS will be in maintaining and demonstrating compliance to environmental regulations. Two examples follow that show how an organisation such as SFNSW could use the FRMS to check whether their roads meet environmental regulations. A third demonstrates how the FRMS could be employed to identify road segments that represent a high environmental risk.

5.4.1 Drainage Structure Spacing Calculation

The conditions of the current Pollution Control Licence (PCL) issued to State Forests of New South Wales by the Environmental Protection Authority contain a requirement to ensure that roads used for harvesting operations are drained at specified intervals (EPA, 1998).

All new roads constructed by SFNSW are drained to specifications, however the majority of existing roads were constructed before the PCL and its conditions came into effect. In preparation for logging, the drainage spacings for these roads have to be checked and extra drainage structures must be installed if the spacing requirements aren't met. The maximum allowable water flow distances are shown in Table 5.2.

Table 5.2 Maximum Distance of Water Flow or Potential Water Flow Along Road Surfaces and Table Drains (EPA, 1998)

Grade (degrees)	Maximum Distance of Water Flow (m)
1	200
2	175
3	150
4	125
5	100
6	90
7	80
8	70
9	65
10	60
11	55
12	50
13	45
14	40
15	40

This table can be approximated as an exponential equation:

$$\textbf{Drainage Spacing (m)} = 198.866 \times 0.890035^{\text{grade (degrees)}}$$

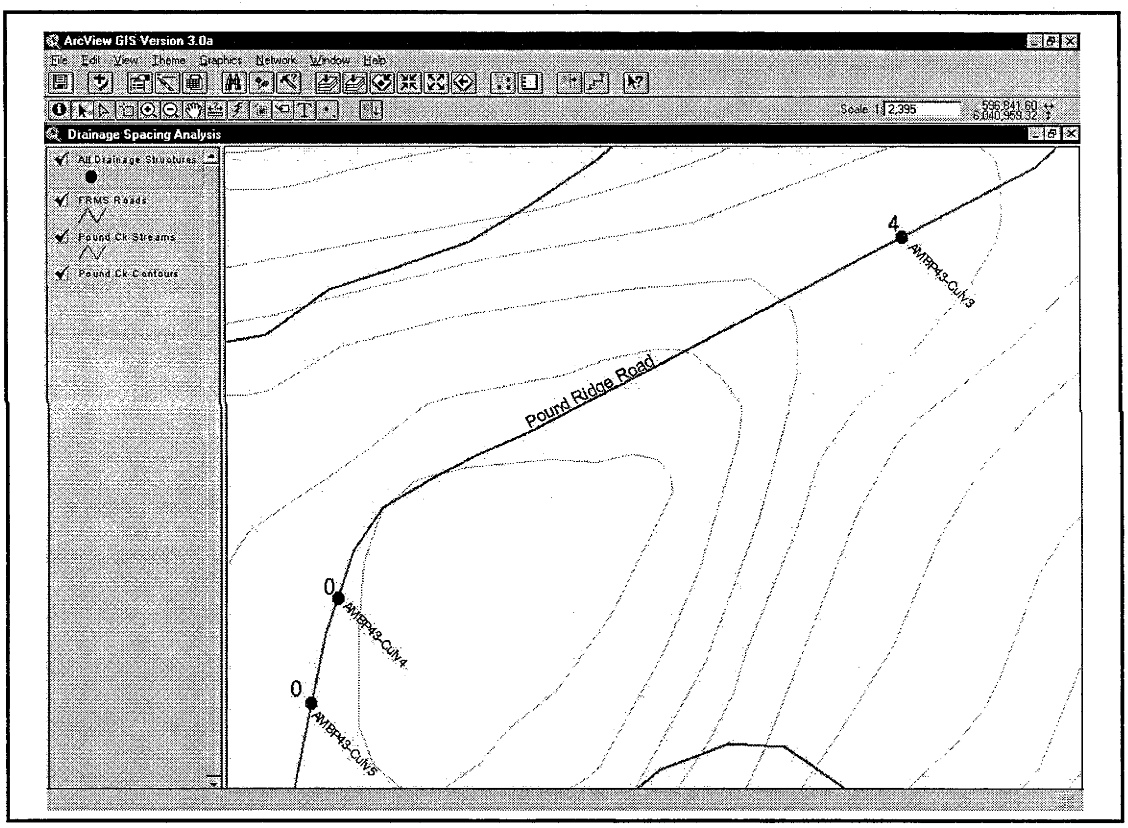
This equation was applied to roads in the Pound Creek study area, using the GIS, to check drainage spacings. Several assumptions were made in the application of the drainage spacing equation. It was assumed that the intersections of two or more roads either facilitated drainage or contained a drainage structure. It was also assumed that drainage feature crossings represented points at which the road surface was drained.

A new theme containing points located at the start and end of all road segments was digitised. The points in this theme were sorted by the id-number of the road segments on which they were located and then by distance from the reference point (located to the south-west of the forest). This was done to define which points represented the start of segments (which were assigned a 'distance along segment' of 0.000 m) and which represented segment ends (these were assigned a 'distance along segment' equivalent to the segment length).

Another theme was created by merging the intersection points theme with the culvert, mitre drain, rollover and bridge themes. The product was a theme that contained all known drainage points (combined drainage point theme) and the distance along their respective segments (in metres). Elevation data, obtained from a Digital Elevation Model (DEM), was attached to this theme's table and then exported to MS Excel®. An Excel macro was written that used distance and grade between drainage points to determine how many additional drainage structures were needed between them to satisfy PCL regulations. Example results of such an analysis are shown in Figure 5.6.

This example shows three culverts located on 'Pound Ridge Road' (Pound Creek Forest Area). The analysis shows that two of the culverts (AMBP43-Culv4 and 5) don't require any additional drainage structures installed between them and their next most south-westerly drainage structures. The other culvert, AMBP43-Culv3, requires 4 additional drainage structures installed between it and the next drainage structure south-west along the road (AMBP43-Culv4) in order to meet PCL conditions.

Figure 5.6 ArcView GIS Screendump showing results of a drainage spacing analysis



This procedure could be automated to provide a useful tool for the roading or harvesting forester. It would not replace field based measurement and assessment of required spacing nor would it be accurate enough to be able to select specific installation points. Its major use would be for the initial appraisal of the costs of extra drainage installations required for roads in a planned harvesting unit.

5.4.2 Checking Road Drainage Prior to Drainage Feature Crossings

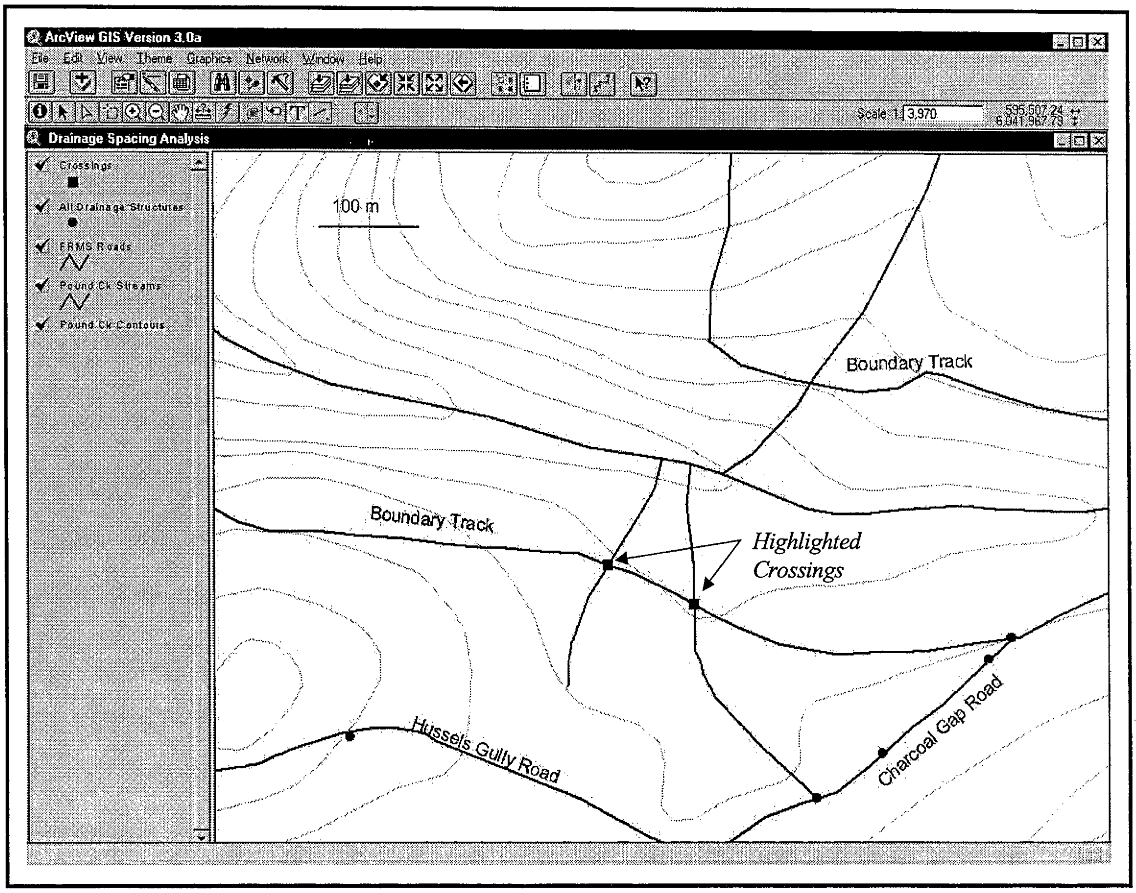
Condition 34, Schedule 5 of EPA (1998) states that:

> " Roads must be drained using a crossbank, relief pipe, spoon drain or mitre drain between 5 metres and 30 metres from the drainage feature crossing ".

The only exception to this condition is if it is impossible to install a drainage structure within this distance due to the road being in box cut (Condition 35 of EPA (1998)).

Development of a procedure for the selection of drainage feature crossings that don't meet these requirements could be easily implemented in the FRMS. The FRMS already has the locations of existing relief drainage structures and crossings stored. Standard ArcView functions can be used to select all crossings within 5 m of a relief drainage structure and then to select, from the remaining crossings, those that are located more than 30m from a relief drainage structure. All crossings that fail to meet PCL Condition 34 are highlighted and the planning of work to rectify this problem can commence. This process was trialled on the Pound Creek plantation dataset and only 2 crossings were detected that didn't meet Condition 35 (Figure 5.7). These crossings were actually only very shallow drainage lines and, as they are located on a boundary track that isn't used for log haulage, they are not covered by the PCL. They have been highlighted for demonstration purposes only.

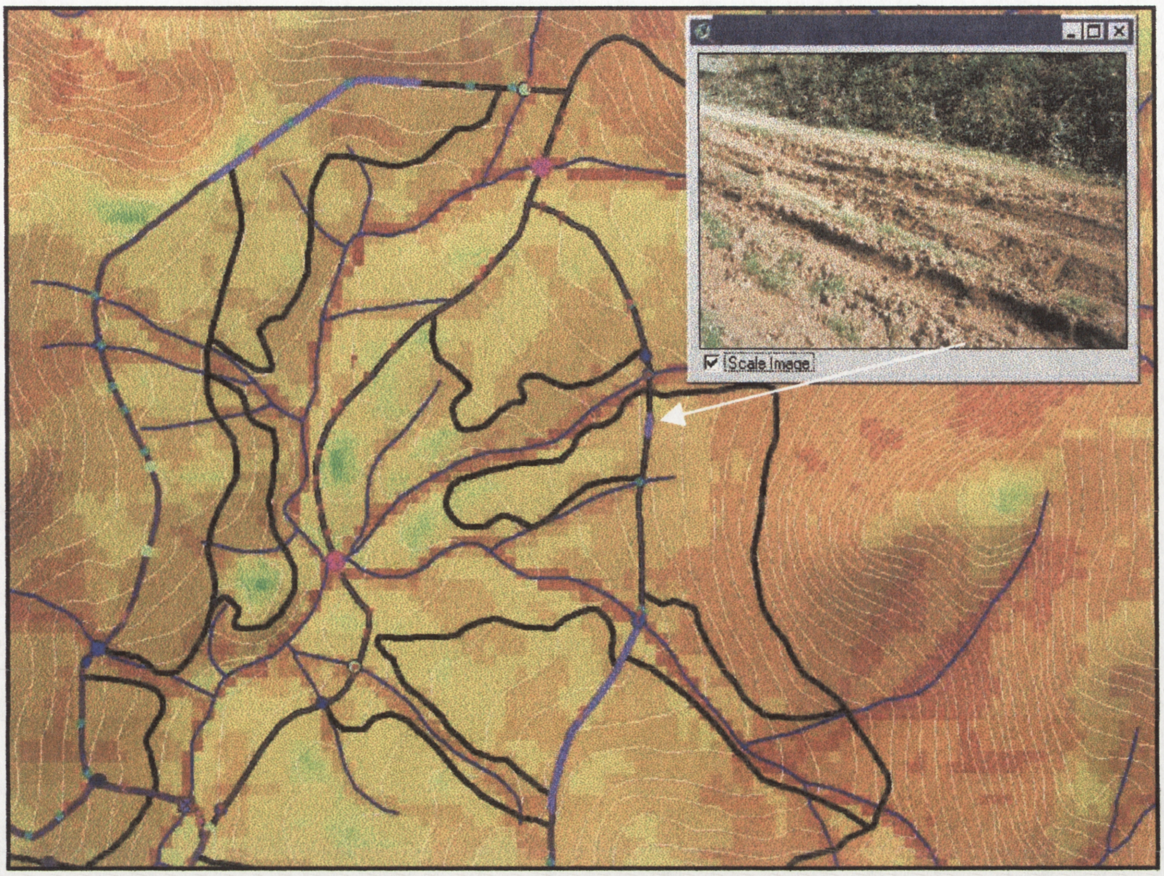
Figure 5.7 Selected crossings greater than 30m from a relief drain - Pound Creek area



5.4.3 Assessing Environmental Risk

The FRMS allows the road manager to identify areas of high erosion risk within the forest road network. Figure 5.8 shows the forest roads theme for the Pound Creek area placed over a grid theme of Stream Power Index (SPI), obtained from the Forest Productivity Research Group, CSIRO Division of Forestry and Forest Products. SPI is an indicator of erosion potential (Moore and Burch 1986). The darker areas have a higher SPI and therefore, higher erosion potential. Culvert and road defect zone themes are also displayed. In this example, a photolog of some rutting has been selected by the user who can evaluate the extent of the damage from the photo as well as placing the defect in context with the potential for erosion. This information can be used to decide how urgent the need for repair is.

Figure 5.8 Example of Environmental Risk Evaluation - Stream Power Index



Road segments constructed in areas of higher erosion potential may require more frequent inspection, more intensive road drainage and higher expenditure on erosion control. Consideration might also be given to minimising the amount of road in these areas through road closures.

The Spatial Analyst extension to ArcView is required to display and query grid themes, such as the SPI grid used in this example. However, other environmental hazard risk assessments (e.g. selecting roads that track watercourses or selecting road segments for which high amounts of erosion have been recorded) can be conducted using standard ArcView functions.

5.5 OTHER FUNCTIONS

The detailed examples of FRMS application provided in this section cover only a small range of the possibilities available. Other possibilities include:

- Keeping a record of trouble spots i.e. pavement failures. Accumulation of these records could be used to identify points on the road network that would benefit from pavement or subgrade improvement.
- Record maintenance costs per road section and then perform an analysis against revenue flow across that road section (a method such as that described in Section 5.3.1 could be used to estimate this). This would illustrate links in the road network that may be uneconomic
- Attach construction cost data to road sections along with year of construction. This data can then be used to calculate the net worth of a road network discounted to the time of query for accounting purposes. The power of a GIS based system would mean that queries could be tailored to answer specific questions eg. "What is the present day value of all Class II Roads?"
- Compare construction costs per kilometre across different terrain, soil types and geologies to identify trends. If trends could be identified, more precise estimates of road construction costs might be realised.
- Maintain a register of quarries and gravel pits located on the forest estate. The register could be used to keep records of crushing costs, amounts of crushed and uncrushed material won per year, bench heights and volume stockpiled
- Record gravel volumes applied to each road section. This information could be cross-linked to the quarry/gravel pit register so that stockpile volume information would be adjusted downwards as material was used

- Maintain a register of roads cleared for firefighting access and highlight road sections yet to be checked and cleared. Road maintenance activities generally focus on forest areas of current commercial importance. Roads overlooked due to lack of current commercial importance or isolation from the main forest estate often assume high strategic value during fire seasons
- Maintain a register of road signs, guardrails, guideposts etc., for use in the scheduling of ongoing maintenance for these structures

5.6 CONCLUSION

Some examples of how the FRMS could be used to support routine road management have been demonstrated. These include a custom application created for the FRMS that summarises the attributes of a road selected by the user and lists the assets and defects located on the selected road. Several transport management applications were also trialled. Once fully developed, these tools will assist managers in route planning and allow the comparison of different routes on the basis of haulage cost. Two examples were also developed to show how the FRMS could be employed to check whether roads meet current environmental protection regulations. Another example was used to demonstrate how the FRMS, in conjunction with terrain models, could identify potential or existing environmental hazard, such as erosion risk.

Some of the examples described in this chapter use only the standard GIS functions while other examples used commercially available extensions. The development of a user-friendly custom application for the FRMS was also described. Further development could automate the more useful of these FRMS functions. The FRMS would then become a practical tool for the forest road manager, available for use on a daily basis to provide support for a range of tasks.

6 ASSESSING SYSTEM IMPLEMENTATION COST

Chapter Objectives:

1. Estimate the time and money costs of implementing the forest road management system in a large forest management area by evaluating the productivity of forestry workers in collecting road data for the system and determining the amount of data to be collected.

6.1 INTRODUCTION

The success of a forest road management system depends largely on the implementation phase. It is important that this phase isn't too long or costly. A number of management systems for forest roads have been proposed (Bassel, 1983; Nieuwenhuis *et al.*, 1984; Eck, 1987; Progisys Incorporated, 1988; Utterback, 1992; DCNR (Vic.), 1995; Provencher, 1997) but little indication has been provided of what the cost to the user organisation might be. The system developed in this study has the advantage of being implemented within a GIS familiar to many forest managers. However, it still requires an initial collection of data on all forest roads in the management area with the location and description of road assets and defects. This represents the major cost in implementing any forest road management system.

An evaluation of the likely cost of the data collection phase of system implementation was made using the following steps:

1. Measure data collection productivity rates
2. Estimate the likely number of road features that would have to be measured
3. Calculate the cost of initial data collection using the products of steps 1 and 2
4. Perform a sensitivity analysis to determine the effect of various factors on this cost

5. Assess the feasibility of relocating and reassessing features visited during initial data collection

6.2 MEASURING ROAD FEATURE DATA COLLECTION PRODUCTIVITY RATES

6.2.1 Procedure

A study was made of the productivity of the data collection process on the 20th to 23rd July, 1998 in Green Hills State Forest (south west of the township of Batlow). The study utilised two road survey foremen working in State Forests' Hume Region. After a half day introduction to the technology and the collection procedure, the field workers commenced data collection. Each field worker collected 10 data points and then swapped with the other who would then collect 10 data points, with this process being repeated throughout the study. The productivity of the two working together was also measured. In this case, one person would drive and the other would operate the GPS and data logger. For inspection of features that required exiting the vehicle (culverts and bridges), both workers would inspect the side of the feature closest to them. The information recorded for the data collection of each road feature was:

- Time for worker to record feature description and for GPS to record location
- Time taken to drive to the feature from the preceding one
- Initials of worker operating the GPS and data logger. "Both" was recorded if both worked together
- Type of forest adjacent to the road

Wet weather precluded data collection on any natural surfaced roads for much of the trial. A total of 37 km of road was surveyed during the productivity study. The roads surveyed represented a mix of recording conditions including mature pine, pre-commercial pine plantation, clearfelled areas, dense unthinned, unpruned, very heavily stocked pine plantation (1987 Ageclass) and areas of difficult topography.

Actual surveying time took 22 hours (Table 6.1). Locations and descriptions of 524 road features were collected with culverts being the dominant feature type (Table 6.2). This equates to a gross productivity of 25 data points per work hour, or 144 seconds per point. Note that this time includes the time taken to drive to the feature.

Table 6.1 Breakdown of Productive Time, Data Collection Productivity Study

DAY	NO. HOURS WORKED
20/7/98	3.5
21/7/98	4
22/7/98	7
23/7/98	7.5
TOTAL	22

Table 6.2 Number of points collected by feature type – GPS Data Collection Productivity Study, 20 to 23 July, 1998.

FEATURE TYPE	NO. POINTS RECORDED
Culverts	205
Mitre Drains	187
Loading Bays	72
Rollovers	31
Drainage Feature Crossings	10
Erosion Points	5
Spoon Drains	4
Truck Turnarounds	3
Gates	3
Cattle Grids	2
Pavement Defect	1
Pulldown (Batter)	1
TOTAL	**524**

6.2.2 Analysis

Three major variables influencing GPS data collection productivity were observed:

1. Efficiency of GPS data logger operator
2. Type of feature being recorded
3. Forest environment affecting the ability of the GPS to record road feature locations

These observations led to the following hypotheses:

1. Data collection productivity is critically influenced by the time taken for the GPS to record a road feature's location. Therefore, productivity of each field worker working individually and as a team is the same.
2. Some features always require inspection from outside the vehicle and are more complex to assess (culvert and bridges). Therefore, data collection rates for these features are slower than for other feature types.
3. The ability of GPS to record its position has been shown by various researchers to be heavily influenced by density of forest canopy. Therefore, data collection productivity is highest in clearfelled areas and lowest in forests with dense canopies.

Productivity Across Different Operators and Road Features

It would have been desirable for the same task to have been repeated using each field worker and then both together. However, this conflicted with the need to cover a variety of recording conditions.

The means and standard deviations for operator trials are presented in Table 6.3. Trial 1 refers to Field Worker 1 working individually, Trial 2 refers to Field Worker 2 working individually and Trial 3 refers to both working together.

Table 6.3 Means and standard deviations for operator trials

OPERATOR	MEAN (secs)	STANDARD DEVIATION (secs)	NUMBER OF OBSERVATIONS
Trial 1	68	48	147
Trial 2	77	70	137
Trial 3	76	74	214

The means and standard deviations for two classes of feature type are presented in Table 6.4.

Table 6.4 Means and standard deviations for two classes of feature type

FEATURE	MEAN (secs)	STANDARD DEVIATION (secs)	NUMBER OF OBSERVATIONS
Non-Culverts	60	40	304
Culverts	95	81	196

The high standard deviation for culverts is due to variation in the ease of their inspection. Relief culverts ranged from being clearly visible to being completely obscured by blackberry and bracken. Most culverts located on crossings had inlets and outlets obscured to some degree by vegetation such as reeds and ferns.

Statistical analyses were performed using the STATISTICA™ statistical program. A 2-way analysis of variance (ANOVA) was conducted to analyse the effect of different operators and road feature types on data collection rates . The results of the ANOVA are presented in Table 6.5. These results did not establish a significant difference between operator regardless of feature type but indicated that recording times for culverts and non-culverts were significantly different across the different operators.

Table 6.5 Results of 2-Way ANOVA comparing the effect of different operators and road feature class on data collection rates

2 WAY-ANOVA RESULTS	df	Mean Sq	F	P
Feature Type*	1	1.84E-05	33.077	1E-06
Operator Trial	2	1E-06	1.060	0.347
Error	492	1E-06		

*Groups within treatment significantly different at 95% confidence level

Productivity Across Different Forest Conditions

The area in which the productivity study was conducted was classified into five different forest conditions:

1. Clearfall area - the term 'clearfall area' was also used to describe areas that had been re-planted but the trees hadn't reached a height that could affect GPS signal reception (age < 7 years)
2. Mature *P. radiata* stands (Thinned, age generally >14 years)
3. "Pre-commercial" *P. radiata* stands (Unthinned, ages 7 to 13 years)
4. Difficult topography (eg. between two hills)
5. "Pre-commercial" *P.radiata* stands of unusually high stocking density resulting in complete canopy closure of many sections of low standard road (firetrail) running through it.

The means and standard deviations for all recording environments are presented in Table 6.6.

Table 6.6 Means and Standard Deviations Data Collection Times for Various GPS Recording Environments

ENVIRONMENT	FEATURE CLASS	MEAN (secs)	STANDARD DEVIATION (secs)	NUMBER OF OBSERVATIONS
Clearfall	Culvert	78	45	31
	Other	36	18	51
	All	52	37	82
Firetrail	Culvert	-	-	0
	Other	75	43	60
	All	75	43	60
Mature Pine	Culvert	108	111	47
	Other	72	82	40
	All	91	100	87
Difficult Topography	Culvert	106	62	27
	Other	69	48	18
	All	92	59	45
Young Pine	Culvert	97	62	12
	Other	96	62	18
	All	96	54	30

A second 2-way ANOVA was performed to examine the influences of recording environment on data collection productivity, across feature types (culverts and other). Data obtained in the 'Firetrail' recording environment were excluded from the analysis due to the lack of culverts or bridges. The results, presented in Table 6.7, show that significant differences exist between the 2 groups of features as well as amongst some of the recording environments. The least significant differences were generated from the ANOVA. This showed that 'clearfall' was actually the only recording environment in which data collection rates were significantly different to those in other types (Table 6.8).

Table 6.7 **Results of ANOVA Comparing the Influence of Feature Type and Recording Environment on Data Collection Productivity**

2 WAY-ANOVA RESULTS	df	Mean Sq	F	P
Feature Type*	1	5E-06	8.544	0.004
Recording Environment*	3	3E-06	4.072	0.008
Error	236	1E-06		

* Groups within treatment significantly different at 95% confidence level

Table 6.8 **ANOVA least significant differences for various recording environments**

Clearfall	Mature Pine	Difficult Topography	Young Pine
	______________	______________	______________

[1]Underbar indicates groups not significantly different at 95% confidence level
[2]Recording environments ranked from left to right in ascending order of mean collection time

Driving Time

Driving time was assumed to be independent of operator, feature type or recording environment. Driving times for 487 points were collected. The average driving time per point was 47 seconds and the standard deviation was 195 seconds. The high standard deviation is a reflection of the variability of road feature spacing. The average driving time per kilometre was 665 seconds; i.e. an average speed of 5.4 km/h.

6.2.3 Conclusion – Productivity Study

The objective of the productivity study was to establish rates for the collection of information regarding the location and condition of points of interest on forest roads and to measure the influence of various factors on collection rates.

In summary, the analysis showed no significance difference between the productivity of operator 1, operator 2 and both working together as a team. Recording environment was shown to affect collection productivity, with rates in clearfall areas being significantly quicker. It also suggested that collection rates for culverts/bridges should be treated separately from other feature types.

6.3 Estimating Number of Points for Data Collection

An estimate of the data collection task for the plantation areas of Bago and Green Hills State Forests was necessary in order to evaluate the likely data collection cost for these forests. This involved the following steps:

1. Random selection of sample segments
2. Location of sample segments in the field and recording the frequencies at which road features occurred
3. Analysis of data to establish road feature frequencies over various conditions
4. Extrapolation of these results across the entire forest area

6.3.1 Selecting Sample Segments

It was hypothesised that a greater number of collection points would occur on roads in steep terrain than on roads in flat country. This was tested by stratifying the roads of Bago and Green Hills State Forests into three terrain classes using the Spatial Analyst extension of ArcView. A DEM (20m grid size) of the area encompassing the two State forests was imported to an ArcView project. Spatial Analyst was then used to derive a slope grid from the DEM. The roads themes for Bago and Green Hills were converted to grids, then functions in the Spatial Analyst extension were used to obtain the underlying slope for each road grid cell.

Road segments were then classified into one of three terrain classes. Table 6.9 describes these classes and the frequency of road segments within them.

Table 6.9 Terrain Class Descriptions and Frequency of Road per Class

TERRAIN CLASS	FREQUENCIES BY FOREST					
	BAGO SF			GREEN HILLS SF		
	Distance (km)	No. of segments	Frequencies	Distance (km)	No. of segments	Frequencies
$< 5^0$	362	1596	4.41	332	2041	6.15
$5^0 - 10^0$	535	1981	3.70	646	2335	3.61
$> 10^0$	520	1460	2.81	391	1324	3.39

A list of random numbers, corresponding to the identification numbers of individual road segments in the ArcView roads theme, was produced using Microsoft Excel®. This random number list was used to select 120 sample segments to be inspected in the field. Segments were only selected if they equaled or exceeded 500m in length in order to make them worth surveying.

The selected sample segments were then divided into three road classes:

1. All weather, two lane, sealed road
2. Major unsealed road – Formation widths ≥ 5.5m, usually gravelled
3. Minor unsealed road - Formation widths < than 5.5m, usually with a natural surface

Allowance for Different Soils

Road construction practices can vary according to the nature of the underlying soils. For example, roads constructed on highly erodible soils will generally be drained more frequently. Therefore, a check was made to ensure that the sample segments selected represented the major soil types of Bago and Green Hills State Forests. The soil classification system used was that of

(Murphy *et al.* 1998), who classified the soil regolith stability for State Forests in Eastern New South Wales. A description of this classification system, along with the extent to which each class is represented in Bago and Green Hills State Forests is presented in Table 6.10. Regolith class R2 occurs to only a very limited extent in these forests.

Table 6.10 Soil Regolith Stability Classification for State Forests in Eastern New South Wales (after Murphy *et al*, 1998)

REGOLITH CLASS	DESCRIPTION	AMOUNT FOUND IN BAGO AND GREEN HILLS STATE FORESTS (%)
R1	Low sediment delivery / High coherence	8.3
R2	Low sediment delivery / Low coherence	1.4
R3	High sediment delivery / High coherence	65.9
R4	High sediment delivery / Low coherence	24.4

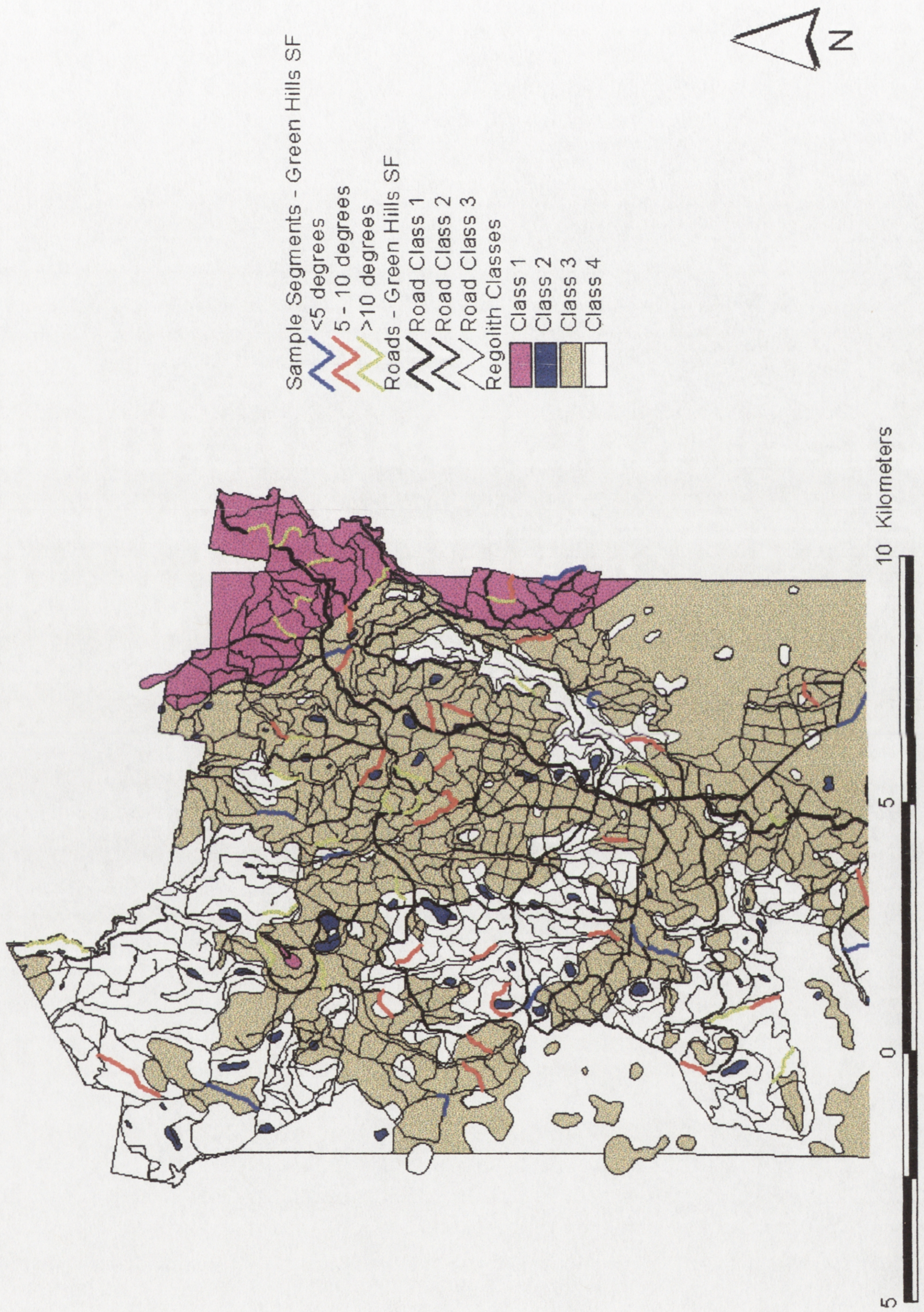
An ArcView theme of the soils of Green Hills and Bago State Forests categorised into these Regolith classes was used to ensure that sample segments included all available Regolith Stability types (Table 6.11).

Table 6.11 Number of Sample Segments per Regolith Class by Forest

REGOLITH CLASS	NO. OF SAMPLE SEGMENTS	
	GREEN HILLS	BAGO
R1	9	3
R2	-	-
R3	38	27
R4	17	-

The sampling strategy is illustrated in Figure 6.1, showing sample segments for the northern section of Green Hills State Forest.

Figure 6.1 **Map Showing Sample Segments for the Northern Section of Green Hills State Forest.**



6.3.2 Survey of Sample Segments

A survey of 117 sample road segments (representing approximately 80 km of forest road) was made during the period 14/9/98 to 22/9/98. The sample segments were surveyed by driving or walking them. Surveying consisted of a simple tally being made of the features located on the sample segments. The features tallied were:

- Culverts and bridges
- Mitre drains
- Crossings
- Rollovers and spoondrains
- Ancillaries (traffic signs, guardrails, borrow pits, dozer loading ramps, batter pulldowns)
- Erosion points
- Pavement defects
- Loading bays and turnarounds

Most of the major roads within Bago and Green Hills State Forests were also surveyed in their entirety as a check on the data collected from the sample segments.

6.3.3 Analysis - Estimating Number of Collection Points

Sample segments were then divided into 9 categories that covered each combination of road class and terrain class. The average number of points per km was calculated by feature type for each of these nine combinations. These results are presented in Table 6.12. This table shows a number of apparent trends, eg. the frequency of culverts and bridges on Road Class 3 segments is much less than for Class 1 and 2 segments and the frequencies of rollovers and spoondrains increase with terrain. Statistical analysis was performed to identify the influence of terrain and road standard on road feature frequencies.

Table 6.12 Frequency of Road Features by Terrain Class and by Road Class (# per km)

FEATURE	TERRAIN CLASS	ROAD CLASS		
		1	2	3
Culverts & bridges	$<5^0$	5.37	5.28	1.09
	$5^0 - 10^0$	5.83	6.75	2.45
	$>10^0$	6.10	6.30	2.13
Mitre drains	$<5^0$	0.00	4.25	4.09
	$5^0 - 10^0$	0.00	2.04	2.11
	$>10^0$	0.00	1.72	1.69
Rollovers/Spoondrains	$<5^0$	0.00	0.00	2.18
	$5^0 - 10^0$	0.00	0.19	3.84
	$>10^0$	0.00	0.00	4.38
Erosion points	$<5^0$	0.00	0.00	0.62
	$5^0 - 10^0$	1.17	0.19	0.76
	$>10^0$	0.00	0.25	1.34
Pavement defects	$<5^0$	1.34	0.57	0.11
	$5^0 - 10^0$	0.00	0.00	0.10
	$>10^0$	4.68	0.25	0.10
Ancillaries	$<5^0$	4.02	0.00	0.11
	$5^0 - 10^0$	1.17	0.00	0.03
	$>10^0$	0.00	0.42	0.00
Loading bays & turnarounds	$<5^0$	2.68	1.74	0.47
	$5^0 - 10^0$	1.17	2.28	1.15
	$>10^0$	1.22	1.47	0.78

Table 6.12 shows apparent differences in the frequencies of feature classes across terrain and road classes. This was supported by a significant difference between the nine combinations of terrain and road class at the 99.95% confidence level (Chi-Square test, 56 degrees of freedom). Different road feature frequencies across the three road classes were found to occur at the 99.95% confidence level (Chi-Square test, 16 degrees of freedom). However, no significant difference was found across terrain classes (Chi-Square test, 16 degrees of freedom). This can perhaps be explained by the fact that some feature types (eg. mitre drains, ancillaries) are installed less frequently in steeper areas than flatter ones, while other features (eg. rollovers, spoon drains, erosion points) occur at a higher frequency on roads in steeper terrain. The results of the three Chi-Square tests described are summarised in Table 6.13.

Table 6.13 Chi-Square test results

NULL HYPOTHESES	CHI-SQUARE	DEGREES OF FREEDOM	CRITICAL VALUE	RESULT
All 9 combinations of road and terrain class had the same road feature frequencies	365	65	91.98	Significantly different
All 3 terrain classes had the same road feature frequencies	3	16	34.21	Not significantly different
All 3 road classes had the same road feature frequencies	64	16	34.21	Significantly different

6.3.4 Analysis by Feature Type

An analysis was made of each feature type across road standard (Table 6.14) and terrain class (Table 6.15). This was done to identify whether terrain or road standard significantly influenced frequencies of these features. It was also done to see if the variance in measured road feature frequencies matched expected results. The data were distinctly non-normal so Wilcoxon's rank sum test was used (Devore 1987).

Table 6.14 Results - Analysis of Frequency of Road Features across Road Class

FEATURE				
Culverts	**Road Class**	1	2	3
	Average Value	5.76	6.11	1.89
		- - -	- - -	
Mitre Drains	**Road Class**	1	2	3
	Average Value	0.00	2.67	2.63
			- - -	- - -
Rollovers /Spoon Drains	**Road Class**	1	2	3
	Average Value	0.00	0.06	3.47
Erosion Points	**Road Class**	1	2	3
	Average Value	0.39	0.15	0.91
		- - -	- - -	
Pavement Defects	**Road Class**	1	2	3
	Average Value	2.07	0.27	0.10
		- - -	- - -	- - -
Ancillaries	**Road Class**	1	2	3
	Average Value	1.73	0.14	0.05
			- - -	- - -
Loading Bays /Turnarounds	**Road Class**	1	2	3
	Average Value	1.69	1.83	0.80
		- - -	- - -	

[1] Underbars indicate groups not significantly different at 90% confidence level

Table 6.15 **Results - Analysis of Frequency of Road Features across Terrain Class**

FEATURE				
Culverts	**Terrain Class**	$<5^0$	$5^0 - 10^0$	$>10^0$
	Average Value	3.91	5.01	4.47
		- - - -	- - - -	- - - -
Mitre Drains	**Terrain Class**	$<5^0$	$5^0 - 10^0$	$>10^0$
	Average Value	2.78	1.38	1.13
Rollovers /Spoon Drains	**Terrain Class**	$<5^0$	$5^0 - 10^0$	$>10^0$
	Average Value	0.73	1.28	1.46
			- - - -	- - - -
Erosion Points	**Terrain Class**	$<5^0$	$5^0 - 10^0$	$>10^0$
	Average Value	0.21	0.71	0.53
			- - - -	- - - -
Pavement Defects	**Terrain Class**	$<5^0$	$5^0 - 10^0$	$>10^0$
	Average Value	2.02	0.03	1.74
Ancillaries	**Terrain Class**	$<5^0$	$5^0 - 10^0$	$>10^0$
	Average Value	1.38	0.40	0.14
		- - - -	- - - -	
Loading Bays /Turnarounds	**Terrain Class**	$<5^0$	$5^0 - 10^0$	$>10^0$
	Average Value	1.63	1.53	1.20
		- - - -	- - - -	- - - -

[1] Underbars indicate groups not significantly different at 90% confidence level

These results are discussed, by feature type, below.

Culverts and Bridges

The frequencies of culverts were similar for road classes 1 and 2 but culverts on road class 3 were spaced, on average, significantly less frequently (Table 6.14). No significant difference was detected across the terrain classes (Table 6.15).

Crossings

Crossing frequency is neither a function of road standard or terrain, therefore the overall average was used in the cost estimate and no analysis was made for this feature type. The average crossing frequency across Bago and Green Hills State Forest was 0.68/km.

Mitre Drains

Mitre drains generally weren't used on the sealed roads of the area (culverts were preferred for these roads) hence the zero count obtained for Class 1 roads. No significant difference was detected between the frequencies of mitres on Class 2 and 3 roads (Table 6.14). However, significant differences in mitre drain frequencies were shown to exist between terrain classes (Table 6.15). This is because mitre drains are used predominantly on roads located in flatter country as roads built in sidecut (most commonly used in steeper areas) preclude their use.

Rollovers and Spoon Drains

None of these structures were encountered on Class 1 or 2 roads expect for several on one gravelled road (Baked Apples Road, Green Hills State Forest) which is an unusual occurrence as rollovers and spoondrains are usually replaced by culverts when a road is gravelled (Table 6.14). Rollovers and spoon drains are used to drain natural surfaced roads in steeper areas. A significant difference was detected between rollover/spoondrain frequencies on roads in flatter areas ($<5^0$) and roads in steeper areas (Table 6.15).

Erosion Points

The lower standard Class 3 roads were observed to have significantly more erosion points when compared with the two higher standard road classes (Table 6.14). It would also be expected that instances of erosion would be more frequent in steeper areas than flatter ones; however, this was not supported by the analysis results (Table 6.15).

Pavement Defects

Number of pavement defects generally often increases as traffic loads and road grade increase (OECD 1990). No differences were detected across road classes (Table 6.14) but differences across terrain classes were significant (Table 6.15). Road Class 1, $>10^0$ had a very high frequency per km because it included a segment with a particularly large number of defects.

Ancillaries

More ancillary types are associated with road user safety (guardrail, advisory signs). Therefore, it would be expected that a greater numbers of these features would be found on roads that receive higher levels of traffic, such as the high standard Class 1 roads. This is confirmed by the analysis (Table 6.14). Roads located in terrain $>10^0$ were found to have significantly less ancillaries, at the 90% confidence level (Table 6.15).

Loading Bays and Turnarounds

Significantly less loading bays/turnarounds were located on Class 3 roads (Table 6.14). This is likely to be a result of the fact that these lower standard roads are used less frequently for haulage operations. No significant difference was detected in the number of loading bays and turnarounds across terrain class as they are required for all haulage operations, regardless of terrain (Table 6.15).

6.3.5 Analysis by Regolith Class

The influence of the different regolith types on road feature frequencies was also investigated. The average road feature frequency per km was calculated for Regolith classes 1, 3 and 4. The Wilcoxon's Rank-Sum test was applied across the three groups. No significant difference was detected between any of the groups at the 90% confidence level.

6.4 CALCULATING IMPLEMENTATION COST

The major implementation cost of any forest road management system is the initial acquisition of the data required to use it. The information gained from the data collection productivity study was used in conjunction with the analysis of the point count study to estimate this cost.

6.4.1 Inputs

Inputs required to calculate the estimated implementation cost are summarised in Table 6.16.

Table 6.16 Summary of inputs required to estimate implementation cost

INPUT	SOURCE
Collection Time for Culverts/Bridges	Productivity Study conducted with SFNSW field staff, 20th – 23rd, July 1998
Collection Time for other road features	Productivity Study conducted with SFNSW field staff, 20th – 23rd, July 1998
Average Driving Time between points	Productivity Study conducted with SFNSW field staff, 20th – 23rd, July 1998
Number of culverts/bridges per km	Sampling study conducted on 14th – 22nd September, 1998
Number of other road features per km	Sampling study conducted on 14th – 22nd September, 1998
Number of km's of road by each terrain/road class	SFNSW/CSIRO GIS roads data
Wages for collector	SFNSW
Vehicle hire/mileage costs	SFNSW
Vehicle mileage completed during a day's collection	Estimate
Number of days required to complete collection	Based on productivity study data and estimate of average number of productive hours per day

6.4.2 Assumptions

Assumptions made during the calculation of the cost estimate were:

- Wages were $25/hr for an 8 hours day
- That the vehicle used for data collection would travel 200 km each day of collection, including driving to and from the job site, and that vehicle cost was $8/hour and $0.10/km.
- That the number of production hours (i.e. time spent actually collecting data) per day was 6.5. This allows for time consumed through problems with the GPS or any other delays (eg. clearing roads) that may be encountered during data collection.

6.4.3 Cost Calculation

Data for road distances, frequency of culvert/bridges, frequency of other feature types and average times measured for the various data collection activities are presented in Tables 6.17, 6.18, 6.19 and 6.20 respectively.

The frequencies of culverts and bridges (Table 6.18) and frequencies of other features (Table 6.19) were multiplied by the road distances (Table 6.17) to produce the total estimated number of culverts/bridges and other feature types respectively. The estimated number of culverts and bridges was multiplied by 142 seconds (collection time + driving time, Table 6.20) and the estimated number of other features was multiplied by 107 seconds (collection time + driving time, Table 6.20). This produced a grand total of approximately 2,972,720 seconds for initial data collection, or 826 hours. Using the assumption of 6.5 productive hours per day for an 8 hour day, the total number of collection days required was calculated at 127. Assuming 8 hours of wages paid at $25/hour, and a vehicle hire rate of $8.00/ hour the daily cost equals $264 plus vehicle mileage. Mileage was assumed at 200 km/day at a cost of $0.10/km, making the total daily cost equal to $284. Therefore, the estimated cost for initial data collection for the plantation areas of the two state forests (comprising 39,200 ha of plantation and containing 2,385 km of forest road) was approximately $36,068. This equals $0.92/ha of plantation or $15.12/km of road. The road density across these two forests (including roads of all standards) is 60.8 m/ha, therefore area covered per day is 310 ha/day and the length of road, 18.8 km (ie. productivity rate of 2.89 km/h). The average number of road features per km (determined from the road feature survey) was 11, so a day's data collection should take in a little over 200 features.

Table 6.17 Road distances (km) for each combination of road and terrain class

TERRAIN	ROAD CLASS		
CLASS	1	2	3
1	25	114	376
2	18	121	856
3	9	128	734

Table 6.18 Frequencies of Culverts and Bridges (no./km) for each combination of road and terrain class

TERRAIN	ROAD CLASS		
CLASS	1	2	3
1	5.37	5.28	1.09
2	5.83	6.75	2.45
3	6.10	6.30	2.13

Table 6.19 Frequencies of other feature types (no./km) for each combination of road and terrain class

TERRAIN CLASS	ROAD CLASS 1	2	3
1	8.05	7.63	7.70
2	4.67	5.41	8.85
3	6.10	4.86	8.93

Table 6.20 Summary of average times for various recording activities measured during data collection productivity study

ACTIVITY	TIME (Seconds)
Record location and description of a culvert or bridge	95
Record location and description of any other type of feature	60
Drive from one feature to the next	47

6.4.4 Sensitivity Analysis

The cost estimate has not included any allowance for the office work component involved in loading the data into the FRMS. This task should be small once procedures have been developed and staff trained. The influence of different scenarios on estimated initial data collection cost was tested. The scenarios tested were:

- Collection always conducted in areas most favourable to GPS recording (clearfelled areas)
- Collection always conducted in areas least favourable to GPS recording (unthinned plantation)
- Exclusion of some road feature types from collection operation (various combinations tested)

Driving time between points was assumed to be independent of recording environment, so 47 seconds was used for this operation in all sensitivity analysis calculations.. The results of the sensitivity analysis are presented in Table 6.21.

Table 6.21 Results of Sensitivity Analysis

RECORDING ENVIRONMENT	FEATURES COLLECTED	COST	$/km ROAD	$/ha FOREST	VARIATION FROM STANDARD (±%)
Most Favourable (Clearfall)	All features	$29,117	$12.21	$0.74	-19.2
Least Favourable (Pre-commercial pine)	All features	$45,427	$19.05	$1.16	+26.1%
Average	Culverts, bridges and crossings only	$13,214	$5.54	$0.34	-63.3
Average	Culverts, bridges, defects, crossings only	$16,165	$6.78	$0.41	-55.1
Average	Drainage Structures Only	$29,645	$12.43	$0.76	-17.7
Average	All features except ancillaries	$32,598	$13.67	$0.83	-9.5

The analysis shows that a saving of approximately 19% can be made if all data collection for the FRMS is conducted in clearfelled areas. This is because of the potential gain in data collection efficiency obtained by operating the GPS in areas where satellite signal is uninterrupted by forest canopy. In the unlikely event that all data collection activities are as slow as those measured in pre-commercial pine, the extra cost will be of the order of +26%. The remaining sensitivity analyses show the cost savings to be made depending on the road feature types targeted. For example, the user might only be interested in collecting information on drainage feature crossings and their associated structures. It is also possible that developments in GPS technology will eliminate the slow performance experienced in non-thinned areas.

6.5 REASSESSMENT FEASIBILITY

A major part of the benefit of operating an FRMS comes from providing a framework for regular reinspection of road conditions. A reassessment trial was conducted on 15th September, 1998 to assess the productivity of this operation. This involved the same field staff involved with the data collection productivity trial.

The first trial was conducted on Green Hills Forest Way (Green Hills State Forest), a 16 km road for which data were collected during the productivity trial. Total productive time was 3 hours to complete approximately 16.5 km, approximately 5.5 km/hour. Green Hills Forest Way had 215 point to reassess so average reassessment time (including driving time) per point was approximately 50 seconds. This compares with the average initial collection time of 2.4 minutes per feature and a productivity rate of 2.89 km/h.

It was concluded that, where possible, the distance at which road features occur along the entire road should be listed on the reassessment forms as well as their location along the individual segments. This will simplify the reassessment process as the surveyor can start at the most southwesterly point of a named road and systematically work along it. The "distance along segment" information can be used if reassessment has to commence part way along a road and then the "distance along entire road" information can be used once the surveyor has located the first road feature. Culverts were the only feature type that required inspection from outside the vehicle. The field workers generally had little trouble locating the features to be reassessed. Several mistakes, made during initial data collection, were identified and this emphasised the necessity for periodic reassessment.

6.6 CONCLUSIONS

The influence of a number of factors on the productivity of forestry field staff using a GPS with electronic data logger to collect information were studied. Productivity was found to be dependent upon:

- Forest conditions – data collection in unthinned plantation forest was found to be significantly slower due to the dense canopy interfering with GPS satellite signals
- Type of feature being assessed – culverts and bridges took longer to assess due to the number of attributes that required measuring for these structures as well as the difficulty often experienced in locating them due to dense vegetation

Average collection time per feature was 2.4 minutes (including driving time).

Road segments of various standards and located in a variety of terrain classes were surveyed in order to determine the likely frequency of data points that would be required to be entered into the FRMS.

These two studies allowed estimations of total time and cost to complete initial data collection in two major softwood plantation forests. The cost was determined to be approximately $36,000, or $15.10/km of road. Sensitivity analyses were conducted on these cost estimates to illustrate the variation of these costs under a mixture of scenarios. It was shown that initial data collection cost could increase by 26% or decrease by 19% depending on the average density of the forest canopy over the collection area. Forest managers can use this information to assess the costs of implementing the FRMS in their management areas.

7 DISCUSSION AND CONCLUSIONS

Chapter Objectives:

1. ***Discuss:***
   - ***The transition of the FRMS from pilot-scale to operational stage***
   - ***How the outcomes of this study relate to previous work; and***
   - ***Possibilities for further research***
2. ***Review this research and summarise the findings***

7.1 DEVELOPING THE FRMS INTO AN OPERATIONAL TOOL

The FRMS designed during this study was developed to pilot scale level to demonstrate proof-of-concept. Some further development is necessary to turn the pilot-scale FRMS into an operational tool. The implementation phase would provide an opportunity to include additional data types if required and to develop clerical and data collection procedures.

Recently introduced technology has the capacity to improve data collection either by increasing the efficiency of data collection or of its downloading to the database.

7.1.1 Additional Data for the FRMS

The tradeoff between road construction/maintenance and transport cost for specific road sections is poorly known. However, there are a number of additional pieces of data that could be added to the FRMS which, when coupled with regularly updated data concerning log truck movements and travel times, would improve our understanding of this relationship.

One important indicator of a road's service life is its integrity (Douglas, 1988). The integrity of the road structure also affects truck speed as the amount of rolling resistance encountered by a log truck is inversely proportional to the stiffness of the road pavement (Douglas, 1988). An unconsolidated, flexible road surface is also more likely to suffer pavement degradation (Morkel, 1994). A number of methods for measuring road integrity are described by Haas *et al.* (1994) (described in Chapter 2). The majority of these methods are costly and unsuitable for use on forest roads. Some methods exist, however, that are much cheaper to purchase and operate. One such system is the Clegg Impact Hammer (Lafayette Instrument Company, 1998) that consists of a tube with a falling weight (the hammer) inside it. The hammer is lifted to the top of the tube and then dropped. Sensors inside the weight measure the deceleration of the hammer as it hits the surface. The weight is dropped 4 times and the average deceleration for the point is recorded. The deceleration rate can be used to describe the stiffness of the pavement being measured. This provides an easy measure of road stiffness or integrity, the results of which can be entered into the road segment theme table of the FRMS database.

General information on the gradient of road segments as well as the cross slope can be calculated within the GIS if a DEM for the area of interest is available, although these can be of limited accuracy. More accurate road gradient data can also be collected, along with information on horizontal alignment and crossfall/superelevation by using road surveying vehicles such as the one developed by the Australian Road Research Board (ARRB) and the University of Melbourne (Australian Road Research Board Ltd., 1994), known as Gipsi-Trac™. This system allows the user to drive the road network with inertial navigation sensors recording vertical and horizontal alignment. The system is linked to a GPS which records overall location and allows the data to be redisplayed in a GIS.

Other information that may be of use to the forest road manager are traffic levels and summer dust levels. Traffic levels could be obtained by using rubber coated sensor wires, commonly used by the Roads and Traffic Authority (RTA) on Australian public roads. Dusting can present a problem on roads near sensitive forest neighbours (eg. rural houses, fruit orchards) or where roads are adjacent to waterbodies. Dusting can be rated using the 'Dust Severity Test' developed by Kramer (1991) in Morkel (1994) and described in Chapter 2.

7.1.2 Increasing Data Collection Efficiency

The average data collection rate determined during this study was 95 seconds for culverts and bridges and 60 seconds for other features. The only comparison that could be obtained from literature studies was with the work of Fawcett (1995). Fawcett used a GPS and integrated data logger to collect sign locations and attributes for a GIS based Asset Management System. He determined that the average collection time was 126 seconds per sign and the average download rate was 36 seconds per sign. Fawcett also describes the GPS sign data collection efforts of Lee Engineering (Washington DC, USA). They surveyed over 2,500 signs using GPS with an average collection time of 240 seconds per sign. This rate was influenced by the need for the GPS unit used to stay at each collection site for at least 180 seconds in order to obtain the required accuracy of 2 to 5 m. This represented an increase of nearly 54% over manual data collection. An average collection rate of 240 seconds (which doesn't include driving time) per feature would cause the FRMS data collection cost to escalate substantially, perhaps to the point of making it infeasible. This illustrates the important role that technology can play in increasing data collection efficiency.

Advances in GPS technology since construction of the units used in this study (manufactured in 1995) give greater accuracy and collection efficiency. Much of this can be attributed to the fact that many GPS units now use a 12 channel receiver as opposed to the 6 channel receiver used in the study. This allows the receiver to track twice the number of satellites simultaneously and continue recording even when some satellites become obscured (Kennedy, 1997). It also results in greater accuracy as the receiver can choose the satellites located highest in the sky, thus reducing geometric error.

Some GPS's are purchased with planning software that allows the user to make accurate predictions about the future positions of satellites and to select times at which a high number are going to be overhead (Sokkia, 1994; Kennedy, 1997). The user can select days, and times during the day in which good satellite availability, hence efficient data collection, can be assured. As Kennedy (1997) points out however, it would not always be practical to limit hours in which field crews could work.

The development of voice recognition software for use with computer applications is resulting in significant gains in rates of collection for road management systems. ESRI (1997) describe a road management system that combines GPS with voice data capture to collect information on road type and repair needs. Data are downloaded into ArcView GIS. The major advantages listed include a vastly increased collection rate, reduction in the number of recording errors and increased efficiency in entering data into the GIS.

Pen Based Computing is another emerging technology that appears to hold benefits for road data collection. Elzarka *et al.* (1997) used pen-based notebook computers during data capture for the inventory database of a Bridge Management System (BMS). The technology was utilised in order to speed up the data collection process, which had previously used paper forms. The pen permits the user to enter data in a number of ways including pointing to menu selections, scrolling through data lists (or options) and writing characters on the screen. This system could make the FRMS reassessment process paper-less.

7.1.3 Data Collection Strategy

A number of implementation strategies are available. One strategy would be to survey roads as they are checked during harvest planning. The advantage of this strategy would be that data collection for the FRMS would be just an additional step in harvest planning. However, this technique could prove detrimental to system implementation. There is a possibility that staff may lose interest in the system if they continually encounter instances where they try to use the FRMS for areas with incomplete data sets. An alternative approach may be to survey the major roads initially in a concentrated effort, and then cover the minor road network to fill in the 'gaps' as time allows.

The most desirable situation would be to have the entire road network surveyed as quickly as possible in order to have the FRMS functioning properly early in the implementation phase. It is also imperative that the user organisation decides exactly what information is required. This decision will require forethought to anticipate the needs of the future.

7.1.4 Office Based Component

Part of the cost of operating the FRMS will be in office based tasks aimed at updating data within the system. Such operations will include:

- Entering initial data
- Updating road feature information eg. culvert that was blocked now clear
- Changing road feature type eg. rollovers replaced with culverts during upgrading
- Adding information eg. major maintenance cost data added to database
- Transferring repaired defects from current database to historical database
- Repairing corrupted data sets

The development of the FRMS was only at pilot-scale so an estimate of the time and cost that will be consumed by such operations was not made. Efficient methods of performing these tasks will, however, need to be developed.

7.2 Results of This Study in the Context of Previous Work

Research into the development of Forest Road Management Systems has generally been focused on modeling and managing road – log truck interactions (USDAFS, 1983; Utterback, 1992; Stewart Scott Inc., 1995b; Provencher, 1997). Little consideration has been given to the problems that many forest road managers are experiencing in achieving and demonstrating adherence to environmental regulations.

The only Australian forest road management systems currently in use are ROADS, used by the Department of Conservation and Natural Resources, Victoria (DCNR (Vic.), 1995), and the system developed by Neve[1] for Forestry Tasmania. Both are useful systems but they are aimed mainly at administration and inventory. They are limited by a lack of a spatial database and don't address environmental compliance issues or support log haulage management.

This research includes the first attempt to quantify the number of road-associated structures located in a large commercial forest. Significant resources are committed to the installation and maintenance of these structures and forest road managers are showing interest in knowing how much they cost and how many they have. For example, some studies have been done on the construction costs of forest road drainage structures (Hewitt *et al.*, 1998; Pulkki, 1996; Thompson, 1996). The results of this research can either be applied directly or the method described can be used to inventory these items across a forest road network.

[1] Ron Neve, Chief Engineer, Forestry Tasmania

7.3 FURTHER RESEARCH AND DEVELOPMENT

The FRMS requires further development to take it from pilot-scale 'proof of concept' stage to a versatile product able to be used on a daily basis by forest road managers. Priorities should be the refinement of the customised querying module described in Chapter 5, development of a GPS to GIS downloading procedure that automates data processing, and the establishment of user friendly processes for database maintenance (eg. updating road feature attribute information, transferring repaired defects from the current theme to a road history theme, the addition of new features based on their position in relation to features already stored in the FRMS).

A number of additional functions would give the FRMS even greater utility. For example, if expected yield data for forest compartments is stored within the GIS, a tool for automatically calculating number of truck loads per operation from a given area along major roads could be designed. If this was achieved pavement degradation prediction models could be developed. One possibility might be to explore the relationship between traffic density, gradient and rainfall influencing pavement degradation of forest roads for use in determining future maintenance requirements and costs. These were the factors identified by Ferry (1994) as being prime causes of gravel loss from rural roads in New Zealand.

Whatever direction further forest road research takes, it should be undertaken with the perspective that the platform for the end use of that research is already in existence (ie the FRMS).

7.4 SUMMARY OF RESEARCH

The objectives of this study were to:

- Develop a management system with the potential to help Australian forestry organisations manage their roads by providing support for improved quality of maintenance, forest transport organisation and service and better identification of the risk of stream water degradation.
- Investigate the feasibility of the resultant system by testing various applications and determining the likely initial data collection cost

7.4.1 FRMS Development

The Forest Road Management System (FRMS) uses a GIS database. ArcView GIS was used, which is noted for being user friendly and is widely used by forest management agencies (McCormack *et al.*, 1995).

GPS was used to input much of the data required for the FRMS. The ability to record road feature's attributes and condition while recording its location in a manner compatible with the GIS made it an extremely useful tool. A paper based data collection system was also developed in recognition of the fact that GPS may not always be available. A set of procedures was developed for naming and classifying roads, road assets and road defects.

A complete data set for the roads of Pound Creek Section, Bago State Forest (between Batlow and Tumbarumba townships, southern NSW) was collected.

This data set included:

- The location of each road feature and its condition
- Information for each road segment on pavement type, pavement width, formation width and where available, maintenance history and construction/upgrade/maintenance costs accrued

This data was imported into the ArcView GIS environment. Adding GPS collected data to the GIS presented only minimal problems that were quickly solved. The pilot-scale FRMS was then developed around the Pound Creek Section roads data set. The data were used to construct layers or themes in the GIS for each road feature type. Themes containing features with a common function were aggregated to form new themes in order to allow certain types of querying. Points in the GIS representing road features were spatially linked to the underlying roads theme. In this way, road features were related to the actual road segments on which they were located.

FRMS development required the design of a procedure for facilitating systematic re-inspection of roads and road features. This procedure also serves to maintain the database of the system. This procedure utilised Microsoft Access® which used dBase files derived from ArcView GIS theme tables to produce condition reports and reassessment forms. The reassessment process was then tested in the field and found to be satisfactory.

7.4.2 Adding Road User Cost Information to the System

Sound road management requires an understanding of road user activities and the level of service being provided by the road network to the road user. Log hauliers are generally the road users of primary interest to forest road managers.

The addition of this data to the FRMS, obtained via stopwatch studies and through GPS, and its ongoing use was investigated. With appropriate data, the creation of regional travel time maps within the GIS was found to be a simple process. The travel time maps can be used to query expected log truck travel time between user defined departure and destination points (ie. coupe landing in forest and mill).

GPS was shown to have potential for collecting these types of data for Australian forestry operations. However, due to limitations in the software of the GPS used, actual trans-segment truck travel times were not obtained. Loss of signal due to deep road cuttings and dense forest canopy were also shown to limit its use in some areas.

7.4.3 Trialling Applications of the FRMS

A number of applications were developed to demonstrate how the FRMS could be used to support forest road and transport management. Trial applications included:

- Condition report module that summarises pertinent information for user selected roads, such as assets and defects, areas requiring work, pavement types and widths
- Photolog capability which allows the user to select a feature which prompts a photograph of the feature to be displayed
- An application to support the selection of gravel sources for road works
- Determining projected log haulage road use
- Calculating the cost associated with log truck re-routing
- 2 examples of how data stored within the FRMS can be used to check compliance with environmental regulations
- example of how areas of the road network that may present a high environmental risk could be identified

7.4.4 Estimating Initial Data Collection Cost

The productivity of forestry field workers in collecting road feature information using GPS was measured over a variety of conditions. Significant differences were detected in the time required to collect information on bridges and culverts when compared with other feature types. This was attributed to the complexity of these structures, the fact that they required inspection on foot (all other types could generally be surveyed from within the vehicle) and to the difficulty in assessing them because of the dense vegetation that is commonly found growing close to them. Productivity was also affected by forest canopy conditions and topography as they can interfere with GPS satellite signals and slow the process of determining geographical location. Data collection was found to be most productive in clearfelled areas and least productive in unthinned pine plantation compartments.

A survey of 120 road segments (all greater than 500m in length) was made to determine the likely frequency of the various features located on forest roads. The sample segments were chosen to represent 3 different terrain classes and 3 different road standards. An allowance for regolith class was made in the sampling strategy. These data were then extrapolated across Bago and Green Hills State Forests to determine the total data collection task for a large plantation forest.

The results from these two studies were combined to determine the likely cost of initial data collection for a large forested area. It was estimated that the initial data collection operation for the 2,385 km of road in Bago and Green Hills State Forests (39,200 ha) would cost $36,033. This represents rates of $0.92 per ha of plantation or $15.10 per km of forest road. It is beyond the scope of this study to comment on the willingness of forestry organisations to pay this price for a road management system. However, a comparison of this cost with those for some routine forest road maintenance operations (source: State Forests of NSW 1996a; State Forests of NSW 1996b) provides some perspective:

- Grading (with Water Cart) : $315/km
- Gravelling: $18,900 / km (5.5 m formation width); $20,100 / km (7.3 m formation width)
- Post harvest road maintenance: $30/ha of plantation
- Relief culvert installation with headwalls (assumes 2.5 sets/km): $415/km

A sensitivity analysis was conducted to show how this cost was influenced by a variety of scenarios. This showed that initial data collection cost could range from $12.20/km of road to $19.05/km, depending on the suitability of the forest canopy to GPS recording. Potential savings for data collection targeting specific road feature types were also derived. Developments in GPS and computer technology could further reduce this cost.

The cost has been calculated as if none of the data collection procedures were already occurring. In reality, most forestry organisations already collect road data during the harvest planning process. The FRMS would provide a method for the systematic storage, display and analysis of these data. The cost figure also assumes that data collection is a 'one-off' operation with a dedicated, full time worker and vehicle. Further cost reductions will be achieved by utilising normally non-productive wet days for data collection (on sealed/gravelled roads) or by using casual workers where possible.

7.5 KEY OUTCOMES

This study has demonstrated the feasibility of developing a Forest Road Management System around a GIS database. GIS was shown to allow the level of operation to vary from the scale of a single culvert to an entire regional log haulage network.

The pilot-scale version of the FRMS has shown potential to be a useful tool for managing forest roads. In particular:

- A set of procedures were developed for classifying and identifying individual road segments and features. This process underpins systematic forest road management.
- Data collection procedures were demonstrated to be suited for use by forestry field staff and able to accommodate the variety of conditions and road features found in production forests
- Systematic inspection of roads and road structures is made possible by the condition reports produced by the FRMS
- The ArcView GIS provides a suitable base for the FRMS and it has the advantage that many forestry organisations are already familiar with its use
- Data collection will account for the major part of FRMS implementation cost. Research showed that this cost will be significant but does not make the FRMS infeasible
- While there would be a significant cost to collect the original location data; once running, the FRMS would greatly enhance a forestry organisation's capability to maintain and demonstrate environmental compliance.
- Further development could automate common procedures and improve the sophistication of the querying process.
- The FRMS would provide a good basis for more intensive management of roading and transport operations.

The research described allows forest managers to assess the benefits of using the FRMS in the management of their roads. It may also raise awareness to the fact that sound, comprehensive management of forest roads and transport can serve the dual purpose of increasing operational efficiency while demonstrating a commitment to best practice and environmental responsibility.

REFERENCES

Ada, N. R. 1979. *The Introduction of Load Limitations into the ACT and their Effect on Log Hauling* Department of Forestry, Australian National University. Canberra, Australia. 151 p.

Amlin, E. 1998. *Traction Enhancement Technologies for Log Trucks.* Proceedings of IUFRO Conference - "Increasing Log Transport Efficiency". Rotorua, New Zealand. 23rd February, 1998. International Union of Forest Research Organisations.

Anderson, D. M. and Macdonald, L. H. 1998. *Modelling Road Surface Sediment Production Using a Vector Geographic Information System.* Earth Surface Processes and Landforms. **23** 95-107

Australian Road Research Board Ltd. 1994. *Gipsi-Trac Mobile Road Mapping System – Brochure.* Australian Road Research Board Ltd. Melbourne, Victoria, Australia.

Ayers, A. N. 1987. *A Road Maintenance Management System for a Local Authority Fourth National Local Government Engineering Conference.* Fourth National Local Government Engineering Conference 17-20 August, 1987. Perth, Western Australia

Bassel, J. R. 1983. *Maintenance Management Systems for Forest Roads: A Summary of Systems to Assist Road Managers.* Report No. 1E01L61 United States Department of Agriculture Forest Service. California, USA.

Beath, T. 1976. *The Effect of Gradient and Load on Speed of Log Trucks - Masters Thesis.* Department of Forestry, Australian National University. Canberra, Australia. 115 p.

Beschta, R. L. 1978. *Long-Term Patterns of Sediment Production Following Road Construction and Logging in the Oregon Coast Range.* Water Resources Research. **14** (6) 1011-1016

Bowling, L. C.; Lettenmaier, D. P.; Wigmosta, M. S. and Perkins, W. A. 1996. *Predicting the Effects of Forest Roads on Streamflow Using a Distributed Hydrological Model.* Poster Presented at the Fall Meeting of the American Geophysical Union. December, 1996. San Francisco, California, USA

Bradley, A. H. 1996. *Trial of a Central Tire Inflation System on Thawing Forest Roads.* Technical Report No. TR-116 Forest Engineering Research Institute of Canada. Vancouver, Canada.

Brice, C. E. 1993. *Glossary of GPS Terms.* Journal of Forestry. August Issue. 15-16

Brown, K. J. 1994. *River-Bed Sedimentation Caused by Off-Road Vehicles at River Fords in the Victorian Highlands, Australia.* Water Resources Bulletin. **30** (2) 239-250

Burroughs Jr., E. R.; Haber, D. F.; Watts, F. J. and Kadoch, T. L. 1983. *Measuring Surface Erosion on Forest Roads and Estimating Costs of Erosion Control - Preliminary Findings.* Low-Volume Roads: Third International Conference, 1983. Transportation Research Record 898 Transportation Research Board. Washington DC, USA.

Burroughs Jr., E. R. and King, J. G. 1989. *Reduction of Soil Erosion on Forest Roads.* Report No. INT-264 United States Department of Agriculture, Forest Service, Intermountain Research Station. Ogden, Utah, USA. 21 p.

Byrne, J. L.; Nelson, R. J. and Googins, P. H. 1960. *Logging Road Handbook - The Effect of Road Design on Hauling Costs.* USDA Forest Service. Washington, USA.

Cairney, P. T. 1984. *Human Factors in Road Condition Ratings.* ARRB Proceedings. **12** (3) 103-111

Cambell, I. C. and Doeg, T. J. 1989. *Impact of Timber Harvesting and Production on Streams: A Review.* Australian Journal of Marine and Freshwater Research. **40** (519-539)

Caroff, G.; LeCaignec, H. and Lecure, P. 1994. *Un Systeme d'Information Geographique Pour la Gestion de l'Entretien (A Geographical Information System for Maintenance Management).* Revue Generale des Routes et des Aerdromes. **724** (13-15)

CartéGraphe Systems, Inc. 1998. *Software Solutions for Public Works Professionals - Product Catalogue.* CartéGraphe Systems, Inc. Dubuque, Indiana, USA.

DCNR (Vic.) 1995. *ROADS System User Manual.* Department of Conservation and Natural Resources, Victoria (*now* Department of Natural Resources and Environment, Victoria). Melbourne, Victoria, Australia.

Deckert, C. J. and Bolstad, P. V. 1996. *Global Positioning System (GPS) Accuracies in Eastern U.S. Deciduous and Conifer Forests.* Southern Journal of Applied Forestry. **20** (2) 81-84

Devore, J. L. 1987. *Probability and Statistics for Engineering and the Sciences.* Brooks / Cole Publishing Company. Monterey, California, SA.

Diggens, B.; Miller, R. G. and Gallaugher, B. J. 1994. *Road Information Management System.* Proceedings of 17th ARRB Conference, Part 3 - Road Rehabilitation, Ashphalt and Surfacings. Melbourne, Victoria, Australia.

Divinsky, M.; Nesichi, S. and Livneh, M. 1997. *Development of Road Rougness Profile Delineation Procedure.* Journal of Testing and Evaluation. **25** (No. 4) 445-450

Douglas, R. A. 1988. *Roadnotes.* University of News Brunswick. Department of Forest Engineering. New Brunswick, Canada.

Douglas, R. A. 1992. *Forest Road Transportation System Design with Truck Performance Models.* Annual CoFE Meeting. August, 1992. Hot Springs, Arkansas, USA.

Douglas, R. A. and McCormack, R. J. 1995. *Pavement Management Systems Appropriate to Forest Haul Networks.* Proceedings, International Union of Forest Research Organisations (IUFRO) XX Congress. 6 - 12 August, 1995. Tampere, Finland.

Eaton, R. E. and Beaucham R. E. 1995. *The Basics of a Gravel Road Management System.* Better Roads. November Issue. 27-31

Eck, R. W. 1987. *A Microcomputer Program to Assist in Low-Volume Road Maintenance Management.* 66th Annual Meeting of the Transportation Research Board. January, 1987. Washington D.C., USA.

Egan, A.; Jenkins, A. and Rowe, J. 1996. *Forest Roads in West Virginia, USA: Identifying Issues and Challenges.* Journal of Forest Engineering. **7** (3) 33-40

Elliot, W. J.; Foltz, R. B. and Luce, C. H. 1995. *Validation of Water Erosion Prediction Project (WEPP) Model for Low-Volume Forest Roads.* Sixth International Conference on Low-Volume Roads. Volume 1. National Academy Press. Washington, USA.

Elliot, W. J.; Foltz, R. B. and Remboldt, M. D. 1994. *Predicting Sedimentation from Roads at Stream Crossings with the WEPP Model.* 1994 ASAE International Winter Meeting. American Society of Agricultural Engineers.

Elzarka, H. M.; Lansford, C. B. and Floyd, R. L. 1997. *Applications of Pen Based Computing in Bridge Inspection.* Computing in Civil Engineering - Proceedings of the Fourth Congress. American Society of Civil Engineers. New York, USA.

EPA. 1998. *State Forests of NSW Pollution Contol Licence.* Environmental Protection Authority. Chatswood, NSW, Australia.

Eriksson, M. O. 1983. *Cost Effective Low Volume Stream Crossings.* Low-Volume Roads: Third International Conference, 1983. Transportation Research Record 898. Transportation Research Board. Washington DC, USA.

ESRI 1996. *ArcView GIS - The Geographic Information System for Everyone.* Environmental Systems Research Institute, Inc. Redlands, California, USA.

ESRI 1997. *ESRI ARC News.* Environmental Systems Research Institute, Inc. Redlands, California, USA.

FAO 1996. *Forest Codes of Practice - Contributing to Environmentally Sound Forest Operations.* FAO Forestry Paper 133. Food and Agriculture Organisation of the United Nations. Rome, Italy.

Fawcett, G 1995. *Applications of Geographic Information Systems to Pavement Asset Management: Linking RAMM to a GIS.* University of Canterbury, Christchurch, New Zealand. Department of Civil Engineering. 100p.

Ferry, A 1994. *Predicting Roughness on New Zealand Gravel Roads.* Proceedings of the New Zealand Land Transport Symposium '94. Volume 1.

Finniear, L. J. and Aik Lim, P. 1994. *Building a Geographic Maintenance Management System for Road Networks.* Proceedings of the New Zealand Land Transport Symposium '94. Volume 1.

Forest Logger and Sawmiller. 1998. *NewLog Jinker Passes Test.* April, 1998.

Friedrichs, D. A.; Shober, S. F. and Duckert, W. D. 1997. *A Bumpy Road.* Civil Engineering. **67** (4) 61-63

Grace III, J. M.; Rummer, B.; Stokes, B. J. and Wilhoit, J. 1998. *Evaluation of Erosion Control Techniques.* Transactions of the ASAE. **41** (2) 383-391

Groves, K. W.; Pearn, G. J. and Cunningham, R. B. 1987. *Predicting Logging Truck Travel Times and Estimating Costs of Log Haulage Using Models.* Australian Forestry. **50** (1) 54-61

Haas, R.; Hudson, W. R. and Zaniewski, J. 1994. *Modern Pavement Management.* Krieger Publishing Company. Florida, USA.

Hallet, J. E. and Jacobsen P. 1994. *Pavement Management Systems for Unsealed Roads.* Proceedings of the New Zealand Land Transport Symposium '94. Volume 1.

Haydon, S. R.; Jayasuriya, M. D. A. and O'Shaughnessy, P. J. 1991. *The Effect of Vehicle Use and Road Maintenance on Erosion from Unsealed Roads in Forests: The Road 11 Experiment.* Report No. MMBW-W-0018 Melbourne Water. Melbourne, Victoria, Australia.

Hewitt, D.; Huyler, N.; Hannah, P. and LeDoux, C. 1998. *Determining Time as a Cost in Constructing Waterbars on Forest Sites in Vermont.* Council on Forest Engineering Proceedings. CoFE Meeting, 20th - 24th, July, Portland, Oregon, USA.

Hopwood II, T.; Sharpe, G. W.; Hutchinson, J. W. and Deen, R. C. 1987. *Automated Data Acquisition for Low-Volume Road Inventory and Management.* Transportation Research Record 1106. 67-73

Hutchinson, M. F. 1997. *ANUDEM Version 4.5 User Guide.* Centre for Resources and Environmental Studies, The Australian National University. Canberra, Australia. 15 p.

Jackson, R. K. and Sessions, J. 1987. *Logging Truck Speeds on Curves and Favourable Grades of Single Lane Roads.* Transportation Research Record No. 1106. 112-118

Jalinier, C. and Courteau, J. 1993. *Forest Road Surveys with GPS.* Technical Note TN-196 Forest Engineering Research Institute of Canada. Pointe Claire, Quebec, Canada.

Jamsa, H. 1983. *Maintenance and Rating of the Condition of Gravel Roads in Finland.* Low-Volume Roads: Third International Conference, 1983. Transportation Research Record 898. Transportation Research Board. Washington DC, USA.

Johnson, B. H. and Demetsky M. J. 1994. *Geographic Information System Descision Suport System for Pavement Management.* Transportation Research Record No. 1429. 74-83

Kennedy, M. 1997. *A Review of GPS Technology and its Applications for the Forest Industry in 1997.* LIRO Limited Logistics Conference. 3 November, 1997. Rotorua, New Zealand.

Koniditsiotis, C. 1992. *An Evaluation of Pavement Management System Packages for Local Government.* ARRB No. 225 Australian Road Research Board Ltd. Vermont South, Victoria, Australia.

Kullas, M. E. 1985. *Maintenance Management of Road Pavements (Summary of Experience in the City of Blue Mountains, Australia).* Proceedings, Pavement Management Systems Workshop. 9-22 August, 1985 Albury, NSW, Australia. Australian Road Research Board.

Lafayette Instrument Company 1998. *Clegg Impact Soil Tester - Affordable, Portable and East-to-use.* Web page: http://www.licmef.com/clegg.html. Accessed on 24/11/98.

Lawrence, M.; Firth, J. and Brownlie, R. 1995. *Three Forestry Applications of the Global Positioning System (GPS) in New Zealand.* NZ Forestry, August Issue. 21-22

Leaf, C. F. 1974. *A Model for Predicting Erosion and Sediment Yield from Secondary Forest Road Construction.* USDA Forest Service Research Note RM-274 US Department of Agriculture, Forest Service. Rocky Mountain Forest and Range Experiment Station.

Liautaud, G. and Faiz, A. 1994. *Factors Influencing the Transferability of Maintenance Standards for Low-Volume Roads.* Transportation Research Record 1434. 73 - 76

LIRA. 1985. *Research and Development in Logging Roads and Transportation.* The Proceedings of a Workshop held in Nelson, New Zealand. July, 1985. NZ Logging Industry Research Association Inc. Rotorua, New Zealand.

Macdonald, L. H.; Anderson, D. M. and Dietrich, W. E. 1997. *Paradise Threatened: Land Use and Erosion on St. John, US Virgin Islands.* Environmental Management. **21** (6) 851-863

Mamlouk, M. S. 1997. *General Outlook of Pavement and Vehicle Dynamics.* Journal of Transportation Engineering. **23** (6) 515-517

Martin, A. M.; Owende, P. M. O.; O'Mahony, M. J. and Ward, S. M. 1998. *Estimation of the Serviceability of Forest Access Roads* - In Preparation.

Massey-Reed, P. 1978. *Truck Travel Times in NSW Forests.* Forestry Commision of NSW.

McCormack, R. J. 1983. *Heuristic Allocation in Centralised Despatch of Log Trucks – Masters Thesis.* Department of Forestry, Australian National University. Canberra, Australia. 206 p.

McCormack, R. J. 1990. *TRUCKSIM - A Log Truck Performance Simulator.* Journal of Forest Engineering. **2** (1) 31-37

McCormack, R. J. 1992. *Truck Performance Simulation on Forest Roads.* IUFRO 3.06 Workshop. August, 1992. Munich, Germany.

McCormack, R. J and Winter, A. E. 1998. *Using GPS to Track Log Trucks in East Gippsland, Victoria.* Proceedings of IUFRO Conference - "Increasing Log Transport Efficiency". Rotorua, New Zealand. 23 rd February, 1998. International Union of Forest Research Organisations.

McCormack, R.J.; Roberts, E.; Delbridge, G and Loane, D. 1995. *Developing a GIS Application to Support Coupe Harvest Planning.* Institute of Foresters of Australia 16th Biennial Conference . Institute of Foresters of Australia.

McCullough, B. F. 1985. *The Pavement Management System Concept.* Proceedings, Pavement Management Systems Workshop. 9-22 August, 1985 Albury, NSW, Australia. Australian Road Research Board.

McMahon, S. 1996. *Measuring Machine Travel With A GPS.* Logging Industry Research Organisation. Rotorua, New Zealand.

Mockler, S. 1998. *Factors Affecting Forest Road Integration with the Natural Drainage in the Cutagee Creek Catchment, SE NSW.* Newsletter of the Cooperative Research Centre for Catchment Hydrology. May, 1998. 4-5

Mockler, S. and Croke, J. 1998. *Prescriptive Measures for the Prevention of Road to Stream Linkage (in Press).* Proceedings of the Second Australian Stream Management Conference. 8-11 February, 1999. Adelaide, South Australia.

Montgomery, D. R. 1994. *Road Surface Drainage, Channel Initiation, and Slope Instability.* Water Resources Research. **30** (6) 1925-1932

Moore, I. D. and Burch, G. J. 1986. *Modelling Erosion and Deposition: Topographic Effects.* Transactions American Society of Agricultural Engineers. **29** 1624-1640

Morkel, R 1994. *The Management of South African Roads in Perspective – Honours Thesis.* University of Stellenboch. Forest Engineering Technology Centre, Faculty of Forestry.

Murphy, C.; Fogarty, P. and Ryan, P. 1998. *Soil Regolith Stability Classification for State Forests of Eastern New South Wales (in Press).* Technical Publication. New South Wales Department of Land and Water Conservation.

Nieuwenhuis, M. A.; Corcoran, T. J. and Schiltz, H. M. 1984. *A Map-Based Information System for Road Network Management.* 1984 Summer Meeting, American Society of Agricultural Engineers. Paper No. NA84-103

O'Connell, D.; Gallant, J.; Ashton, L. and Hill, C. 1995. *The Use of Global Positioning Systems (GPS) for Soil and Vegetation Survey in Forested Landscapes* Institute of Foresters of Australia 16th Biennial Conference.

OECD 1990. *Road Monitoring for Maintenance Management.* OECD Publication Service. Paris, France.

OECD 1995. *Road Maintenance Management Systems in Developing Countries.* Organisation for Economic Cooperation and Development. Paris, France.

Oluwoye, J. 1996. *A Decision Support System for Pavement Management with GIS* GIS User. **17** 39-41

Paredes, M.; Fernando, E. and Scullion, T. 1990. *Pavement Management Applications of GIS: A Case Study* Transportation Research Record No. 1261. 20-26

Pearn, G. J. 1983. *Truck Performance and Haulage Costs Along Road Sections in the Circular Head Region of North-Western Tasmania – Honours Thesis.* Department of Forestry, Australian National University. Canberra, ACT, Australia. 219 p.

Plamondon, J. A. 1995. *Measuring the Effect of Slope on the Productivity of Skidders Using GPS.* Field Note: Skidding / Forwarding - 30 Forest Engineering Research Institute. Quebec, Canada.

Progisys Incorporated 1988. *Forest Roads Management System – Brochure.* Quebec, Canada.

Provencher, Y. 1997. *A Pavement Management System for Forestry Road Networks Thin Pavements, Surface Treatments, Unbound Roads: low cost, low volume...high tech!* UNB Forest Engineering. New Brunswick, Canada.

Provencher, Y. and Methot L. 1994. *Controlling the State of the Road Surface Through Grading Management.* Technical Report TR-110 Forest Engineering Research Institute of Canada. Quebec.

Pulkki, R. 1996. *Water Crossings Versus Transport Cost: A Network Analysis Case Study.* Journal of Forest Engineering. **7** (2) 59-64

QDPI Forestry 1997. *Forestry Roading Manual.* Queensland Department of Primary Industries Forestry Engineering Services. Brisbane, Queensland, Australia.

Queiroz, C. A. V. 1983. *Calibrating Response-Type Roughness Measurement Systems Through Road-and-Level Profiles.* Low-Volume Roads: Third International Conference, 1983. Transportation Research Record 898. Transportation Research Board. Washington DC, USA.

Reid, L. M. and Dunne, T. 1984. *Sediment Production from Forest Road Surfaces.* Water Resources Research. **20** (11) 1753-1761

Riverson, J. D. N.; Sinha, K. C. and Scholer, C. F. 1987. *Some Considerations for Local Unpaved Road Surface Management.* Second North American Conference on Managing Pavements. 2 - 6 November, 1987. Toronto, Canada.

Roberts, E. and Panyin, A. 1995. *Snig Track Management - Stage 1: Tracking and Mapping of Timber Harvesting Machines in Pinus radiata plantations.* Internal Report PN 003.95. CSIRO Division of Forestry and Forest Products. Canberra, ACT, Australia.

Roohanirad, A. 1994. *PMS for Low-Volume and Built-Up Roads.* Public Works. January Issue, Volume 44.

Rothwell, R. L. 1983. *Erosion and Sediment Control at Road-Stream Crossings.* The Forestry Chronicle. 62-67

Rummer, B.; Baumgras, J. and McNeel, J. 1998. *Forest Operations for Ecosystem Management.* Proceedings of the Sustainable Forestry Working Group at the IUFRO all division 5 conference. July 7-12, 1997. Pullman, Washington, USA. U.S. Department of Agriculture, Forest Service. Madison, Wisconsin, USA

Sedlak, O. J. 1988. *Maintenance of Forest Roads.* FAO Forest Operations Training Course. November, 1987. Phillipines.

Shaw, S. N. 1974. *Operational Efficiency of the Uriarra Forest Roads- Honours Thesis.* Department of Forestry, Australian National University. Canberra, Australia. 142 p.

Sokkia 1994. *Spectrum PC Users Guide.* Sokkia Technology, Inc.

Spear, B. D. and Cottrill B. 1993. *GIS Manages Grand Teton, Yellowstone Park Roads.* Geo Info Systems. **3** (10)

Standards Australia. 1989. *AS 2482-1989: Geographic information systems - Geographic data - Interchange of feature-coded digital mapping data.* Standards Australia. Melbourne, Victoria, Australia.

State Forests of NSW 1996a. *Capital Project Submission - Dog Tree Road.* State Forests of NSW. Tumbarumba, NSW, Australia.

State Forests of NSW 1996b. *Capital Project Submission - Pound Creek Area Gravelling Upgrade.* State Forests of NSW. Tumbarumba, NSW, Australia.

State Forests of NSW 1996c. *Forest Soil and Water Protection: A Manual for Machine Operators.* Forest Planning and Environment Division, State Forests of NSW. West Pennant Hills, NSW, Australia.

Steve, T. 1994. *"Hi-Tech Fleet Management" - Reprint of an article that appeared in 'Canadian Resources Review' magazine, August 1994.* Web page: http://www.truckbase.com/realtime/rt_reprint.html. Accessed on 19/6/98.

Stewart Scott Inc. 1995a. *Forestry Road Management System (FRMS).* Stewart Scott Inc. Consulting Engineers. Sandton, South Africa.

Stewart Scott Inc. 1995b. *Forestry Road Management System (FRMS).* Stewart Scott Inc. Consulting Engineers. Sandton, South Africa.

Swift Jr., L. W. 1984. *Gravel and Grass Surfacing Reduces Soil Loss from Mountain Roads.* Forest Science. **30** (3) 656-671

Tan, J. 1992. *Planning a Forest Road Network by a Spatial Data Handling Network Routing System.* The Society of Forestry in Finland and The Finnish Forest Research Institute. Helsinki, Finland.

Tarte, M. 1992. *Total Quality Management - Course Notes.* Ibex Consulting Pty Ltd. Sydney, Australia.

Thompson, J. D. 1996. *Water Quality Impacts from Forest Road Stream Crossings- Masters Thesis.* Auburn University. Auburn, Alabama, USA.

Thompson, J. D.; Delbridge, G. D.; McCormack, R. J. and Coleman, J. R. 1998. *Tracking forest harvesting machines with global positioning system (GPS) in South Eastern Australia.* 1998 ASAE Annual International Meeting . 13th - 17th July, 1998. Orlando, Florida, USA.

Ullidtz, P. 1985. *Pavment Management Systems in an European Context.* Proceedings, Pavement Management Systems Workshop. 9-22 August, 1985 Albury, NSW, Australia. Australian Road Research Board.

USDAFS 1983. *Pilot Test of Methodology to be Used for Developing A Database for the Forest Service Pavement Design & Management System.* United States Department of Agriculture Forest Service.

Utterback, P. 1992. *Testing an Urban Pavement Management System on a Forest Service Road Network.* Oregon State University. Corvallis, Oregon, USA. 135

Visser, A. T. and Curtayne, P. C. 1987. *The Maintenance and Design System: A Management Aid for Unpaved Road Networks.* Transportation Research Record 1106. 251-259

Visser, A. T.; de Villiers, E. M.; Genade, H. B. and van Heerden, M. J. J. 1995. *Optimizing Resources Through Unpaved Road Management System in the Cape Province of South Africa.* Proceedings of the Sixth International Conference on Low-Volume Roads, 1995.

Wallis, G. and McMahon, S. 1994. *The Impacts of Forest Management on Erosion and Sedimentation: A New Zealand Review.* LIRO Report Vol. 19, No. 2 Logging Industry Research Organisation. Rotorua, New Zealand.

Wang, K. C. P.; Li, X. and Elliot, R. P. 1997. *Capabilities and Structures of a Multimedia Based Highway Information System (MMHIS).* Computing in Civil Engineering - Proceedings of the Fourth Congress. American Society of Civil Engineers. New York, USA.

Waugh, G. 1996. *Restructuirng Opportunities for the Andrews Group of Companies - Client Report.* CSIRO Forestry and Forest Products. Clayton, Victoria, Australia.

Wemple, B. C.; Jones, J. A. and Grant, G. E. 1996. *Channel Network Extension by Logging Roads in Two Basins, Western Cascades, Oregon.* Water Resources Bulletin. **32** (6) 1195-1207

Winter, A. E. 1995. *A Study of Log Truck Travel Times in the Eden Region – Honours Thesis.* Deparment of Forestry, Australian National University. Canberra, Australia. 102 pages

Yamamoto, M. 1981. *An Effect of Sight Distance on the Driven Speeds of Vehicles on Mountainous Forest Roads.* 17th Annual IUFRO World Congress, 1981. 11 p.

APPENDIX A – GLOSSARY OF FOREST ROADING TERMS

Ageclass – A group of compartments in a plantation in which all the trees were planted in the same year

ArcView – A *Geographical Information System* produced by the Environmental Systems Research Institute (ESRI).

Back Loading – A type of log haulage operation that allows trucks to cart loads on their return to the forest, thereby minimising 'dead-running'. Eg. A truck carting sawlogs from a forest in the north of a region to a sawmill located in the south of a region can then pick up a load of chiplogs from a southerly forest coupe and deliver them to a chipmill located further north in the region during its return run to the sawlog coupe.

Batter – An earth slope formed during construction either by placing fill material or by cutting into the natural hillside

Borrow Pit – A pit left excavating material required due to a shortfall in fill material

Box Culvert – A rectangular concrete structures sometimes used in place of round culverts on creek and stream crossings

Box Cut – A situation in which the entire road surface is lower than the surrounding natural surface. This situation isn't always desirable as the water can't be dispersed from the roadway. A box cut immediately adjacent to a drainage feature means that water running off the road surface will be channelled directly into the feature.

Carriageway – The area of the road available for the passage of vehicles

Causeway – A natural or man-made crossing which enables a vehicle to cross ford a drainage feature.

Central Tyre Inflation – Technology that allows a log truck driver to adjust the tyre pressures of the truck, while driving, to suit the road conditions. This has benefits in decreasing wear and tear on both truck and roads.

Corduroy – The use of bundles of small round wood as a pavement material. Sometimes used at stream crossings.

Crossfall – An incline in the road pavement perpendicular to the direction of the road designed to shed water from the road surface.

Culvert – One or more adjacent enclosed conduits for conveying water underneath a road.

Cut – A section of road that has been constructed so that it is below the natural surface of the land the road is passing through *OR* Material excavated during the process of constructing such a road section.

Dropdown – A trough-like device for channelling water down a cut batter without chance of erosion, prior to dispersal of the water onto a more stable surface.

Energy Dissipater – A device installed at the outlet of a drainage structure that reduces the momentum of water exiting the structure, hence reducing the chance of scouring. Common dissipaters are rocks or logs deliberately placed at the outlet.

Erosion – Removal of soil through the actions of wind, rain or running water, or a combination of these factors.

Fill – Material used to build up a road so that the pavement is situated above the natural landscape.

Gabion – A retaining wall constructed from rock-filled wire baskets. Often used to support slumping batters.

Geographical Information System – A computer package that allows spatial analysis

Gloucester - Crossing constructed by placing a number of small diameter culverts (parallel to stream flow) in the drainage feature and then placing concrete or rock over the top of them

Global Positioning System – A device that uses satellite signals to determine its position on the earth's surface.

Gravel – Loose rock used to surface roads and improve bearing capacity

Gravel Pit – similar to a *Quarry* but usually used to refer to site that isn't managed as intensively.

Guardrail – A metal barrier used to prevent out-of-control vehicles from leaving the road carriageway where it would be dangerous to do so eg. Steep cut batter/bank., trees close to the road

Guidepost – Lightly coloured post used to delineate the shoulder of the road.

Headwall – A concrete device installed at either end of a culvert to prevent the fill material over the culvert from eroding due to the velocity of water entering and/or exiting the culvert.

Landing – A cleared, sometimes gravelled, site at a logging operation at which logs are stockpiled, debarked, processed and loaded onto trucks. Used in native logging operations and cable harvesting.

Loading Bay – An area constructed to allow either: (i) trucks to park off the road while being loaded; or (ii) a loading machine an area to work off the roadway with the truck parked on the road. Loading bays are used in plantation harvesting operations.

Mitre Drain - A drain constructed by a grader or backhoe that runs at an angle of approximately 45° to the direction of the road (Should run to limit grade and hence runoff velocity)

Pavement – A load bearing surface. The term is usually applied to transport related infrastructure e.g. roads, airport runways and railway tracks

Pulldown – A section of cut batter that has been excavated or 'laid back' to allow access from the road to the forest by harvesting machinery (esp. forwarders). The practice of constructing pulldowns is now banned by most forestry agencies as they concentrate water flow down the batter face causing erosion.

Quarry – A site from which sand, gravel or rock is excavated. Quarries are often the site at which gravel is crushed and stockpiled.

Relief pipe/culvert – A pipe used to direct water from a table drain and under a road

Rollover – Earth banks constructed on low-use roads such as firetrails in place of culverts. The banks are designed to be negotiable by 4WD vehicles.

Scouring – The removal of soil by fast moving water. Usually used to refer to damage caused by water exiting a drainage structure.

Sidecut – A description of the formation of road built on the side of a hill. Sidecut roads are characterised by having a cut batter on the upslope and a fill batter on the downslope.

Sight Distance – The extent to which a driver of a vehicle can see through a corner or over a crest. This often dictates the speed at which a driver feels comfortable negotiating a corner.

Spoon Drain – A shallow depression running across the road surface used to drain the pavement. These are often used where culvert installation isn't justified but heavy traffic use is anticipated.

Subgrade - The section of road beneath the pavement

Sump – A concrete box forming the inlet of a relief culvert. Sumps are usually used when a road is in *sidecut* to drain water collecting in the inside table drain.

Superelevation – The formation of a road corner to include banking. Installed to allow vehicles to negotiate corners safely at higher speeds.

Table drain – The side drain of a road adjacent to the road shoulders. Table drains run parallel to the road.

Turnaround – An area constructed to allow log trucks to turn about.

APPENDIX B - ILLUSTRATIONS OF FOREST ROAD TERMINOLOGY

Figure B. 1 Illustration of Forest Road Terms (after LIRO, 1985)

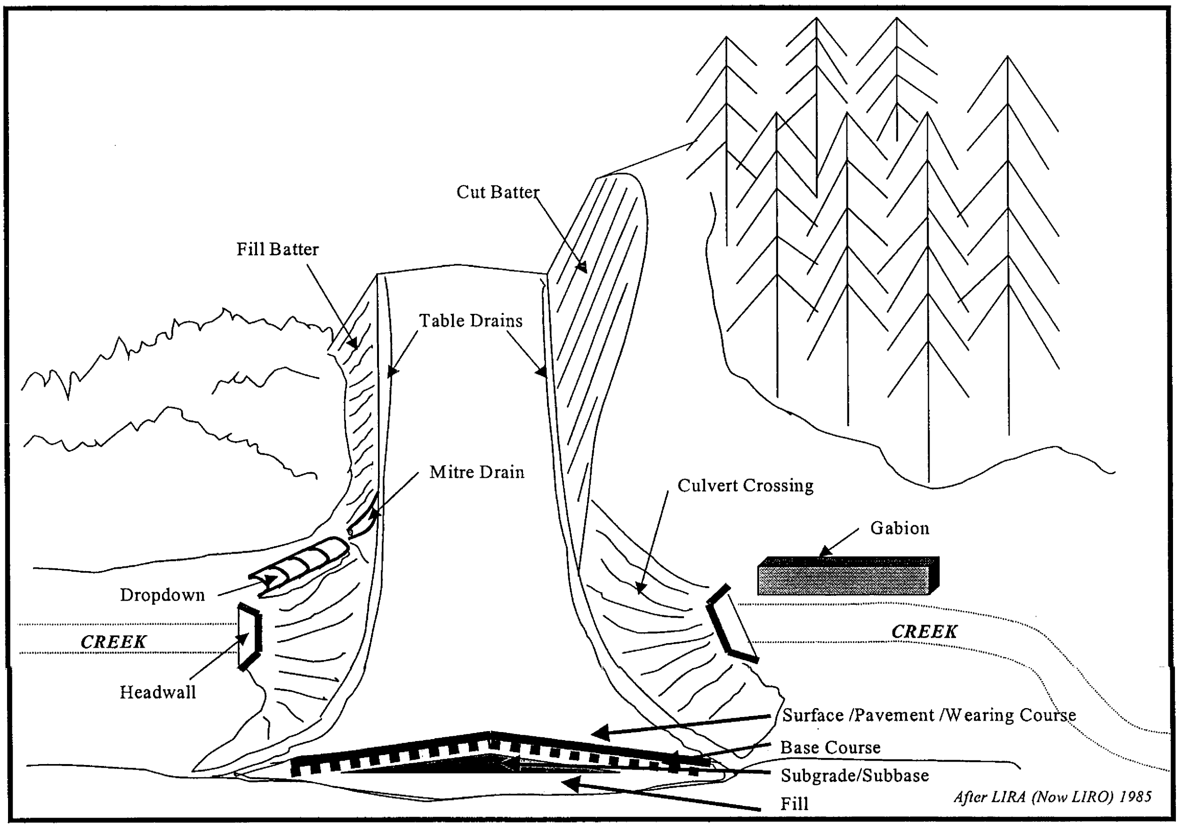
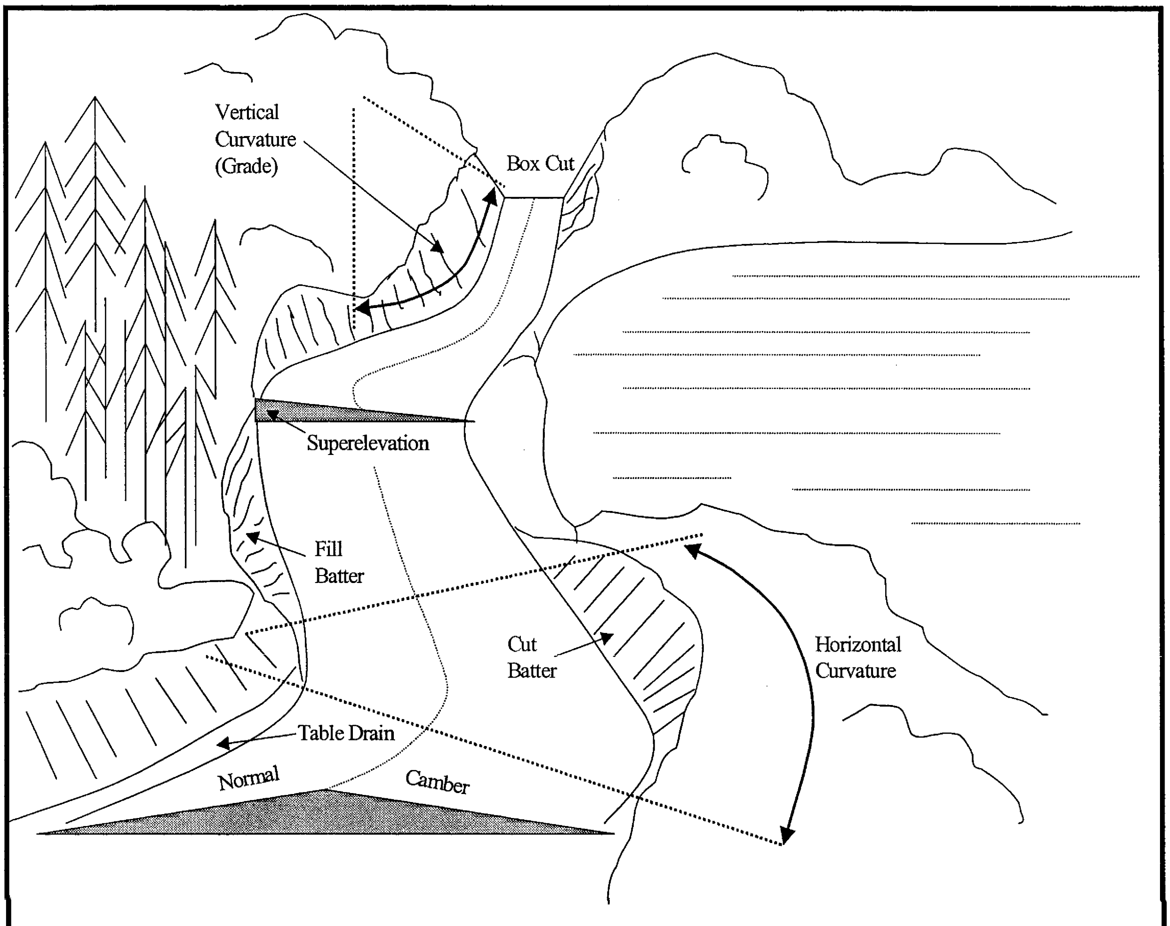


Figure B. 2 Illustration of Forest Roading Terms



After LIRA (Now LIRO) 1985

Figure B. 3 Cross Section of Forest Road (A) - after DCNR, 1995.

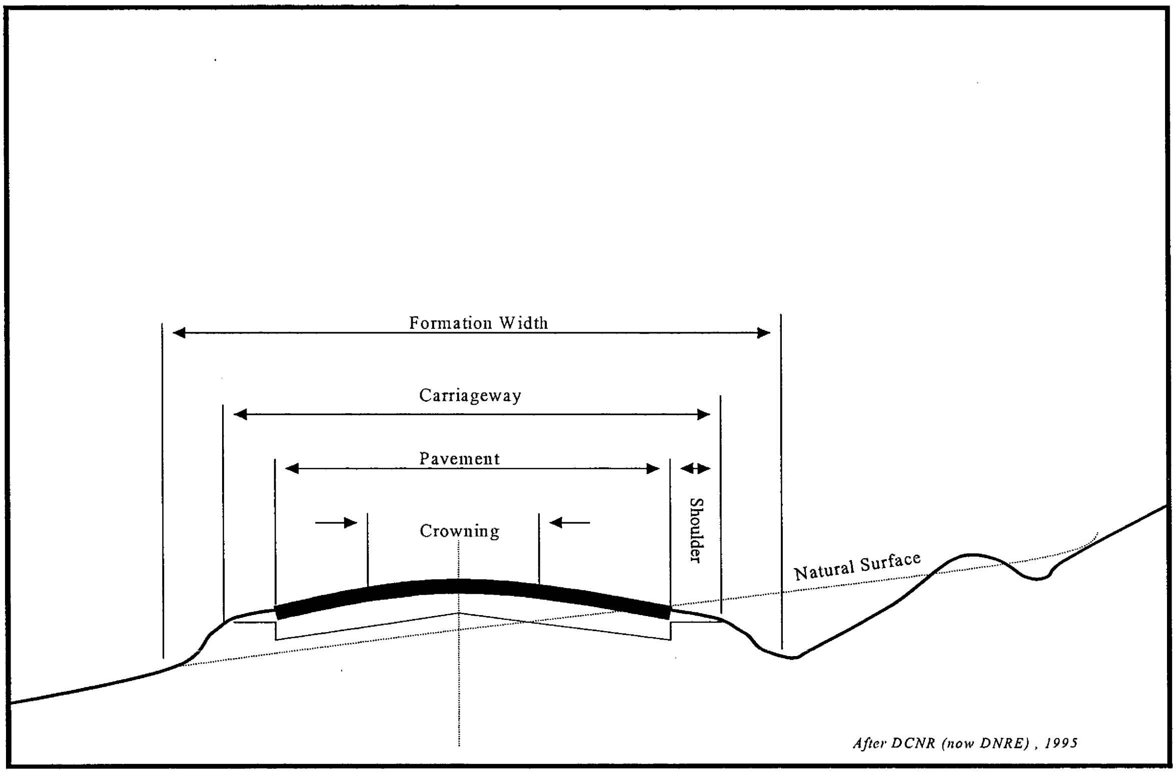
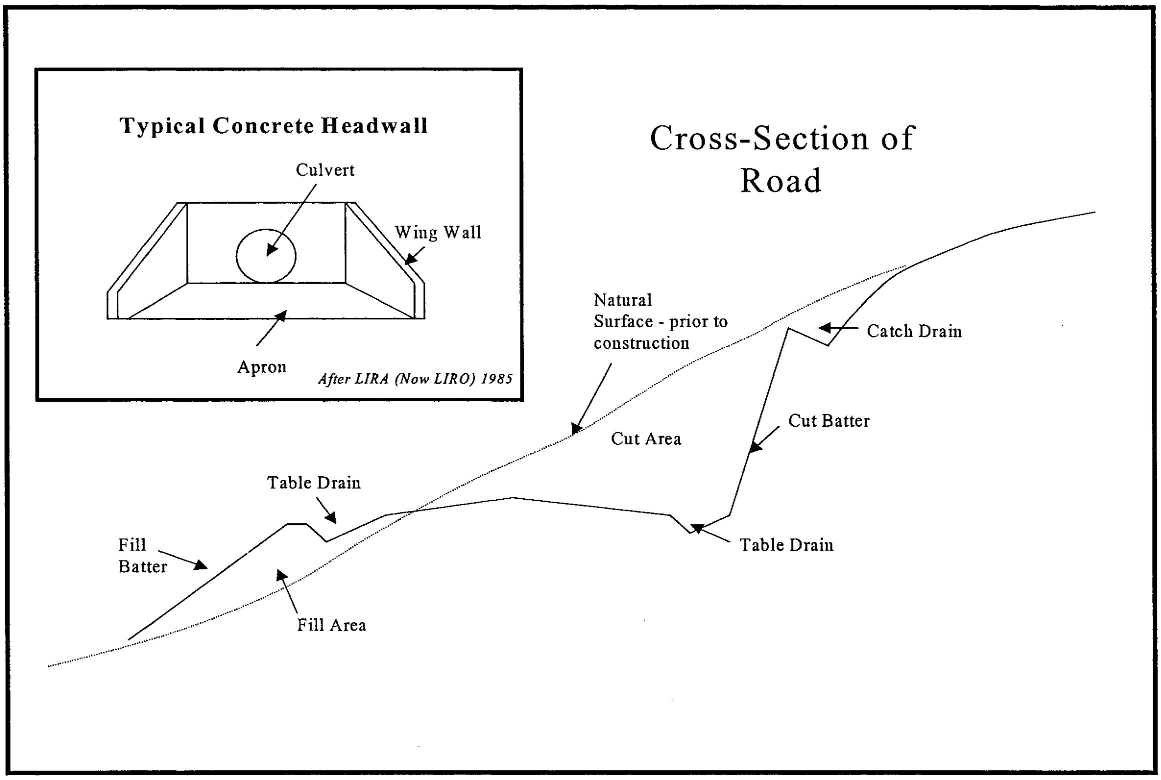


Figure B. 4 Cross Section of a Forest Road (B). Culvert Headwall Terms illustrated in *Inset* (after LIRO, 1985)



APPENDIX C - FOREST ROAD MANAGEMENT SYSTEM DATA COLLECTION INSTRUCTIONS

This set of instructions lists the attributes to be collected for each road feature type during data collection. The instructions can be used to program an electronic data logger (such as the Sokkia Packer data logger used in conjunction with GPS in this study). Most road feature types have a definition supplied, however the more common ones do not. Each attribute, used to describe the condition of a road feature, has a listing of the data type (eg. integer, text); mode of measurement; and, for data types that require a selection, a list of choices. Where necessary, the choices have the parameters detailed beside them. Sources used in the formulation of these instructions are referenced in the text and listed at the end of Appendix C.

BATTER

Definition:

AN EARTH SLOPE FORMED DURING CONSTRUCTION EITHER BY PLACING FILL MATERIAL OR BY CUTTING INTO THE NATURAL HILLSIDE (*STATE FORESTS OF NSW, 1996*).

Type
Data Format: Text Select
Measurement: Visual
Choices:

Cut (Default)
Fill
Side

Depth-Average or Max
Data Format: Integer
Measurement: Estimate or 50 m tape
Choices

3 (Default) — **** For sidecut situations, that have both cut and fill batters, add the depths of both batters***

1 to 20 metres

Length
Data Format: Integer
Measurement: Estimate or 50 m tape
Choices

50 (Default)
20 to 300 metres

Condition
Data Format: Text Select
Measurement: Visual
Choices

Stable (Default)	Batter in no danger of erosion
Revegetating	Batter revegetating satisfactorily but should be checked again in **6** months
Eroding	Evidence of erosion of batter face occurring with little or no revegetation
Washed Out	Evidence of deeply channelled water flow down batter face during, or immediately after, heavy rainfall **OR** batter is slumping so that batter toe is in table drain

BORROWPIT

Definition:

A PIT LEFT AFTER EXCAVATING MATERIAL REQUIRED DUE TO A SHORTFALL IN FILL MATERIAL (DURING ROAD CONSTRUCTION).

Length

Data Format: Integer
Measurement: Estimate or 50 m tape
Choices

- 5 (Default)
- 1 to 30 metres

Depth

Data Format: Integer
Measurement: Estimate or 50 m tape
Choices

- 2 (Default)
- 1 to 10 metres

Stability

Data Format: Text Select
Measurement: Visual
Choices:

- Stable (Default)
- Revegetating
- Eroding

BRIDGE

Type
Data Format: Text Select
Measurement: Visual
Choices

Log (Default) - Bridge constructed entirely from logs

Arch Span - Crossing constructed from prefabricated, corrugated metal arch pieces

Box Culvert - Square or rectangular, prefabricated concrete culverts, capable of handling large volumes of water

Concrete - Bridge made primarily of concrete

Concrete/Metal - Bridge constructed using metal girders and concrete decking and kerbing

Timber - Bridge primarily constructed of sawn timber

Helcor Pipe - Crossing constructed of cylindrical pipe manufactured from prefabricated, corrugated, galvanised metal. Diameter approximately 2 metres.

Condition
Data Format: Text
Measurement: Estimate or detailed testing
Choices

'*Stable*' (Default)
Up to 40 characters

CAUSEWAY

Definition:

INCLUDES BOX CULVERTS AND CAUSEWAYS

Type
Data Format: Text Select
Measurement: Visual
Choices

Natural Causeway (Default)
- No crossing structure in place, vehicles drive through drainage feature

Corduroy
- Crossing composed of small logs placed on the stream / creek bed

Built Causeway
- A man-made structure enabling vehicles to ford a drainage feature

Hollow Log
- Hollow log used in place of a culvert

Log Fill
- Type of crossing made by pushing logs into drainage feature and then covering with fill material to allow vehicles to cross

Sill
- Crossing comprised of two lines of logs placed perpendicular to stream flow and spaced a little more than a vehicle width apart

Gloucester
- Crossing constructed by placing a number of small diameter culverts (parallel to stream flow) in the drainage feature and then placing concrete or rock over the top of them

Condition
Data Format: Text
Measurement: Estimate or detailed testing
Choices:

'*Stable*' (Default)
Up to 40 characters

CULVERT

Size

Data Format: Integer
Measurement: Tape measure, across diameter of inlet or outlet
Choices:

375 (Default)	
375 - 2100	mm

Condition

Data Format: Text Select
Measurement: Visual / Tape measure
Choices:

Stable (Default)	Culvert functioning properly
Unit Blocked	Culvert should be rated as blocked if entire culvert is over one-third blocked
Inlet Blocked	Inlet is over one-third blocked
Outlet Blocked	Outlet is over one-third blocked
Washed Out	Fill has been washed from around the culvert sufficient to prevent a vehicle from safely passing over it
Cracked	Cracked or broken to the extent that it diminishes the performance of the culvert in any way

* If more than one fault is applicable, assessor should choose the fault that is most costly to repair

Headwalls

Data Format: Text Select
Measurement: Visual
Choices:

None (Default)	No Headwalls on Culvert
Inlet	Headwall located on inlet side only
Outlet	Headwall located on outlet side only
Both	Headwalls located on both sides
RIH	Requires headwall on inlet
ROH	Requires headwall on outlet
RBH	Requires headwall on both sides

Sumps
Data Format: Text Select
Measurement: Visual
Choices:

None (Default)	No sump present or required
Sump	Functioning Sump present
RS	Sump Required
BS	Sump exists but is blocked by debris and requires cleaning

Dropdowns
Data Format: Text Select
Measurement: Visual
Choices:

None (Default)	No dropdown present or required
Drop Down	Functioning Drop Down present
RD	Drop down Required

Rip-Raps ***(Energy Dissipaters)***
Data Format: Text Select
Measurement: Visual
Choices:

None (Default)	No rip-rap present or required
Rip-Rap	Functioning Energy Dissipater present
RR	Rip-Rap Required

Erosion
Data Format: Text Select
Measurement: Visual / Tape measure **OR** ruler
Choices:

None (Default) — No significant erosion at either inlet or outlet

Outlet Eroding

The outlet should be considered as eroding if:
- a channelled gully has formed that is deeper than 10 cm
- if the culvert has been undermined by more than 10 cm.

Inlet Eroding

The inlet should be considered as eroding if:
- a channelled gully of depth >10cm has formed for more than 1 metre up the table drain
- if the culvert inlet has been undermined by more than 10 cm
- if there is evidence that the water is flowing beside the culvert rather than through it.

No. of Cells
Data Format: Text Select
Measurement: Visual
Choices:

1 (Default), 2, 3 or 4

EROSIONPOINT

Site
Data Format: Text Select
Measurement: Visual
Choices:

- Pavement (Default)
- Batter
- Table drain

Extent
Data Format: Text Select
Measurement: Visual or Tape measure / ruler
Choices:

Severity Rating (SR) 1 (Default)	Erosion depth < 10 cm
Severity Rating (SR) 2	Erosion depth 10 – 30 cm
Severity Rating (SR) 3	Erosion depth > 30 cm

Zone
Data Format: Text Select
Measurement: Visual
Choices:

Point (Default)	Erosion occurs at a point
A	Start of an eroded zone - most south westerly point
B	Start of an eroded zone - most north easterly point

FURNITURE

Definition:

ANY MAN-MADE ITEM ASSOCIATED WITH THE ROAD BUT NOT INFLUENCING THE PERFORMANCE OF the PAVEMENT. USUALLY ASSOCIATED WITH SAFETY.

Type
Data Format: Text Select
Measurement: Visual
Choices:

- Guardrail
- Guidepost (Default)
- Gate

Condition
Data Format: Text Select
Measurement: Visual
Choices:

- Good (Default)
- Poor

GRID

Definition:

STRUCTURE THAT ALLOWS VEHICLES TO PASS OVER IT BUT IS DESIGNED SO THAT CATTLE CAN'T CROSS IT.

Condition
Data Format: Text Select
Measurement: Visual
Choices:

Good (Default)
Poor - Grid ineffective due to build up of dirt and litter underneath it or grid presents danger to traffic

INSTALL

Definition:

USED TO INDICATE THAT AN ASSET IS REQUIRED TO IMPROVE THE PERFORMANCE OR SAFETY OF THE ROAD.

Item
Data Format: Text Select
Measurement: Visual
Choices:

- Pipe (Default)
- Rollover
- Spoondrain
- Sign
- Guidepost
- Guardrail
- Cattlegrid

Comments
Data Format: Text (*Up to 30 characters*)

LANDING

Definition:

A CLEARED (SOMETIMES GRAVELLED) SITE AT A LOGGING OPERATION AT WHICH LOGS ARE STOCKPILED, DEBARKED, PROCESSED AND LOADED ONTO TRUCKS.

Surface
Data Format: Text Select
Measurement: Visual
Choices:

Gravel (Default)
Natural Surface

Width
Data Format: Integer
Measurement: Estimate or Tape measure
Choices:

50 (Default)	
10 to 200	m

Length
Data Format: Integer
Measurement: Estimate or Tape measure
Choices:

100 (Default)	
10 to 200	m

Operation
Data Format: Text Select
Measurement: Visual / prior knowledge / harvesting records
Choices:

Conventional (Default)	
Cable	Select if landing specific to cable operation
Chipping	Select if landing specific to chipping operation

LOADINGBAY

Definition:

AN AREA CONSTRUCTED TO ALLOW EITHER: (I) TRUCKS TO PARK OFF THE ROAD WHILE BEING LOADED; OR (II) A LOADING MACHINE AN AREA TO WORK OFF THE ROADWAY WITH THE TRUCK PARKED ON THE ROAD. LOADING BAYS ARE USED IN PLANTATION HARVESTING OPERATIONS.

Surface
Data Format: Text Select
Measurement: Visual
Choices:

Gravel (Default)
Natural Surface

Length
Data Format: Integer
Measurement: Estimate or Tape measure
Choices:

40m (Default)
20 to 150m

MITREDRAIN

Definition:

AN EXTENSION OF THE TABLE DRAIN CONSTRUCTED BY A GRADER OR BACKHOE THAT RUNS AT AN ANGLE OF APPROXIMATELY 45^{O} TO THE DIRECTION OF THE ROAD.

Condition
Data Format: Text Select
Measurement: Visual
Choices:

Good (Default)	
Debris	Debris or slash is preventing mitre from diverting water from road surface
Sedimentation	Evidence of heavy sediment deposition within the drain or at outlet
Not Functioning	Eg. Mitre running uphill or is failing to divert water due to poor construction.

PAVEMENT (*DEFECT*)

Defect
Data Format: Text Select
Measurement: Visual
Choices:

Corrugations (Default)
- Severity Rating (SR) 1:
  Corrugations don't affect vehicle travel speed
- Severity Rating (SR) 2:
  Vehicle must slow down to negotiate
- Severity Rating (SR) 3:
  Vehicle must slow to walking pace to negotiate

Rutting
- Severity Rating (SR) 1: Depth of ruts < 10 cm
- Severity Rating (SR) 2: Depth of ruts 10 – 20 cm
- Severity Rating (SR) 3: Depth of ruts > 20 cm

Potholes
- Severity Rating (SR) 1: < 5 per 100 m section
- Severity Rating (SR) 2: 5 – 15 per 100 m section
- Severity Rating (SR) 3: > 15 per 100 m section

OECD (1990)

Gravel Loss

Gravel has been removed from the road such that a clearly defined 'wheelpath' of exposed subgrade can be seen. No severity rating is necessary.

Dusting

Vehicle driving at appropriate speed produces dust cloud:
- Severity Rating (SR) 1: < 1 m
- Severity Rating (SR) 2: 1 – 2 m
- Severity Rating (SR) 3: > 2 m =

(based on *Kramer (1991) in Morkel (1994)*).

Extent
Data Format: Text Select
Choices:

Severity Rating (SR) 1 (Default)
Severity Rating (SR) 2
Severity Rating (SR) 3

Zone
Data Format: Text Select
Measurement: Visual
Choices:

Point (Default)	Defect occurs at a point
A	Start of a defect zone - most south westerly point
B	Start of a defect zone - most north easterly point

Comments
Data Format: Text (*Up to 30 characters*)

PULLDOWN

Definition:

A SECTION OF CUT BATTER THAT HAS BEEN EXCAVATED OR 'LAID BACK' TO ALLOW ACCESS FROM THE ROAD TO THE FOREST BY HARVESTING MACHINERY (ESP. FORWARDERS). THE PRACTICE OF CONSTRUCTING PULLDOWNS IS NOW BANNED BY MOST FORESTRY AGENCIES AS THEY CONCENTRATE WATER FLOW DOWN THE BATTER FACE CAUSING EROSION.

Condition

Data Format: Text Select
Measurement: Visual
Choices:

Stable (Default)
Eroding

QUARRY

Definition:

A SITE FROM WHICH SAND, GRAVEL OR ROCK IS EXCAVATED. QUARRIES ARE OFTEN THE SITE AT WHICH GRAVEL IS CRUSHED AND STOCKPILED.

Name
Data Format: Text (*Up to 20 characters*)

Product
Text Select
Choices:

Gravel (Default)
Rock
Sand

ROLLOVER

Definition:

AN EARTH BANK CONSTRUCTED ACROSS A ROAD TO DIVERT WATER FROM ITS SURFACE (ALSO CALLED *CROSSBANKS* or *WATERBARS*).

Stability
Data Format: Text Select
Measurement: Visual
Choices:

Adequate (Default)	Rollover functioning properly
Eroding	Actual structure is being eroded
Fluming	Heavy sediment deposition at outlet side
Overrun	Structure fails to prevent water continuing down road surface

SEALEDRD

Definition:

DEFECT TYPES CONFINED TO SEALED ROADS.

Distress Item
Data Format: Text Select
Measurement: Visual
Choices:

Stripping (Default)
- Aggregate removed from bitumen by passage of vehicles (also known as *fretting* or *ravelling*)

Rutting
- Permanent depressions in wheelpaths. Often bordered by excess material displaced by the rutting process (*OECD 1990*).

Corrugations
- Shallow and evenly spaced ridges of pavement that have formed perpendicular to the road direction (*OECD 1990*).

Potholes
- Depressions in surface of the road caused by vertical pavement settlement. Often the pavement material is cracked or has lifted out (*OECD 1990*).
- Round holes caused by loss of pavement (*OECD 1990*).

Transverse Crack
- Rupture of the width of the road (*OECD 1990*).
Longitudinal Crack
- Cracks in pavement running parallel to direction of travel (*OECD 1999*).

Interconnected Crack
- Network of cracks in all directions, linked together. Either localised in wheelpaths or covering the full width of the road (*OECD 1990*).

Shoulder Crack
- Cracking and disintegration of the edges of the bitumen pavement (*OECD 1990*)

Bleeding
- Localised accumulation of bitumen at road surface, making road appear black and/or shiny (*OECD 1990*)

Zone
Data Format: Text Select
Measurement: Visual
Choices:

Point (default)	Fault occurs at a point
A	Start of n fault zone - most south westerly point
B	Start of n fault zone - most north easterly point

Comments
Data Format: Text (*Up to 50 characters*)

- **Even minor instances should be recorded due to their potential to lead to very expensive damage and/or to create dangerous road conditions (vehicles travel at relatively high speeds on sealed roads).**

SPOONDRAIN

Definition:

A SHALLOW DEPRESSION RUNNING ACROSS THE ROAD SURFACE USED TO DRAIN THE PAVEMENT.

Stability

Data Format: Text Select
Measurement: Visual
Choices:

Adequate (Default)	Spoon drain functioning properly
Eroding	Actual structure is being eroded
Fluming	Heavy sediment deposition at outlet side
Overrun	Structure fails to prevent water continuing down road surface

TURNAROUND

Definition:

AN AREA SPECIFICALLY CLEARED OR CONSTRUCTED FOR LOG TRUCKS TO TURN AROUND.

Type
Data Format: Text Select
Measurement: Visual
Choices:

- Circular (Default)
- T-Shape
- L-Shape
- Irregular

Surface
Data Format: Text Select
Measurement: Visual
Choices:

- Gravel (Default)
- Natural Surface

WALL *(IE. RETAINING WALL)*

Definition:

A STRUCTURE INSTALLED TO PREVENT BANKS / BATTERS FROM SUBSIDING.

Type
Data Format: Text Select
Measurement: Visual
Choices:

Gabion (Default) - ie. Retaining wall constructed of rock filled wire baskets
Log
Other

Condition
Data Format: Text Select
Measurement: Visual
Choices:

OK (Default)
Needs Repair Retaining wall not effective

XING (*CROSSING*)

Definition:

INTERSECTION OF ROAD NETWORK AND DRAINAGE NETWORK.

Permanence
Data Format: Text Select
Measurement: Visual
Choices:

Drainage Line (Default)

Concentration of natural water only during or immediately after periods of heavy rainfall. Characterised by having an incised channel >30cm deep, or by showing signs of active erosion or soil deposited between banks and beds (*State Forests of NSW 1996*).

Depression

Gently inclined, open depression that conveys water only during or immediately after periods of heavy rainfall. Generally found above drainage lines in the upper slopes of catchments (*State Forests of NSW 1996*).

Water Course

Has a well defined bed and bank, down which water flows on a permanent or semi-permanent basis. ie. streams, creeks and rivers (*State Forests of NSW 1996*).

Swamp

Extended area of low-lying country that is waterlogged for the most of the year

Dam

Body of stationary water that has an overflow point

Type
Data Format: Text Select
Measurement: Visual
Choices:

Culvert (Default)

Bridge

Natural Causeway

No crossing structure in place, vehicles drive through drainage feature

Corduroy

Crossing composed of small logs

Built Causeway

A man-made structure enabling vehicles to ford a drainage feature

Hollow Log

Hollow log used in place of a culvert

Log Fill

Type of crossing made by pushing logs into drainage feature and then covering with a fill material to allow vehicles to cross

Sill

Crossing comprised of two lines of logs placed perpendicular to stream flow and spaced a little more than a vehicle width apart

Gloucester

Crossing constructed by placing a number of small diameter culverts (Parallel to stream flow) in the drainage feature and then placing concrete or rock over the top of them

REFERENCES USED IN APPENDIX C

Morkel, R. 1994. *The Management of South African Roads in Perspective*. Unpublished honours dissertation, University of Stellenboch, Forest Engineering Technology Centre, Faculty of Forestry.

OECD. 1990. *Road Monitoring for Maintenance Management.* (Volume 1: Manual for Developing Countries ed.). Paris, France: OECD Publication Service.

State Forests of NSW. (1996). *Forest Soil and Water Protection: A Manual for Machine Operators*. Forest Planning and Environment Division, State Forests of NSW. West Pennant Hills, NSW, Australia.