AN ABSTRACT OF THE THESIS OF

Dunstan T.K. Shemwetta for the degree of Doctor of Philosophy in Forest Engineering presented on May 7 1997. Title: Comprehensive Timber Harvest Planning for Plantation Forests on Difficult Terrain: Sokoine University of Agriculture Training Forest, Tanzania.

Abstract approved: John J. Garland

John J. Garland

Plantation forests on mountainous areas in Tanzania, East Africa, were successfully established in the 1950's. Harvesting started in the 1970's to meet increased national timber demand. Current problems of unharvested areas and potential environmental degradation are associated with uncontrolled harvests, mismatch of harvest systems to site needs, and post-harvest practices. Comprehensive harvest planning is offered as the needed solution. Effective timber harvest planning is proposed for successful harvesting using a suggested process and protocol. Planning for difficult terrain in the United States Pacific Northwest (PNW) provides valuable lessons for objective refinement, systems selection, monitoring and planning tools of the protocol.

An area on the Sokoine University of Agriculture Training Forest (SUATF), Tanzania, with difficult terrain, valuable timber, and environmentally sensitive conditions is used to develop a planning protocol and monitoring guidelines for harvesting. A reference area on the Warm Springs Indian Reservation (WSIR) of Oregon provides comparative data for the project. Plan objectives, planning tools, harvesting systems options, implementation requirements and monitoring criteria were explored through observation, interviews and analytical procedures.

A planning procedure incorporating the technical, economical and institutional timber harvesting factors of Tanzania and other similar circumstances is demonstrated. Guidelines for monitoring plan execution and harvesting impacts are shown, with a new emphasis on research monitoring. The study recommendations and summary will help Tanzania national forestry policy to avoid crisis management in harvesting operations.

Comprehensive Timber Harvest Planning for Plantation Forests
on Difficult Terrain: Sokoine University of Agriculture Training Forest, Tanzania.

by

Dunstan T.K. Shemwetta

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

DOCTOR OF PHILOSOPHY

Presented May 7, 1997
Commencement June 1997

©Copyright by Dunstan T.K. Shemwetta

May 7, 1997

All Rights Reserved

Doctor of Philosophy thesis of Dunstan T.K. Shemwetta presented on May 7, 1997.

APPROVED:

John J. Garland

Major Professor, representing Forest Engineering

Head of Department of Forest Engineering

Dean of Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Dunstan T.K. Shemwetta, Author

ACKNOWLEDGMENTS

I wish to acknowledge the full sponsorship I received for this program from the Norwegian Agency for Development Co-operation (NORAD), through its support to the Faculty of Forestry, Sokoine University of Agriculture in Tanzania. These institutions made this study a reality.

I would like to express my profound appreciation to Dr. John J. Garland, my Major Professor, for his constant inspiration, guidance and perseverance during the course of my studies. My appreciation also goes to Dr. Ward Carson, my Minor Professor for his support and positive impact in my efforts to acquire new knowledge. I wish to convey my gratitude to Professor John Sessions and Professor Paul Adams for their critical but constructive contributions towards my achievement. I would also thank Professor Everett Hansen for serving as Graduate Representative in my committee. To all of them I express my sincere appreciation for making this a smooth and excellent program.

I also wish to thank Professors S.A.O. Chamshama and R.C. Ishengoma, the former and current Deans of the Faculty of Forestry, Sokoine University of Agriculture, for their commitment to this program. I will not forget the good foresters at University Training Forest in Olmotonyi, especially Mr. Lotana Reteu; and those at Warm Springs, who cooperated magnificently during this study. And to all those who in one way or the other contributed to the success of this endeavor, I say "Ahsante Sana".

Finally I would like to express my heartfelt accolade to my family who kindled my hopes and courage throughout the tough times: To my wife, Rebecca, who accepted and performed magnificently the difficult responsibilities to our family in my absence, while providing me with love and continuous encouragement. I also cherish the abstinence of my children Blandina, Chancellor, Aksa and Samuel, to whom I say "Tizavota".

DTKS, 1997.

Table of Contents

Table of Contents (Continued)

Table of Contents (Continued)

Page

List of Figures

List of Tables

List of Appendices

To my mother, Ester; and my father, Tahona.

You gave me courage and resilience.

Comprehensive Timber Harvest Planning for Plantation Forests on Difficult Terrain: Sokoine University of Agriculture Training Forest, Tanzania.

CHAPTER 1

INTRODUCTION

"Without sound planning, crisis management is inevitable" (Brink *et al.* 1994)

1.1 Background

Timber harvesting is necessary to gain benefits from a forest enterprise. It is the first in a sequence of events and activities to convert a forest from a community of trees into consumer products. The success of timber harvesting depends on existing physical, economic and institutional factors. Whereas timber harvesting was taken to be solely an economic venture, recent concerns for the environment have brought in other strong factors. Effects of timber harvesting on soils, residual trees, wildlife and water regimes have to be considered along with the economic implications. Timber harvesting on steep terrain can increase effects on the environment and tighten physical constraints. Soils are more prone to disturbance; harvesting systems reach limitations; and accessibility becomes more difficult. The first ten years of harvesting publicly owned plantation forests in Tanzania has shown efficiency and environmental problems, especially on areas of difficult terrain. This suggests a need for comprehensive timber harvest planning protocols to make plantation harvesting as successful as how the plantations were established.

In its simplest form, planning is a statement of intended actions. Timber harvest planning is organizing proposed processes and actions to achieve intended goals of harvest operations. Planning timber harvesting is a part of overall forest management planning (Dykstra & Heinrich, 1996). After all, timber harvesting is only one realization of the broad forestry goals for an area. Many factors can be considered in timber harvest planning: accurate information on the timber and terrain characteristics, climate, labor and harvesting systems. Of late, forestry is no longer focused exclusively on the production of commercial timber but on the environment and the aspirations of the local community. Biological diversity, non-timber products, cultural values, and environmental concerns have made forestry a more complex and demanding discipline (Cubbage, O'Laughling & Bullock III, 1993). What used to be a straightforward production undertaking now requires a serious, multi-resource, comprehensive planning to accomplish timber harvesting goals and objectives.

Listed below are factors considered during timber harvest planning, (not in order of priority):

- Objectives of the owner or administrator
- Harvest scheduling
- Cost efficiency
- Capital requirement
- Information needs for terrain, timber, social and environment
- Available harvesting technologies
- Transportation options, systems, costs and effects
- Environmental effects to soil and water
- Associated production aspects, e.g., agroforestry, cropping and grazing
- Wildlife and fisheries concerns

- Rare and endangered plants, animals and habitats
- Aesthetic concerns for visual quality
- Workforce requirements and utilization
- Infrastructure and maintenance demands for harvesting systems
- Post-harvest operations for reforestation or other purposes, e.g., slash treatment to reduce fire hazard
- Long term monitoring requirements
- Control of quality and quantity of production
- Legal and regulatory obligations
- Safety and health implications
- Concerns for implementation and administration.

The list shows timber harvesting to be a complex undertaking requiring the balance of many factors. In summing up the essential components, I advance the definition of timber harvest planning as *the process of organizing intended harvest operations to achieve refined objectives while accounting for the physical limitations, economic expectations and environmental concerns. The organization must include objectives definition, area description, identification of economic and environmental and cultural values, selection of all-round feasible harvesting system, plan implementation and the associated plan evaluation and monitoring of the harvesting effects.*

1.2 Plantation Forests in Tanzania

Research on plantation forestry in Tanzania began almost 90 years ago in the fields of silviculture and wood utilization as a necessity to save over-utilization of slow growing native forests. The need to establish plantation forests to meet future wood demands called for silvicultural research on suitable tree species for afforestation. The need for useful wood products also compelled research on good quality timber species. Plantation forests eventually became established in the 1950s, mostly on mountainous areas. The plantations are on public lands and hence publicly owned, being managed by the Ministry responsible for natural resources. These plantations are softwood species of pines and cypress, plus hardwood species such as eucalyptus, grevillea and teak (Abeli & Maliondo, 1992). The annual growth of these species varies from 25 to 35 cubic meters per hectare, yielding a rotation of 25 years for the softwoods. At present, there are 19 industrial forest plantations in Tanzania covering a total area of about 89,000 hectares (Nshubemuki, Chamshama & Mugasha, 1996). Ahlaback (1992) reported that the potential allowable annual cut from these plantations in 1990 was estimated at 2.2 million cubic meters, whereas only 0.5 million cubic meters were removed.

Before 1970, almost all industrial timber came from natural forests where traditional harvesting methods of simple tools and pit-sawing were sufficient to meet the demand. Demand for wood products became significant in 1970, mainly driven by population growth, causing over-utilization of indigenous forests (Abeli, 1992). At this same time, plantation forests came into harvest rotation age and significantly contributed to meeting increased demand; hence, the introduction of new harvesting systems. Timber harvesting thus became one of the main tasks of forest management, demanding efficient and effective logging and transportation systems.

1.3 Research Problem

Unlike forest establishment and species selection, timber harvesting did not have local research-based information before significant activity was undertaken. Some studies have contributed to the improved design and construction of forest roads, development of labor-intensive logging methods and tools, and performance data on different harvesting systems and logging scenarios (Abeli, 1992). However, there is no tangible indication that research findings were used in timber harvest planning in the Tanzania plantations. Literature shows that negative effects of harvesting practices on the environment are either ignored (Maganga & Chamshama, 1984; Fue & Migunga, 1992) or misconstrued (Tarimo, 1996). Timber harvesting in Tanzania, especially the way it is planned, need to be assessed with respect to the advanced definition. What is termed as timber harvest planning starts with an inventory and ends with the allocation of compartments for harvesting. Harvesting systems, transportation systems, logging and associated environmental and social effects, and post-harvest activities are not currently considered as essential parts of forest management planning. In general, there is no timber harvest planning in the real sense of the term.

Currently, Tanzanian plantation forest management objectives are broad statements of management for sustained yield and protection of natural resources. Timber harvesting is performed under voluntary guidelines interpreted from the "Forest Division Standing Orders", which lack the present-day technical, economical and environmental implications. Apart from brief statements of volumes to be harvested and areas involved, no efforts are made to produce well-documented harvesting plans. Harvesting methods applied are geared to suit available techniques rather than seeking techniques which meet appropriate criteria. In general, the plans are too simplistic for practical purposes of dealing with diverse and complex considerations. The force behind timber harvesting is mostly driven by volume with no apparent regard for harvesting efficiency and environmental conservation. The fact that most of the plantation forests are on mountainous areas further complicates planning. There is evidence that inappropriate logging systems may induce erosion and possibly negatively affect the hydrologic regimes.

The consequence of inappropriately planned timber harvesting, and especially mismatched harvesting systems are economic, technical and environmental problems. Obvious problems include uncontrolled harvests, waste of resources, site degradation, and adverse effects on soils, water and other non-timber forest benefits. Furthermore, because of social and economic pressures, there are urgent needs for better forest management, better harvesting methods, conservation and environmental protection a planning solution helps provide. Sokoine University of Agriculture Training Forest (SUATF) is a good representative of Tanzanian plantation forests in almost all aspects. While other compartments within the Training Forest have been harvested once and are in second generation, substantial areas bearing mature volumes remain unharvested. They are exposed to heart rot and vandalism due to inaccessibility attributed to "difficult terrain" (Shemwetta & Garland, 1996). Within the SUATF study area, the magnitude of the planning problem is identified and a probable solution protocol advanced by this study.

1.4 Research Premise

Forestry in North America, specifically in the United States, has undergone tremendous developments in the 200 years of the nation (MacCleery, 1992). Timber harvesting practices on federal/public lands in the United States of America Pacific Northwest (PNW), are carried out after elaborate planning, followed by close monitoring to ensure efficiency and minimum effects on the environment. Comprehensive timber harvest planning is an obligation under federal law, addressing significant issues and controversies surrounding management of US forests such as: protection of remaining old-growth forests, maintenance of biological diversity, protection of endangered species, avoiding loss of wetlands, use of herbicides and issues of atmospheric pollution to just name a few (MacCleery, 1992).

Planning protocols and the effectiveness of timber harvest planning in the U.S. Pacific Northwest provide some valuable lessons. The accomplishments of plan objectives, planning tools, harvest systems options, implementation requirements and monitoring criteria have been examined in different settings. Assessments of planning protocols practiced provided a basis for developing effective planning procedures for Tanzanian timber harvesting situations and other similar circumstances. The U.S. Pacific Northwest illustrates many forms of timber harvest planning to go with the spectrum of ownerships (small private forest owners to large US Forest Service) and the broad institutional and technical bases and their associated problems. Proven effective planning procedures as well as failed attempts provide a rich base to learn more about what constitutes effective harvesting planning.

1.5 The Thesis

A comprehensive timber harvesting plan is asserted to be the needed solution for problems associated with timber harvesting in Tanzania. This thesis seeks to provide the first protocol of comprehensive planning and monitoring of timber harvesting on difficult terrain of Tanzania plantation forests.

A planning procedure intended for the technical, economical and institutional timber harvesting situations of SUATF in Tanzania and other similar circumstances should improve the efficiency of timber harvesting and safeguard the environment from expected effects. A comprehensive timber harvesting planning protocol is presented in the this dissertation. It includes an environmental assessment procedure developed for compartments of SUATF which have been heretofore classified as "inaccessible" due to terrain and other characteristics. Benefits from such a plan will be reduced logging damage to the environment, increased system productivity, enhanced management and reduced timber harvesting costs on the SUATF. It should also serve as a model for other areas and situations in Tanzania.

Comprehensive timber harvest planning will help solve many technical, economic and environmental problems associated with timber harvesting on plantation forests of Tanzania and similar areas, upon successful implementation.

This study was intended to produce a digitized map for Laikinoi section of SUATF and experience on digital elevation model (DEM) generation. The model of comprehensive timber harvesting planning for some compartments of Laikinoi section of SUATF intends to yield predictable results that meet land management objectives. It includes transportation systems designs and alternative harvest systems with associated volumes, expected minimum impacts on soils, water, wildlife and residual vegetation plus guidelines and proposed procedures for monitoring environmental effects.

1.6 General and Specific Study Objectives

The general goal is to develop a comprehensive planning protocol for timber harvesting on difficult terrain and the monitoring procedure for associated environmental effects for Tanzanian plantation forests.

Specific objectives are to:

1. Review and assess timber harvesting planning application in the U.S. Pacific Northwest for relevance to Tanzania
2. Assess and utilize remote sensing as a tool for providing key information to support harvest planning in Tanzanian conditions
3. Determine physical, economic and environmental constraints of Sokoine University Training forest and relate these to steep terrain plantation forests in Tanzania
4. Formulate, within the institutional limitations, alternative comprehensive timber harvesting model plans under the constraints
5. Determine the optimum timber harvesting system for each alternative plan model
6. Establish guidelines for monitoring environmental-effects of timber harvesting

7. Establish a basis for continuing research and experimentation with this comprehensive planning protocol at Sokoine University of Agriculture Training Forest.

1.7 Summary

This chapter introduced the problem that justifies this study. Terrain conditions have hindered harvesting in some areas in Tanzania plantation forests and there are indications of environmental degradation on areas currently being harvested. The situation apparently results from lack of attention to economic, technical and environmental planning requirements. I propose comprehensive timber harvest planning to be the solution. In presenting this study, chapter 2 reviews literature on timber harvest planning for steep terrain, and chapter 3 presents the methods and materials of data collection. Data analysis and results are given in chapter 4, along with discussion and interpretation of the results chapters 5 and 6 present study discussion and concluding remarks.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The growing demand for timber in Tanzania calls for the evaluation and potential improvement of existing timber harvesting methods in the plantation forests. Both labor-intensive and semi-mechanized methods are recommended to meet future demands (Abeli & Ole-Meiludie, 1991). There is a dire need to introduce comprehensive timber harvest planning to achieve not only harvesting efficiency but better socio-economic welfare and maintenance of a sustainable forest ecosystem (Shemwetta & Garland, 1996).

In this chapter, relevant literature on comprehensive timber harvest planning on steep terrain is presented. After an introduction of concepts of planning for timber harvest on steep terrain, planning scales and environmental issues in harvesting are briefly reviewed. Planning protocols and an in-depth review of harvesting systems selection are also presented. Finally monitoring and evaluation of harvest plans are given. Consideration of forests and operating conditions typical of Tanzania help provide a focus for the discussion.

2.2 Timber Harvest Planning

A timber harvesting plan is directly defined as a narrated sequence of future events surrounding the felling, extraction and transportation of timber from a forest area to a market (Robinson, 1994). Treatment of logging debris and site preparation can also considered as a component of timber harvesting (Adams & Andrus, 1991). Heinrich (1994) reiterated that for sustainable forest utilization, comprehensive harvest planning, appropriate monitoring, execution of operations and post-harvest evaluations are prerequisite. Planning for steep terrain is more challenging because physical limitations of different harvesting systems, operational methods, costs and the environmental factors are especially emphasized.

2.3 Timber Harvesting on Steep Terrain

Most productive forests in the world are growing in mountainous areas (Heinrich, 1994; Clark, Kellogg & Johnson, 1996). The Intermountain West region of North America, which is the Rocky Mountain chain from British Columbia and Alberta in Canada to the southwest United States, is a major lumber-producing region representing up to 44% of employment and labor income in some states. Approximately 57% of Canada's annual harvest comes from the Western Region: British Columbia, Alberta and Saskatchewan. The U.S. Pacific Northwest Region including Washington, Oregon, northern California and southeast Alaska, remains the Nation's leading lumber producer (Clark *et al.*, 1996). The mountainous region of south China contains one half of the forest resources and timber output in the nation (Jinyun, Feng, Cheng & Jijung, 1994). Regulations and silvicultural prescriptions are particularly specific on timber harvesting on steep terrain. In a number of countries, clear-cutting is not permitted or limited in size (Heinrich, 1994). Harvest systems become more limited and environmental factors such as soils, water and even landscape concerns become more sensitive. Therefore, it is crucial to effectively plan for timber harvesting on steep terrain.

2.4 Planning Scales

Timber harvest planning is the ultimate implementation of harvest scheduling, defined by Davis and Johnson (1987) as efforts seeking for patterns, in areas and volumes, that maximize harvest quantities over the planning period. The authors gave a history of forest scheduling, driven by pursuit of organized forest property which provides even flow of timber over the years. Basic variables in forest scheduling are volumes and areas, but of recent ecological and environmental variables are incorporated. Brodie and Sessions (1991) presented the evolution of analytical approaches to spatial harvest scheduling, conceding that environmental concerns have created demands for spatial requirements in scheduling solutions. While importance of harvest scheduling is acknowledged, this study assumes an existing schedule of harvesting and proceeds to address comprehensive planning to achieve the schedule.

Three major levels of planning based on space and time dimensions commonly used in timber harvest can be identified. The broadest level of timber harvest planning is ***strategic planning,*** referring to broad statements of intent for large areas, up to 4,000 hectares (Approximately 10,000 acres), over long periods stretching to twenty years or more. It is also known as total-chance-area-planning. At the medium level is ***tactical planning***, also known as midterm planning for areas of up to 4,000 hectares (approximately 1,000 acres) for a period of three to five years. The most specific level is

operational planning which covers small single units or compartments of up to twenty hectares in one season (synonymously known as sale planning or sale layout). Each of these planning procedures yield a strategic plan, a tactical plan or a unit plan as shown in Figure 2.1 (Shemwetta & Garland, 1996).

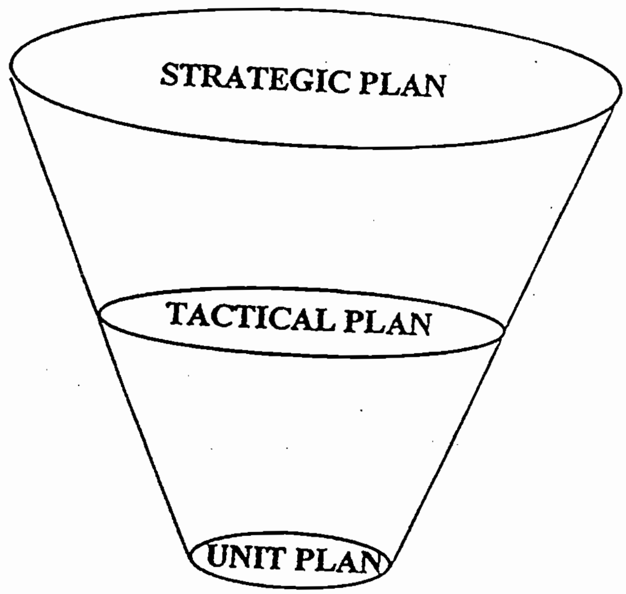


Figure 2.1 Levels of timber harvesting plans.

On a functional basis, Dykstra and Heinrich (1996) identified two levels of harvest planning: ***strategic*** and ***tactical***. The strategic harvest plan identifies broad objectives, the type of harvesting, areas, and time to carry out the harvesting. In essence, the strategic plans demarcate non-harvest areas, divide the harvest area into project areas and design the main transportation system. The tactical plan answers the questions: how, who and when, and which regarding timber harvesting. It is a short term plan, normally prepared by the team directly responsible for the operation.

Aulerich (1993) distinguished three scales of timber harvest planning as defined earlier, elaborating on the functions of harvesting systems and stages. ***Strategic plans*** determine types of harvesting systems, tentative road standards and the harvesting sequence on large tracts of land over long periods. Considerations in the strategic plans include terrain, timber characteristics and harvesting system specifications. Topographic maps, aerial photographs and the ability to interpret them are essential tools at this planning level. In the ***tactical plan***, refinements to the strategic plan are made. Control parameters such as landings, unit boundaries, skid directions, and volumes are identified. Haul routes, specific harvest systems and their associated productivity are also determined in the tactical plan. The ***operational plan*** deals with single units, normally in one season. Detailed maps and narration of daily activities compose operational plans. Activities range from marking boundaries, cutting, yarding, sorting, loading and hauling to details of post harvest activities.

Brink, Kellogg and Warkotsch (1995) stated the main aim of a ***tactical plan*** as to match the most appropriate equipment with the terrain and site conditions for a designated harvesting area. The authors also introduced another level of planning based on time scale and budget, finer than tactical but broader than operational planning, which they called *annual planning of operations*. As the name implies, it involves technical planning as a major input to the annual budget. The annual plan of operations ensures capital requirements for operations scheduled during the year.

This study concentrated on the ***tactical*** and ***operational*** levels of timber harvest planning.

2.5 Environmental Issues

Utilization of forests for timber production represents a vital opportunity for a national economy, but also increases risks of adverse soil and water effects, especially on mountainous areas. Adams and Andrus (1991) proposed that timber harvest planning should focus on systems and equipment that reduce soil exposure and compaction, and layouts that minimize machine activity near streams and small drainages. Maganga and Chamshama (1984) reported appreciable soil disturbance, including changes in bulk density, on clear-felled areas in Meru Forest Project in Tanzania after skidding logs with farm tractors.

Many conflicts have arisen between forest operators and those concerned about environmental protection. The influence of environmental protection requirements on timber harvesting practices is extensive, reflected by many environmental regulations and court orders affecting timber harvest planning. In North America, a code of forest practice is mandatory in more than a dozen states, such as Chapter 629 of Oregon Department of Forestry's *Forest Practice Administrative Rules* (ODF, 1995). The federal forest planning in the US today is a convoluted process to meet the intent of the many laws governing natural resources, particularly the National Forest Management Act

(NFMA) and the National Environment Policy Act (NEPA) (Cubbage *et al.*, 1993). It is through these regulations that comprehensive harvest planning becomes a necessity. Evidence of comprehensive harvest planning is often a determinant in litigation of forest harvesting conflicts.

2.6 Requirements of a Planning Process

Planning processes are often generally prescribed but not specified, without the benefit of any kind of formal, written directives. Other planning processes have "evolved" without specific consideration of planning variables. While forest harvest scheduling is a necessary step in forest management, carrying out of the actual harvesting requires consideration of significant variables beyond the volumes and areas stipulated in scheduling. The technical feasibility, economic profitability and environmental acceptance need to be contemplated. Effective planning has to be complete, addressing all necessary steps in the planning protocol. Incomplete plans can lead to disconnected operations, uncoordinated use of resources and ultimate failures resulting in expensive operation, or abortive operation altogether. While there are generalities in the principles of planning, and timber harvesting, the protocols should address specifically the context for application, for example, in this case the unique circumstances of plantation forests in Tanzania.

Dykstra and Heinrich (1996) name potential characteristics of inadequately planned harvesting operations as ones a) difficult to coordinate, b) impossible to control their effects, and c) producing a crisis rather than systematic management.

2.7 Planning Protocol

2.7.1 Procedures and Priorities

Protocol is defined in this context as *a code prescribing strict adherence to correct etiquette or precedence* (Webster's New Collegiate Dictionary, 1979). A forest harvesting planning protocol is the sequence of proprieties necessary for a complete timber harvesting plan. A literature survey and review of current timber harvest planning in North America and New Zealand exhibited the following sequence of steps as the most common (Schiess *et al.*, 1988; Aulerich, 1993; Robinson, 1994; Shemwetta & Garland, 1996; Anwar, 1994).

1. Objectives definition: Involves the identification of specific objectives and constraints;
2. Area description: The gathering of all available information of the planning area, market and the harvest systems. Included are the analysis of logging and transport alternatives from office data, reconnaissance field survey to confirm office data (maps and aerial photographs) and delineation of problem areas. Some planning procedures apply functional terrain classifications, which are slope classes according to machine capability, operational methods and cost of operations, to plan for harvest systems (Anwar, 1994);
3. Action planning: The specific analysis and synthesis of alternatives. Objectives are refined, in-depth field data collection and subsequent

analysis is performed, systems analysis and cost appraisal are carried out to determine predictable outcomes;

4. Sale layout: Preparation of logging plan for the timber sale. Produces a display of the harvest area on a topographic map and a narration of the information pertinent to meeting the sale objectives. More that one alternative plans are normally produced;

5. Implementation: Prescription of instructions, responsibilities, schedules and control mechanisms for plan execution.

There is significant variation from the stated sequence of steps and amount of detail in each step between plans. The variation comes with the planning scale, region and the institutional conditions. Brink and others (1994) summarized the procedure for tactical planning of a harvest project as illustrated by Figure 2.2. Data describing the stand, site, logistics and market situation is converted to a functional classification. The functional classification is then used to evaluate possible alternatives which meet physical, economical, environmental, social and silvicultural constraints. A schedule of compartments to harvest in order to optimize harvesting systems is then made for the 3-5 year planning period.

When planning for a 8.2 ha radiata pine woodlot in New Zealand, Robinson (1994) proposed the following process :

1. Assessment and description of area to be logged
2. Identification of environmental values
3. Identification of feasible harvesting systems

5. Determination of environmental acceptability

6. Determination of economic performance

7. Formulation of contract documents

8. Plan Implementation

9. Performance Monitoring

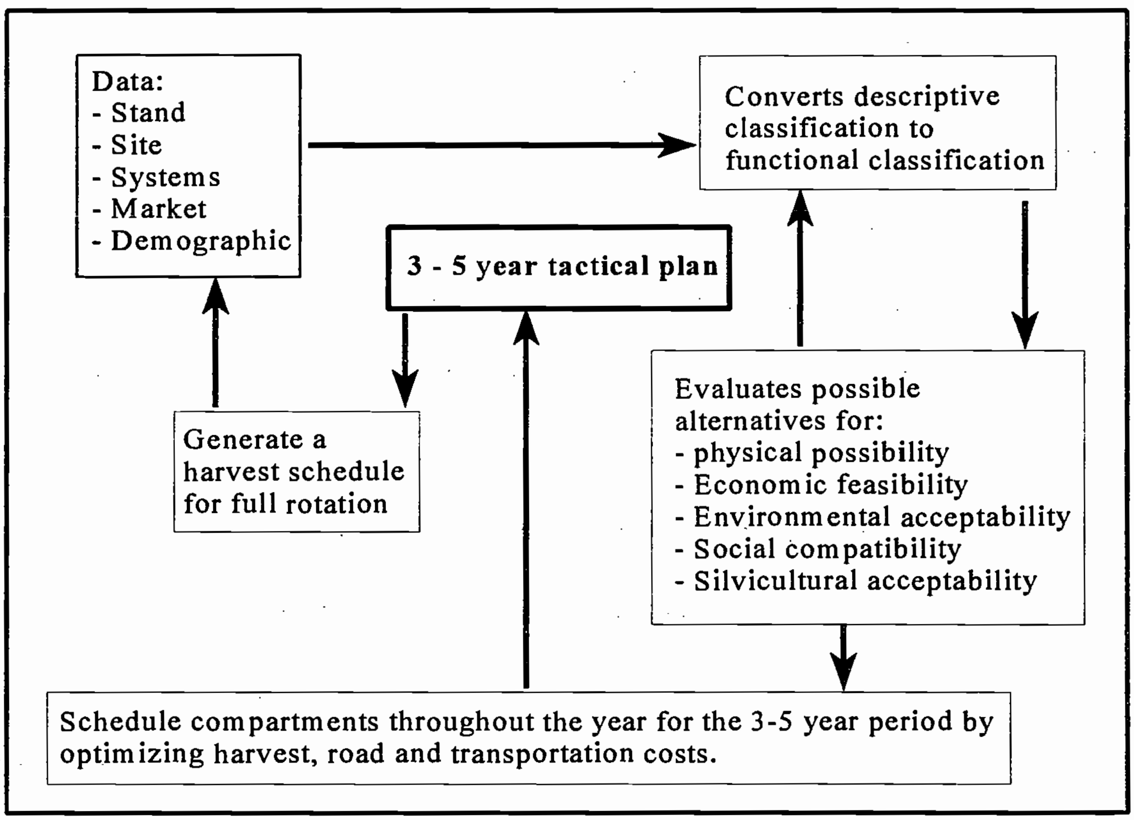


Figure 2.2 Activity flow in compiling a tactical plan (Adopted from Brink *et al.*, 1995).

To proceed to steps 5, 6 and 7 positive responses on the preceding steps are required; i.e. the feasibility of harvest system is a decisive step in timber harvest planning.

In developing an integrated toolkit for comprehensive timber harvest planning, Cullen and Schiess (1992) outlined a series of discrete steps:

1. Project selection: based on state priorities and availability of human resources and data;
2. Preliminary data collection: land cover, ownership, soils, streams, management objectives and constraints. Data sources include aerial photographs, topographic maps and office records. Availability of geographical information systems (GIS) of the area is highly appreciated;
3. Preliminary field reconnaissance: systematic field examination of the timber harvest planning area by a forester;
4. Selection of method of analysis: specific methods of analysis, procedure and technology are selected for the project. Determination of level of analysis is essential.
5. Location of landings and analysis of settings: to be based on physical feasibility and optimal economic average yarding distance. Several alternatives may be generated;
6. Generate road system: all possible roads to create loops for the transportation analysis software;
7. Analysis of alternatives;

8. Field verification of alternatives;

9. Review alternatives and select plan for implementation;

10. Document plan;

For these authors, computer technology greatly expedites the planning process and increases accuracy, documentation and storage of plans.

2.7.2 Goals and Objectives

Goals are broad results that are desired and objectives are the statement of more specific intent of the plan document. These are the outcomes expected to be achieved by the plan. The success of any plan for multiple land use depends on the compatibility of the set of objectives in the plan for that land. In North America, the demand for environmental protection and consideration of endangered species have greatly modified land use objectives. This amplifies the need for information in area description and strict constraints to operational planning. In the United States, there often is a legal obligation for public and private forest owners to observe regulatory requirements when making decisions on timber harvesting (Cubbage *et al.,* 1993; ODF, 1995).

Objectives at tactical and operational levels of planning are the reflection of strategic plan goals and objectives. Satterlund and Adams (1992) emphasized that management policy are most effective if they proceed from the broad to the specific. In large scale timber harvesting, objectives can be delineated according to the **strategic plan**, which in most cases rests some time and distance away from the actual project. For example, a regional office may receive volume quotas to fulfill in a given period and binding regulatory requirements under given financial and other resource capabilities. Implementation becomes a problem in most cases because either the plan is already obsolete (different local conditions compared to the averaged conditions in the strategic plan) or because of conflicting objectives (such as last minute discovery of an owl nest in an area planned for harvesting). Failure of harvest plans for large scale areas and objectives has been laid on the intricacies of resources involved, uncertainty and changing parameters with time. However, realistic objectives, more common at small scale timber harvesting, could be used to make improvements. Schiess and others (1988) pointed out the inadequacy of planning methods at the tactical level to capture the financial gains envisioned through complex strategic planning. He recommends shifting efforts towards site-specific planning where realistic information results in effective plans.

For purposes of this study, it is assumed that goals and objectives are harmonized with expectations of harvesting in difficult conditions in Tanzanian plantation forests. However, the process for this merits further elaboration, explanation and research.

2.7.3 Area Description

The accuracy of any plan depends on the accuracy of the basic data. An area description is one of the principal data bases in timber harvest planning. Descriptive features are terrain characteristics in terms of slope grades and lengths, and soils; hydrologic regime in terms of streams location, discharge, seasonality; sensitive areas as far as environment and ecology in general are concerned; and, timber characteristics in sizes, species, and market values. Also included in area description are the socio-economic characteristics of the surrounding community. Sources of these data include office records, maps, aerial photographs, and satellite imagery. Geographic information systems (GIS) have proven to be useful for collection, analysis and display of spatially referenced data. Digitized maps and associated attributes in GIS have revolutionalized spatial planning (McGaughey, 1991; Jaeger & Becker, 1995; Dykstra, 1992; Carson & Warner, 1992; Sessions & Sessions, 1992).

While discussing the value of photogrammetry to forest engineering, Carson and Warner (1992) pointed out the validity and reliability of photogrammetric measurements. There is a growing use of analytical photogrammetry within the forestry profession, especially with the advent of personal computers. The authors illustrate the value of analytical photogrammetry whereby, by using the familiar Cartesian coordinate system, available software can be used to derive accurate and reliable measurements from an aerial photograph. For instance, a 1:15,000 scale photograph can provide an object's location on the ground to within a range of 1.0 to 1.5 meters.

The specifications and functions of one analytical instrument called the AP190 are described in detail by Carson (1987). One common use of photogrammetry is the creation of digital elevation models (DEM) known also as digital terrain models (DTM). A DTM is an organized block of elevation that models the earth's surface. Warner (1989) summarizes the approach to DTM development in two steps. The first step is to digitize points on the stereo-model, either randomly or systematically, using a PC based analytical plotter, such as the AP190. Then enter the photo co-ordinates into a DTM software program that is designed to organize the data for the area. There are many software packages commercially available for DEM creation. The critical point in the process is the supply of sufficient photogrammetric data to accurately represent the ground surface.

Recently the generation of digital maps, especially the presentation of DEM, have contributed to planning timber harvesting on steep terrain (McGaughey, 1991; Warner & Carson, 1992). McGaughey (1991) outlined the development of DEM generating tools both at the US Forest Service Geometrics Service Center and those of the US Geological Survey (USGS). Currently a 30 m x 30 m DEM is available from the USGS for every 7.5 minute quadrangle map.

Uses of DEM pertinent to harvest planning include:

- Extracting cross-sections: analysis of cable logging system operations, stream flows in watersheds and road design on mountainous areas.
- Volumetric analysis: the calculations of cut and fill volumes
- 3-D perspective scene generation: activities that involve changes in terrain surfaces such as ground-based harvesting systems.
- Others: Visibility analysis, slope and aspect modeling and hydrologic modeling are other uses of DEM which improve planning of a harvesting operation on steep terrain.

One of the photogrammetric systems which, because of its simplistic design, has good potential for Tanzanian and African applications, is the digital monoplotter (MDSD) (Warner, Carson & Bjørkelo, 1993). The mono-digitizer stereo-digitizer

(MDSD) utilizes a 2-dimensional digitizing board for coordinate collection from aerial photographs. A system would cost less than $5,000, including a personal computer. However, if maps need to be made from stereo photos, or if extensive photo interpretation is necessary, one would need a full photogrammetric mapping system such as the AP190 analytical plotter. The AP190 is an optical-mechanical instrument that passes encoded coordinates from the photographs to a PC where they are converted into digital forms. It involves the process of orientating the photographs, computation of ground coordinates from photo measurements, graphical and digital information display, and eventually transfer of the data (ASCII format) to a geographic information system (GIS) or computer aided design (CAD) system. It is more expensive than a simple mono-plotter, approximately $50,000; however, this is justified in a situation where much photogrammetric work is required

Development of a DEM for the Training forest in Tanzania is a positive step toward improvement of planning the process and making available data for incorporation into a Tanzanian GIS currently under development.

2.7.4 Selection of Harvesting Systems

2.7.4.1 The Systems

A harvesting system is a larger term describing the technologies to move trees from the stump to a processing facility or mill. A harvesting system which could be applied in an area must be physically possible, economically feasible, environmentally acceptable, socially agreeable and silviculturally acceptable (Brink *et al.,* 1995). Harvesting systems can be classified in three ways according to: (1) type of transport used to move the material from the stump to the landing, (2) the form of material moved to the landing, and (3) the major component of motive force used if biological or mechanical (Brink *et al*., 1995; Hartsough, 1996; Heinrich, 1994; Dykstra & Heinrich, 1996).

Considering the type of transport, a harvesting system may be either a ground-based, tractive, or cable system. In the ground-based system, the transport machine or animal travels on the ground, where yarders and suspended cables lift and transport materials in the cable systems. According to the form of material, a harvesting system may be: whole-tree system where the tree is transported as is from stump to landing; tree-length is the whole tree less branches and the top; and the cut-to-length (CTL) is system where trees are delimbed, topped and bucked at the stump. In most cases these two criteria are combined for complete description of a system, e.g., "tractive-CTL"

A system may be manual or mechanized with regard to the major component in the entire harvesting process. Timber harvesting is becoming more mechanized with time and the advancement of technology. Heinrich (1994) classified harvesting methods as manual and mechanized. In manual harvesting, trees are felled, delimbed and bucked by hand or power saws and axes; extraction is done by pushing, pulling or rolling. This is regarded as the most basic harvesting technique, more often used on steep terrain and most common in developing countries. Mechanized harvesting is presented in different levels: <u>low-level</u> where felling delimbing and bucking are done manually and wood extraction and transportation are by animals; <u>medium-level</u> where felling, delimbing and bucking are done by powersaws while extraction and transportation are by specialized machines such as farm tractors with forestry attachments, skidders, crawler tractors, cable systems and trucks; high-level mechanization: using felling with powersaws and extraction, delimbing, bucking, debarking and hauling done by machines; and complete mechanization where all operations from felling to hauling are done by machines. Complete mechanization is not very common on steep terrain.

2.7.4.2 Harvesting Systems Used in Tanzania

Abeli and Ole-Meiludie (1991) summarized timber harvesting as practiced recently in Tanzania. Their coverage with respect to plantation forests is reviewed. Tree cutting is done manually using two-person crosscut saws, axes or powersaws, usually on a task work basis. The authors reported some studies in which productivity varies according to forest types. In plantation forests, a 2-person crosscut saw produced 1.6 m^3/h and 1.8 m^3/h in thinning and clear felling respectively, while that of the chainsaw was 3.4 m^3/h.

Manual sulky skidding and forwarding, especially in the first and second thinning, are common. Log size limits this system in clear felling with exception where manual rolling on steep slopes without obstacles is done. Rarely are skid trails prepared in advance or logs pre-choked during skidding operation. Where terrain allows and logs are scattered, "terrain trucks" may be preferred for hauling logs from the stump to the central landing. Under 100 m skidding distance, sulky skidding productivity was 1.2 - 1.5 m^3/h, while tractor skidding in thinning produced 5.5 - 8.3 m^3/h. A forwarder (Valmet 872K) had 11.2 m^3/h productivity on a clear-felling operation.

Short wood trucks and tractor-trailer combinations, manual or self-loading, are common hauling systems. The productivity of these systems is as summarized in Table 2.1 below. While standard cable yarding is not practiced currently in Tanzania, a permanently installed, gravity operated skyline serves for secondary transportation over a 1.9 km distance in one location (Abeli & Shemwetta, 1988).

2.7.4.3 Systems Selection

The selection of a harvesting system is one of the critical decisions of a planner. Elaborating the qualities of a competent timber harvesting planner in the FAO *Model Code of Harvesting Practice*, Dykstra and Heinrich (1996) specify knowledge in timber harvesting technology, and its application based on scientific and engineering principles,

Table 2.1 Log hauling in plantation forests, Tanzania. (Adopted from Abeli and Ole-Meiludie, 1991).

Machine	Capacity (ton)	Vol/trip (m^3)	Distance (1-way km)	trips/day	Productivity (m^3/day)
Tractor & trailer	-	6.0	12	2.2	13.2
Straight truck	8	9.3	36	2.1	19.5
Straight truck	15	13.9	38	2.6	36.1
Truck & Trailer	25	30.1	13	2	60.2
Combination rig	21	34	11	2	68.0

as a prerequisite. To select the appropriate system, the planner is expected to be competent on harvesting equipment and techniques, planning and control methodologies, scientific knowledge and engineering principles, education, training and current relevant practices.

The approach practiced in the Pacific Northwest is to match a logging system to fit the situation. In essence the prevailing physical, technical and socio-economic conditions act as screens to all possible logging systems to achieve the most suitable. The best approach to handle harvesting system selection requires in-depth knowledge of performance categories of different harvesting systems (Garland, 1996), as well as a clear description of the prevailing conditions of the harvest area. These conditions should first be refined to state specific ranges and standards, which in turn act as screens of acceptability to all possible harvesting systems. For example, a timber type and size category should be refined to state the species, size class and other possible subsequent conversion for saw logs or pulp wood. Likewise, terrain should be stated in terms of constraining slope class. Category refinement during planning forms an important reference by setting ranges and standards relevant to the area as well as ranking dominance of the categories as specified by the planning objectives. The screening should include explicit statement about interaction of harvesting systems with the site characteristics, such as road requirement; i.e., road density and yarding distance relationship (Adams & Andrus, 1990).

In comparing productivity of skidding with farm tractors, Skaar (1990) found that a forwarder with hydraulic grapple had twice as much production as a farm tractor with a winch (56 m^3/day compared to 28 m^3/day) at a 50% more cost. However, one could argue about the disadvantages of capital intensive logging systems in Tanzania. The forwarder with hydraulic grapple loader, for example, is highly dependent on imported special equipment compared to the farm tractor with a winch. This consideration should be adequately and objectively analyzed during consideration for the appropriate system.

Prior studies established cost per cubic meter per kilometer on the access roads of mountainous areas in Tanzania (Abeli & Ole-Meiludie, 1990) and sulky skidding productivity (Ole-Meiludie & Omnes, 1979). On tree length skidding, Ole-Meiludie and Dykstra (1982) found that farm tractors compare favorably with articulated skidders in spite of lower productivity. Comparing data on similar conditions in Tanzania and Kenya, the authors concluded that farm tractors were more sensitive to distance, losing their advantage at longer skidding distances. Likewise, large volumes favor the articulated skidder. However, these authors argue in favor of the farm tractors because the skidding distances are normally short, volumes modest, and two small farm tractors have lower probability of breakdown than a single, large and expensive articulated skidder.

The concern for environmental protection has pushed for preference of cable systems on steep slope timber harvesting. Though cable systems stand out as trade-marks of the U.S. Pacific Northwest logging, ground-based systems are used as well where slopes and soils permit. Forest practices regulations, developed by policy processing in state and federal agencies, help foresters and forestry enterprises select practices to follow in forest management and utilization operations (Berg, Gustafson, Halvorsen & Miley, 1993). The systems allocation must be evaluated for all activities along the harvesting process: i.e., from the stump to the mill. The optimum combination of systems will be the one with minimum cost and with system costs reflecting stand and site characteristics, capital and operation costs, environmental protection and the market value of the forest products at the mill.

In presenting how harvesting interacts with reforestation in southwestern Oregon and northern California, Jarmer, Mann and Atkinson (1992) summarized that, while harvesting systems are evaluated on basic physical, economic and operational criteria, attention should be given to many operational quality control considerations that determine success or failure.

2.7.4.4 Tools in Systems Selection

Over the years, foresters and engineers provided different ways of computer aided planning for timber harvesting. Optimum road spacing, harvest scheduling, systems selection and even handling of environmental issues are addressed by different programs and software (Shemwetta & Garland, 1996). Sessions (1992) developed the NETWORK algorithm which can be used to assist planners in determining road standards, road locations, and transport routes. The algorithm can also be used to make simultaneous choices of harvesting systems and road standards, and to identify transfer and sortyard locations. Sessions also discussed possibilities of using mixed integer programming in network analysis for small problems.

While the physical feasibility can be treated in a "go/no-go" situation, the environmental and social values present a problem of comparable tangible terms. Most of the timber harvesting impacts on the environment, such as soil disturbance, and systems' feasibility, can be considered as "costs" in the harvesting operation just like labor, fuel, taxes and the like. Environmental impacts usually cannot be compared in monetary terms like the other costs. This problem can be overcome by adopting representative index numbers to represent values. This approach was demonstrated by Garland (1994) in evaluating technology and also by Lihai (1992) in calibrating the degree of working safety in plan assessment. Riggs and West (1986) used scores 0 to 10 in analysis of productivity performance by objective matrix (OMAX) at the Oregon Productivity Center.

Harvest planning tools can include those aids used to make a harvesting plan. These include: maps; aerial photographs; inventory data sets; devices and programs for data recording, analysis and display; and the expertise to use the tool for decision making. Information is increasingly easy to obtain and accuracy increased in the current information revolution. Tedious, traditional timber harvesting planning methods, which made use of contour maps, aerial photographs and timber cruise data, are being replaced by fast and more accurate computer-based analytical and display tools from GIS to simple tailor-made programs.

Currently, harvesting in Tanzanian plantation forests does not address the issue of appropriate systems to fit the terrain and timber conditions, nor are there any procedures to monitor the effects the systems have on the environment. This thesis introduces procedures for measuring the performance of the current and potential new systems with a reflection of their effects on the environment.

2.8 Plan Implementation

The owner or a contractor may implement a timber harvest plan. Until recently, timber harvesting in Tanzanian plantation forests was by the forest project management crews; i.e., customers purchase logs at roadside landings (Tarimo, 1996; Migunga & Kabuka, 1996). In the United States, there are many individual timber harvesting companies; hence, a contractor system is utilized as I observed at Weyerhaeuser company in Springfield and Warm Springs. Plan implementation starts with contractor selection and consequent hiring. A bidding system is the norm; and, once a company is selected, a contract is agreed upon and the plan is communicated to the contractor. Payment for services may be in whole or by installments. A series of sub-contractors may also be hired, e.g., for felling, log transport and post-harvest activities.

2.9 Post-harvest Operations

Most logged areas are left for natural regeneration or planted, in some cases because of legal requirements for reforestation. In the temperate countries, post-harvest activities are common. These include: debris treatment, often for fire hazard reduction and preparation of the area for reforestation. Such treatment must be well planned and supervised to minimize unacceptable effects of soil compaction, disturbance or erosion.

Compacted skid trails may be tilled to improve growth potential or water bars constructed to decrease erosion (Adams & Andrus, 1991).

In some tropical countries, including Tanzania, villagers and forest plantation workers are given the right to cultivate agricultural crops immediately after timber harvesting, a system known as *taungya* (Chamshama, Monela, Sekiete & Persson, 1992). In the *taungya* system, clear-felled areas or areas located for a new forest plantation are marked into plots assigned to villagers, through their leadership, or to forest workers. The plots are then cleared and used for annual food crops such as corn, potatoes and beans. Within three years, the forest plantation management comes to plant tree seedlings on the plots at the agreed spacing, normally 2.5 by 2.5 meters. From this point until tree canopy closes, the plot holders are obliged to tend the trees as they do for their own crops.

The *taungya* system started in Burma (now Mayanmar) in 1856 and spread to all parts of Africa (King (1968) in Chamshama *et al.*, 1992). The authors also cite other studies showing the system's benefits for both the Forest Division and the peasant farmers. The Forest division benefits from reduced costs of plantation establishment and initial stages of tending while peasants get plots for food crops, hence less land pressure. The system tends to ameliorate negative land-use effects of ground-based harvesting systems. Tillage for the crops can be down to 30 cm (1 ft), implying that the system will not be effective to remove compaction by heavier machines able to induce compaction beyond this depth. With respect to this study, the *taungya* system reduces soil compaction and disturbance as potential impacts of timber harvesting activities.

2.10 Plan Monitoring

Monitoring is defined as to check or observe a process for specific purpose. Monitoring is an integral, but often overlooked or poorly supported part of many planning processes. It has a significant role in comprehensive timber harvest planning for immediate rectification as the operation proceeds or as feedback to future planning. Although timber harvesting monitoring has been biased towards effects on the environment by soil disturbance, habitat degradation and adverse effects on hydrologic regimes, it also measures the plan performance against objectives, including the validity of the objectives themselves. There are three types of monitoring for management of timber harvesting (USDA-FS, 1991; Warm Springs Tribal Council, 1991): ***implementation monitoring,*** where answers are sought as to whether the plan is being implemented as planned or not; ***effectiveness monitoring***, which checks whether the goals envisaged were achieved; and, ***validation monitoring***, to determine whether the assumptions and data used in planning and goal getting were realistic. Monitoring is distinguished from inventory and assessment by being a series of observations over time for the purpose of detecting change (MacDonald, Smart & Wissmar, 1991). Dykstra and Heinrich (1996) defined plan assessment as a systematic check to determine the degree a harvesting operation has followed the harvesting plan and met its stated objectives, while complying with established standards of practice.

In a document to provide guidance for designing monitoring projects and selection of parameters, MacDonald and others (1991) started by declaring expertise in study design and statistical analysis as necessary tools because monitoring is a sampling procedure. They emphasized selection of monitoring parameters as a function of designated uses, management activities, sampling frequency, monitoring costs, accessibility and the physical environment. As an important item in planning the harvest of a forest woodlot, Robinson (1994) presented an impact appraisal process recommended by the New Zealand Forest Owners' Association. It starts with identification of the important environmental values of the site: soil, water, cultural, scenic and ecological values; and then, the identification of operations with potential for adverse effects on the values. The appraisal ends with the rating of each operation for the duration and severity of its potential impact. There is no indication on how the ratings are used in gauging the plan implementation, or how these can be taken to improve future plans.

As a recommended protocol for timber harvesting monitoring Dykstra and Heinrich (1996) stated that post-harvest assessment should be carried out after the harvest operations are complete and sufficient time has elapsed for major impacts to appear but not too late for a corrective action on future actions and mitigation of past wrong actions. The recommended period can be up to one year, including one full rain season, but not beyond two years. Activities in harvest plan monitoring include:

- Comparison of actual to planned location of roads, landings and skid trails and the explanation of any difference;
- Assessment of the condition of roads, landings and trails: maintenance level of permanent roads, or to check if temporary roads and skid trails are closed and cross-drains installed or revegetated;

- Determination of percentage of the operated area disturbed by roads, landings, skid trails and cable corridors. Also determine average disturbed width and compare it with standards specified in the plan;
- If applicable, measurement of the remaining and intact buffer strips;
- Determination of timber waste by measurement of stump heights and abandoned valuable logs;
- Location of trees wrongly left or felled with respect to markings during planning;
- Equipment inspection to determine its appropriateness and compliance with safety regulations;
- Assessment of availability, suitability and use of safety and protective equipment .

Equipment assessment and safety concerns are immediate concerns during the course of operation.

The importance and benefits of monitoring to the planning process depend on the pertinence of the measures of comparison. The standards and best management practices (BMPs) stipulated in many regulations need to have their scientific and cause-and effects proved or reinforced (Berg *et al.*, 1993). This leads to my identification of ***research monitoring***, another type of monitoring, aimed at improving the planning of goals and objectives. Apart from facing harvesting systems mismatch as a result of acquiring the 'wrong' systems for the right conditions, invalidated decision making modules and decisive assumptions for Tanzania provide another avenue for 'wrong' cause-and-effect pertinent to the local conditions. Research monitoring intends to identify facts through studies to improve knowledge for decision making.

Sampling procedure in any monitoring process must be in line with the expected output. It is noted that monitoring typically is not a research project of its own hence the cost of time and resources should be justifiable. Aerial photographs are effective tools in monitoring, among other forestry activities, timber harvesting effects. The list of harvesting activities to monitor given above can be effectively accomplished through photo interpretation, especially if taken in intervals over a definite time. In the U.S. PNW industrial forest managements, such as Weyerhaeuser and WSIR conduct aerial photography once every 2-4 years, resulting into a rich resource for detecting changes aids for effective decisions. Since monitoring is aimed at validation of assumptions and expectations used in plan objectives, use of surrogate measures and importation of study findings from a different area defeats the basic principle and can lead to erroneous assumptions and decisions.

2.11 Plan Evaluation

Evaluation of the potential effects of forest operations requires not only a clear description of the proposed actions, but also a thorough inventory of relevant site conditions (Adams & Andrus, 1991). Details on topography, timber characteristics, soils, and climate are important data for a realistic planning. A plan is said to be successful if it was effective in attaining the goals and objectives sought. Evaluation of harvesting plans is a complex undertaking due to the number and diverse issues involved. Lihai (1992) suggested five factors as criteria for evaluating and scoring harvesting operation plans:

- amount of operation cost per unit of production

- degree of working safety
- ratio of forest resources input to timber production output
- degree of harvest damage on soil and
- amount of harvest damage on residual stands in the operation site.

The best plan is the one with an overall higher score. The author called for other factors provided they are independent, authoritative in illustrating the action or system under study, qualitatively observable and quantitatively measurable. More important, a harvest plan can be judged successful if it meets criteria that are technical, economic and institutional in nature (Brink *et al.*, 1995; Dykstra & Heinrich, 1996; Aulerich, 1993).

2.12 Summary

Challenges of planning timber harvesting on steep terrain in selected regions throughout the world, including environmental considerations, were reviewed. Approaches for a planning protocol by different settings were given. The importance of harvesting systems selection was presented, with consideration of different tools for the task and importance of using site characteristics as the basis. Plan monitoring procedures and evaluation were given as necessary components of a plan.

There is potential knowledge and opportunity to improve timber harvest planning in Tanzania plantation forests given a refined planning protocol and guidelines for environmental effects monitoring. The materials and methods presented in the following chapter are derived from the literature reviewed.

CHAPTER 3

METHODS AND MATERIALS

3.1 Introduction

After the introduction and relevant literature review in the preceding chapters, this chapter presents methods and materials of the study. The study area will be introduced followed by data collection and analysis methods. To collect data, I observed, conducted interviews and carried out measurements to obtain the values of study variables. Preliminary data provided background for the actual study development. While data analysis and results are given extensively in the following chapters, this chapter will mention some to aid the flow of presentation.

3.2 Study Area

A plantation forest in Northeast Tanzania (Figure 3.1) served as the main study area while a site in the Pacific Northwest in the United States with some similar characteristics provided a reference area for environmental issues. Sokoine University of Agriculture Training Forest (SUATF) was the principal study area; however, time limitation could not accommodate actual harvest and research implementation on the site. In this context, I collected data on the technical and economical variables at the Tanzania study area and used the Warm Springs Indian Reservation (WSIR) forest in Oregon, Pacific Northwest, for environmental variables in a before-and-after fashion. At the time of this writing, plans are under way to initiate a demonstration project of the planning protocol and environmental effects assessment procedure in Tanzania.

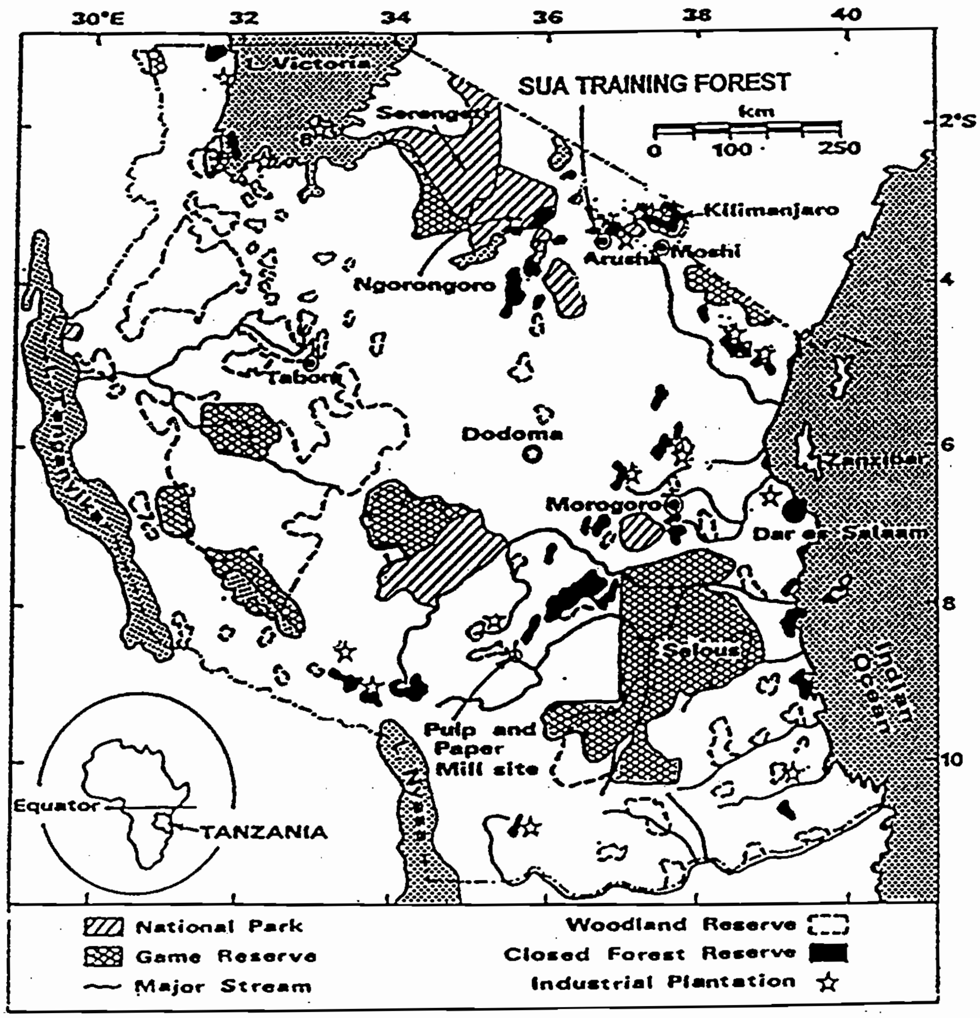


Figure 3.1 Map of Tanzania showing forests and wildlife areas (Adapted from Dykstra, 1983).

3.2.1 **Sokoine University of Agriculture Training Forest**

3.2.1.1 Introduction

The Sokoine University of Agriculture Training Forest (SUATF) covers about 860 ha. Located at longitude 36° 42' E and latitude 3° 17' S at Olmotonyi, the forest lies at an elevation between 1,740-2,320 meters above sea level and receives about 800 to 1,500 millimeters annual precipitation (Mwambu-Magomu, 1991).

Access to the training forest from Arusha Municipality is at Ngaremtoni, 15 kilometers northwards towards Nairobi. This leads to a 4.5 kilometers access road to Sokoine University of Agriculture Training campus, and 6.1 kilometers further to the forest gate as shown by the vicinity map in Figure 3.2. The access road network within the SUATF totals 17.6 kilometers.

The training forest is bordered to the east by the indigenous forests of Meru Forest Reserve, to the north and west by Olmotonyi and Oldonyo Sambu Blocks of Meru Plantation Forest Project, and to the south by farms and settlements of Wa-Arusha, the indigenous people of this area. The forest consists of two blocks: Laikinoi on the upper and Narok on the lower part. The blocks are further divided into units, called compartments, according to stand characteristics of species, age and site classes. Streams, ridges, roads and fire-breaks serve as boundaries of compartments. There are 37 compartments in total.

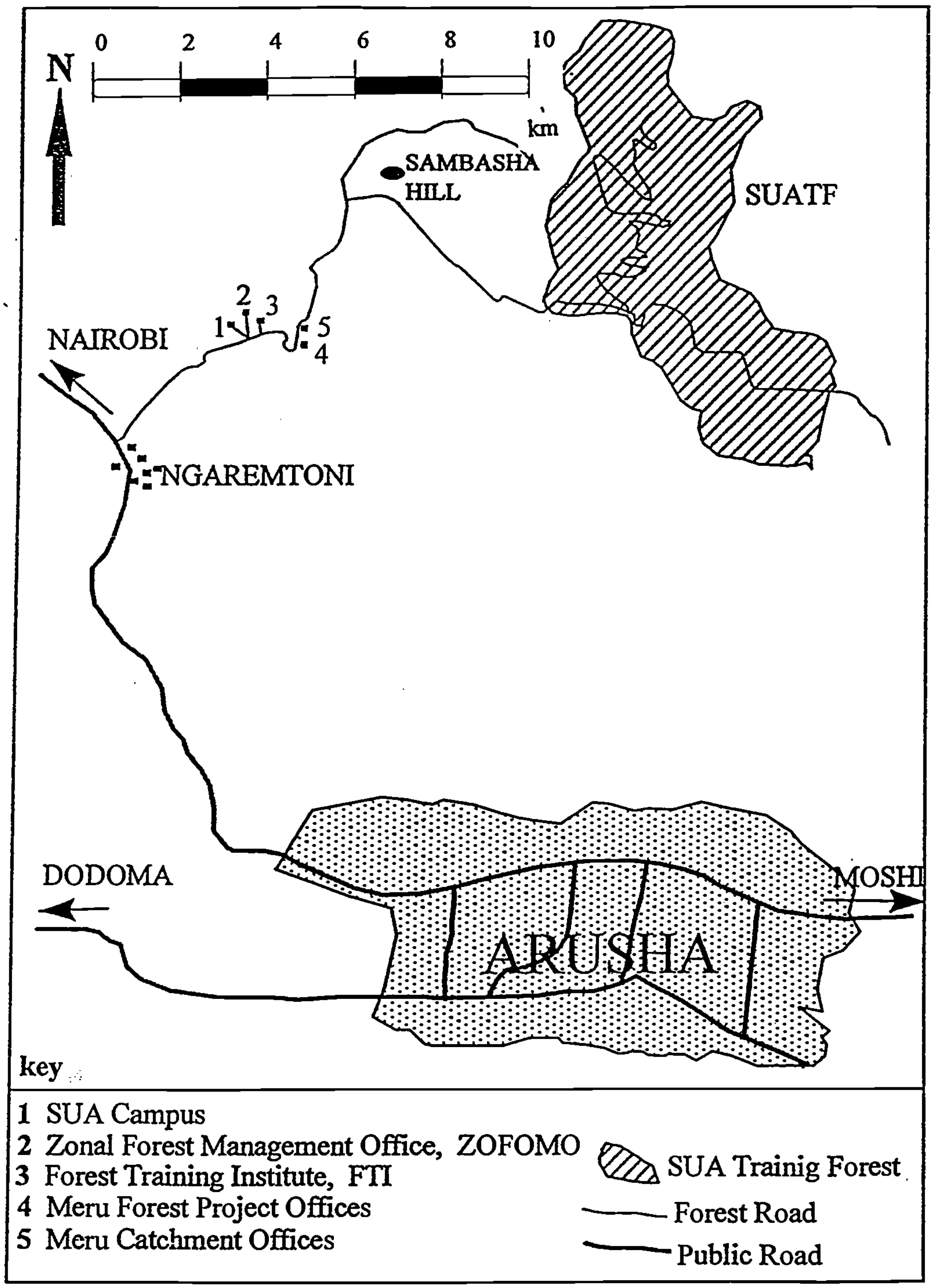


Figure 3.2 Vicinity map showing the location of Sokoine University of Agriculture training forest.

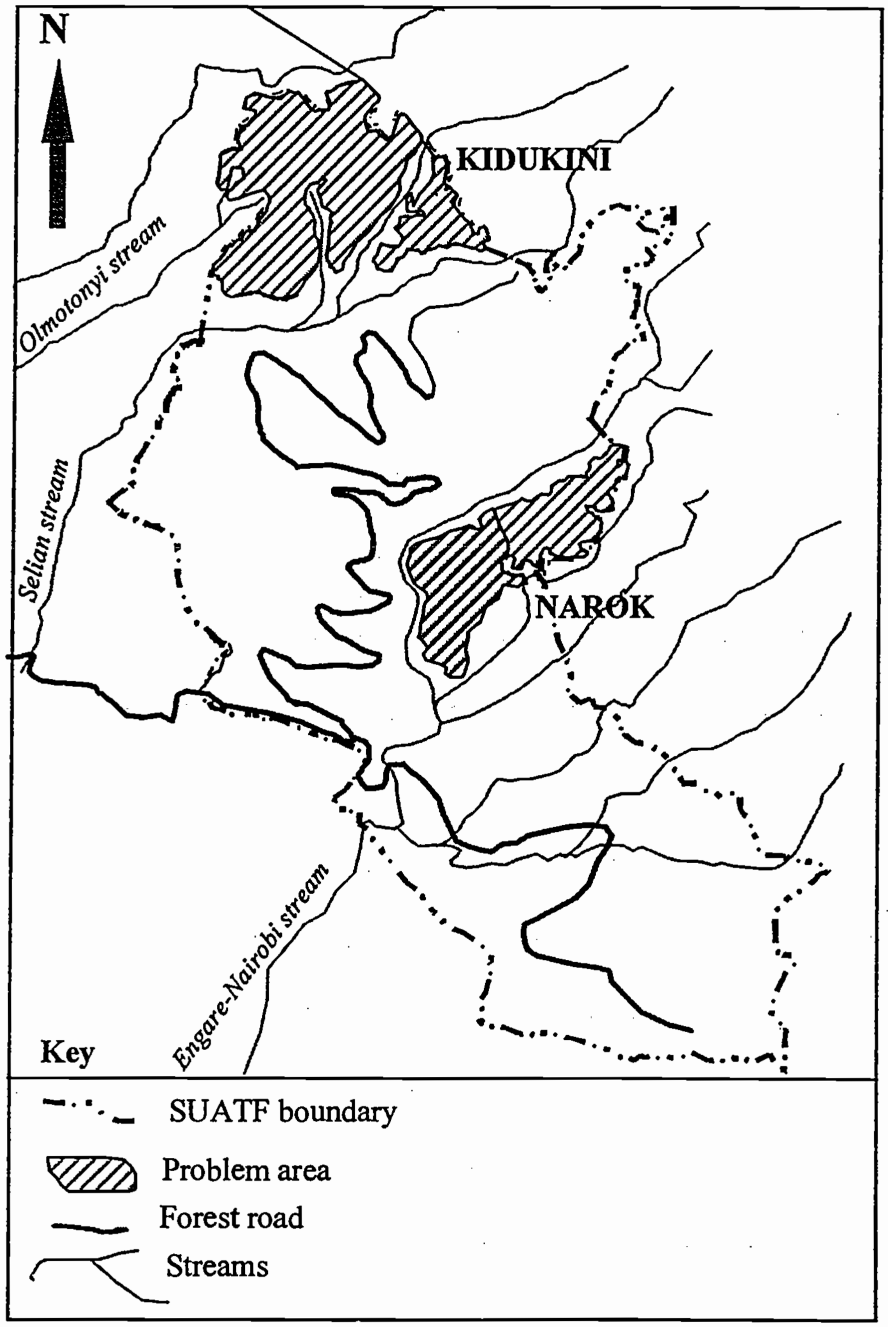


Figure 3.3 Sokoine University of Agriculture Training Forest showing 'problem area' compartments.

3.2.1.2 Background

History: In 1920, a 26,000 hectare area on the southern face of mount Meru was gazetted (mapped and designated) by General Notice No. 232 of Tanganyika as a forest reserve with a general intent to preserve a natural forest estate, conserve soils and maintain constant water supply to the settlements on the lower slopes and the growing Arusha town. In 1930, about 6,000 hectares of the reserve were cleared of the natural forest to establish a pyrethrum plantation (for use in insect repellant) under lease by a private owner. The natural forest was retained along the steep stream and river valleys. In the late 1940s, forest plantation trials were initiated on the pyrethrum plantation area by the Tanganyikan Government. By 1978 the pyrethrum plantations were totally replaced by a softwood plantation, known as Meru Forest project. In the same year, the Faculty of Agriculture, Forestry and Veterinary Medicine of the University of Dar-es-Salaam acquired over 800 hectares of the project area, with the objective of using it as a training and research forest. In 1984 the Faculty, now based in Morogoro, was upgraded to become the Sokoine University of Agriculture and hence the area became Sokoine University of Agriculture Training Forest (SUATF). The goals of the training forest are:

- to provide facilities for training in forest practices and management;
- to provide an area and facilities for forestry research;
- to manage the forest profitably and supply a sustained yield of forest produce to the local wood-based industries and people.

The forest is administered by a forest manager answering to a forest management committee formed within the Faculty of Forestry, Morogoro. The management committee is in turn answerable to SUA Training Forest Management Board. The Board members are from the Sokoine University and the Ministry of Natural Resources Tourism and Environment (MNRTE). The Management Board has overall powers over activities performed within the forest.

Associated Institutions: The SUATF campus is within a kilometer radius of five other forestry institutions as shown in Figure 3.2: Forest Training Institute (FTI), offices of Meru Forest Project, Zonal Forest Management Office (ZOFOMO) and Arusha Catchment. Recently the SUA campus was expanded to accommodate an added task of serving as a SADC Center for Practical Forestry. SADC is the Southern Africa Development Conference made up of nine countries of southern Africa. The SADC center offers short courses on practical forestry to forest officers from member countries. Meru Forest Project Office serves as a connection of the SUATF to the Ministry.

FTI, which is directly under the Ministry of Natural Resources, Tourism and Environment, conducts two year Diploma and Certificate courses in forestry. Graduates from this institute make up the majority of Tanzania forestry society. The Zonal Forest Management Office (ZOFOMO), an agency under the Ministry, is responsible for forest roads construction and logging operations in the northern zone of plantation forests. The zone includes Meru Forest Project (5,636 ha), North and West Kilimanjaro Forest projects (6,060 and 4,387 hectares respectively) and Usa-River (1,314 ha). ZOFOMO is expected to coordinate all the logging and road construction activities in these projects because it has the equipment and experts in this field. Arusha Catchment office deals with the management of the natural forest within and beyond the plantation up to the end of the tree line. The office oversees all the catchment forests in Arusha region.

3.2.1.3 Descriptive Features

From office records and my own experience over the years, SUATF can be briefly described as follows. The training forest lies in the middle and lower slopes of mount Meru, an extinct volcano. The mountain slopes, particularly on the location of the training forest, are mostly steep, ranging from 4% to over 60%. There are many deep and steep valleys with slopes above 100% in places. The valleys run from north to south and streams flow readily following the slope pattern, forming deep gullies and gorges in the area. Three main streams drain the training forest: Engare Olmotonyi, Selian and Engare Nairobi (Figure 3.3). All the streams are normally permanent although the flows are diminished towards the end of the dry season.

Climate is controlled by altitude and range from sub-tropical to temperate. There are two distinct rain seasons a year: short rains in November-December and long rains in March to June. Rainfall is 800 to 1,500 mm a year, decreasing towards South-West. Rainfall, number of days, and amount of precipitation from dew are higher at Laikinoi, the upper part of the training forest. Mean daily temperature ranges are 15°C to 28°C a year, January and February being the hottest. Wind is common, usually severe during the night.

Geology of this area is closely related to the faulting and volcanism associated with formation of the Rift Valley of eastern Africa. Deep rocks are the ancient Precambrian metasediment and granites and do not outcrop. Surface rocks are volcanic, varying from vesicular grey lavas to fine grained basalt, overlain by deep soils originating from volcanic ash. Some exposures of coarser deposits with gravel layers are seen along the stream lines.

Soils are generally deep, black or dark brown, erode easily during rains, have low bearing strengths and provide poor traction. In dry season the surface layers become extremely powdery and dusty, with the same unfavorable qualities as during rains. All weather access is guaranteed only on raised, drained and reinforced roads. Soil fertility is relatively high and the sites have high values for permanent crops.

Mount Meru is a Game Reserve, bordered to the north by Longido Controlled Area (Ngaserai) and to the east by Arusha National Park. The most common animals found in the training forest are the white Colobus monkeys, (which are protected), blue monkeys and the red forest duiker. While these animals are easy to find, incursion by elephants and buffaloes into the training forest is rare and only remain as history. A variety of birds can be found in the forest. Wildlife management is not a stipulated land-use anywhere in the plantation area .

Plantation for commercial wood products is the principle land use of the area. Other land uses are 'protection forest' and 'unproductive' areas as summarized in Table 3.1. The plantation area is composed of both softwoods and hardwoods. Softwoods are mainly *Cupressus lusitanica* and *Pinus patula*. *Pinus radiata*, which was a favored species during the plantation establishment is not planted now due to a disease. The remaining plantation area is covered by hardwoods species which include *Acacia melanoxylon, Grevillea robusta, Olea welwetschii* and *Eucalyptus*.

The protection areas consist of indigenous vegetation, with a total area of about 155 hectares. The vegetation includes *Cordia abyssinica, Ficus thonningii, Albizia gummifera, Entandophragma excelsum, Rauvolvia abyssinica* etc., all of which are found in the upper storey. The middle storey include species like *Croton megalocarpus, Macaranga spp, Dombeya goetznii* etc. The ground floor is composed of ferns, brambles (*ribus*), Mauritius thorn, bushes and grasses. The unproductive area in the Sokoine University training forest has a total of 8 hectares, occupied by Milkha Sigh Saw Mill.

Table 3.1 Land-Use Classification of the Training Forest.

Land-use	Area (ha)	%total area
Plantation	702.3	81.1
Protective forest (Natural vegetation & valleys)	155.1	17.9
Unproductive (Milkha Singh)	8.4	1.0
TOTAL	865.8	100.0

The silvicultural activities follow a sequence of planting, tending, pruning, thinning and clear felling, with a 25 years rotation. Planting spacing is 2.5 by 2.5 meters, making up to 1,600 stems per hectare. Three thinnings are now prescribed over the rotation at 10, 14 and 18 years, decreasing basal area by 30% each. The first thinning is mechanical, i.e., removing every third row, while the last two are done according to some selection system. All thinnings are commercial, the first one being mainly for poles.

3.2.1.4 Timber Harvesting

Harvesting operations encompass tree cutting, primary transportation and secondary transportation. Tree cutting is manual, either by two-person crosscut saws or power saws. Axes are used mainly in limbing and as an accessory during felling. Primary transportation includes all those activities of moving felled tree from the stump to the landing at the roadside, while secondary transportation is from the landing at the roadside to the mill.

With the exception of transmission poles, industrial timber harvested in plantation forests in Tanzania is in the form of shortwood, with lengths varying from 3 to 6 meters. In thinning operations, trees with diameter at breast height (dbh) between 18.0 to 20.0 centimeters yield about 0.3 m^3 merchantable volume. In clear felling operations, trees with 20 to 60 centimeters dbh over-bark yield between 0.74 to 1.1 m^3 merchantable volume.

Primary transportation is exclusively terrain-based, manual or mechanical. In a few instances, logs are rolled downhill by gravity; however, sulky or tractor skidding is the most common in the plantation forests. Designated skid roads or log pre-choking during skidding operations are uncommon. Secondary transportation is mainly done using trucks and tractor trailers. In some situations, semi and full trailers are used. Apart from self-loading trucks, loading is manual or by a winch on tractor trailers.

3.2.1.5 Timber Harvest Planning

The management of SUATF determines the amount of volume and particular compartments to be harvested each year from the current 5-year forest management plan. The decisive variables are market demand, accessibility and allowable cut based on growth models.

3.2.1.6 Problem Area

The problem area that is the focus of this analysis concerns eleven compartments as shown in Figure 3.3. Nine are located at northern SUATF, an area known as Kidukini; and the other two at east-central SUATF, known as Narok. The compartments make up 143 hectares of the plantation area shown in Table 3.2 according to species. All the mean timber sizes in each compartment provide ranges of different species over the Problem area. *Cupressus lusitanica* and *Pinus patula* species have dbh range of 27-38 cm, height range of 21-37 m, standing volume range of 235-298 m^3/ha with an average Current Annual Increment (CAI) range of 15-60 m^3/ha. By observation, this area has the most difficult terrain and is the least accessible in the whole Meru forest plantation. From this point forwards, this area will be referred to as the **'problem area'**.

Table 3.2 Description of the compartments of the problem area.

Area	Compt #	Species	Age yrs	Area ha
	1a	*Pinus patula*	34	44.4
	1b	*Pinus patula*	33	9.6
	1c	*Pinus patula*	33	4.4
Kidukini	1d	*Pinus patula*	34	5.9
	1e	*Cupressus lusitanica*	23	1.9
	2a	*Cupressus lusitanica*	24	12.3
	3a	*Pinus patula*	33	4.5
	3b	*Pinus patula*	33	0.9
	4a	*Cupressus lusitanica*	22	10.3
Narok	16a	*Cupressus lusitanica*	23	27.0
	17a	*Pinus patula*	34	21.6

3.2.2 Warm Springs Indian Reservation Forest

3.2.2.1 Introduction

The Warm Springs Indian Reservation (WSIR) is a 261,720 hectare area in the Deschutes River Drainage of Central Oregon, just south of latitude 45°N between longitudes 122°W and 123°W. The eastern and southern boundaries are determined by the Deschutes and Metolius rivers, the western boundary scales the crest of the Cascade Range to a point where the northern boundary starts as a straight line slightly southwest to meet the eastern border near latitude 45° north of the Deschutes river. The forest lies mostly in Jefferson and Wasco Counties, with small portions in Linn, Clackmas and Marion Counties. Figure 3.4 shows the location of the reserve in Oregon and the study area within the reserve. The forest occupies close to 70% of the total reservation area and 52% of the forest area is designated accessible and commercial. For their similarity in soils, terrain and timber size to the principle study area, selected blocks

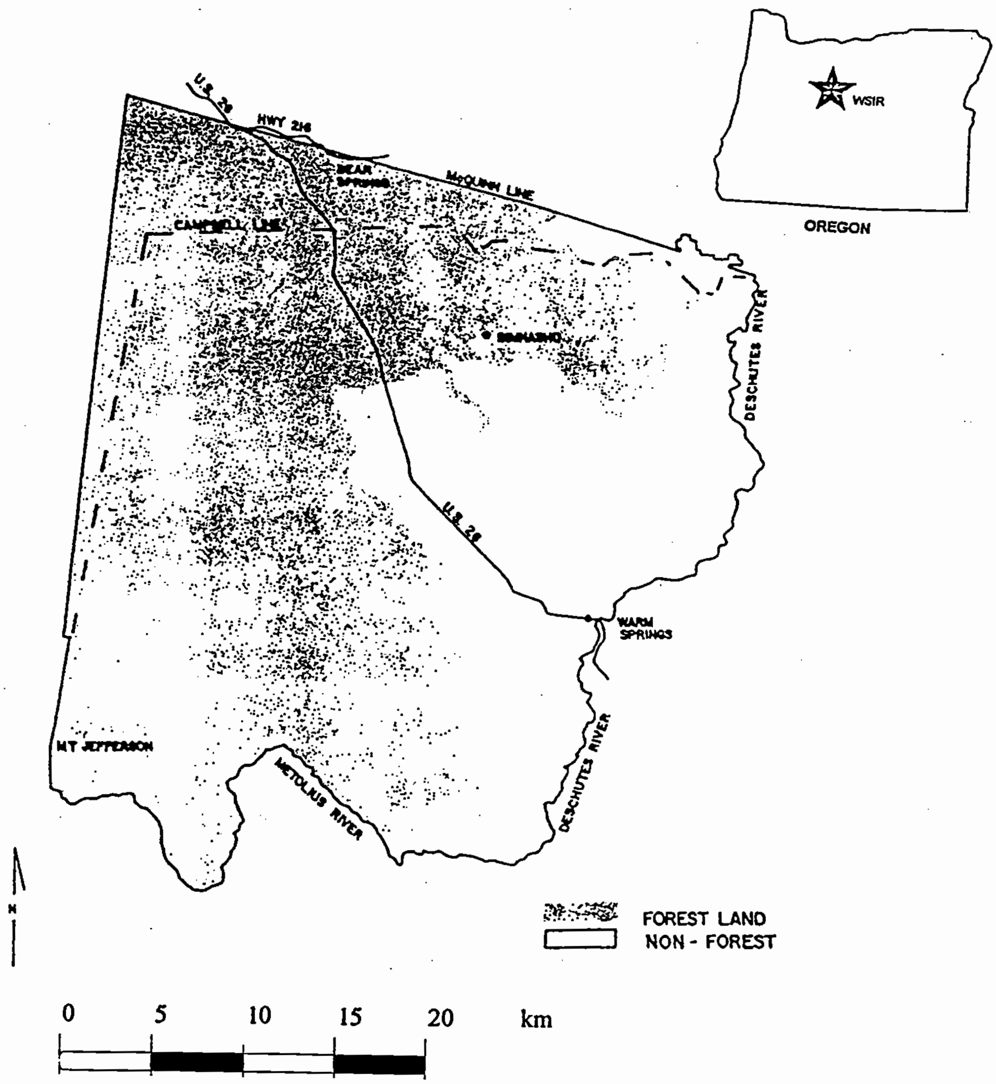


Figure 3.4 Warm Spring Indian Reservation (WSIR): study site in Pacific Northwest.

of WSIR forest represented an ideal site to represent the principle study area in addressing environmental effects during timber harvesting planning.

3.2.2.2 Descriptive Features

From reconnaissance visit and review of office records (Warm Springs Tribal Council, 1991) the WSIR study area is described as follows. Warm Springs Indian Reservation benefits appreciably from natural resources including forestry; hence, they perform articulate comprehensive management of the area. The Blocks assigned to this study, in designated numbers, were 61, 62, 63A, 64B, 64C, 70 and 71. They are located in Long Willow II sale, northeast part of the reserve as highlighted in Figure 3.5. Summer fires during the time of this study limited post-harvesting diagnosis to Blocks 61 and 71 only. Records show that these blocks were selectively logged in 1965 under the Deadman Springs Logging Unit and Block 64B was selection logged in 1976 under the First Big Spring Logging Unit (Loughman, 1996).

The Reserve is divided into eight management areas according to plant associations. Management groups have similar silvicultural treatments and growth potentials that permit planting, thinning and harvesting in the same manner. The study area was in management group 2 of Ponderosa pine - Douglas-fir (mutton) plant association. It is a well-accessed mountainous area of gentle slopes and volcanic soils.

Climate is primarily continental, especially during winter, while summer is generally arid. Temperatures range between -39 °C to 45 °C and precipitation in the Cascade Range averages 3,000 mm; however, rangelands covers two thirds of the

Reservation resulting in only 500 mm annual precipitation. Annual snowfall at 1,300 m elevation is a mere 400 mm compared to 5,000 mm at the crest of the Cascades.

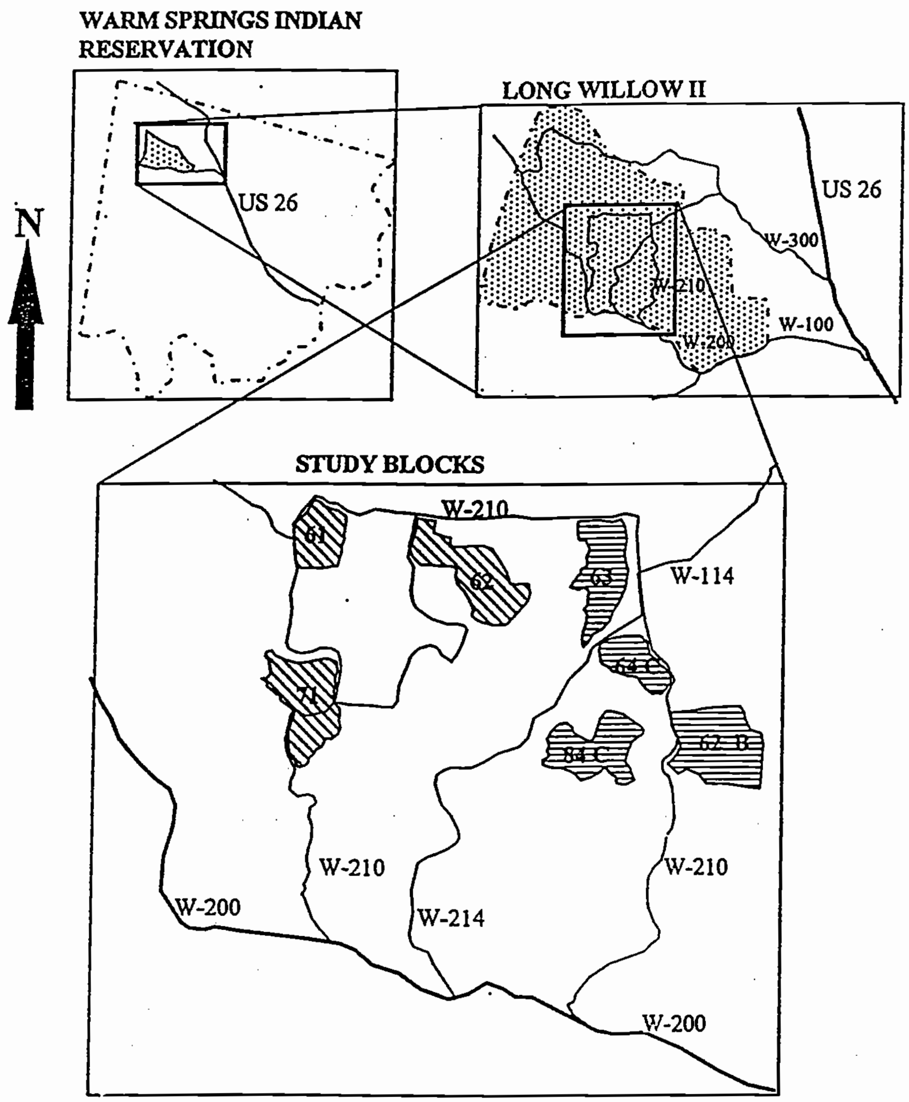


Figure 3.5 Warm Springs Indian Reservation: Long Willow II harvesting blocks and road network.

The Long Willow Logging Unit is located in Township 6 South, Range 9 East Willamette Meridian. Area to be logged was 550 hectares (1,360 acres) with a total estimated volume of 27,940 Mbf. And the contractor was Alco Construction company. Felling was manual by powersaws, whole trees were either skidded or mechanically processed at the stump. At the landing, whole trees were mechanically delimbed and bucked, sorted and loaded onto trucks. The equipment used by this contractor were powersaws, a processor, two crawler tractors with high tracks, two rubber tired skidders, a delimber and a loader.

3.2.2.3 Timber Harvesting and Monitoring Practices

The WSIR carries out environmental assessment in compliance with key federal laws: National Environmental Policy Act (NEPA), Historic Reservation Act (HRA) and Endangered Species Act (ESA). With respect to timber harvesting, the objectives of the WSIR are designed to fulfill, supplement and enhance:

- The goals of the Integrated Resource Management Plan (IRMP) of the forest area;
- The goals and objectives for the individual resources.

The individual resources are categorized as trees, water, visual, air, wildlife habitat, soils, forage and cultural foods and sites. For example in management Group 2 of Ponderosa Pine - Douglas-fir association, even-aged timber harvesting is the standard although selection cutting may be an acceptable alternative in healthy stands. On moderate sites, maximum block size is 40 acres while on harsh sites the block sizes are smaller. The harvesting method prescribed is primarily clear cutting; however, visual areas and riparian 'B' zone resource areas are selectively cut, and no timber harvesting activity is allowed in riparian zone 'A' areas.

Harvesting systems are selected according to terrain and slope: Ground-based in areas under 30% and some form of cable logging beyond that limit. Other criteria are soil type, soil moisture, transportation system and silvicultural objectives. In any timber sale, all activities follow federal and tribal regulations. There is an elaborate procedure for harvest planning, contract administration and strict monitoring of the operation and its subsequent post-harvesting activities.

3.3 Data Collection

3.3.1 <u>Preliminary Data</u>

A short visit to the principle study area in Tanzania enabled collection of preliminary data. Office records, aerial photos and interviews furnished preliminary information. Preliminary data provided general information of the study area. Ministry of Land in Dar-es-Salaam, Tanzania Forestry Research Institute (TAFORI) Morogoro, Meru Forest Project, Sokoine University of Agriculture Training Forest (SUATF), and the Northern Zonal Forest Management Office (ZOFOMO) made available office records and illustrations of the study area. I obtained forest management plans, maps, aerial photographs and publications of past research of the area.

The study area in Tanzania is located on the following sources:

- Tanzania Map Series Y 503 sheet SA-37-13; Scale 1:250,000
- Tanzania Map Series Y 742 Sheet 55/3; Scale 1:50,000
- Old Planimetric map of Meru Plantation, issued by the Forest Division 1986, Sheets 3,4 and 5; Scale 1:10,000
- Map of University Training Forest by Kjellsen, University of Dar-es-Salaam. 1979; Scale 1:10,000
- Meru Forest Plantation Maps. 1987; Scale: 1:10,000; Contour Interval 10m. Prepared by "Forest Maps" G. Glesåen AB (1987). Sheets 4, 5, 6, 7 and 8.
- Series of aerial photographs:
    - 1977; 1:25,000 and 1:30,000; Job 77/10 by Aerial Photography Geosurvey International Ltd. Exposures 4478-4781 & 4800-4801
    - 1982; 1:50,000; Job 210 by Department of Survey (DOS). Exposures No. 111-114, and 146-151
    - 1987; 1:30,000; By Photomap International. Exposures Nos. 6174-6183, 6214-6222, and 6901-6912.

These documents provided the initial information needed for planning more detailed field data collection. I reviewed the following tasks on the documents:

- Examination of forestry objectives of the area to identify the type of harvesting operation intended and the associated limitations;
- Delineation of the harvesting area;

- Determination of approximate spatial distribution with respect to destination mills;
- Identification of the general terrain features: slopes, streams, ridges and level areas;
- Making preliminary decisions about harvesting systems to be employed.

To facilitate the office data, my Major Professor and I carried out on-the-ground reconnaissance to verify, and at the same time, to get more information of the site characteristics not provided by the maps, photographs and office records. Interviews with the forest staff in the plantation projects, sawmill owners, loggers and forest owners in Tanzania and the US augmented our research base. (The use of plural forms indicates activities my Major Professor and I performed together).

The information derived from preliminary data of the Tanzanian site contributed to the identification of particular blocks in the Warm Springs Indian Reservation based on similarity in soils and timber size.

3.3.2 Main Data

3.3.2.1 Planning Protocols

Field observations and literature review provided different procedures applied in other timber harvest operations in Oregon. Weyerhaeuser Company at Springfield represented large companies owning large tracts of forest land while Mealy Farm and McDonald-Dunn Forest (around Corvallis) represented small forest owners. Review of forest plans for some federal and state forests in Oregon (ODF, 1993; USDA-FS, 1991; USDI-BLM, 1992 (a) & (b)) provided the general trend of forest planning while USDA-FS (1992) specialized on timber sale preparation. The experience at WSIR and SUATF also provided ample data for formulation of a planning protocol suitable for comprehensive timber harvest planning. What I sought were the protocol steps starting from an idea to the realization of a harvesting operation. Highlights of the interviews included specifics on volume determination methods, identification of harvest areas, planning of the harvesting operation, systems selection, supervision, post-harvest operations, and monitoring the operation and its effects on the environment. Through more refined interviews and observations, I identified who does the planning, what tools are used for planning, and which terms of reference are consulted for economic and environmental values.

Detailed interviews with the management of Sokoine University Training Forest, Meru forest project and the Zonal Forest Management Office (ZOFOMO) provided the current procedures followed in planning and implementing timber harvesting. From literature review shown in sections 2.7 and 2.8, I obtained different planning protocols used by different harvesting organizations.

3.3.2.2 Planning Factors

To carry out a comprehensively acceptable timber harvest planning for an area, physical characteristics, economic and environmental considerations must be considered together with the institutional variables. The following sections provide methods used and data obtained on these harvest planning factors.

3.3.2.2.1 Physical Variables

Timber: To obtain timber characteristics in terms of dbh, height and volume, I traversed the compartments of the problem area and neighboring areas using the 1:10,000 map by Glesåen (1987). On randomly pre-chosen points on the map, 0.01 ha (5.64 m radius) plots were used to collect timber characteristics and slope percentage in each compartment. A caliper was used to measure the diameter at breast height (dbh) while a hypsometer was used to measure the height of all trees in each plot. To determine the "design tree" for cable logging analysis, I took the height and dbh of largest trees in any plot, and other big trees randomly found elsewhere in the compartment. An example of a field form for timber characteristics is shown in the Appendix A.

Terrain: A clinometer was used to determine slope percentage. Slope breaks were identified with a criterion that a break in slope occurs where there was a gradient difference of more than 20% within a slope distance of at least 50 meters. Places suitable for landings were identified by considering slopes, areas and links to access roads. To estimate average skidding distance to each landing, I used maps to estimate half the distance to the extreme boundary of a harvesting unit (polygon).

Harvesting systems: Identification of harvesting stages was followed by detailed information on harvesting systems. Through interviews, I identified current and potential felling, extraction and hauling systems. Studies done in the area and similar conditions elsewhere provided each system's performance with respect to the physical, economical, environmental and social requirements. Important variables included productivity in cubic meters per hour per crew, crew size, number of trips per day per system and operation costs. The system limitation in terms of timber size, slope and infrastructure were established as closely as possible based on past studies, experience and judgement. Site specifications provided a screen of the systems' performance for determination of the most appropriate, all factors considered.

Literature review and visits to some logging operations in the United States provided information and experience on systems performance with respect to difficult terrain.

Accessibility: Reliable access to the harvesting site is very important. Using maps and on-ground surveys, I identified existing transport systems. Since a most significant management objective for an area is to make it accessible, all the possibilities within the physical, environmental and economical limitations were explored. I conducted a survey of the existing access road for renovation or reconstruction. For new roads, I considered slopes, horizontal and vertical curves, width, distances, surfacing and drainage structures. Distances were determined between proposed intermediate landings, and from the landings to all potential mills by all systems. Contour maps and field surveys facilitated this activity.

Interviews and office documents from ZOFOMO provided data, including a report (Appendix B) on structured costs of road construction and rehabilitation of a proposed road to Kidukini. This report also served as a reference for cost determination of other roads. Cable systems clearance (draws) between ridges, landing locations and distances were measured, on the map and in the field. LOGGERPC computer software (FE-OSU, 1995b) was used to determine the feasibility of potential corridors.

The physical characteristics of the study area and systems performance together determined harvest area units (polygons) for detailed planning and execution of harvesting operation.

Mapping: A digitized map of the training forest was developed from the Glesåen AB (1987) maps and generation of DEM from diapositives was demonstrated. A 100 x 100 m grid on the contour map Sheet 6 provided data for elevation *Z* at corresponding *X* and *Y* values. A surface mapping system, SURFER (Golden Software, 1993) was used to develop surface maps and as a storage of the digital data of the problem area. Development of digitized maps is of great advantage for incorporation into GIS and other terrain analytical tools.

3.3.2.2.2 Economic Variables

Sources of cost in timber harvesting operation were identified for inquiry. Currently, the Tanzanian economic system is undergoing rapid structural changes, out-dating most office records regarding finances. However, I sought the production costs, fees, and all associated costs at each stage of the entire harvesting operation, as conditions allowed. Market prices, rather than office records, represented more realistic conditions of costs at the time of the study.

Methods used to calculate current values of royalty (stumpage), silvicultural and road fees were expressed by the Zonal Forest Management Office (ZOFOMO), and verified at the SUATF and Meru Forest Project Offices. Actual costs paid by private saw-millers per cubic meter of mill-delivered timber in Arusha municipality and its suburbs were provided by the dealers.

3.3.2.2.3 Environmental Variables: Warm Springs Indian Reservation

Observation and measurements were made in a before-and-after fashion on selected environmental variables at Warm Springs Indian Reservation, Oregon. The immediate effects on soils, residual trees and wildlife habitat were of primary concern. As a contribution to long-term planning, potential effects on hydrologic regime were considered. Office records provided the area description on species, soils, and the hydrologic regime. Sale delineation, layout of skid trails and landings, as well as road design are critical planning activities with respect to environmental effects and were our concern during field work.

Soil: Existing skid trails and landings were identified before harvesting by evidence of retarded vegetation and accumulation of decaying harvesting debris. While office records provided information on soil densities and infiltration rates, some tests were performed as a verification for monitoring practices. In Block 62, I collected random samples at 5 cm and 15 cm (2 and 6 inch) depths on old skid trails and undisturbed forest for general characterization of soil condition regarding compaction on previous operations. A 72 cc volume core ring was used to collect samples which were later weighed in the laboratory. Unfortunately, post-harvest measurements could not be obtained due to a large wildfire that halted the harvesting operation. Using the ring infiltrometer method, I did a few tests to get the feel of the infiltration rates. I recorded the time taken for a known volume of water to completely infiltrate on randomly selected points both on old trails and undisturbed forest. We examined if the old skid trails followed the current required pattern to minimize impacts. The logging contractor provided his plan of skid-trails he expected to follow during the operation.

Residual trees and wildlife habitat: By observations we noted evidence of tree damage from past logging activities on the area. Scars on standing trees close to old skid trails, discarded damaged logs and crooked stems indicated damage. Trees marked as leave trees were examined to check their pre-harvest condition for comparison with post-harvest condition. We also looked to see if old trees with bird nests were marked as leave trees and that wildlife habitat areas were well marked.

Streams: With reference to stream protection regulations, we surveyed how the boundaries of the sales were delineated close to streams. Although there was no running stream within the blocks allocated for felling, we paid close attention to depressions which showed potential seasonal streams either within or at the borders of the sales.

3.3.2.2.4 Environmental Variables: SUA Training Forest

The SUATF and Meru forest reserve in general lack local and detailed data on climate and environmental variables. While efforts are under way by the University and related institutions to establish a hydrologic data base for the area, I collected some data as an initial step to present the general hydrologic regime, and creation of a reference database of environmental effects of plantation forestry on Mount Meru ecosystem.

Precipitation: Rainfall records for the past 5 years were obtained from a weather station at Narok, within the Problem Area. The monthly records were analyzed for annual rainfall, average annual rainfall for the past 5 year period, and the dry and wet periods. The record of rain days for the most recent five years enabled the estimation of rainfall intensity, in mm/day, during the rainy season.

Stream flow and proximity: Stream flows were measured at different points to estimate the discharge. The estimation was done at the end of the dry season; thus, the discharge should be taken as approaching the lowest. Two methods were applied, the average of three repetitions for each method was taken as the representative flow.

a. Floating object method: Applied where the flow could not be controlled but it was possible to determine the cross-sectional area of the stream. The time taken for a floating object to be carried by the stream current over two marked points, together with the measured distance between the points and the cross-sectional area of the water-body at that point determined the rate of flow in cubic meters per second.

b. At a point where collection of the whole stream flow into a container of known volume was possible, the average time taken as and the container volume determined rate of flow in cubic meters per second.

While method (a) was applied at a point where the access road crosses Selian stream, just before the culvert bridge, method (b) was applied at one of Selian stream tributaries on the old road near Compartment 1a. Of the two methods, (a) is relatively more accurate since the 'whole' stream was collected into a known volume over observed time, whereas differential stream velocity across the width and with depth, and the material properties of the floater, present sources of error in method (b). The condition of stream bed and possibility of subsurface flows also contribute to flawed data. However, method (a) was only possible for that particular stream morphology. When more accurate data is required, more sophisticated methods should be applied.

The distances from plantation boundaries to streams were checked and field surveys were made. Again, the indigenous forests in stream valleys are not disturbed by the plantation forests. While the forest plantations' influence on stream ecology is yet to be determined, logging, road construction and livestock activities are the potential threats through sedimentation and removal of vegetation cover on the stream banks. Potential crossings for roads or cable corridors were critically scrutinized for effects by looking at the vegetation cover, slope grade and length. Judgement from our experience was applied in the first-cut decision making.

3.3.2.2.5 Institutional Variables

The goals and objectives addressing the study area were sought from all relevant sources at national, regional and local levels. I examined documents of the forest policy of Tanzania, Meru District, and objectives of Meru Forest Project and the SUATF. In all levels of planning, the decision makers were identified and their expectations derived from the policies. The statements of Tanzania and Meru District forest policies, and the terms of reference under which the SUATF operates are presented in Appendix C.

Technical Orders, documents issued by the Forest Division with directives on forest practices, were also pursued with regard to harvesting operations. Where documents were unavailable, we interviewed experienced officials. Data obtained refines the institutional constraints regarding timber harvesting on the difficult terrain of SUATF.

3.3.2.3 Plan Implementation, Evaluation and Monitoring

Interviews and field observations provided harvesting techniques applied in the study area, Weyerhaeuser, Warm Springs Indian Reservation and other places visited in the United States. Issues considered included sale contract administration, supervision and inspection during the operation.

Plan evaluation and monitoring were scrutinized through literature reviews and discussions. Evaluation criteria, monitoring types and guidelines for appropriate harvest planning in Tanzanian plantations are developed. Research monitoring is considered as a necessary contribution towards achieving a site specific monitoring.

3.4 Summary

This chapter outlined the materials, procedures applied and sources of data for this study. Effective harvest planning is dependent on site characteristics and limitations of influential factors. The study areas were introduced and background information was presented. Methods and data of the preliminary and actual research were described. The following chapter presents the analysis procedure and interpretations drawn from all the data.

CHAPTER 4

ANALYSIS AND RESULTS

4.1 Introduction

This chapter summarizes data analysis and presents results and interpretation. Comparison, judgement and structured analysis furnished study results and interpretations. Results are presented in forms of maps, diagrams, tables and specified procedures and check-lists. The presentation begins with my overall planning protocol followed by analysis at each step in the proposed flow of the planning process. Whereas physical, economical and environmental considerations are covered separately, institutional constraints are considered within each step they influence. The overall study results and contributions will be briefly discussed in chapter 5.

4.2 Planning Protocol

Through discussions and comparisons I developed a planning protocol designed to fit into the routine management practices of Tanzanian forest plantations. Using the background of the U.S. Pacific Northwest planning approach, evidenced from of Forest Service, Bureau of Land Management, and private companies as reviewed in section 3.3.2.1, all activities of a harvesting operation were examined and ranked in order of precedence. The strongest criterion used was to consider if an earlier action would solve problems experienced at a given harvesting stage. That earlier action is then explored to see if it is a definite step in planning. In this manner I identified the best set of steps for harvest planning. For example, lack of planning for the best harvest system may result in using inefficient or destructive systems, hence economic and/or environmental sacrifice.

4.2.1 U.S. PNW Insights

Literature surveys and observations made on current timber harvest planning in the U.S. Pacific Northwest revealed the following sequence of steps as the most common:

1. Objectives
2. Area description
3. Action planning
4. Sale layout
5. Implementation

Most of the small land owners have complete control of all five steps because of the scale of their operations, which is not the usual case for large land owners and public forests, especially with objectives and implementation steps.

At the Weyerhaeuser Company in Springfield, timber harvesting is planned in a long-term, mid-term and operational basis in that order. The planning is comprehensive, incorporating many tools in a systematic process. Storage, retrieval and manipulation of inventory and all spatial data is through GIS tools. Three years prior to the execution of the operational plan, both office and field activities start in earnest. Areas for harvesting are identified; data is retrieved and scrutinized; boundaries are refined; stand characteristics are validated and road design and sale layout are finalized. Road building and contract administration are processed a year before harvesting. Choice of the contractor favors the contracting company with appropriate equipment for the sale. Harvesting operations are closely monitored during implementation and afterwards against the operational plan.

4.2.2 SUATF Planning and Execution

At the Sokoine University of Agriculture Training Forest (SUATF), harvesting operations are stipulated in a five year management plan; however, each year has a realistic annual plan of operation which shows actual volumes from specific compartments. Harvesting volume is a total of commercial thinning and clear felling volumes. Inventory of the forest stock is carried out once every five years to determine the compartments due for commercial thinning and clear felling. Site class index and growth formulas developed over the years determine the current annual increment (CAI) on each compartment and forecasts of harvesting volumes for the next five years. After allowance for low stocking, which is normally 20%, the annual potential yield of the forest is the summation of all the CAI values for all stands in the plantation. Because forest management is moving toward a regulated forest, the annual allowable cut is the same as the annual potential yield.

While SUATF crews carry out logging for the University sawmill, other customers perform their own logging under contract and supervision of the SUATF management. The contractors acquire standing volume through payment of stumpage (royalty), silvicultural and road fees. The stumpage is paid to the Treasury through Meru Forest office while the Training Forest keeps the fees.

Timber harvesting in the plantations is done according to very broad guidelines. There are no clearly identifiable processes of carrying out the operation. Harvesting differs with time and individual managers due to lack of a prescribed planning procedure. The success depends on personal initiative and experience, making it difficult to assess and monitor results. One clear example was how stumpage price determination differed between Meru forest project and SUATF. This alone is a strong indication of a needed planning protocol.

4.2.3 Comprehensive Timber Harvest Planning Protocol

Timber harvesting is no longer a single activity affecting a single resource in one season; thus, the need for comprehensive planning. The essence of comprehensive planning is the consideration of multiple-resources, interrelated activities and effects over many periods. A thorough progression of planning is the only way to ensure success. Based on my analysis, the following sequence of steps, illustrated in Figure 4.1, are proposed as the best for the study area and Tanzania forest plantations in general:

I. Refine objectives: The compilation of all objectives and goals concerning the harvest area, identification of decision makers and their expectations and, more important, to resolve conflicting goals and objectives so as to have streamlined, acceptable and workable objectives.

II. Describe harvesting area: The characteristics in area, terrain, timber characteristics and all peculiar features which in a way affect the harvesting operation.

Accessibility, environmental, timber market and socio-economic characteristics are considered.

III. Identify values and limitations: Site specific characteristics on the economic and environmental values as well as the physical limitations are identified.

a. Identify socio-economic values: Specify the economic values involved with the harvesting operation at the local, regional and national levels, and variation of these values and economic opportunities with time. The consideration should be so comprehensive as to include economic values directly related to timber, non-timber and human resources involved.

b. Identify physical limitations: Performance of the harvesting systems depends on the maximum slope, grade and distance; maximum timber size; and the sorts needed. Other limits include the soil's physical limitations, road standards and infrastructural limitations.

c. Identify environmental values: High levels of consideration of environmental issues pertaining to timber harvesting in the U.S. PNW have been recognized. Rationale will be exercised to choose what practices are adaptable and workable in the Tanzanian physical, climatic and social settings.

IV. Establish plan expectations: For all possible systems, establish capability with respect to physical limitations, productivity, maintenance and infrastructure utilization.

a. Determine economic performance: a more in-depth analysis of economic performance is needed. The economic transformation under-way in Tanzania is expected to reform the existing imbalance between the value of standing tree and wood-based consumer goods. Economic performance is one of the critical assessments of a plan. Knowledge of all factors will ensure adopting the revenue maximizing and cost minimizing alternative.

b. Determine technical feasibility: determine what can be technically possible under given physical limitations. Will a certain system be able to operate in a given terrain or slope? Is it possible to skid a given log size with sulky or oxen?

c. Determine environmental acceptability: harvesting operations are recognized as causing temporary disturbances to the forest environment. Comprehensively planned operations will identify the acceptable levels and duration of the expected disturbance. Planning will avert most harmful damages to the environment as well as identify mitigating activities to go along with the operation.

V. Identify feasible harvesting systems: the decision of the most appropriate system after consideration of all possible systems and applying them to the prevailing physical, environmental and socio-economic conditions. More important, avoid application of the first system available as this may have long term effects which could have been avoided. All harvesting systems possible should be given consideration, taking advantages of many tools for systems analysis available.

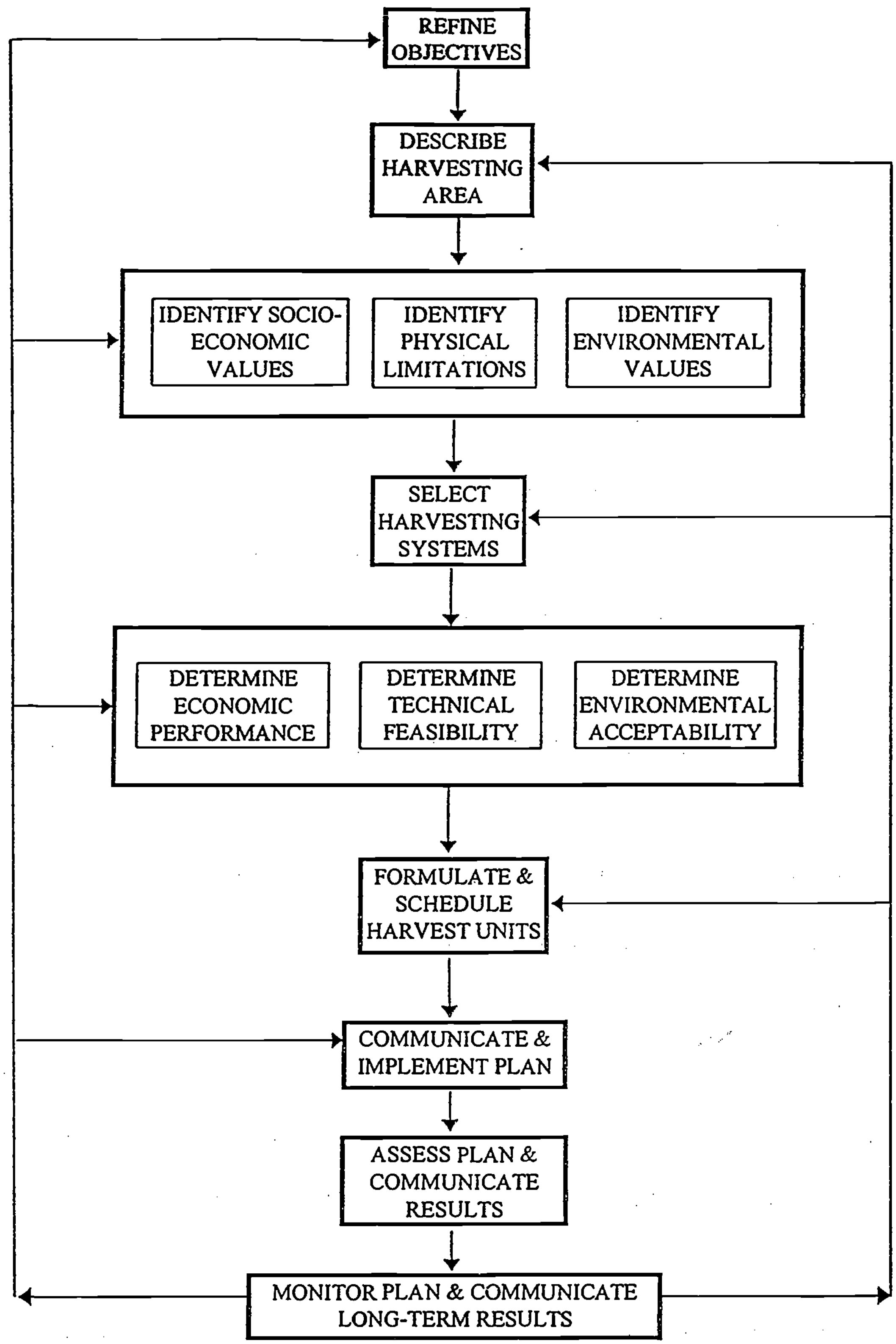


Figure 4.1 Illustration of Timber Harvesting Planning Protocol.

VI. Formulate and schedule harvest units: Volume and area allocation with time periods ensures balanced harvesting, sustained output and avoids loss due to over-mature conditions (heart rot) and over-utilization of other areas.

VII. Communicate and Implement the plan: the identification of who, what, when of the operation articulates the operation and improves the efficiency. The plan must be effectively communicated to persons who will execute it. The supervisors, foremen and even operators should be aware of their responsibilities in plan implementation. This step also identifies the bottlenecks and key points to improve or strengthen in subsequent plans

VIII. Assess Plan and Communicate Results: as a measurement of the plan success, it has a future bearing on the planning process itself rather than the harvesting operation. During the planning process, there should be ways to have draft of the plan evaluated by key individuals in the harvesting operation such as the management board, supervisors, foremen and representatives of the community with which the project interacts. The results of plan evaluation should be effectively communicated to the planner to ensure adjustments are made for improved future plans.

IX. Monitor Plan and Communicate Long-term Results: this is the evaluation of the harvesting operation planned with reference to the expectations. While there is a bearing on the improvement of the planning process, energy is directed toward improving the harvesting activities as well as the variables considered in the planning process. This part of the protocol should also include establishment of channels to communicate expected long-term results to key individuals in harvesting operations. Seminars, workshops and short training courses for the plantation project managers, supervisors and foremen could be examples of communication avenues.

The details of the planning protocol depend on the size of the harvesting operation and the complexity of circumstances surrounding the harvesting operation. Tanzania forest plantations, by design, have less conflicting land-uses, and may be less complex. On the other hand, advanced knowledge of the planning circumstances and wide choices of harvesting systems and planning tools available in the U.S. Pacific Northwest are missing essentials in Tanzania.

4.3 Objectives Refinement

For smooth and successful harvesting, the plan must have clear and compatible objectives that are communicate to key individuals. Incompatible and conflicting objectives produce not only an expensive plan, but an unfeasible one, and hence, subsequent failures in implementation. Before embarking on comprehensive timber harvest planning, the goals and objectives for the area, which reflect expectations of all relevant authorities, must be refined to get categorical statements of how timber harvesting should be carried out.

The goal of the SUATF is to meet the University mission of training, research and production. In this context, the forest management objectives and timber harvesting objectives are expected to contribute to the goals and at the same time satisfy expectations of the different levels of the area ownership. At a national level, the Tanzania forestry policy presents a broad vision of national expectations, and the local district authority focuses on the immediate requirement of its local society (Appendix C), while the SUA had the University mission as its target. The short and long term objectives of the SUATF reflects all the expectations of the higher authorities. The objectives are:

1. to provide facilities for training students in forest practices and management;
2. to provide an area and facilities for research;
3. to become a center for demonstration, refresher courses and conferences;
4. to protect the soil and maintain the quality of water supply to the local people and Arusha municipality throughout the year;
5. to manage the forest profitably and supply a sustained yield of forest products to the local wood-based industries;
6. to benefit the local people through employment and cultivation plots through the *taungya* system practice.

Objective No. 5 above deals with timber harvesting; however, refinement is needed to make it clearer and stronger in purpose. In order to reflect the 'forest profits ... to the local based wood industries' in an efficient way harvesting must be self supporting but also ensure sustainable output. I propose the objective be further elaborated in the comprehensive plan to read as follows:

- to provide an income stream which at least covers the cost of forest operations

- to prepare a harvesting schedule with harvesting volumes to ensure long-term productivity of the forest
- to conform to specified standards and guidelines of planned logging operations to safeguard environment conservation and ensure harvesting efficiency.

Ranking of the level of decision making puts the Ministry (responsible for Forestry) at the top followed by the Regional and then District authorities. Management of Meru Forest Project and then Sokoine University Training Forest, in that order, are at the lowest level. However, the SUATF and Meru Forest Project communicate directly with the Ministry through their Board meetings, in which the Regional and District authorities are just co-opted members. The local authorities have a direct influence in the implementation of daily activities.

The SUATF is a plantation forest, and according to the statement of the National Forestry policy it falls under the category of "providing sustained yield of forest products" which, in this case, are timber volumes. While timber harvesting in the U.S. PNW is on natural indigenous forests, where land-use is multiple and competing, the plantation forests in Tanzania are primarily commercial, with less conflicting objectives. A conclusion that timber harvesting is the primary responsibility of the plantation forest is justifiable for the foreseeable future. However, to make the production sustainable, it calls for well planned harvesting practices, especially comprehensive planning to avoid adverse effects to the productivity of the land.

The biggest challenge facing the Training Forest timber harvesting operations is lack of a logging plan and a reference to harvesting standards and guidelines. While there is an elaborate documentation of rules and guidelines for plantation establishment, as seen in the "Standing Orders", a comparable reference to standards and guidelines of timber harvesting is missing. The sample logging directives of McDonald-Dunn Forest of the College of Forestry, Oregon State University (Appendix D) can be good references, noting they also fall under a comprehensive state "Forest Practices Act".

4.4 Area Description

The problem area's physical characteristics rank high as prerequisite to many decisions in harvest planning. Timber, terrain, accessibility and the associated physical limitations are critical variables in harvest planning. Maps, aerial photographs, office documents and field observations were studied to develop an explicit description of the area, especially the physical characteristics. Figure 4.2 is a contour map of the northern half of SUATF (Glesåen, 1987) showing the steep ravines of the streams and the existing road network. Photo-interpretation, photogrammetry, digitizing and mathematical approaches were used to make surface planes, harvest area polygons and proposed access routes.

4.4.1 Mapping

Contour maps and aerial photographs were used to prepare layouts of the harvest area. Final maps included corrections on boundaries and attributes as observed during field surveys. Features not originally shown on the maps include:

- a wide fire break surrounding compartment 1e;

- a patch of *Cupressus lusitanica* stand at the southeast border of compartment 17a.
- an old road across compartment 3a.

The contour maps of the area were digitized into surface planes, serving also as potential input to GIS data bank for future detailed planning. The aerial photographs were limited for DEM creation due to tree canopies obstructing the ground, which is the critical requirement for terrain presentation. However, use of an AP190 stereo-plotter for the creation of DEM was learned and demonstrated for another area. The 10 m contour interval, 1:10,000 scale contour maps of SUATF were used to develop a 100 x 100 m resolution digital surface map of the northern half of the training forest. The X, Y, and Z data was analyzed by SURFER software to develop the surface map shown in; shown in Figure 4.3. Actually, a resolution near 5 x 5 m or certainly not greater than 10 x 10 m is needed to determine the physical limits for most harvesting systems. Note the steep terrain of the problem area as also shown in the contour map Figure 4.2.

A map is a tool of great importance in timber harvest planning. It is on a map that a planner controls the planning in the office and from which a foreman or an operator transfers the plan to the field. Timber harvest planning requires topographical maps to derive the slopes and distances, that are essential components in road building and determination of harvesting systems best suited for the area. It is also from such maps that the magnitude of effects on the environment can be stipulated through knowledge of the slopes and the drainage patterns.

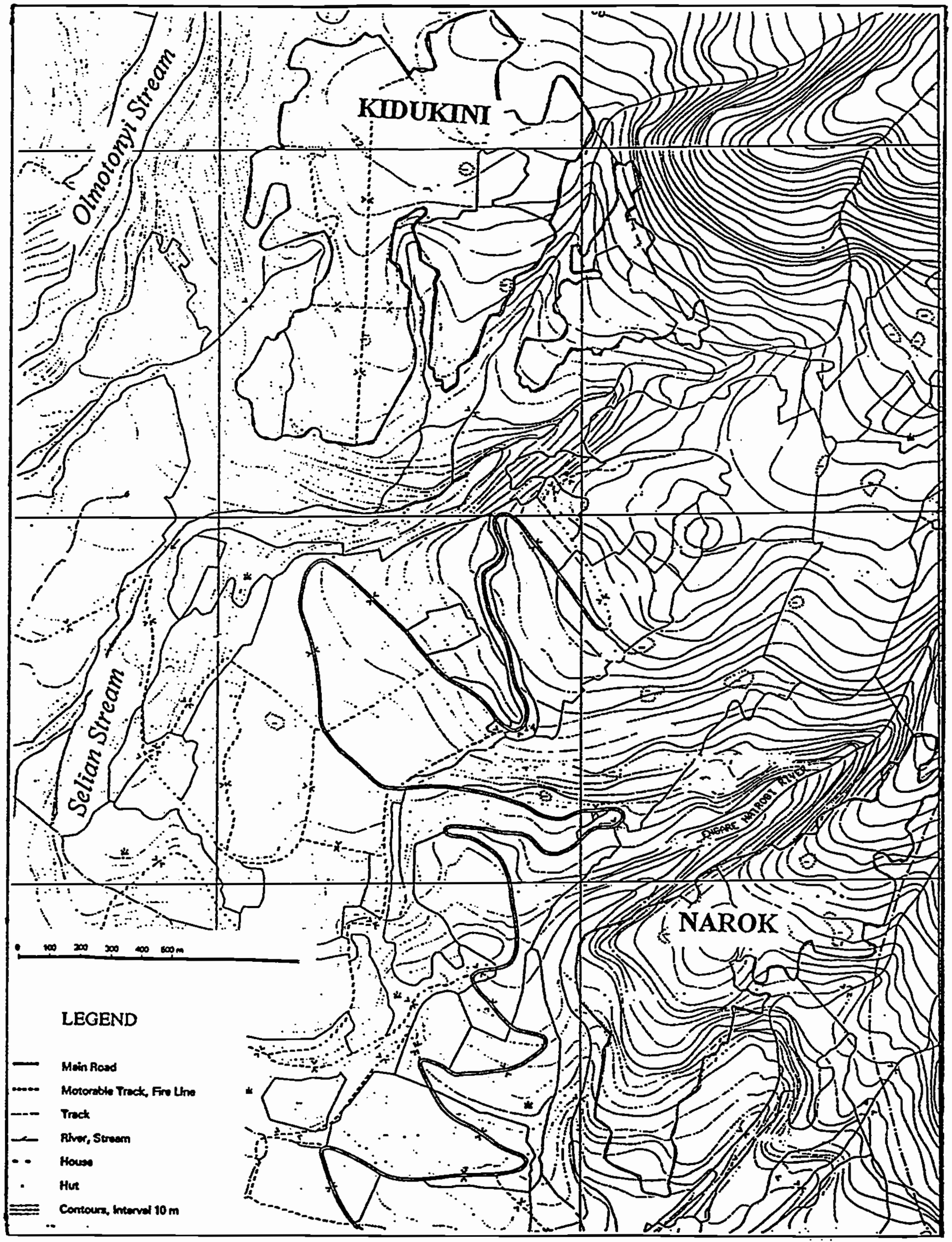


Figure 4.2 Contour map of Northern part of SUA Training Forest (Adopted from Glesåen, 1987).

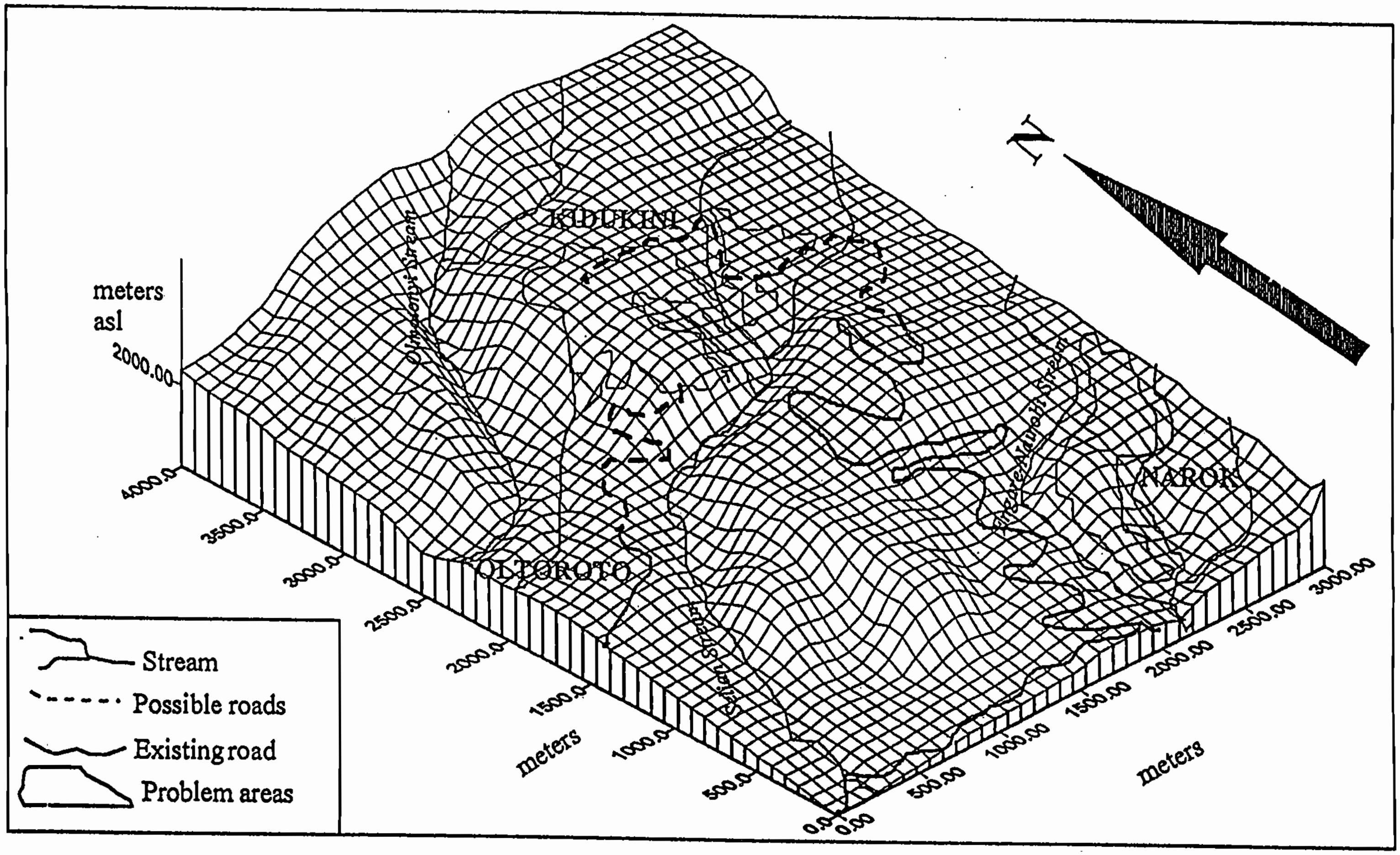


Figure 4.3 Surface presentation of Northern SUATF showing the problem area, streams and roads.

This study was advantaged by having maps ready for the planning. In a situation where maps are not available, there should be ways to prepare one for the area. Mapping an area from scratch is an expensive undertaking, the cost varying with the goal of the project. It can be as simple as a field survey with simple equipment such as a chain, compass and clinometer, to a complex one using GPS data capture and an analytical plotter. In principle, mapping an unsurveyed area requires establishment of control points in the area. Aerial photos can be oriented with this control and all visible features that are necessary for the plan can be mapped into a useful coordinate system.

The aerial photographs, once control points are identified, can be used also to refine maps and add useful data such as vegetation covers. The first step, therefore, in any planning process is really to ensure that the maps and photo resources are adequate to support the process. If not, an aerial photo survey and map making should be completed first.

4.4.2 Timber Characteristics

Standard volume tables (MNRT, 1971(a) & (b)) were used on diameter and height field data to determine timber volume in the area. The volume tables for respective tree species were used to obtain representative volume per tree, and eventually volume per hectare, after summing the count of all trees in each plot. Volume per hectare for the whole compartment was taken as the average of all the plots measured. The total volume for the compartment was the multiplication of volume per hectare by the compartment area determined from the corrected maps. All volumes considered were total volume, over bark. Table 4.1 summarizes the volumes, over bark, for the compartments in the problem area. The volumes so obtained were consistent with the office records, which were developed from studies and constantly upgraded by University students during field exercises.

To determine design payload for cable yard analysis, the largest current log dimensions found in the area were used in Huber's formula, and greenwood density used to arrive at an estimated weight per design log. Largest dimensions are 4 m length and 60 cm dbh, which approximates 1 m^3. An assumed density of green wood of close to 1 g/cc makes a metric tonne weight per single log, the design payload. In normal circumstances an average log measures 3.2 meters long and 31 centimeters middle diameter, making an approximate volume of 0.24 cubic meters.

The economic values and institutional factors used to be the sole determinants of decision on cutting volumes. In comprehensive timber harvesting, requirement for a sustained forest introduced a limit on harvesting volumes to satisfy sustained production. While this is being addressed in forest management plans by *Harvest Scheduling*, which has become an important management strategy, harvesting volumes should be checked to ensure that this requirement is met. Environmental requirements such as leave trees, nest trees and wind breaks, habitat clusters and riparian zones are considered at this juncture.

Because the compartments of the problem area have gone far beyond the rotation age, commercial thinning was not considered. The environmental requirements stated above are not in the SUATF objectives; thus, the whole volume can be harvested. With a 20% allowance for understocking, toppings and errors in data collection and calculation,

Table 4.1 Summary of timber characteristics in the Problem Area.

Compt #	Species	Age yrs	Area ha	Avg dbh cm	Avg HT m	Stand m^3/ha	Total Vol m^3
1a	*P. patula*	34	44.4	30.6	36.5	1,147.26	50,938.22
1b	*P. patula*	33	9.6	29.1	35.0	767.05	7,363.68
1c	*P. patula*	33	4.4	32.1	34.0	1,178.40	5,184.96
1d	*P. patula*	34	5.9	38.0	31.0	681.00	4,017.90
1e	*C. lusitanica*	23	1.9	27.8	27.3	951.90	1,808.61
2a	*C. lusitanica*	24	12.3	33.7	27.3	656.00	8,068.80
3a	*P. patula*	33	4.5	32.4	37.0	1,017.75	4,579.88
3b	*P. patula*	33	0.9	29.4	38.0	1,013.70	912.33
4a	*C. lusitanica*	22	10.3	25.6	20.0	575.20	5,924.56
16a	*C. lusitanica*	23	27.0	32.9	30.5	949.00	25,623.00
17a	*P. patula*	34	21.6	32.0	32.8	1,008.20	21,777.12
			Average	31.2	31.8	904.13	
						Total	136,199.05

not less than 110,000 cubic meters of high quality merchantable volume of timber is held in the problem area of the Sokoine University of Agriculture Training Forest.

According to the 1990-1996 SUATF management plan, in 1990 there was potential demand of about 44,000 m^3. If an increase of demand by existing customers and introduction of new private sawmills around Arusha over the time is considered, I assumed a 5% annual increase of demand, giving 62,000 m^3 as the market demand for 1997. Two years are therefore needed to harvest and sell the volume in the problem area.

To ensure sustained forestry, the Training Forest is managed toward a regulated forest by conforming to the allowable cut. According to the 1990-1996 management plan, the annual allowable cut for the whole forest is approximately 18,000 m^3. Without consideration for thinnings and clear felling other compartments achieving rotation age, the volume in the problem area alone needs eight years to harvest. The fact that the standing volume in this area is vulnerable to heart rot, vandalism and potential fire damage outweighs the allowable cut philosophy. After all, the allowable cut is supposed to give each part of the forest an equal chance to be harvested when rotation is achieved, but the compartments in the problem area have been ignored for close to ten years. I propose to make allowance for this volume and distribute the delayed harvests on accessible areas across the forest, subject to management approval.

4.4.3 <u>Terrain and Accessibility</u>

The terrain data as reduced represents functional classes of slope in the harvest areas. References to the performance of different harvesting systems were used to identify slope breaks on maps, and later verified during field observations. The slope classes served to define harvesting units within compartments. While strategic plans demarcate large harvesting areas, this stage in the tactical and operational plan identifies the feasible harvesting units.

The knowledge of harvesting units and road system is critical in harvest planning. Accessibility consideration starts at the stump where the tree/log has to be taken to the landing. Prior to economic and environmental considerations, physical feasibility of a system must be determined. Location of landings, accessibility to existing roads and layout of yarding corridors contributed to the final delineation of harvesting units. Where necessary, polygons established on the basis of terrain and other factors were modified to suit the accessibility requirement.

In the SUATF problem area, the average slope within the compartments ranges between 7% to 32%. While it was possible to find up to 1 hectare with average slope under 5% in some areas of compartment 1, compartments 2, 3 and 4 have slopes between 5 and 30% and most areas of compartments 16a and 17a have slopes over 30%, reaching 60% at other places. The valleys which border compartments have slopes over 100% and slope distances down to 80 meters. When roads are considered as means of access to this area, at least two points for the compartments at Kidukini, and only one for compartments 16a and 17a are possible. This qualifies the area as "difficult terrain".

Accessibility: Figure 4.4 illustrates access possibilities to the problem area. Using maps and field surveys, I measured the distances of proposed roads and cable swing profiles from the existing access road to possible landings in the compartments.

A. Three possibilities were considered to access Kidukini area:

1. Extend the access road from point **I** to point **A** (through **D** and **B**) by reconstruction of 4 km road and two bridges as recommended by Zonal Forest Management Office (ZOFOMO) (1996) in Appendix B. This option will enable access to compartments 1a, 1b, 1c, 1d, 1e, 2a, 3a, 3b and 4a.

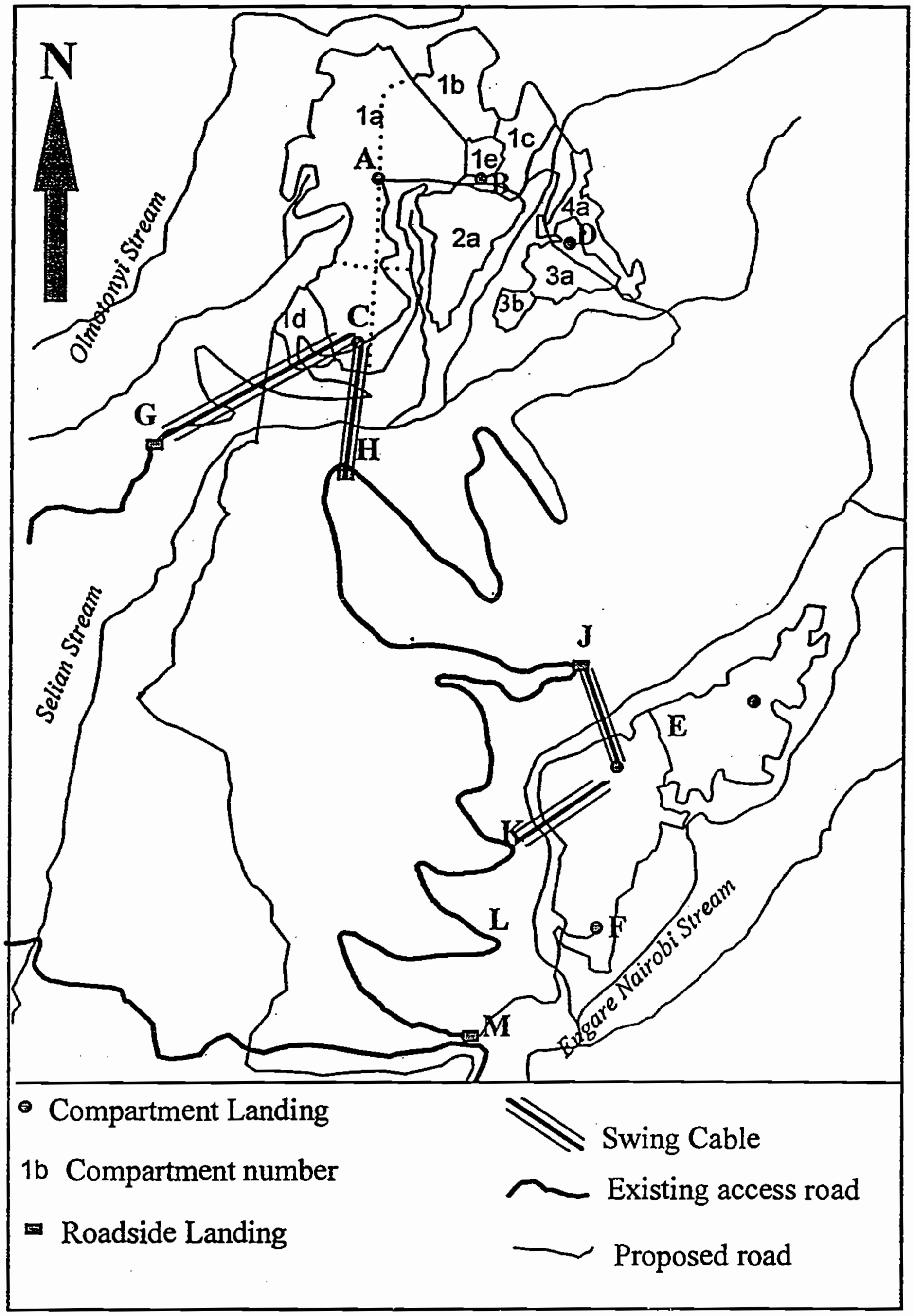


Figure 4.4 Harvest polygons and proposed access to the problem area.

2. Construction of a 1.5 km steep road (average 12% grade) from the south of Compartment 1a and 1d, point **C** to point **G** outside the SUATF at Oltoroto, connecting an existing road on Meru Forest Project at Point E.

3. Establish a skyline system (swing cable) corridor from Compartment 1, at point **C**, across the Selian valley to the existing road at point **H** or southwards to point **G** on Meru Forest project at Oltoroto.

B. Since access of compartments 16a and 17a from the east side is extremely difficult, due to two deep and steep valleys of tributaries of Engare Nairobi stream as indicated in Figure 4.2, two possibilities were considered:

1. Construction of a new road from the junction at **M** on the existing road to the bottom tip of Compartment 17a at point **F**. A drift will be suitable at crossing of Engare Nairobi stream. There is also (undetermined) considerable amount of cutting needed to access the steep side of the stream on the compartment 17a side, which is a potential environmental hazard.

2. Establish a skyline from a point at the border of 16a and 17a at point **E** to point **J** on the existing road. This option calls for upward cable yarding within both compartments. While a landing around point **E** can serve yarding the whole of compartment 17a, a temporary landing is needed close to the tip of Compartment 16a to facilitate upward yarding. Tractor trailers, with brakes, will then be used to collect logs at point **E** for swinging across to point **J**. Terrain slope is favorable for this approach.

Detailed planning for the road construction can apply the rates used in the ZOFOMO proposal. Environmental effects peculiar to the area and cable yarding details need further studies. In all cases, the economic values of the volume, socio-economic loss if the area remains unharvested, and potential success of well planned harvesting operation justifies harvesting the area.

Cable Corridors: In considering cable as a logging and/or extraction system, critical profiles drawn from the contour maps were analyzed using LOGGERPC computer software. The analysis was based on at least the 1,000 kg (2,200 lbs) design log weight as determined in section 4.4.2, and meeting all the equipment requirements. Tailspar and headspar points for the corridors were verified for suitability in the field. Table 4.2a shows the equipment summary used for the analysis and Table 4.2b the main features of the analysis.

My feasibility study proposes a cable system as a means to access the problem area from the existing roads. In the Kidukini compartments, areas are too level for cable logging, but logs can easily be cable yarded (swing) south eastward across to point H on the SUATF access road, or southward to point G, an access road on Meru Forest Project side. In compartments 16a and 17a, terrain is too steep for conventional ground-based systems and transport access is difficult. However, the same slopes are conducive for cable logging. Thus, cable logging in this area solves both access and logging problems.

Table 4.2a Yarder and Carriage specifications.

Yarder: 30-40 feet, 3-drum slack pulling tower

Wire rope	Diameter (in)	Type	Weight (lbs)	Safe Load lbs	Length (ft)
Skyline	0.75	IPS	1.04	17,067	1,965
Mainline	0.50	IPS	0.46	7,667	2,600
Haulback	0.50	IPS	0.46	7,667	4,000
Slack-pulling	0.50	IPS	0.46	7,667	2,000

Carriage: Radio-controlled, Mechanical slack-pulling

Wire rope	Diameter (in)		Length
	minimum	maximum	(ft)
Skyline	0.75	0.87	-
Mainline	0.50	1.00	-
Dropline	0.87	-	200

Table 4.2b Summary of LOGGERPC analysis for critical corridors of swing cable from points in the problem area to points on the access road.

Tailspar	Headspar	Payload	Heights (ft)		Chord slope
(in Compt)	(point on access road)	(lbs)	Tailspar	Headspar	(%)
1a @ C	H	2,462	45	35	-21.3
1a @ C	G	2,206	60	50	-34.2
16a @ E	J	2,419	30	33	-22.0

The profile analysis brought forth by this study advances the possibility of adopting cable logging and extraction from the problem area and similar areas in Tanzania. Further layout and on-the-ground analysis is needed, as recommended by this study. Terrain characteristics need to be ascertained and possible cable systems have to be considered: standing, running and live skyline and other possible systems. Being a new technology in the Tanzania logging context, capital and expertise investments must be fulfilled before proceeding to practical application, i.e., the system must be made available, operation crews must be adequately trained and a maintenance program established.

4.4.4 Working Units (Sales)

The area was divided into working units according to the prevailing characteristics of timber, terrain, accessibility and harvesting systems characteristics. Table 4.3 presents seventeen polygons of the problem area based on the following criteria, in priority order:

1. Compartment boundaries: The existing compartment boundaries were used as the first-cut criteria since the boundaries already represent type of species, age and natural barriers such as valleys and ridges.
2. Slope classes: Both diagnostic and functional classes were considered. Diagnostic classification was based on uniform slope whereby any significant change of terrain slope implies a change of class. Functional classes were based on harvesting system's performance.

Table 4.3 Seventeen polygons by timber and terrain characteristics.

Compt #	Polygon	Species	Age yrs	slope %	ASD m	Area ha	Volume m^3/ha	Total Vol m^3
1a	*i*	*P. patula*	34	>35	75	4.8	1,147.26	5,506.83
	j	*P. patula*	34	25-35	80	12.7	1,147.26	14,570.17
	k	*P. patula*	34	5-25	50	9.4	1,147.26	10,784.22
	l	*P. patula*	34	0-5	100	12.7	1,147.26	14,570.17
	m	*P. patula*	34	20-35	80	4.8	1,147.26	5,506.83
1b	*n*	*P. patula*	33	0-20	100	9.6	767.05	7,363.68
1c	*o*	*P. patula*	33	10-25	150	4.4	1,178.40	5,184.96
1d	*p*	*P. patula*	34	>35	50	5.9	681.00	4,017.90
1e	*h*	*C. lusitanica*	23	0-5	50	1.9	951.90	1,808.61
2a	*q*	*C. lusitanica*	24	5-20	250	12.3	656.00	8,068.80
3a	*r*	*P. patula*	33	10-20	70	4.5	1,017.75	4,579.88
3b	*s*	*P. patula*	33	5-15	60	0.9	1,013.70	912.33
4a	*t*	*C. lusitanica*	22	15-25	100	10.3	575.20	5,924.56
16a	*u*	*C. lusitanica*	23	10-25	600	8.0	949.00	7,592.00
	v	*C. lusitanica*	23	25-40	450	13.5	949.00	12,811.50
	w	*C. lusitanica*	23	10-20	200	5.5	949.00	5,219.50
17a	*x*	*P. patula*	34	5-15	100	8.6	1,008.20	8,670.52
	y	*P. patula*	34	35-60	350	8.7	1,008.20	8,771.34
	z	*P. patula*	34	10-30	100	4.3	1,008.20	4,335.26
							966.62	136,199.45

While all other compartments made one polygon each, the size and variable terrain of compartments 1a, 16a and 17a resulted into more than one polygon. Likewise some adjacent polygons have similar terrain and close timber characteristics to justify them being treated as one polygon in the systems analysis. Polygon ***h*** in compartment 1d and polygon *j*, which is part of compartment 1a, could be considered as one.

4.5 Problem Area: Harvesting Alternatives

With the increased demand of wood, and depletion of the natural forest source, demand is shifting to plantation forests. Abeli and Ole-Meiludie (1991) commented on future harvesting strategies in Tanzania forests. They argued that volume consumption by current mills does not warrant heavy felling machines, such as feller-bunchers and tree harvesters. They advocate that manual cutting and powersaws could be improved by training, proper use and maintenance. I add that use of powersaws should be encouraged to harness their increased productivity with expectation that the current availability of saws and parts due to trade liberalization will eliminate the scarcity which defeated their initial introduction. This is an example of an institutional obstacle.

Ground-based systems are the norm in plantation forests; however, this study showed them incapable of harvesting in most of the problem area. While skidding tractors with rear-mounted winches could skid logs from short steep slopes by standing on a less steep area nearby, this option does not work for long slopes. It is also less environmental friendly compared to cable systems. Cable systems have proved their usefulness in mountainous terrain all over the world, and added the advantage of less site disturbance (Jarmer *et al*., 1992; Aulerich, 1993). A major disadvantage is the need for capital investment and trained staff along with a necessary commitment to enable harvesting of the valuable stands and as an investment for the future.

Not only skidding, but also accessibility to the compartments, will be made possible by cable systems across the environmentally sensitive valleys. In dealing with accessibility problems, this study considers intermediate landings at points on the existing access roads. Systems candidate for extraction from compartment landings to these road landings include tractor-trailer, forwarders and short straight trucks; however, cable swing is also considered the most plausible, especially for compartments 16a and 17a. The Mkumbara skyline in Tanzania is an encouraging example of an efficient, profitable and environmentally friendly system (Abeli & Shemwetta, 1988).

Of the different alternatives to be considered in the numerical analysis in section 4.8, five alternatives are worth discussing here. Skidding and extraction are regarded as one activity where the same straight trucks, forwarders, and tractor-trailers are used to extract logs from the stump to the intermediate landings. In the same fashion extraction and hauling are considered as one activity when the same tractor trailers, straight trucks and even forwarders are used either from the stump or the compartment landing straight to the mill.

Alternative 1: Renovation of road to Kidukini: It is a plausible alternative both technically and economically as summed up in the ZOFOMO report (1995) shown in Appendix B. Skidding and extraction will be feasible once the road is in place. All the points of the compartments will have easy access except Compartment 1d and 4a, with slopes beyond 25%, where some type of cable yarding is needed. There is environmental concern on soils and vegetation disturbance for road construction, especially crossing the streams (Selian tributaries). Let this road be known as the 'upper road'.

Alternative 2: Installation of swing cable across Selian: Technically feasible for a 40-ft tower with radio-controlled carriage in terms of clearance, payload and distance. From the southern tip of compartment 1a, pre-skidded logs from all compartments in Kidukini, with the exception of 3a, 3b and 4a, can be extracted through this route. Environmentally sound too since the protective forest and soils on the valleys and the stream will have minimum disturbance. Concern is the capital and technical investment on the cable system. Only the economic gains in harvested volume and environmental gains in protected resources will warrant the expense of cable systems and the necessary training and maintenance required. This alternative may be considered alongside a cable swing from **C** to **G**.

Alternative 3: Construction of road from Kidukini to the south. This may be known as the 'lower road' compared to the upper road considered in (1) above. More study is needed to lay out the road on the ground. However, the report for the upper road could be used to estimate the costs. There are advantages and disadvantages compared to the upper road. The slope is steeper and narrower, calling for switch-backs and hence heavy cutting. The road will be scaling the maximum slope of 15%, hence suitable for tractors only, braking trailers being essential. By having no streams to cross, this road is not subject to water disturbance; however, well placed and maintained drainage structures are prime requirements to avoid run-off and erosion hazards during rains.

Alternative 4: Installation of a cable swing across Engare-Nairobi ravine: The cable system option is vital for log skidding as well as extraction in compartments 16a and 17a. Access to this area is hindered by the steep walled streams of the tributaries of Engare Nairobi. Figure 4.2 shows the eastern side to be even worse because it needs to cross two streams to connect to the existing road. Within compartments 16a and 17a, the slopes above 35% eliminate almost all possible ground based systems. Use of a cable swing to points on the access road to the west of the area is thus advanced. Technical and economical arguments are the same as (2) above, but stronger. The environmental concern is stronger considering the short and steep valley through which a road would be constructed. The amount of earthwork and vegetation disturbance would be tremendous. Apart from slope as the hindrance for ground-based systems, lack of a road in place across the ravine is the major problem. Point **J** can also be a possible destination.

Alternative 5: Construction of road across Engare-Nairobi. This would be the current conventional choice for timber harvesting in Tanzania. The difficulty with implementing this alternative in the past is evidenced by the length of time passed without harvesting the problem area. Road alignment and construction across Engare-Nairobi valley is difficult by both steepness and shallow rocks of hardened lava. Large economic and environmental degradation costs would be expected from this construction, which will permanently serve this area; whereas an investment on cable (alternative 4 above) will serve other places where cable can be used, and for a long time.

4.6 Economic Values

The economic justification of a harvesting venture is the profit margin expected from the undertaking after accounting for all costs, including risk. While economics of the forest industry is well treated elsewhere (Davis & Johnson, 1987), direct economic implications with timber harvesting are considered in this study, not as an economic analysis, but as partial fulfilment of planning decisions. Knowledge of economic values from a harvested volume brings closer the decisions of what systems to use, what risks to take, as well as what benefits can be foregone.

Production cost rates were associated with possibilities for different alternatives applied to harvest the area. While more sophisticated analytical procedures are needed to establish actual cost and benefit figures, the first step must be taken to establish the economic feasibility. Before bringing in the environmental values, an economic feasibility based on general terms of expected profit margin would be determined.

In the United States, I observed a procedure whereby a company wins a logging contract by a bidding process based on the merchantable volume. The cost and benefit considerations, including risk, are all tied in the process. The contract covers all timber harvesting activities from roads, felling, hauling and post-harvest activities. Even with its own logging crews, Weyerhaeuser, a large company operating in U.S. Pacific Northwest auctions some of its forest stands scheduled for harvesting, indicating serious consideration of the economic implications.

In the SUATF study area, both office and market rates were considered in determining the economic value of the stand in the problem area. Revenues obtained are stumpage, silviculture and road fees. Stumpage, commonly known as a royalty, is defined as the payment to the government for the value of land over the entire time it was occupied by the plantation. Determination of stumpage entails a complicated procedure involving site class, average tree volume and species to be represented by a tariff number.

Using a table provided by the Ministry, this tariff number has a corresponding economic value. Each compartment, or part of it, has a unique tariff number.

In the past, the management used to charge felling and skidding fees, together with silviculture and road fees, when customers bought logs at the road side. Currently, because customers conduct felling and skidding on their own, the management charges silviculture and road fees only. The rate of these fees are agreed annual values calculated on the basis of total costs expected to be expended in silvicultural activities and road construction and maintenance divided by total annual harvest expected. All costs are presented in Tanzania shillings per cubic meter.

Market values were used to estimate harvest costs because at the time of the study harvesting was done by private companies. Table 4.4 below summarizes the component

Table 4.4 Average Unit cost at the Mill

Cost Item	Cost, US\$/m^3	Equivalent Shs/m^3
Stumpage	15.00	9,000
Felling	2.00	1,200
Skidding	2.33	1,400
Loading	1.83	1,100
Hauling	15.50	9,300
Total unit cost	36.66	22,000

cost per cubic meter downtown Arusha, irrespective of type of system used. The mills pay a lump-sum per truck, through a contractor, or individual payments to part-time laborers for felling, skidding, loading and hauling operations. Stumpage and fees must be paid before hand. Hauling and stumpage are the most expensive items. Average distance from the forest to the Mills is 30 kilometers, making unit hauling cost of $0.52 (Shs348) per cubic meter per kilometer of road one way. Determination of economic performance, on the cost side, is illustrated in the systems analysis demonstrated in sub-sections 4.8.3 and 4.8.4.

4.7 Environmental Values

4.7.1 Introduction

Environmental values are the benefits a community enjoys from an environmental condition or the costs it has to pay by the removal, damage or pollution of that condition. For example, if the water supply for settlements down the Selian stream is degraded by sediments as a result of harvesting up-stream, then clean forest water represents the "value" while to treat the sediments, or to get an alternative source represents the "costs". In planning for timber harvesting, the environmental values of the area should be stipulated in the objectives. The values are safeguarded by harvesting guidelines and regulations (Best Management Practices) which would be observed during proposed harvests.

While there is a big contrast between environmental values of the WSIR and SUATF due to different land-uses and culture, the harvesting effects on soils and streams are expected to be similar. Environmental values should be given due consideration in timber harvesting operations at SUATF and similar situations in Tanzania. Values are mentioned in institutional goals of various organizations but specific practices will need to be addressed during planning.

Apart from providing a harvesting operation for this study, other advantages of WSIR were availability of established environmental data, harvesting controls through code of harvest practices in place, and an elaborate monitoring procedure. I reviewed the environmental variables, practiced their measurements and observed compliance of environmental protection harvesting regulations. As a practice for adoption into Tanzania forest projects, I collected some environmental data at WSIR, which I compared with the established data base, and also at SUATF as a demonstration for data establishment and monitoring activities.

4.7.2 Environmental Variables at WSIR

At Warm Springs Indian Reservation, bulk density was obtained though normal calculations on the weights and known volume to get grams per cubic centimeter. The bulk density range was from 0.68 to 0.98 g/cc for 25 samples randomly selected on old trails and undisturbed forest in Block 62. According to soil interpretation record from the office (USDA-SCS, 1993), this is the expected density for *mackatie-kutchner complex* soils at 46.7 cm (0-18 inch) depth. The bulk density was nearly the same at 15 cm (6 in) depth but higher at 2.54 cm (1 in) on old trails than undisturbed area. Bulk density at 2.54 cm (1 in) depth was still higher than that at 15 cm (6 in) depth on old trails. This is consistent with studies that it takes up to 16 years or more for a compacted area to resume its original form and also that compaction is more severe on the top layer (Froehlich, 1979). Infiltration tests done on 13 random points in Blocks 61 and 71 averaged 18.8 mm/hr (0.74 in/hr), which is also within the levels expected of the soil (Table 4.5.)

Measurement of soil disturbance in blocks 61 and 71 in percentage total area occupied by skid trails and landings indicated 9.5% and 8.7% respectively. Apart from broken branches due to felling trees, there was no significant machine damage on the leave trees of these Blocks, which are also far from any streams or riparian areas. The one acre habitat clump in each Block were intact after harvesting. Summary of environmental data of the study area in Warm Springs Indian Reservation (WSIR) is shown in Table 4.5.

4.7.3 Environmental Variables At SUATF

In SUATF, and Tanzanian plantation forests in general, skid trails are not normally designated in harvesting operations. Skid trails are dictated by rows and columns during thinnings, but by the discretion of the skidding operator during clear felling. Except on steep areas beyond 20% slope where the *taungya* system is prohibited, designated skid trails may be considered less critical since the *taungya* system has the potential to ameliorate compaction through tillage prior to planting of crops. However, shallow crop tillage may not loosen deep compaction (e.g., 30-60 cm) from heavy logging equipment.

Table 4.5 Summary of soils characteristics of Blocks 61 and 71, Warm Spring Indian Reservation forest. (Compiled from USDA-SCS, 1993; and WSIR office records).

Character	Block 61	Block 71
Soil Management Unit (SMU)	415	417: Very strong sandy loam;
Soil type	Mackatie/Kutchner complex	Howash
Class (AASHTO)	A-2, A-4, A-6	A-1, A-2, A-4
Slope	0 - 12%	12 - 30%
Precipitation	low: 40-60 inches annual	low: 40-60 inches annual
Landscape	Concave and slightly convex	southern aspect of side slopes
Soil properties	•deep (40-60 in); •well drained; •moderately slow permeability: 0.2-6.0 in/hr; •bulk density: 0.8-1.6 g/cc.	•very deep (>60 in); •excessively drained; •moderately rapid permeability: 0.2-6.0 in/hr; •bulk density: 0.8-0.9 g/cc.
Management limitation	wetness, compaction, susceptible to displacement; Logging restricted Nov-April due to snow and wetness	stoniness, wetness, susceptibility to displacement; Logging restricted Nov-April due to snow and wetness
Use and Management	Restrict equipment use to dry periods; use designated skid trails; rip trails and landings; Minimize slash piling; Site preparation required.	Minimize excessive disturbance in harvesting and road building; Site preparation required immediately.

Designated skid trails are also necessary to improve efficiency of harvesting because their location seeks to find the shortest distance from stump to landing. Pending further research, it is fair to state that because of the *taungya* system practices, slope and climate remain the significant factors when considering harvesting effects on soils. Thus the sloping areas and seasonality were taken as significant variables for this factor. While some studies have shown both economic and environmental benefits of the *taungya* system (Chamshama *et al.* 1992), there is still need to monitor the system with respect to soil erosion and stream protection

Livestock is illegal in the forest; however, my observations showed widespread use of the forest for grazing. The management is not serious about enforcing existing regulations banning livestock in protected forest where trails are highly eroded due to years of use. The amount of dust at the time of field work suggested that erosion is still progressing at a high rate. Studies are needed to establish the significance of livestock and logging to forest degradation.

Post harvest treatment of a harvest area through tillage, making of water bars and debris disposal at Warm Springs Indian Reserve is not relevant to the Tanzanian context where *taungya* system follows harvesting operations. However, the environmental monitoring is essential to ensure that both timber harvesting and *taungya* have minimum impacts as well as explaining the signs of site degradation for on-site management.

Rain data from Narok station was analyzed for interpretation. Annual rainfall was uniform between 1,000 to 1,200 millimeters per year. Average annual rainfall for the past five years was 1,120 mm, April and May being the wettest, August and September completely dry (Figure 4.5). The highest intensity over the period was 29 mm/day in April 1996 when 16 days of rainfall recorded 469 mm. Since hourly precipitation was not reported it was not possible to get intensity in per hour basis. Timber harvesting can therefore be done all-year round except April and May. In fact these months are used by

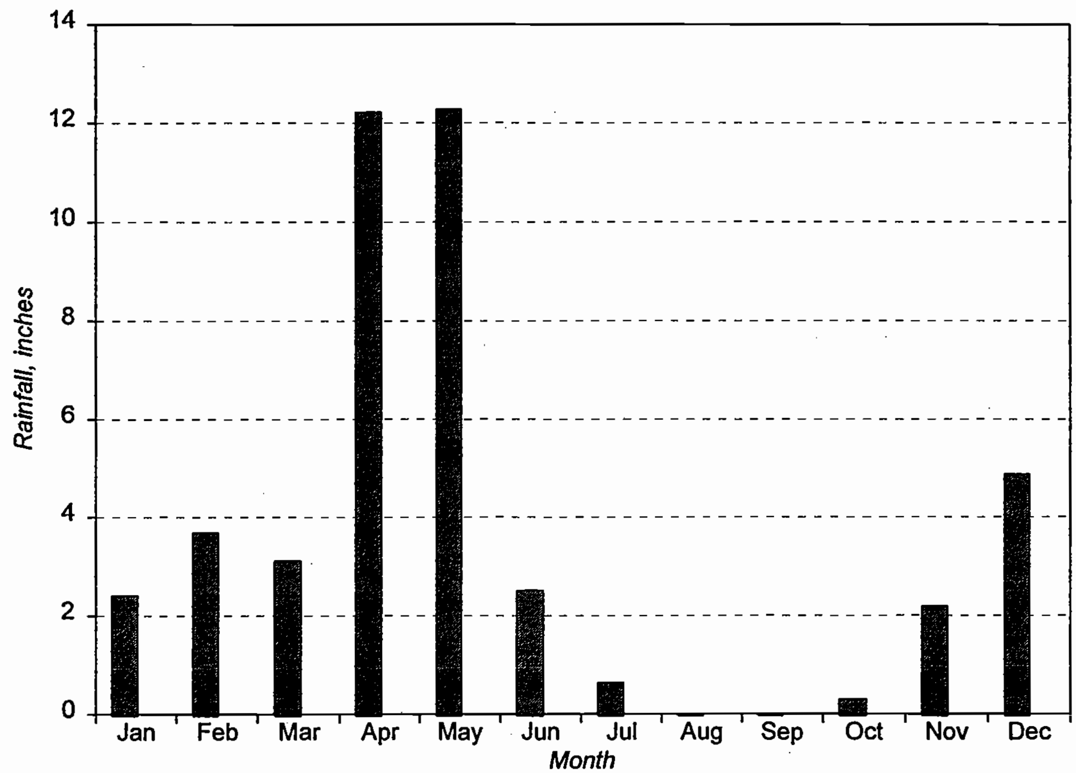


Figure 4.5 Annual rainfall pattern of Meru Forest Plantations.

the management to mobilize planting and replanting (beating-up) operations. Streams draining the training forest are shown in Figures 3.3 and 4.2. Stream flow was calculated from data collected at the three points: Time taken to fill a 5 liter averaged 33 seconds,

hence the flow at the Selian tributaries at Kidukini bridge was 0.00015 m^3/sec. At the culvert bridge where Selian stream has been increased by underground flow emanating from the steep rocks where the tributaries join. The flow, calculated through cross-section area X distance to get volume, and the volume divided by average time.

Cross-sectional area	=	0.1705 m^2
Floater distance	=	2.0 m
Volume	=	0.341 m3

Average time (3 trials) = 7 sec

Flow = 0.0487 m3/sec

This brief measurement indicated that the flow at one of the tributaries of Selian stream is only 0.3% of the flow downstream at the culvert bridge. The connection to other tributaries and the underground flows which turns surface flow just before the tributaries connect can explain this increase. Also because velocities are generally highest near the center and surface of a channel, this method is expected to overestimate the average total flow by perhaps 10-30%. However, more research is needed to explain the hydrologic regime of the Meru Forest plantation and the catchment forest in general.

4.7.4 Summary on Environmental Values

Comprehensive planning for timber harvesting must ensure minimum impacts on the environment. A code of practice is essential as a consistent reference for this protection. Identification of the environmental values, establishment of harvesting controls to ensure protection and establishment of measurable variables for compliance measurement and monitoring are essential in planning. Practices observed at WSIR provide valuable lessons of comprehensive planning for harvesting plantation forests of Tanzania.

4.8 Systems Selection

Comprehensive harvest planning calls for combined assessment of all factors befitting an appropriate harvesting system. Physical ability to handle timber and terrain constraints, productivity, impact on the environment, availability and its performance in relation to social-economics and available infrastructure should be considered simultaneously.

This section identifies the harvesting stages practiced in Tanzanian plantation forests. After mentioning systems currently used, I will introduce and rationalize potential systems for solving the accessibility problem. Following the applied judgement as a first cut to eliminate technically and institutionally unacceptable systems, I will demonstrate the use of mathematical analysis to select the optimum harvesting system.

4.8.1 Current Harvesting Stages and Systems

Three harvesting stages identified were:

I. Felling: Involving cutting, limbing and bucking. Both limbing and bucking are done at the stump, the tree length system is rarely except in harvesting for transmission poles.

II. Extraction: Transporting of felled tree to the landing at roadside.

III. Hauling: Long distance transport of logs from landing at roadside to the Mill.

Tree cutting is entirely manual by either two-person cross cut saw or powersaw. Although powersaws are common and have high productivity, cross-cut saws are the most popular due to low maintenance and problems of availability and high maintenance requirement of powersaws. Extraction is entirely ground-based, either manual or mechanical. Manual rolling is practiced in clear felling on terrain above 15% slope.

Sulky and oxen skidding are limited to small sized logs, under 20 cm butt end; thus, they are mostly used for thinning operations. The crawler tractors, once popular in harvesting indigenous forests, are forbidden due to their destructive impact on soils. Apart from a permanent skyline at Mkumbara (Abeli & Shemwetta, 1988), cable yarding is not practiced in Tanzania. Aerial systems, helicopter and balloon logging have never been introduced into the country.

Cable systems are the most promising solution for access in the problem area. The slopes within compartments at Kidukini can be favorable to ground-based systems, but the eventual transportation to the existing road still faces steep terrain. Slopes within compartments 16a and 17a are beyond 30% and terrain-based access to this area is nearly impossible because of steep and long valleys carrying the tributaries of Engare Nairobi stream surrounding it, as shown in Figures 4.2 and 4.3. The valleys offer good clearance for cable systems, as shown by LOGGERPC profiles in section 4.4.3, and big trees to serve as tail anchors are available. While terrain conditions and infrastructure are ideal for the cable system, appropriate expertise must be provided.

4.8.2 Preliminary System Selection

Following the area demarcation into polygons, we conducted selection of suitable systems based on experience and performance charts such as that by Studier and Binkley (1974) shown in Figure 4.6. Balloon, helicopter and crawler tractors are ruled out as explained in subsection 4.8.1, and the logs are too big for ox and sulky skidding. Table

4.6 presents slope classes dictated by harvesting systems after this initial elimination, all other factors being the same.

Table 4.6 Functional terrain classes with possible harvesting systems

Slope Class	Harvesting system
0 - 15%	Straight truck, Forwarder
0 - 25%	Skidder
0 - 35%	Farm Tractor, with chain or winch
20 - 40%	Manual rolling
over 35%	Cable yarding

In the United States, and most of the world where mountainous logging is carried out, ground-based systems are more productive on slopes less than 35% (Aulerich *et al.*, 1974). The conventional harvesting systems in Tanzania have always been ground-based. Their performance is acceptable in suitable terrain, but not in areas like Narok and Kidukini, where more than 110,000 cubic meters of high value timber are subject to rot, vandalism or fire if harvesting is not done soon. Cable yarding stands out as the most promising system because it satisfies technical feasibility, economic acceptance and is environmentally friendly. While ground-based systems have always been the first choice for being less expensive, they are limited to gentler slopes, and their disadvantage of ground disturbance is accentuated by steeper slopes. Cable systems have been chosen on steeper slopes; however, they tend to be more expensive and may require more skilled labor than ground-based logging.

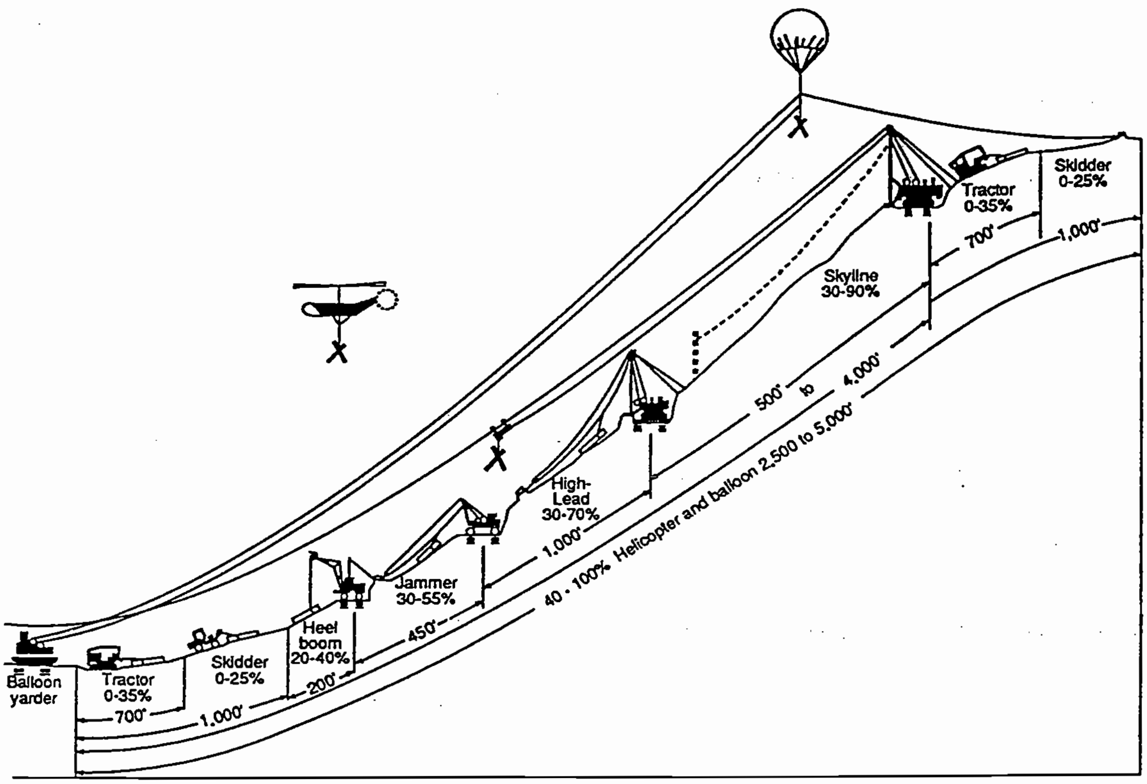


Figure 4.6 Optimum yarding distances and slope percent for different logging systems used in SW Oregon and Northern California (From Studier and Binkley, 1974).

4.8.3 Analytical Approach

In order to use a mathematical analysis for determining the optimum harvesting system allocations, variables need numerical values. On this basis, the values of productivity variables adopted from various studies in Tanzanian plantation forests, structured and current market costs were used. Production rates, which formed the basis for variable costs were taken from studies and experience in similar conditions; whereas, effective hourly costs ($/SMH) for mechanized systems were constructed. Fixed costs are in the form of representations of costs to the environment and institutional limitations developed through a logical use of index numbers and actual costs, hereby known as indexed costs.

4.8.3.1 Variable Costs

Variable costs are costs per unit of production, in $\$/m^3$, at each stage of the harvesting operation. Ideally, these costs are determined from the operation costs and productivity of the systems under consideration. At the time of this study, these variables were not readily available, especially for systems which are not currently employed in Tanzanian timber harvesting operations. However, because determination of the most efficient system requires comparison between each system's cost of unit of production, ways to estimate these were sought.

For the felling function of the timber harvesting operation, which is mainly manual, the variable costs in $\$/m^3$ can be obtained either by constructed costs, adjusted average costs of proportions of all possible systems used, or any justifiable close approximation. Based on observations of relative productivity (powersaw 1.56 m^3/hr and 2-person crosscut saw 0.94 m^3/hr (SUATF office records, 1996)), and relative frequency of system use (I estimate greater than 85% of felling is by the manual saw), my allocation of local average cost of \$2.00 per m^3 to be from powersaw felling costs of \$1.28/m^3 and manual saw felling cost of \$2.13/m^3. Constructed costs need to be developed from local information for this function but would likely follow the same relationship.

The market cost - productivity approximation is inappropriate for the other systems due to differential relationship among the systems to these two factors. Hence variable costs for all other systems, apart from felling, were constructed using "*Logger Budget*", a computer program based on a spreadsheet (FE-OSU, 1995a). Capital costs and expected working lives of mechanized systems were used to construct hourly costs, and these were used on hourly productivity to obtain cost unit of production This analysis assumes machine cost to include terminal (loading and unloading) operations .

Constructed costs for these systems using "*Logger Budget*" is illustrated in Appendix E and summarized Table 4.7 below. For the extraction and hauling systems, the variable costs \$/m^3 were reduced to \$/m^3/km, using estimated travel speed (kph), to account for distances between landings and the mills.

4.8.3.2 Environmental and Institutional Costs

This section presents an approach adopted to obtain representative fixed costs, the indexed costs. In comprehensive timber harvest planning, fixed costs include not only the capital and costs unrelated to production units, but also the costs to meet environmental and institutional limitations. This is an important part in planning because it reflects the goals and objectives of policy makers. To meet this challenge, I adopted an index number procedure to obtain a representative monetary value of each system's

Table 4.7 Summary of variable costs for all possible systems.

	YARDER	TRUCK	FARM TRACTOR	FOREST TRACTOR	SKIDDER	TRACTOR-TRAILER	TRUCK-TRAILER	COMBI-RIG	FORWARDER
Productivity (m^3/h)	8.00	4.61	5.20	6.00	8.00	3.63	15.00	17.00	3.50
Wage ($/hr)	3.00	1.00	1.50	1.50	2.00	1.50	2.00	3.00	3.00
Number of operators	4.00	10.00	3.00	3.00	3.00	5.00	2.00	1.00	1.00
Operation cost ($/hr)	12.00	10.00	4.50	4.50	6.00	7.50	4.00	3.00	3.00
Total cost ($/SMH)	42.30	35.11	24.65	25.45	30.71	30.93	34.40	37.30	23.80
Unit cost $/$m^3$	**5.35**	**5.45**	**3.58**	**3.28**	**3.01**	7.00	**1.61**	**1.65**	**6.83**
Speed (kph)									
Access road		40.00				15.00	35.00	35.00	15.00
Extraction road		15.00				10.00			10.00
Cost $/$m^3$/km									
Access road		0.14				0.47	0.05	0.05	0.46
Extraction road		0.36				0.70			0.68

institutional and environmental cost for the harvesting operation. This procedure, adopted from development of objective matrix (OMAX) in using index numbers to evaluate productivity over time by Riggs and West (1986), is here modified for this study. Five steps are involved:

1. Identification of environmental and institutional factors: As a preliminary step, factors were identified to represent, as closely as possible, the institutional and environmental limitations stipulated in the management policy. These factors are many and vary according to site in consideration. For this study the following were selected:
   - Soil disturbance: considered in terms of percentage total area covered or disturbed by roads, trails and landings. However, to be fully representative, this factor has to consider relative distribution of the compacted points within the area, in relation to trees and proximity to drainage paths. Percentage disturbance alone may not be a satisfactory factor.
   - Damage to residual trees: represented by expected number of damaged trees per hectare;
   - Availability: represented by the percentage of foreign components in the system. The higher the dependence, the higher the index value;
   - Technical feasibility: depicted by the suitability of a system with respect to the physical characteristics of area and timber such as terrain, slopes, distances and log size;

- Training requirement: portrayed by the level of training requirement for the system's operators;
- Maintenance requirement: determined by how crucial maintenance is to the system, and the availability of maintenance expertise and spare parts;
- Social component: The social contribution of the system to the community such as employment opportunities and accessibility (opening roads).

2. Allocation of index numbers: on a subjective basis by the planner, each system was allocated an index number according to each factor identified in (1): The procedure uses numbers 1 to 10 with increasing impact, where 1 represents the least cost and 10 the most cost of a system for a given factor. These values could come from interactions summarizing concerns with decision makers. For example in soil disturbance, manual rolling with least impact is allocated 1 while a forest tractor with chain gets a 9 as an indication of higher disturbance; 2-person cross cut saw gets 1 while powersaw a 5 due to maintenance requirements; ox-skidding a 1 in social contribution while a self-loading combination rig gets a 8. Table 4.8 shows the planner's raw index numbers of each system by each factor.
3. Ranking of the Environmental and Institutional Factors: the environmental and institutional factors, as stipulated in the management goals and objectives, differ in importance according to specific location and socio-economic conditions. In a allocation of 1 as least and 5 as most important, the factors were ranked. The rankings, in reflection of the priorities and conditions of the study area, gave soil disturbance the least value because of post-harvest *taungya* systems practiced,

Table 4.8 Allocated raw index numbers on systems according to institutional and environmental factors.

Stage	System	Soil disturbance	Damage Res. trees	Availability (Dependence)	Technical Feasibility	Training requirement	Maintenance requirement	Labor (Social)
Felling								
	2-person crosscut saw			2	5	3	3	1
	Powersaw			7	1	7	8	8
Skidding								
	Manual rolling	1	3	1	8	1	1	1
	Ox skidding	3	2	2	8	3	3	1
	Sulky skidding	1	2	3	7	2	2	1
	Farm tractor with chain	7	5	5	3	4	5	5
	Farm tractor with winch	8	6	6	2	5	6	6
	Forest tractor with chain	7	5	7	5	5	5	6
	Forest tractor with winch	9	6	8	1	6	6	7
	Articulated Skidder	10	8	9	1	7	7	8
	Articulated forwarder	6	10	10	3	8	8	9
	Straight truck	8	10	7	7	5	5	5
	Cable	4	4	10	1	10	8	8
Hauling								
	Tractor-trailer manual loaded	7		2	8	4	5	1
	Tractor-trailer winch loaded	7		6	6	5	6	4
	Straight truck manual	7		4	5	4	5	1
	Straight truck self loaderl	7		8	2	7	7	6
	Truck trailer self loader	7		9	5	8	7	7
	combination rig self loader	8		9	6	8	7	8

while availability and social contribution were given highest ranks. Percentages of individual rank to the sum of all ranks produced the weighting of the factors shown in Table 4.9.

Table 4.9 Ranking of the environmental and institutional factors and the corresponding weighting.

Instructional Factor	Rank	Percentage (weight)
Soil disturbance	1	5%
Damage to residue trees	2	10%
Availability (Dependence)	4	20%
Technical feasibility	3	15%
Training requirement	3	15%
Maintenance requirement	3	15%
Social cost	4	20%
Total	20	100%

4. Determination of weighted index numbers: each of the raw index numbers was multiplied by the percentages of the corresponding factors to obtain a weighted index number. For example the weighted index number of cable logging system with respect to technical feasibility is 1.5, which is a multiple of its raw index of 1 by 15% weight of technical feasibility factor. The sum of all weighted index numbers of a system across all factors represented a weighted environmental and

institutional number, which have same characteristics of impact severity and range as the raw index numbers. This number represents the scale, out of 10, to be used in step (5).

5. Representative Environmental and Institutional Costs: within each stage of the harvesting operation (felling, skidding and hauling), the current market cost was taken to be about the same importance as total environmental and institutional costs. Costs used were those average costs currently incurred by Arusha mills presented in section 4.6, Table 4.4; i.e., felling = $\$2/m^3$; $\$2.33/m^3$ for skidding up to 500 m distance; and hauling cost, typical to short straight truck, of $\$0.52/m^3/km$. For each system, the representative cost is the multiple of the stage cost and weighted sum out of 10 obtained in (4) above. For example: skidding using a farm tractor with winch, a weighted sum of 5.35 out of 10 will have environmental and institutional cost of:

$$(5.35/10 * 2.33) = \$1.25/m^3$$

Table 4.10 summarizes steps 4 and 5.

For each polygon, the fixed cost is a multiple of the derived unit cost and polygon volume, on the assumption that the effect of the system will be proportional to the volume. It is worth noting that the considerations were ranked according to the Tanzanian socio-economic characteristics, and on the assumption of a linear relationship between index numbers and the corresponding costs. Most important, the numbers are representations of partial fulfilment for decision making.

Table 4.10 Weighted index numbers for each factor on each system and the corresponding institutional/environmental costs.

System	Soil Disturbance	Damage to Residual Trees	Availability (Dependence)	Technical Feasibility	Training Requirement	Maintenance Requirement	Labor (Social)	Score out of 10	Institutional/Environmental Costs		
	Weighted number										
FELLING									$/m³		
2-person cross-cut saw	0.00	0.00	0.40	0.75	0.45	0.45	0.20	2.25	0.44		
Powersaw	0.00	0.00	1.40	0.15	1.05	1.20	1.60	5.40	1.05		
								Skid distance (m)	>500	500-999	>1000
SKIDDING								*Cost for the distance* ($/m³)	2.33	3.17	4.00
Manual	0.05	0.30	0.20	1.20	0.15	0.15	0.20	2.25	0.53	0.71	0.71
Oxen chain	0.15	0.20	0.40	1.20	0.45	0.45	0.20	3.05	0.71	0.97	0.97
Sulky	0.05	0.20	0.60	1.05	0.30	0.30	0.20	2.70	0.63	0.86	0.86
Farm tractor chain	0.35	0.50	1.00	0.45	0.60	0.75	1.00	4.65	1.09	1.47	1.47
Darm tractor winch	0.40	0.60	1.20	0.30	0.75	0.90	1.20	5.35	1.25	1.69	1.69
Forest tractor chain	0.35	0.50	1.40	0.75	0.75	0.75	1.20	5.70	1.33	1.81	1.81
Forest tractor winch	0.45	0.60	1.60	0.15	0.90	0.90	1.40	6.00	1.40	1.90	1.90
Articulated skidder	0.50	0.80	1.80	0.15	1.05	1.05	1.60	6.95	1.62	2.20	2.20
Articulated Forwarder	0.30	1.00	2.00	0.45	1.20	1.20	1.80	7.95	1.86	2.52	2.52
Straight truck	0.40	1.00	1.40	1.05	0.75	0.75	1.00	6.35	1.48	2.01	2.01
Cable Yarder	0.20	0.40	2.00	0.15	1.50	1.20	1.60	7.05	1.65	2.23	2.23
HAULING									$/m³		
Tractor-trailer: manual	0.35	0.00	0.40	1.20	0.60	0.75	0.20	3.50	6.09		
Tractor-trailer: winch	0.35	0.00	1.20	0.90	0.75	0.90	0.80	4.90	8.52		
Straight truck manual	0.35	0.00	0.80	0.75	0.60	0.75	0.20	3.45	6.00		
Straight truck (loader)	0.35	0.00	1.60	0.30	1.05	1.05	1.20	5.55	9.65		
Truck trailer (loader)	0.35	0.00	1.80	0.75	1.20	1.05	1.40	6.55	11.39		
Semi-trailer (loader)	0.40	0.00	1.80	0.90	1.20	1.05	1.60	6.95	12.08		

4.8.4 Demonstration of Systems Analysis

Using the variable costs so constructed in section 4.8.3.1, indexed costs formulated in 4.8.3.2 above and standard fixed costs, such as cost of constructing a road section, I demonstrated a mathematical approach to systems analysis by NETWORK (Sessions, 1992) and Mixed Integer Programming by LINDO (Schrage, 1981). The optimum set of harvesting systems is that with the least cost from cutting to extraction and eventual hauling to the mill, obtained through the following three steps:

Selection of feasible systems: Based on physical, economical and environmental constraints, some systems are ruled out from further consideration. In skidding, sulky and manual rolling are eliminated by log size although the later may supplement tractor or cable logging on slopes above 20%. Crawler tractors and all the aerial systems are not considered in the current institutional context, and therefore not considered in this demonstration analysis. To minimize number of variables, farm and forest tractors with chain were not considered too. Cable logging was included as an extraction (skidding) system in compartments 16a and 17a as indicated in Figure 4.4.

To solve accessibility problems discussed in section 4.4.3, cable yarding (swing) across the steep valleys are considered from a point in Kidukini (Compartment 1a) and two points in Compartment 17a to points on the access road shown in Figure 4.4. All possible hauling systems listed in Table 4.10 were evaluated.

Development of operation network and problem formulation: Using activity, systems and structures as roads and cable corridors as links, and transfer points as nodes, I developed a harvesting operation network from the sources (polygons) to the destinations (mills). Each link has a variable cost reflecting the production cost derived from studies, and fixed cost developed from index procedure in section 4.8.3 pegged to the total volume of polygons contributing to that link. For example the fixed cost for a skidder operating for polygons *h, i* and *j* is the multiple of the institutional/environmental cost per m^3 derived in section 4.8.3 and the total volume of the polygons. Appendix J(A) presents the network and Appendix F summarizes both fixed and variable harvesting systems' costs.

The variable and fixed costs of all links are formulated for a minimization mixed integer problem as shown graphically in Figure 4.7:

Minimize Costs:

$$Minimize \sum_{i=1}^{m} \sum_{j=1}^{m} v_{ij} * x_{ij} + \sum_{i=1}^{m} \sum_{j=1}^{m} F_{ij} * Y_{ij} + \sum_{i=1}^{m} \sum_{j=1}^{m} R_{ij} * Y_{ij}$$

Subject to:

Conservation of flow

$$\sum_{j=1}^{m} x_{ij} - \sum_{k=1}^{m} x_{ki} = 0 \qquad i = 1, \ldots, m$$

Meet lower and upper capacity requirements

$$x_{ij} \geq l_{ij} \qquad i,j = 1, \ldots, m$$

$$x_{ij} \leq u_{ij} \qquad i,j = 1, \ldots, m$$

Trigger fixed cost and road construction cost

$$x_{ij} - M * Y_{ij} \leq 0 \qquad i,j = 1, \ldots, m$$

Where:

v_{ij} = variable costs ($/m³) for each system in each link ij

x_{ij} = volume (m³) for each system in each link ij

F_{ij} = Fixed cost ($) for each system in each link ij

R_{ij} = Road construction cost ($) in each link ij

Y_{ij} = {0,1} trigger function:

1 if system allocated/road constructed;

0 otherwise

M = some large number, larger than largest link capacity

The flow of this network is one direction as illustrated in Figure 4.7; i.e., there is no two directional link. Figure 4.7 also shows node k to demonstrate conservation of flow that all what flows into i flows out to j. Appendix H shows parts of the formulated problem.

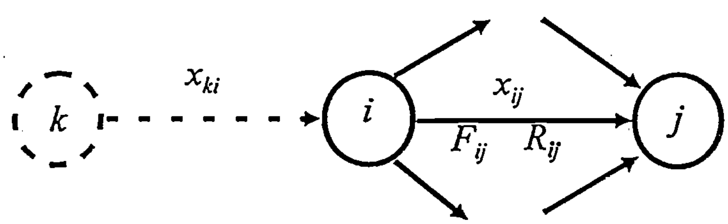


Figure 4.7 Graphical representation of problem formulation variables.

Problem analysis: The complexity of formulating mixed integer program for 267 links, 122 nodes and 21 sales was abated by using NETWORK program first to enter the network so developed, Appendix G. Then associated MPS file generator and path-finder programs, by Sessions and Sessions (1993), enabled use of NETWORK *link* and *sales* files by LINDO program to solve for path of minimum total constructed and indexed costs. This was obtained through the following procedure:

1. Build Link (.LNK) and sales (.SLS) files in NETWORK program
2. Perform the NETWORK program to ensure plausible network. The network solution was not needed in this case because NETWORK could not handle mill capacity limits.
3. To introduce limits to mill capacity, upper and lower bounds are added for the links leading immediately to destination nodes. The bounds are stated in a Bounds (.BND) file developed in any text editor, with same name as the .LNK file.
4. Execute GEN-MPS program to generate O.MPS file which is the input file for the problem solver, LINDO for this case.
5. Input the MPS file and run LINDO program, ensuring the controls direct the output to a SOLN file.
6. Use the associated FINDPATH and REPO programs to read the LINDO solution and develop the path and summary of the optimum option.

US Dollar ($) equivalent to Tanzanian shillings (Shs) was used in order to lessen the number of digits in each number in the analysis. In 1996/97, 1US$ = 600Shs. Link, Sale and Bound files are listed in Appendix G, and summary of the optimum path in Appendix I.

Results: In the first run, the Objective function obtained was at **$1,814,647** total variable and fixed (indexed) costs for the **136,200 m^3**, which is equivalent to **$13.32/$m^3$** if harvesting is done in a year (Appendix H). This is the minimum cost for the combination of systems over the entire operation. While whole polygons *h* through *v*, *x* and *y* were harvested for single destination each, polygons *w* and *z* were split into different destinations (Appendix H).

In the this first run, the analysis favored powersaw over 2-person crosscut saw by 17 to 4. Cable yarding, skidder, straight truck and forwarders were not allocated as skidding systems, favoring forest and farm tractors to skid logs from stump to landings within compartments. Cable swing and forwarders were allocated for extracting logs from compartment landings to the access road terminals. In log hauling from access road terminals to the mills, straight trucks and truck-trailers were the least cost systems. Appendix J illustrates the network diagrams: all possible systems and the selected optimum system.

To access the problem area, reconstruction of the upper road (Kidukini road & two bridges across the Selian tributaries) or cable swinging across the valley are dismissed in favor of a new lower road. The proposed road across Engare Nairobi stream was also rejected by this analysis.

This analysis has shown that new systems need to be introduced into the area, which are forwarders and the cable swing at Narok (Compartments 16a and 17a); however, other systems were not allocated, such as cable swing across Selian stream in Kidukini and also cable yarding within Compartments 16a and 17a. The following factors will encourage the introduction of new systems to a harvesting area.

- Technical feasibility: The terrain of up to 60% slope within compartments 16a and 17a are ideal for cable yarding. Use of ground-based systems is technically difficult and prone to adverse effects on the soils. In this analysis, indexed costs on technical feasibility, infrastructure, and disturbance on soils and other resources by these systems should be lower compared to the competing systems.
- Economic advantage: The systems could also be favored by having lower production coat in \$/hr and higher productivity in m^3/hr. Cable yarding minimizes, or eliminates altogether, fixed costs on roads. These systems must contribute favorably to social, institutional and environmental related economic gains.
- Incentives to use new technology: Introduction of new systems to an area can be accelerated through incentives such as:
    - Subsidy to capital and unit cost of the system by the Government or other organizations. This will result in lower operating costs and hence making the system more competitive than the existing systems.

- Inducement for system allocation through volume availability, stumpage reduction and alleviation of institutional costs by training and provision of appropriate infrastructure.

Applying one of these factors by subsidizing cable yarding in the Narok compartments, i.e., making operation cost for the yarder to be zero, did not change the allocation of systems to incorporate the yarder. I conclude that it is the fixed cost component of environmental and institutional factors represented by indexed costs, such as infrastructure, which need to be improved to accommodate this system. Also this system requires a subsequent transport activity to bring timber to the cable swing landing

This numerical approach can be improved with refinements in data available for these constraints and consideration of additional constraints. These include:

- Average capacity per system such as volume per powersaw per time, volume per trip, and mill capacity for a given period
- Number of trips per day or crews per limited area
- Periods: If the harvesting is going to involve more than one period, interest, depreciation, and inflation rates will constrain the operation
- Volume available for harvesting, upper and low bounds
- Mill requirements with periods: upper and lower bounds
- Limitations on traffic volume over certain links or periods or both, upper and low bounds
- Budget funds available for the project, e.g., threshold level for capital expenditure.

4.9 Plan Implementation and Evaluation

4.9.1 Plan Implementation

Observations at Warm Springs and Weyerhaeuser at Springfield showed harvesting being a step-wise implementation of written procedures. After the planning process and approval of the planning document, which involved management as well as the field supervisors, a contract was ready for operation. Post harvest operations are stipulated as part and parcel of a harvesting operation.

Contract and Operations: What is stipulated in the harvesting contract is the area, species and volumes, stumpage rate, product specifications time table and compliance of harvesting practices (USDI:BIA, 1992). The contract is strict on compliance with Best Management Practices (BMPs) and environmental protection regulations in particular. Also specified are the details of the whole logging process from skid trails layout, leave trees and habitat cluster, sorting, and post harvest activities such as slash disposal and site preparation. During the harvesting process, a supervisor from land management patrols harvesting sites to make sure that the operation is being carried out according to the contract and to Best Management Practices (BMPs).

At SUATF, the project manager is the overall in-charge of a harvesting operation. A foreman supervises the logging crews and tractor operator. With the introduction of contractor logging, strong supervision is not observed. Stand appraisal, identification of trees to fell and operation inspection leaves much to be desired. My general observation is that introduction of private logging (contractors) currently weakens the control of harvesting activities in the forest, which were not very strong in the first place. Increased supervision of contractors could help improve this situation.

Post-harvest Operations: At WSIR, the logging company is required to perform slash treatment after harvesting by grapple piling (a trucked loader with a specialized grapple piles slash). Stipulations direct slash piles to be located a minimum distance of 16 m (50 feet) from leave trees and that landing slash should be piled throughout the block.

In Tanzanian plantations, *taungya* system is practiced immediately after logging. The forest management, in collaboration with local village leaders, distribute plots in the area to the neighboring villagers. Forest workers also receive some plots to cultivate food crops. Soil tillage to about 30 cm is common, and regulations call for planting these areas within three years. As a move to control soil erosion, areas with slopes beyond 20% are not offered for *taungya* practice. At SUATF, harvesting operations are carried according to the annual plan of action if budgeted funds are made available.

4.9.2 Plan Evaluation

Evaluation is a systematic process which attempts to conduct an objective assessment of the relevance, effectiveness and effects of the project in the context of the projects' objectives (FAO, 1985). Evaluation is normally done at the end of the project. In harvest planning, evaluation will determine the overall achievements of the planned operation in terms of its activities, outputs, effects and impact and to provide clues for future plans. Systems productivity, costs and benefits, product quality, safety and timetable are some variables in plan evaluation. Before any evaluation on the plan performance, its 'completeness' with respect to the planning protocol should be ascertained. Skipped steps in planning may result in problems because of ignorance of an important factor or embracing a wrong assumption.

My review on plan evaluation suggests adoption and modification of plan evaluation by Lihai (1992). The following criteria are advanced for evaluating a comprehensive harvest plan:

1. Total operation cost: With its significant correlation to productivity and efficiency, total cost determines a plan's value. Without consideration of stumpage cost to customers and other costs associated with forestry, the demonstration of harvesting system selection by this study can result in improvements in harvesting performances as measured by indexed costs.
2. Ratio of resources input to timber product output: Input resources include capital, labor and even the other forms of land-uses foregone for forestry. Output is the volumes of timber as well as other benefits from the industry, such as employment.
3. Degree of harvest damage to soils, vegetation and residual stands of the operation area: these criteria evaluate how the plan addresses the protection of environmental values as stipulated in the goals and objectives. It is well covered in effective monitoring in the following section.
4. Degree of working safety: representing what Lihai called the 'civilized level of a production system', a plan with better safety measures fares better than one without.

Plan evaluation tends to be subjective. To minimize disadvantages of this subjectivity, the methods and models to be applied must be relevant to the local conditions, especially socio-economic, of the harvesting site.

In order to have effective plan implementation and evaluation, all key individuals involved in planning, implementation and evaluation must be informed of all the relevant information, including results. Therefore means of communications must be established and compartmentalized practices should be discouraged.

4.10 Monitoring

4.10.1 Introduction

Discussions, literature reviews, interviews and field observations produced an outline of timber harvesting monitoring guidelines befitting the Tanzania situation. In very simple terms, monitoring can be summed up as the activity done with intent "to watch" or "to check", by series of observations over time, for the purpose of detecting change. The applied definition of "observations for expectations and using the results to rectify an ongoing operation or as input for future operations" (McDonald *et al.*, 1991) is perfectly appropriate to this study. Monitoring is a strong tool in operation management. In this study, I present monitoring as both a check upon the plan itself, reflected by a planned harvesting operation, which I term ***monitoring of operations***; and an observation of the associated harvesting effects on the environment, which I call ***monitoring of harvesting effects***. However, both are subject to the three common types applicable to management of a harvesting operation: implementation, effectiveness, and validation monitoring. They are also both subject to the research monitoring, in ratifying the cause-and-effect issues used in decision making. While monitoring is a broad subject commonly dealt with at the forest management level, my emphasis is on timber harvesting plan implementation and associated effects on the environment. However, remarks are made about overall forest management decisions relevant to timber harvesting.

4.10.2 <u>Monitoring of Operations</u>

Starting from the plan objectives, each item along the planning protocol has to be monitored with respect for immediate rectification or improvements in future planning. More often, implementation monitoring calls for immediate results and actions; effectiveness monitoring calls for results after an appreciable time; and validation monitoring needs to go back to the basis of goals and objectives for decisions after assessing the outcome. Research monitoring seeks answers for unknown or poorly quantified key factors, rectification of inappropriate assumptions and customizing models and procedures proven effective elsewhere. As an effective management tool, the plan performance should be monitored. Using the example of a comprehensive plan to harvest the problem area, monitoring operations should be undertaken according to the following general directives:

(A) Implementation Monitoring: Assessing whether the plan is being implemented or not. A check list includes:

- Is the plan implemented at all? Some plans are expensive to prepare but in the end they remain in paper form without being implemented. This has been more the case with strategic plans than those at lower scales. Smaller companies have higher probabilities of plan implementation than large companies. According to my selected observations of several ownerships in U.S. PNW all plans by small private industrial land owners were implemented whereas in large corporations like Weyerhaeuser one of every five plans has not been implemented. For the present study, this checks whether the comprehensive plan to harvest the problem area is being implemented or shelved.
- Timetable: To see whether harvesting is being carried out within the time frame envisaged. In the US, contractors are expected to follow the given timetable as part of the agreement. The problem area is expected to be harvested within two years according to this plan.

(B) Effectiveness Monitoring: Checking plan performance against objectives, i.e., whether the individual activities associated with the harvesting operation had the desired effect. Achievement of the values identified in the plan such as:

- Economical efficiency and safety, e.g., is a farm or forest tractor more productive with chain or winch? Answers will be given on economic performance of different alternative access to the problem area, especially comparing the economics of the cable swing across the streams to the construction of new road.

- Environmental protection issues with respect to planned activities, e.g., is the allowance for *taungya* systems meeting the requirement for soil protection for sustained forestry? The effectiveness of ground-based systems against cable logging systems will also be established.

(C) Validation Monitoring: Checking authenticity of planning assumptions which led to planning decisions. In most cases the assumptions are based on modeling. The assumptions used in this study for systems analysis face the challenge of proving their own validity. The most significant planning assumption was the index numbers to generate the fixed costs as described in sub-sections 4.8.3 and 4.8.4. Use of models developed and verified elsewhere also brings concern because some variables may not vary in significance, be irrelevant or missing altogether in the material context.

(D) Research: Identifies needed research on the basic information used in planning. While the output of validation monitoring is either acceptance or rejection of the assumptions and models used in decision making, research monitoring brings forth the appropriate references for decision making. In addition to the three types of monitoring I advance adoption of research monitoring to:

- bring scientific causes to implementation and management of harvesting operations;
- identify key research projects that can bring facts forward;
- help establish and direct Best Management Practices (BMPs); and
- avoid adoption of inappropriate standards.

Research monitoring attempts to identify if cause-and-effect relationships were established in the particular planning situation. In the study area, an assumption that a powersaw is more socially expensive than a cross-cut saw with respect to labor cost and employment opportunities needs to be corroborated in the current Tanzanian economic conditions.

4.10.3 Monitoring of Harvesting Effects

Effects of harvesting operations on the environment satisfies a major component of comprehensive planning in ensuring minimum adverse effects to the environment. In the U.S. PNW where harvesting on public land is often in native forests, all resources dependent on that land may need to be considered, hence the amplified concern of harvesting effects on the environment. Based on the current goals of the plantation forests in Tanzania, soils and water are the main environmental concerns. While calling for refinement of goals and objectives to address other resources, this study focuses on harvesting effects on these two resources and the 'protective' native forests along the stream valleys. Based on assumed or proven causes and acceptable thresholds of the effects, the plan is expected to specify harvesting practices to ensure that the effects will be avoided, minimized or mitigated. Monitoring of effects checks for compliance of planned practices (implementation), performance against the set thresholds (effectiveness) and authenticity of planning assumptions (validation). Research may be deemed necessary to ascertain the cause-and-effect of the assumptions, and the associated thresholds, and/or customize any applied procedure.

Brief elaboration of monitoring harvesting effects on soils and water for the study area is given in the following sub-sections, and summarized in Table 4.11.

4.10.3.1 Soils

Effects of timber harvesting on soils is reflected by soil compaction, erosion and disturbance. During harvest planning, there should be guidelines to specify alleviation, minimizing, or mitigation of harvesting effects on soils. These include: plan and use of designated skid trails, road designs to ensure minimum cutting, less impacting harvesting systems, soil recovery and treatments after harvesting. Thresholds of tolerable effects should be specified in the objectives, because it is against these that the monitoring results are gauged. However, it should be recognized that such thresholds may have no functional significance with respect to environmental processes. Common parameters for measuring compaction, and related effects on runoff, are changes in bulk density in g/cc and infiltration in depth units of mm/hr (or in/hr) (Adams & Andrus, 1991; Froehlich, 1979; Maganga & Chamshama, 1984). Soil erosion and sedimentation are measured by the amount of soil movement from an area. There are many techniques for measurements such as erosion plots, erosion stakes, suspended sediment, etc., (Brooks, Ffolliot, Gregersen & Thames, 1991). Soil disturbance, which includes exposure, shearing, displacement and puddling, is commonly measured by the percentage of area disturbed. As suggested earlier, information about the nature and distribution of this area can be very important in interpreting actual or expected effects. The experimental design for the measurement of these parameters depend on the severity of the impacts expected, costs, physical access, and the monitoring project administration.

In the study area, tillage practices of *taungya* system may be expected to ameliorate some adverse effects on the soil such as compaction; however, roads and areas beyond 20% slope are not subject to this practice. Thus protective measures must be implemented for these steeper areas. Table 4.11 summarizes monitoring for effects on soils where the planned soil protective measures are checked for implementation, effectiveness, their validity and needed research.

4.10.3.2 Hydrologic Regime

Much is yet to be established on the hydrologic regime of the study area to justify any planned action on water related effects of timber harvesting. Preliminary monitoring of water flows and quality is advanced as the starting point. Water from the forest is primarily for domestic use and there are no records of fish being present in the Mount Meru streams. Effects of timber harvesting on stream flow needs observation over long periods to understand micro- and macro-climate and associated ecological processes; however, road construction involving modification of a drainage pattern of the watershed may show immediate effects. Water quality should be monitored through concentrations of debris, sedimentation and other contaminants. While the harvest plan should specify water protection measures such as proper road drainage, harvesting away from streams, avoidance of soil exposure to curb erosion and subsequent sedimentation, and to prohibit spillage of fuel, chemicals or dumping of waste into streams, monitoring of effects should be initiated within the capacities of SUATF.

Many techniques and analysis are available for measuring water flows and water quality (Brooks *et al.*, 1991; McDonald *et al.*, 1991), but simple and straightforward methods such as the floating object method for flows, and ocular observation for sediments are sufficient for general monitoring. Research monitoring is likely to justify adoption of more sophisticated measurements. Table 4.11 summarizes implementation, effectiveness, validity and research monitoring for effects on water flows and quality against the planned protective measures.

4.10.4 Over-view on Monitoring

Different than plan evaluation, monitoring is a continuous surveillance over the implementation of the project for its benefits to the current rather than future planning projects.

In the WSIR, all harvesting activities are required to follow federal and tribal regulations. Timber sale officers (TSOs) have the duty to monitor the compliance by inspecting all phases of the logging operations at least three times a week. The checklist includes:

- Review of all timber designated for cutting before commencement of felling activities
- Utilization of all merchantable materials

Table 4.11 Monitoring for harvesting effects on the environment in the problem area.

Issue	Control	Parameter	Implementation	Effectiveness	Validation	Research
Soil compaction	-plan skid trails -road design -*taungya*	-bulk density -infiltration rate				-is compaction a problem? -is *taungya* an ameliorating activity?
Soil erosion	-plan skid trails -road design -logging system	-area & continuity of exposed soil -erosion rate *versus* slope				-compare harvesting, *taungya* and livestock for erosion significance?
Soil disturbance	-plan skid trails -road design -*taungya* -logging system	-area & continuity of exposed soil -rut depths and length versus slope	Check for application controls	Check parameter against threshold: during and after harvesting	Check authenticity of planned controls and thresholds	-determine contribution of *taungya*?
Water flow	-activities away from streams -areas & degree of harvest	-flow rates (seasonal, low, peak)				Determine regional and local hydrologic regime
Water quality	-activities away from streams	-pollution -sediments				
Residual tree damage	Appropriate systems	-trees per ha damaged				Validate thinning prescription

- Conformity to the contract requirement
- Following of timber sale plan guidelines
- Proper road maintenance and use
- Logging activities ensuring minimum damage to the residual resources.

In SUATF and Tanzania plantation forests as a whole, monitoring of timber harvesting is a necessary activity to ensure achievement of goals and objectives, especially in the long term. Lack of a code of harvesting practice makes it difficult to have a standard measure for monitoring; however, refinement of the objectives can be the starting point for identifying parameters and thresholds for effectiveness monitoring. Because SUATF is surrounded by many associated institutions, the problem area has great opportunities for validation and research monitoring.

As for implementation and evaluation, the results of monitoring should be communicated to the key individuals to ensure implementation of corrective measures on an ongoing process, and better future plans.

4.11 Summary

Comprehensive timber harvest planning is needed in Tanzania to meet physical, economical and environmental requirements. This chapter dealt with diagnosis and development of comprehensive timber harvest planning for the plantation forests. Data analysis, results and their interpretation were presented. I advanced a planning protocol suitable for Tanzania forest plantations. Following the flow of the planning protocol, this chapter presented the application of each step to the problem area. I addressed the need to have goals and objectives refined for effective plan implementation. Presented also are: Description of the principle and supporting study areas, SUATF and WSIR respectively; WSIR as an ideal site with established environmental data, prescribed control and monitoring of harvest effects; SUATF's problems of accessibility, lack of appropriate systems and the current management of harvesting operations. I also made a demonstration of systems selection which incorporated an artificial approach for environmental and socio-economic "institutional" concerns along with relevant costs. I addressed plan implementation and evaluation, advancing criteria to be used. This chapter ends with an exposition of plan and harvesting effects monitoring. Guidelines for monitoring the plan execution and the associated effects on the environment are given. Research monitoring is advanced as an important component to SUATF and Tanzanian forest plantations.

CHAPTER 5

DISCUSSION

5.1 Introduction

Following the discussion of individual results given in the preceding chapter, a discussion of overall study achievements towards solving problems facing timber harvesting on steep terrain of Tanzania forest plantations is presented in this chapter. Conclusions and recommendations on the comprehensive planning protocol and monitoring of environmental effects are summarized in chapter 6.

Present day timber harvesting involves a number of factors and issues which have to be considered concurrently. Where steep terrain is involved, physical and environmental constraints are tightened (Heinrich 1994, Jinyun *et al.,* 1994), making the harvesting yet more difficult. It is only through planning in a comprehensive way that timber harvesting will meet the expected results. This study sought to explore this thesis with a comprehensive planning process to solve current problems experienced by Tanzania forest plantations on steep terrain.

It is worth comparing performance against the study objectives: The study reviewed and assessed timber harvest planning in the U.S. PNW and identified procedures and practices relevant to the problem area. Remote sensing tools were effectively used in area description and development of spatial data, in the form of a digital map, as a contribution for future planning and research. The physical, economical and environmental constraints of SUATF, which represent the worst scenario of Tanzania plantation forests, were determined. These were used, within the institutional limitations, to formulate practical harvesting alternatives. This study went further to demonstrate development of environmental, institutional and economic variables and application of numerical analysis for optimum harvest systems allocation. Plan and effects monitoring, as important components of planning and implementation, were identified and proved to be essential. In-depth discussion of key areas of the study follows.

5.2 Study Area Selection

The economic attraction of the unharvested volume, environmental sensitivity of the stream valleys and indigenous vegetation, and the physically difficult terrain of the problem area in Sokoine University of Agriculture all combine as an ideal site for this study. The research for appropriate species and areas for plantation establishments back in the 1910s identified Tanzanian highlands, with their temperate climate, as ideal areas for the plantations. This is the case throughout eastern and central Africa with softwood plantations. Nearly all plantations are on mountainous conditions; however, the problem area represents the worst scenario, especially with respect to accessibility. Based on this fact, my planning solution for the Tanzania area should be applicable to other plantations in Africa.

The Warm Springs Indian Reservation provided a practical site for observing implementation of a harvesting plan, monitoring a harvesting process and assessment of compliance for environmental protection against harvesting effects. While these sites provided background for timber harvest planning, my experience of the current logging practices in the U.S. Pacific Northwest contributed to how planning in a comprehensive way serves as a solution to multi-faceted predicaments.

This study represented difficult terrain whose proposed solution will apply to possible scenarios within Tanzania plantation forests. The experience at Warm Springs Indian Reservation and Weyerhaeuser provided valuable lessons and evidence of the success of a planned harvesting operation. The examination of the planning procedures in the U.S. Pacific Northwest enhanced the knoeledge base for generalization of harvesting practices in Tanzania plantation forests. However, the uniqueness of the Tanzanian study area requires proper selection of feasible lessons to adopt.

5.3 Comprehensive Timber Harvest Planning

That timber harvesting is no longer an isolated activity in forest management has been established (Adams & Andrus, 1991; Brink *et al.,* 1995; Dykstra & Heinrich, 1996; Schiess *et al.*, 1988). To meet the current land management goals, timber harvesting has to account for not only economic goals, but also the physical capability and environmental protection. Steep terrain and the sensitive environment tighten the constraints and justify more comprehensive planning.

This study advocates comprehensively planned timber harvesting as the solution to the problem area. The forest plantation management in steep uplands in Tanzania must consider physical and environmental requirements with the same intensity as economic obligations. I contend that if any of the easier alternatives developed in this study were given serious consideration, the problem area would have been harvested on time. Only considering the 'conventional' harvesting systems and lack of proper decision-making on how to address environmental effects by harvesting brought on the current conditions of over-mature stands. The contribution of the *taungya* system as the solution to harvesting effects on soils needs an evaluation.

The economic considerations need wider consideration such as investment in new equipment versus leaving areas to rot; vandalism and fire hazards; new technology to achieve efficient harvesting versus retaining the 'conventional' methods with limited accessibility to other areas; achieving higher productivity and safety; and expansion of socio-economic benefits to the local populace to accommodate more mechanized systems.

A successful harvesting operation is one carried out according to planned activities using systems which meet a site's economical expectations, physical capability and environmental acceptance.

5.4 Planning Protocol

In order to achieve planning efficiency and functional plans, this study proposes an order of precedence in the planning process. Failure of many harvesting plans is attributed to flaws in the planning process such as incompatible objectives, ignorance of the environmental values and mismatch of harvesting systems to site and timber characteristics. While the plantation forest goals and objectives appear to have no conflict in terms of land uses, there is need to refine the objectives to magnify the expectations of harvest operations, not only towards economic gains, but for best management practices to ensure sustained forestry. The social and cultural characteristics of the neighboring community should be addressed accordingly in the objectives, values identification and acceptability of harvesting systems.

Imbedded within the plan should be allowance for communication of the plan to key individuals, especially at the implementation, assessment and monitoring stages of the protocol. Knowledge of their responsibilities by key individuals elevates the plan's effectiveness and success. A plan is incomplete without evaluation and monitoring of the harvesting results. Success of this study will be measured by having plan evaluation and monitoring within the plan protocol. Evaluation will take care of the plan's performance in terms of efficiency, safety, costs and damage to the environment. Monitoring will help ensure acceptable interaction with the environment.

At the time of this study, logging activities in the U.S. Pacific Northwest are under intense pressure from environmental groups which challenge land use objectives and harvest planning in general. Cubbage and others (1993) discuss how regulations governing natural resources in the United States have complicated planning for forest management. Knowledge and application of a planning protocol will contribute to reducing the signs of environmental degradation starting to show up in most plantation forests of Tanzania and will improve harvest systems selection.

Identification of physical limitations, environmental and economic values, and the related performance of different systems is a logical approach to achieve a balanced outcome, the underlying goal of comprehensively planned harvesting.

5.5 Planning Tools

With technology development, harvest planning has been made easier. Comprehensive timber harvest planning advocated by this study would have been difficult without a computer. Remote sensing activities and the subsequent data collection and interpretation, analysis and storage with geographic information systems (GIS) have revolutionalized planning of spatial features. Rapid and accurate determination of areas, distances, slopes and even volumes contributed to the success of this study. Digital maps for the Sokoine University Training Forest developed in this study and the experience in generation of DEM is a contribution towards SUA GIS. Although time and resources limited demonstration of DEM development to another area, the experience gained offers potential to future implementation.

Depending on the planning scale and activity, computer based tools are available from harvest scheduling to cable corridor layout. This study demonstrated the use of LOGGERPC in cable layout. NETWORK and Linear Programming (LINDO) were demonstratively used in systems analysis. Like any other technology, program utility will depend on the available input data, infrastructure and expertise. It is worth emphasizing that availability of correct and relevant data is the fundamental requirement for a meaningful use of these tools. All tools applied in this study are compatible with the current infrastructure and forestry expertise in Tanzania, as evidenced by the associated institutions surrounding the SUA campus at Olmotonyi. Application of these tools and expertise to modify them, or development of new ones, to suit site conditions, is a contribution both to the Tanzania plantation forests and the forest engineering profession.

5.6 Plan and Effects Monitoring

This study emphasizes the importance of monitoring in the planning process, especially with comprehensive planning involving environmental protection. After elaborating the three basic types of monitoring: implementation, effectiveness and validation monitoring, this study advances a supportive type called research monitoring. Research monitoring identifies needs for specific research to bring forth findings specific to the planning site. Monitoring will ensure efficient use of resources as well as making better decisions on appropriate technology and methodologies. Communication of the monitoring results to key individuals must be practiced to ensure immediate and future corrective actions. In a situation where management is influenced by experiences from different sources, as in management of Tanzania plantation forests, research monitoring plays a major role of sorting research findings developed elsewhere to check their relevance to local conditions.

While this study contributes general monitoring as a new planning activity to the Tanzania context, it acknowledges changes in management objectives and legal requirements of land-uses and natural resources as a driving force for monitoring. Tanzania's lack of national code of harvest practices means absence of formal harvesting controls to safeguard the environment; thus, presently there are no specific monitoring references.

5.7 Harvesting the Problem Area

After consideration of all factors, this study presents five possible access alternatives, with associated harvesting systems to harvest all the compartments. Tools and expertise for the task are demonstrated. Systems analysis has indicated a more effective harvesting operation compared to the current practice, even with inclusion of other 'costs' and new systems not considered before.

The most significant contribution presented by this study to harvesting systems is recommending cable systems for skidding as well as means of accessibility. The feasibility of this system on steep terrain is proven throughout the world, Mkumbara skyline being a local evidence. This study indicated technical feasibility for cable path and loads on the proposed points of cable swing, thereby making the problem area accessible for harvesting. Initiation of cable systems in logging and accessibility would be a turning point for timber harvesting in Tanzania plantation forests. Plans are underway for developing a practical pilot project for implementing this study's comprehensive plan.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

After reviewing the study, the advanced hypothesis, and data collected and analyzed, this dissertation concluded that comprehensive timber harvest planning is a key solution to current problems experienced by Tanzanian forest plantations. This study showed:

- There should be a planning protocol encompassing the following steps: Objectives refinement; area description; determination of physical limitations, economical and environmental values of the area; determination of all possible systems within the physical, economical and environmental limitations established; selection of the optimum system; plan implementation; plan evaluation; monitoring of the plan and associated environmental effects.
- Adoption and implementation of this procedure in Tanzanian forest management planning will lead to more efficient timber harvesting, harvesting systems matched to site characteristics and more certain environment protection.
- Introduction of cable systems is an alternative to gain access to the problem area while safeguarding the protected stream valleys and indigenous vegetation.
- Monitoring of plan implementation and environmental effects will benefit rectification of on-going harvest operations as well as improve future plans. Research monitoring is essential to establish the cause-and-effects of key

assumptions and controversies associated with harvesting effects on the environment and to customize models and tools used in decision making.

- There is a need to identify the degree to which timber harvesting, grazing in the forest or the *taungya* system have significant effects on the current soil conditions.
- The successes and failures of timber harvesting in the U.S. Pacific Northwest provided a valuable source of knowledge and experience. With appropriate modifications and circumspection, timber harvest planning and environmental assessment practiced in the U.S. Pacific Northwest is a valuable asset to Tanzania forest plantations.
- Given the necessary infrastructure, planning tools used in this study will improve timber harvesting and forest management on difficult terrain.

6.2 Recommendations

For the improvement of Tanzania forest plantations, especially following successful stand establishment, this study recommends:

- Establishment of a data base on physical, economical and environmental variables as an initial step toward computer-based resource management. The data base will serve future plans and environmental monitoring while being updated by research and monitoring findings. While physical variables were collected in this study, economic and environmental variables can only be established by more detailed study. Detailed studies are necessary to establish a database to take advantage of planning tools provided by current technology.

- Planning and implementation of a pilot project on the study area is recommended. Its success will set a precedence and elevate the overall management of plantation forests in Tanzania.
- Research monitoring will, if used, validate and customize assumptions and models in key-decision planning points, such as harvest system allocation.
- To achieve better timber harvest practices, there is need to have a national code of harvest practice. Following the success of stand establishment through the application of silvicultural and wood utilization research, adoption and implementation of harvesting study results will help achieve the basic goal of plantation forests in Tanzania.
- While efforts are initiated for a national forest practices guideline and possibly an act, management of forest plantations should adopt a formal timber harvest planning protocol. As a beginning, harvesting operations should be planned and paper plans should be a requirement. There should be a uniform procedure and a legal contract between forest management and the contractors in order to control harvesting operations. Post-harvest operations should be stipulated to those areas where *taungya* is not practical, starting with minimization of harvesting effects to ensure conditions favorable for fast revegetation. Although field observations during this study have shown fast vegetation growth following a clear

felling operation, soil erosion mitigating measures such as construction of water-bars on abandoned skid roads should be implemented. The *taungya* system must be properly controlled to avoid degradation of the environment in the disguise of inexpensive site preparation.

- Efforts should be made to encourage use of timber harvesting research findings, as was the case with earlier biological and wood utilization research.

Incorporation of a comprehensive timber harvesting plan into the overall forest management plans is advanced for the forest plantations of Tanzania. By accepting and executing this practice, Tanzania National forestry policy can be enhanced and management by crisis will be substantially reduced or eliminated.

REFERENCES

Abeli, W.S. 1992. Forest Engineering research priorities. *In:* Abeli, W.S., A.S.M. Mgeni, S.A.O. Chamshama, S. Iddi, and A. O'Ktin'gati. (Eds). Proceedings of Joint Seminar/Workshop on Forestry Research in Tanzania. Forest Record No. 53. Faculty of Forestry Sokoine University of Agriculture, Morogoro, Tanzania. Pp 53-61.

Abeli, W.S., and S. Maliondo. 1992. Silvicultural management and harvesting operations in forest plantations in Tanzania. *In*: Proceedings of IUFRO Meeting on Silvicultural and Harvesting Operations in Tropical Forests. 1992 Kuala Lumpur, Malaysia. Pp 45-52.

Abeli, W.S., and R.E.L. Ole-Meiludie. 1990. Estimation of truck hauling costs in mountainous forest areas. Forest Record No. 46. Faculty of Forestry, Sokoine University of Agriculture, Morogoro. Tanzania. 20 p.

Abeli, W.S., and Ole-Meiludie, R.E.L. 1991. Future harvesting strategies in Tanzania forests. *In:* Forest Engineering Inc. (Compiler). Proceedings of Symposium on Forest Harvesting in Southeast Asia; 1991 June 17-20, Singapore. Forest Engineering Incorporation, Corvallis, Oregon. Pp 123-130.

Abeli W.S., and D.T.K. Shemwetta. 1988. Skyline logging in Usambara mountains *In*: Atkinson, W., and J. Sessions (Eds). Proceedings of the International Skyline Symposium. 1988 Dec 12-14. Portland. Department of Forest Engineering, Oregon State University. Pp 173-177.

Adams, P.W., and C.W. Andrus. 1990. Planning secondary roads to reduce erosion and sedimentation in humid tropic steeplands. *In*: Research Needs and Application to Reduce Erosion and Sedimentation in Tropical Steeplands. Proceedings of the Fiji Symposium. June, 1990. IAHS-AISH Publ. No.192. Pp 318-327.

Adams, P.W., and C.W. Andrus. 1991. Planning timber harvesting operations to reduce soil and water problems in humid tropical steeplands. *In*: Proceedings of a Symposium on Forest Harvesting in Southeast Asia. Department of Forest Engineering. Oregon State University. Corvallis, USA. Pp 24-30.

Adams, P.W., and W.A. Atkinson (Compilers). 1993. Watershed resources: balancing environment and social factors in large basins. Symposium proceedings, 14-16 October 1992, Portland, OR. College of Forestry, Oregon State University, Corvallis.

Adams, P.W., A.J. Campbell, R.C. Siddle. R.L. Beschta, and H.A. Froehlich. 1986. Estimating stream flows on small forested watersheds for culvert and bridge design in Oregon. Oregon State University Forestry Research Lab Research Bulletin No. 55.

Adams, P.W., J.J. Garland, and H.A. Froehlich. 1985. Research and extension programs led to effective management of forest soil compaction in the Pacific Northwest. *In*: Proceedings of the 1985 Society of American Forest Practices National Conference, Fort Collins. Pp 121-124.

Adams. P.W., and J.O. Ringer. 1994. The effects of timber harvesting and forest roads on water quantity and quality in the Pacific Northwest: Summary and annotated biography. The Oregon Forest Resources Institute (Supplement No. 5 to Cooperative Agreement). Forest Engineering Department, Oregon State University, Corvallis. USA. 147 p.

Ahlaback. A.J. 1992. Why and how to mobilize all people of Tanzania to tree planting. Unpublished Ph.D. Thesis. Faculty of Graduate School. University of Minnesota. 408 p.

Anwar, K. 1994. Forest operations under mountainous conditions in northern Pakistan. *In:* Sessions. J. (Ed). Proceedings of the International Seminar on Forest Operations under Mountainous Conditions. 1994 July 24-27; Harbin, P.R. of China. Department of Forest Engineering, Oregon State University, Corvallis. USA. Pp 96-104.

Aulerich, D.E. 1993. Harvest planning. Focus on forest engineering, FESA conference, Pietermaritzburg, South Africa. 9 p.

Aulerich, D.E., K.N. Johnson, and H. Froehlich. 1974. Tractors or skylines: What is best for thinning young growth Douglas-fir? Forest Industries 101(12):42-45

Avery, T.H., and G.L. Berlin. 1992. Fundamentals of remote sensing and air photo interpretation. 5th Edition. Macmillan Publishing Company. New York. 472 p.

Baumgrass, J.E. 1996. Environmental concerns affecting forest operations on public lands in the Central Appalachians. *In*: Blinn, C.R. and M.A. Thomson, (Eds). Planning and implementing forest operations to achieve sustainable forests: Proceedings of papers presented at the joint meeting of the Council On Forest Engineering and International Union of Forest Research Organizations. 1996 Jul. 29 - Aug. 1. Gen Tech. Rep. NC-186. St. Paul MN. USDA, Forest Service. North Central Forest Experiment Station. Pp 40-46.

Berg, S., E. Gustafson, K. Halvorsen, and E. Miley. 1993. State forest practices throughout the United States: A Review of Forest Laws, Practices Acts and Best Management Practices. Report. American Forest & Paper Association and Wisconsin Paper Council. 74 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.

Beschta, R.L., and W.S. Platts. 1986. Morphological features of small streams: significance and function. Water Resources Bulletin. 22(3):369-379.

Bettinger, P., K.N. Johnson, and J. Sessions. 1996. Forest planning in an Oregon case study: Defining the problem and attempting to meet goals with a spatial-analysis technique. Environmental Management, 20(4):565-577.

Brink, M.P., L.D. Kellogg, and P.W. Warkotsch. 1995. Harvesting and transport planning - a holistic approach. Suid-Afrikaanse Bosboutydskrif (South African Forestry Journal). No. 172. Pp 41-47.

Brodie, J.D., and J. Sessions. 1991. The evolution and analytical approaches to spatial harvest scheduling. In Proceedings of the Symposium on Systems Analysis in Forest Resources. 1991 March 3-7. Charleston, South Carolina. Pp 187-191.

Brooks, K.N., P.F. Ffolliott, H.M. Gregersen, and J.L. Thames. 1991. Hydrology and the management of watersheds. Iowa State University Press. Ames, Iowa. 392 p.

Brown, G.W. 1973. The impact of timber harvest on soil and water resources. Oregon State University Extension Service Bulletin. EB 827.

Carson, W.W., and W.S. Warner. 1992. Applied photogrammetry for forest engineers. *In:* Session, J. (Ed). Proceedings of the Workshop on Computer Supported Planning of Roads and Harvesting. 1992 Aug.26-28. Fildafing, Germany. Department of Forest Engineering, Oregon State University. Pp 256-263.

Chamshama, S.A.O., G.C. Monela, K.E.A. Sekiete, and A. Persson. 1992. Suitability of the *taungya* system at North Kilimanjaro Forest Plantation, Tanzania. Agroforestry Systems (17):1-11.

Cubbage, F.W., J. O'Laughling, and C.S. Bullock III. 1993. Forest resource policy. John Wiley and Sons Inc. New York. Pp 342-347.

Cullen, J., and P. Schiess. 1992. Integrated computer aided timber harvest planning system. *In:* Schiess, P. and J. Sessions (Eds). Proceedings of the International Mountain Logging and eighth Pacific Northwest Skyline Symposium. 1992 Dec. 14-16; Bellevue, Washington. College of Forest Resources, University of Washington. USA. Pp 22-33.

Davis, L.S., and Johnson, K.N. 1987. Forest Management. 3rd Edition. McGraw-Hill Inc. New York. 190 p.

Dykstra, D.P. 1983. Forestry in Tanzania. Journal of Forestry. 81(11): 742-746.

Dykstra, D.P. 1992. GIS as a supporting tool for timber harvesting scheduling on the Fort Apache Indian Reservation, Arizona. *In:* Session, J. (Ed). Proceedings of the Workshop on Computer Supported Planning of Roads and Harvesting. 1992 Aug.26-28. Fildafing, Germany. Department of Forest Engineering, Oregon State University. USA. Pp 143-150.

Dykstra, D.P., and R. Heinrich. 1996. FAO model code of forest harvesting practice. Food and Agriculture Organization of the United Nations. Rome, Italy. 85 p.

Dykstra, D.P., and J.L. Riggs. 1977. An application of facilities location theory to the design of forest harvesting areas. AIIE Transactions 9(3).

FAO. 1985. Monitoring and evaluation of participatory forestry. Forestry Paper No. 60. Food and Agriculture Organization of the United Nations. Rome. Pp 4-7.

FE-OSU. 1995a. Logger Budget. (Spreadsheet template to estimate and plan for logging costs). Oregon State University. Corvallis, USA.

FE-OSU. 1995b. LOGGERPC. Ver.3.1. (Computer software for cable profile analysis: load path and allowable load). Oregon State University. Corvallis, USA.

Froehlich, H.A. 1979. Soil compaction from logging equipment: Effects on growth of young ponderosa pine. Journal of Soil and Water Conservation. 34:276-278.

Fue G.E., and G.A. Migunga. 1992. A record of forest engineering research and its application to forestry development in Tanzania. *In*: Abeli, W.S., A.S.M. Mgeni, S.A.O. Chamshama, S. Iddi, and A. O'Ktin'gati. (Eds). Proceedings of Joint Seminar/Workshop on Forestry Research in Tanzania. Forest Record No. 53. Faculty of Forestry, Sokoine University of Agriculture. Morogoro, Tanzania. Pp 125-139.

Garland, J.J. 1994. Understanding technology and progress in forest harvesting (Entendimiento tecnologia y progreso en aprovechamientos forestales) Primera Reunion de Ecologia Aplicada en los Aprovechamientus Forestales Maderables. Universtidad Autonoma Chapingo, Division de Ciencias Forestales. Chapingo, Mexico. 14 p.

Garland, J.J. 1996. Timber harvesting options. Circular No. 858. Oregon State University Extension Service. Corvallis. 1 p.

Glesåen, G. 1987. Meru Forest Plantations. Map 1:10,000. Swedforest Consulting AB. AB-Älvsby, AB-Älvsby 1988. Nos. 4, 5, 6 & 7.

Golden Software. 1994. SURFER®. 1994. SURFER for windows: Contouring and 3D Surface Mapping. Golden Software Inc. Colorado.

Hartsough, B. 1996. Harvesting systems and their capabilities. *In:* Natural Resource News. Special edition. Blue mountains Natural Resource Institute. Pp. 5, 11 & 15.

Heding, N., and R.E.L. Ole-Meiludie. 1979. Pilot study of ox-skidding in conifer thinnings. Forestry Record No. 10. Division of Forestry, Faculty of Agriculture, Forestry and Veterinary Medicine. University of Dar-es-Salaam. Tanzania. 13 p.

Heinrich, R. 1994. New developments in harvesting systems for mountainous forests from an international perspective. *In:* Sessions. J. (Ed). Proceedings of the International Seminar on Forest Operations under Mountainous Conditions. 1994 July 24-27; Harbin, P.R. of China. Department of Forest Engineering, Oregon State University, Corvallis. USA. Pp 324-335.

Jaeger, D., and G. Becker. 1995. Computer supported, interactive detailed planning of opening-up and harvesting operations on the basis of digital terrain models (DTM). *In:* Session, J. (Ed) Proceedings of the Technical Sessions IUFRO XX World Congress. Subject group 3.06 Forest harvesting under mountainous conditions. 1995 Aug. 6-12. Tampere, Finland. Pp 25-32.

Jarmer, C.B., J.W. Mann, and W.A. Atkinson. 1992. Harvesting timber to achieve reforestation objectives. *In*: S.D. Hobbs, S.D. Tesch, P.W. Owston, R.E. Stewart, J.C. Tappeiner and G.E. Wells (Eds). Reforestation Practices in Southwestern Oregon and Northern California. Forest Research Laboratory (FRL), Oregon State University. USA. Pp 202-230.

Jarmer, C.B., and J. Sessions. 1992. Computer based skyline analysis: LOGGERPC 3.0 -- a new tool for logging planning. *In:* Session, J. (Ed). Proceedings of the Workshop on Computer Supported Planning of Roads and Harvesting. 1992 Aug.26-28. Fildafing, Germany. Department of Forest Engineering, Oregon State University. USA. Pp 128-134.

Jinyun, S., H. Feng, Z. Chen, and Z. Jijung. 1994. Mountain forest operation system in south China. *In:* Sessions. J. (Ed). Proceedings of the International Seminar on Forest Operations under Mountainous Conditions. 1994 July 24-27; Harbin, P.R. of China. Department of Forest Engineering, Oregon State University. USA. Pp 105-115.

Johnson, L.R., L.D. Kellogg, and M. Clark. 1996. Spotlight on forest operations: Intermountain west, Pacific Northwest and western Canada regions. *In:* Bryce Stokes (Ed). USDA Forest Service, Southern Research Station. Forest Products Society. 46(6):17-24.

Kellogg, L.D. 1983. Handling the small trees resources with cable systems. Forest Products. 33(5):25-32.

Lihai, W. 1994. Methods for comprehensively evaluating forest harvesting operation plans. *In*: Session, J. (Ed). Proceedings of the International Seminar On Forest Operations Under Mountainous Conditions. 1994 July 24-27; Harbin, P.R. of China. Department of Forest Engineering, Oregon State University. USA. Pp 301-323.

Loughman, R. 1996. Background on logging practices of Warm Springs Indian Reservation (WSIR). Personal communication.

MacCleery, D.W. 1992. American forests: A history of resilience and recovery. United States Department of Agriculture (USDA), Forest Service. FS-540. 59 p.

MacDonald, L.H., A.W. Smart, and R.C. Wissmar. 1991. Monitoring guidelines to evaluate effects of forestry activities on streams in the Pacific Northwest and Alaska. Report: EPA/910/9-91-001. US Environmental Protection Agency (EPA) & Center for Stream side Studies, AR 10. University of Washington, Seattle. USA. 166 p.

Maganga, S.L., and S.A.O. Chamshama. 1984. Impacts of wood harvesting on soil and residual trees in plantations on Mount Meru, Tanzania. Forest Record No. 32. Division of Forestry, University of Dar-es-Salaam, Morogoro. Tanzania. 13 p.

McGaughey, R.J. 1991. Timber harvest planning goes digital ... PLANS - Preliminary Logging Analysis System. The Compiler. 9(3):10-17.

Migunga, G.A., and S. Kabuka. 1996. Plantation timber harvesting management: A case study of Southern Paper Mill company woodlands Directorate. *In:* Proceedings of Workshop on the Management of Tanzania Forest Plantations. September 1995. Faculty of Forestry, Sokoine University of Agriculture, Morogoro. 5 p.

Ministry of Natural Resources and Tourism (MNRT). 1971a. Tanzania standard volume table for *Cupressus lusitanica*. MNRT, Forest Division. Tanzania LITHO Ltd, Arusha. 57 p.

Ministry of Natural Resources and Tourism (MNRT). 1971b. Tanzania standard volume table for *Pinus patula*. MNRT, Forest Division. Tanzania LITHO Ltd, Arusha. 58 p.

Nshubemuki, L., S.A.O. Chamshama, and A.G. Mugasha. 1996. Species diversification in Tanzania forest plantations: Time for reprisal? Forest Record No. 63. Faculty of Forestry, Sokoine University of Agriculture. Morogoro, Tanzania. 12 p.

ODF. 1993. Elliot state forest management plan. Oregon department of Forestry (ODF). Coos District. 423 p.

ODF. 1995. Forest practices administrative rules. Chap. 629: General Rules, Reforestation and Water Protection Rules. Oregon Department of Forestry (ODF). Salem. 45 p.

Ole-Meiludie, R.E.L., and D.P. Dykstra. 1982. Terrain transport by farm tractors at Sao Hill, Southern Tanzania. Forest Record No. 24. Division of Forestry, Faculty of Agriculture, Forestry and Veterinary Science, University of Dar-es-Salaam. Tanzania. 18 p.

Ole-Meiludie, R.E.L., and E.L. Omnes. 1979. The use of sulkies in thinning softwoods. Forest Record No. 9. Division of Forestry, Faculty of Agriculture, Forestry and Veterinary Science, University of Dar-es-Salaam. Tanzania. 13 p.

Riggs, J.L., and T.M. West. 1986. Engineering economics. 3rd Edition. McGraw-Hill. New York. 879 p.

Robinson, D. 1994. Planning the harvest of a woodlot. Report. Logging Industry Research Organization, LIRO. Potorua, New Zealand. 19(16):8.

Satterlund, D.R., and P.W. Adams. 1992. Watershed management policy and planning. In: Wildland Watershed Management, Chapter 13. 2nd Ed. John Wiley & Sons Inc. New York. Pp 404-420.

Schiess, P., J. Cullen and S. Brown. 1988. Long-term timber sales planning. *In*: Atkinson, W. and J. Sessions (Eds). Proceedings of the International Skyline Symposium. 1988 Dec 12-14; Portland. Department of Forest Engineering, Oregon State University. USA. Pp 82-86.

Schrage, L. 1981. Linear, integer and quadratic programming with LINDO. The Scientific Press. Palo Alto. 274 p.

Sessions, J. 1985. Network analysis using microcomputers for logging planning. *In*: Proceedings of the Symposium in Improving Mountain Logging Planning, Techniques and Hardware. IUFRO Mountain Logging Section and Sixth PNW Skyline logging Symposium. May 8-11, 1985. Vancouver, B.C. Pp 87-91.

Sessions, J. 1992a. Cost control in harvesting and road construction. Food and Agriculture Organization of the United Nations (FAO), Rome. Forestry Paper No. 99. 121 p.

Sessions, J. 1992b. Using network analysis for road and harvest planning. *In:* Session, J. (Ed). Proceedings of the Workshop on Computer Supported Planning of Roads and Harvesting. 1992 Aug.26-28. Fildafing, Germany. Department of Forest Engineering, Oregon State University. USA. Pp 26-35.

Sessions, J., and J.B. Sessions. 1992. Tactical forest planning using SNAP 2.03. *In:* Session, J. (Ed). Proceedings of the Workshop on Computer Supported Planning of Roads and Harvesting. 1992 Aug.26-28. Fildafing, Germany. Department of Forest Engineering, Oregon State University. Pp 112-120.

Sessions, J., and J.B. Sessions. 1993. Using NETWORK II and MPS. Unpublished paper.

Sessions, J., and Y.H. Yeap. 1989. Optimizing road spacing and equipment allocation simultaneously. Forest Products. 39(10):43-46.

Shemwetta, D.T.K., and J.J. Garland. 1996. Timber harvest planning in the Pacific Northwest: Lessons for Tanzanian plantation forests. *In:* Blinn, C.R. and M.A. Thomson, (Eds). Planning and implementing forest operations to achieve sustainable forests: Proceedings of papers presented at the joint meeting of the Council On Forest Engineering and International Union of Forest Research Organizations. 1996 Jul. 29 - Aug. 1. Gen. Tech. Rep. NC-186. St. Paul MN. USDA, Forest Service. North Central Forest Experiment Station. Pp 212-219.

Skaar, R. 1990. Manual versus capital intensive logging systems including environmental impact. *In*: Mgeni A.S.M. *et al.* (Eds). Proceedings of a joint seminar/workshop SUA and IUN on "Management of natural forests of Tanzania". Forest Record No.43. Faculty of Forestry, Sokoine University of Agriculture, Morogoro, Tanzania. Pp 97-101.

Studier, D.D., and V.W. Binkley. 1974. Cable logging systems. USDA Forest Service, Region 6, Division of Timber Management, Portland, Oregon. Miscellaneous Publication. 211 p.

Tarimo, T.G. 1996. Management of forest Plantations: Realities and problems in implementation of management plans - Meru Case Study. *In:* Proceedings of Workshop on the Management of Tanzania Forest Plantations. September 1995. Faculty of Forestry, Sokoine University of Agriculture, Morogoro. Tanzania. Pp 186-192.

USDA-FS. 1990. Land resource management plan - Willamette National Forest. U.S. Department of Agriculture - Forest Service, Pacific Northwest Region. 488 p.

USDA-FS. 1991. Steps of the journey: Forest plan implementation strategy. U.S. Department of Agriculture - Forest Service, Pacific Northwest Region. R(S).

USDA-FS. 1992. Timber sale preparation handbook, w/o Ammendment 2409.18-92-4, effective 11/23/92. Chaper 30. Sale Area Design. Gate 2. U.S. Department of Agriculture - Forest Service, Washington D.C.

USDA-SCS. 1993. Soil interpretation record. Warm Springs Indian Reservation. U.S. Department of Agriculture - Soil Conservation Service (USDA-SCS) Report No. 10-93. Warm Springs Indian Reservation, USA. Pp 48 & 52.

USDI-BIA. 1992. Timber contract for the sale of estimated volumes. US Department of Interior, Bureau of Indian Affairs. Form No.5-5324. Warm Springs Indian Reservatio. Oregon, USA.

USDI-BLM. 1992(b). Resource management plans and environmental impacts assessment. Executive summary. Western Oregon draft. U.S. Department of Interior - Bureau of Land Management. 20 p.

Warm Springs Tribal Council. 1991. Environmental assessment and integrated resource management plan for the forested area. Jan., 1992 - Dec.31, 2001. Confederated Tribes of the Warm Springs Reservation of Oregon. Miscellaneous Publication. 124 p.

Warner, W.S., W.W. Carson, and K. Bjørkelo. 1993. Relative accuracy of monoscopic 35-mm oblique photography. Journal of Photogrammetric Engineering & Remote Sensing. 59(1):101-105.

--- 1979. Webster's new collegiate dictionary. Springfield, MA: G&C Merrian Publishing Co. 2532 p.

APPENDICES

APPENDIX A

INVENTORY DATA FORM

Compartment #____________________ Plot #________

Species ________________ Year planted _______

Terrain:-

Slope(%) ___________ Shape ___________

Ground cover _____________ Minor Forest product ___________

Remarks _____________________+++___________________________

tree #	dbh	height	tree #	dbh	height
1			11		
2			12		
3			13		
4			14		
5			15		
6			16		
7			17		
8			18		
9			19		
10			20		

Largest trees:-

height_______________ dbh______________

height_______________ dbh______________

height_______________ dbh______________

APPENDIX B

ROAD CONSTRUCTION ESTIMATES (ZOFOMO 1995)

Adopted from ZOFOMO office records, 1995.
1US$ = 600Shs

RENOVATION COST ESTIMATES FOR KIDUKINI (LAIKINOI) ROAD AND TWO BRIDGES CROSSING THE SELIAN RIVER TRIBUTARIES

Introduction:

Area:	The road will serve 93 .3 ha of which 68.8 ha are of *Pinus patula* stands and 24.5 ha of *Cupressus lusitanica*. Most of which are over-matured.
Volumes:	*Pinus patula* 48,100 m^3, *Cupressus lusitanica* 9,000 m^3
Road:	The road is single lane, 4 m wide carriage way. Needs re-alignment to lower the current gradient of 19%.
Bridges:	One was built in 1984, by uncreated Eucalyptus logs. The other one ha already collapsed. Across both points new bridges need to be erected.
Expected use:	Considering trucks of 6 m^3 minimum capacity, road will be for 8,300 round trips

1. ROAD RENOVATION

(a) Road formation and widening: A stretch of 250 m, needs cutting filling, requiring heavy machine.
Estimated to take 10 effective machine hours (EMHr) to complete the task at a rate of 32,000 Shs/EMHr

10 x 32,000 .... 320,000/-

Transportation of the machinery to the site and back at a rate of Shs 1,500 per km or a 30 km distance:

30 x 1,500 .... 45,000/-

Sub-total 365,000/-

(b) Drainage Systems

i. Culverts:

4 point identified to require culvert installations
7 pieces, 24" diameter for a point
total number of 4 x 7 = 28 pieces.
Purchase price for each = 10,000/-

10,000 x 28 .... 280,000/-

Transportation of the pieces to the site at a rate of 300/- for 120 km distance:

300 x 120 .... 36,000/-

5 mandays/point: For the 4 points: 4 x 5 = 20 mandays
Rate per manday = 800/-

20 x 800 .... 16,000/-

ii. Materials for culvert outlet and Inlet reinforcements

Cement: 70 bags @ 3,800/-	266,000/-
Sand 1 m^3 @ 30,000/-	30,000/-
Chippings (½ or 3/4) 20 m^3 @ 30,000/-	60,000/-
Shuttering boards in running meters (rm):	
10 rm of 1" x 10" @ 500/-	5,000/-
3 rm of 2" x 2" @ 170/-	500/-
Nails (3" - 5") 3 kg @ 500/-	1,500/-
Transportation of materials to site at a rate of 300/- for 60 km	
60 x 300	18,000/-
Labor force (by contract)	50,000/-

iii. Side Drains

To be done manually 80,000/-

Subtotal ***843,000/-***

c) Grading, Camber formation, spreading of Murram:
To be done by a motor grader. Estimated to take 10 MHrs
The rate is 30,000/- per MHr

10 x 30,000/- 30,000/-

Subtotal ***300,000/-***

(d) Murraming (Graveled earth surfacing material)
Due to the weak bearing capacity of the subgrade, it is suggested that a 20 cm layer of murram (before compaction) should be added to the grade in order to improve its bearing capacity.
The total volume of gravel (murram)

0.2m thickness x 4m width x 500m distance = 1,600 m^3.

This is equivalent to 400 trips of 7 ton (4 m^3) capacity tipping trucks. The burrow-pit is within 1 km from the working sites, round trip of 2 km. The hiring rate for the truck is 300/- per km.
Therefore the total distance traveled will be 400 x 2 = 800 km.

Haulage cost: 800 x 300/- 240,000/-

Excavation and loading will take 30 MHr for the excavator,
At a rate of 20,000/- per MHr

Excavation cost: 30 x 20,000	....	600,000/-
Transportation of excavator to site	....	45,000/-
Sub-Total	....	***885,000/-***

NB: The murraming program should be done during or after the short rains. Compaction done during the movements of the motor grader and the tipping trucks is adequate.

(e) Summary of Road Renovation Estimates:

Road Formation	....	365,000/-
Drainage Systems	....	843,000/-
Grading	....	300,000/-
Murraming	....	885,000/-
TOTAL	....	***2,393,000/-***

2. RENOVATION OF THE TWO BRIDGES

The rivers have the same span of 4.5 m, thus 7 m span bridges is required for each. Their depths are 2.5 m in one and 1.5 m in the other, need supporting walls or wing walls of different heights.
Below is the cost estimate to renovate both bridges. Note that similar items are listed together:

(a) BEAMS
The total number of beams needed is 6 pieces of 7 m length for each bridge. Making 12 pieces for the two bridges:

12 x 7 rm = 84 rm

It is advised to use treated eucalyptus logs of not less than 30 cm middle diameter. But if Loliondo (*Olea welwetschii*) or equivalent materials are will be of advantage. Cost of treated eucalyptus from FAL is 600/- per running ft, which is equivalent to Shs 2,000/ per running meter (rm).

The cost: 84 rm x 2,000/-	....	168,000/-
Transportation to the site	....	40,000/-
Sub-total	....	***208,000/-***

(b) RAILINGS (Cross members)
The width of the bridge is 6 m, which is supposed to be the length of the railings. These are pieces of hardwood timber, or treated eucalyptus.
A total of 36, 6 m length pieces of 2" x 6" or 3" x 6" are needed for each bridge. That is 72 pieces for the two bridges, and a 72 x 6 = 432 rm. Rate is 100/- per rm.

The cost 432 rm x 100/-	....	432,000/-
Transportation to the site	....	9,000/-
Sub-total	....	***441,000/-***

(c) SLIPPERS (Decking)
The length of the bridge is 7 m, which is also the length of the slippers. They should be hardwood of 1" x 8" to cover 11.2 m^2 peer bridge.

8" = 20.32 cm, = 0.2 m

Total number of running meters required is 11.2/0.2 = 56 rm for one bridge, hence 112 rm for both. Purchasing price is 200/- per rf, equivalent to 200/- per 0.3 rm.

The cost: (200 x 112)/0.3	....	74,670/-

(d) NAILS
Estimated 50 kg 6" nails are needed. Special bridge nails will be a better choice. Purchasing price is 500/- per kg:

Cost: 50 x 500/-	....	25,000/-

To be transported with other purchases, hence no added cost.

Sub-total	....	***25,000/-***

(e) WING NAILS (Supporting walls)
They are stone walls that support the beams and they have fitting places on top for the beams to fit or lay in.
Below are the materials requirements, and their costs.

Cement 80 bags @ 3,800/- per bag	....	304,400/-
Sand 5 m^3 @ 30,000/- per 5 m^3	....	30,000/-
Chippings (1/2") 5 m^3 @ 30,000/- per 5 m^3	....	30,000/-
Stones 20 m^3 @ 15,000/- per 5 m^3	....	60,000/-
Cement transport to the site	....	18,000/-
Sub-total	....	***442,000/-***

(f) LABOR

Labor (by contract)	....	200,000/-
	Sub-total	***200,000/-***

(g) SUMMARY [Renovation of the two Bridges]

Beams	....	208,000/-
Railings	....	441,000/-
Slippers	....	74,670/-
Nails	....	25,000/-
Wing Walls	....	442,000/-
Labor force	....	200,000/-
	TOTAL	***1,390,670/-***

3. SUPERVISION

The work is expected to take one month (30 days).

Transport:

Estimated to travel 30 km per day in a small vehicle, cost of 30 km x 310/- per km making 3,900/- per day.

The cost: 30 days x 3,900/-	....	1,170,000/-
Lunch allowances and overtimes payment	....	100,000/-
Security (watchmen)	....	60,000/-
	TOTAL	**277,000/-**

4. TOTAL RENOVATION COST OF THE PROGRAM:

Road	....	2,393,000/-
Bridges	....	1,390,000/-
Supervision	....	277,000/-
	TOTAL	**4,060,670/-**
+ 20% Unforeseen (contingencies)	....	812,134/-
GRAND TOTAL	....	**4,872,804/-**

Signed: Dr. H. Chilembu
FOREST ENGINEER, ZOFOMO

APPENDIX C

STATEMENT OF FOREST POLICIES AND TERMS OF REFERENCE

C.1 *Statement of Tanzania Forestry Policy*

- To demarcate and reserve in perpetuity, for the benefit of the present and the future inhabitants of the country: sufficient forested land and land capable of afforestation to preserve and improve local climates and water supplies, stabilize land which is liable to deterioration and provide a sustained yield of forest products of all kinds for internal, local use and for export.
- To manage this forest estate and all forest growth on public lands so as to obtain the best financial returns on capital value and the cost of management in so far as such returns are in consistent with the primary aims above.
- To encourage and assist the practice of forestry by local government bodies, private individuals and enterprises.
- To undertake and promote research and education in all branches of forestry and to build up by example and teaching a real understanding among the people of the country, of the values of forestry to them and to their descendants.

C.2 *The Forest Policy of Arumeru District*

- The protection of catchment areas to ensure continued supply of water to the settlements around mount Meru;
- The establishment of enough plantations to cater for expanding demand of wood for industrial use, construction and fuel.

C.3 *Terms of Reference for the Management of Sokoine University of Agriculture Training Forest*

- The Training Forest shall be used to train undergraduate and post-graduate students in practical forestry, for research purposes and for demonstrations, refresher courses and conferences related to forestry.
- Complete responsibility for the management of the Training Forest rests with the faculty of Forestry, Sokoine University of Agriculture for renewable 10 year periods from January 1, 1978. Management plans for the Training Forest shall follow the same time periods as those of Meru forest Project.
- The Training Forest shall as far as possible be operated as a normal forest project in Tanzania. daily operations shall be led by a forest manager who is a member of the staff of the Faculty of Forestry, Sokoine University of Agriculture.
- The Board of the University Training Forest has full powers to decide on all activities in the Training Forest, and should meet at least twice a year to draw up policies, indicate guidelines and formulate regulations. Work programs and estimates are to be prepared each year by the Training Forest Project Manager and approved by the Board.
- All sales of the products from the Training Forest shall be handled by the Forest Division, Ministry of natural Resources and Tourism, and all revenues directed to the Ministry of Finance and Planning. Complete records of all transactions shall be immediately available to the Faculty

of Forestry, Sokoine University of Agriculture. Sokoine University of Agriculture in will in turn apply for funds from the Government to operate the training Forest.

- Free access between the Training Forest and Training Center at Olmotonyi must be granted. Similarly, in no way shall the Training Forest complicate access to and from any part of the Meru Forest. Certain funds for capital investments and operations in the Training Forest will be provided by Donors through the University. All equipments bought from such funds will remain the property of the faculty of Forestry, Sokoine University of Agriculture.

APPENDIX D

LOGGING DIRECTIVES OF THE MCDONALD DUNN FOREST, OREGON STATE UNIVERSITY

- A logging plan shall be prepared for each stand before harvest, including regeneration harvest, catastrophic salvage and commercial thinning. This plan shall be written or approved by someone with qualifications equivalent to a graduate forest engineer.
- The logging plan shall include a description of those logging requirements needed to meet the objectives of the silvicultural prescription. The silviculturist and forest engineer should develop silvicultural prescription together which can be implemented, considering desired residual stand condition, soil and water management objectives, and subsequent stand activities for this stand and adjacent stands which will be affected by the logging plan.
- The logging plan should contain the location of any new road construction and a description of construction and road operation requirements to maintain soil and watershed values consistent with the forest plan. The logging plan should include a cost estimate of the proposed harvest activity which can be included in the annual performance report.
- On any operation, trees left for future harvest shall be adequately protected from damage resulting from harvest operations to assure their survival and growth.
- Waste from logging operations, such as crankcase oil, filters, and grease oil containers, machine parts, old wire rope and used tractor tracks shall be removed from the forest immediately following termination of harvesting operations.

Adopted from Oregon Forestry Practices Act, 1993.

APPENDIX E

SYSTEMS VARIABLE COSTS CONSTRUCTED IN *LOGGER BUDGET*

CONSTRUCTED COSTS	YARDER	TRUCK	FARM TRACTOR	FOREST TRACTOR	SKIDDER	TRACTOR-TRAILER	TRUCK-TRAILER	COMBI-RIG	FORWARDER
INITIAL COST	$180,000.00	$80,000.00	$30,000.00	$45,000.00	$90,000.00	$45,000.00	$100,000.00	$130,000.00	$200,000.00
RESIDUAL VAL.	$38,000.00	$12,000.00	$8,000.00	$9,000.00	$18,000.00	$9,000.00	$20,000.00	$28,000.00	$40,000.00
YEARS, LIFE	10.00	10.00	10.00	10.00	8.00	12.00	10.00	10.00	10.00
DEPRECIATION.	$8.99	$3.00	$1.50	$2.25	$5.62	$1.87	$4.99	$6.49	$9.99
AAL	$115,200.00	$38,400.00	$19,200.00	$28,800.00	$58,500.00	$28,500.00	$64,000.00	$83,200.00	$128,000.00
INSURANCE	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
PROP TAXES	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
REPAIR(% DEP)	50.00	40.00	40.00	40.00	50.00	40.00	40.00	50.00	50.00
REPAIR COST	$4.49	$1.20	$0.60	$0.90	$2.81	$0.75	$2.00	$3.25	$4.99
FUEL.(GAL/SMH)	7.00	5.00	5.50	5.50	6.00	7.00	6.00	7.00	7.00
FUEL.($/GAL)	$1.90	$1.90	$1.90	$1.90	$1.90	$1.90	$1.90	$1.90	$1.90
FUEL COST	$13.30	$9.50	$10.45	$10.45	$11.40	$13.30	$11.40	$13.30	$13.30
OIL & LUBE	$2.00	$1.43	$1.57	$1.57	$1.71	$2.00	$1.71	$2.00	$2.00
TIRES ($/SMH)	$0.00	$0.00	$0.00	$0.00	$0.31	$0.00	$0.00	$0.00	$0.00
CABLE ($/SMH)	$2.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
OTHER ($/SMH)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
INT. ($/SMH)	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
TOTAL ($/SMH)	$30.78	$15.12	$14.11	$15.18	$21.85	$17.92	$20.10	$25.03	$30.28
Productivity	8.00	4.61	5.20	6.00	8.00	3.63	15.00	17.00	10.00
wage $/hr	0.47	0.21	0.26	0.26	0.32	0.32	0.32	0.47	0.47
# of operators	4.00	10.00	3.00	3.00	3.00	5.00	2.00	1.00	1.00
operation $/hr	1.88	2.10	0.78	0.78	0.96	1.60	0.64	0.47	0.47
Unit cost $/m3	4.08	3.74	2.86	2.66	2.85	5.38	1.38	1.50	3.07
Speed kph	Access	40.00				15.00	35.00	35.00	15.00
	Extract	15.00				10.00			10.00
Cost $/m3/km		0.09				0.36	0.04	0.04	0.20
		0.25				0.54			0.31

APPENDIX F

SUMMARY OF VARIABLE AND FIXED COSTS OF EACH SYSTEMS BY HARVESTING POLYGONS

		Polygons: Volumes and Associated Institutional Cost per System						
Harvesting System								
		hij	klm	nopq	rst	uvw	xyz	Total
		24,100.00	30,900.00	22,400.00	11,400.00	25,600.00	21,800.00	136,200.00
	Variable			Fixed costs				
FELLING	$/m^3			$/System				
2-man saw & Axe	2.13	5,390.57	6,911.56	5,010.32	2,549.90	5,726.08	4,876.11	30,464.53
Power Saw & Axe	1.28	10,781.13	13,823.12	10,020.64	5,099.79	11,452.16	9,752.23	60,929.07
SKIDDING	$/m^3			$/System				
Manual (Rolling)	3.29	12,652.50	16,222.50	11,760.00	5,985.00	13,440.00	11,445.00	71,505.00
Ox Skidding	3.33	17,151.17	21,990.50	15,941.33	8,113.00	18,218.67	15,514.33	96,929.00
Sulky Skidding	4.67	15,183.00	19,467.00	14,112.00	7,182.00	16,128.00	13,734.00	85,806.00
Farm Tractor & Chain	3.58	26,992.00	34,608.00	25,088.00	12,768.00	28,672.00	24,416.00	152,544.00
Farm Tractor& Winch	3.58	30,084.83	38,573.50	27,962.67	14,231.00	31,957.33	27,213.67	170,023.00
Forest Tractor & Chain	3.28	32,053.00	41,097.00	29,792.00	15,162.00	34,048.00	28,994.00	181,146.00
Forest Tractor & Winch	3.28	33,740.00	43,260.00	31,360.00	15,960.00	35,840.00	30,520.00	190,680.00
Articulated Skidder	3.01	37,395.17	47,946.50	34,757.33	17,689.00	39,722.67	33,826.33	211,337.00
Articulated Forwarder	6.83	39,644.50	50,830.50	36,848.00	18,753.00	42,112.00	35,861.00	224,049.00
Short Straight Truck	5.45	35,427.00	45,423.00	32,928.00	16,758.00	37,632.00	32,046.00	200,214.00
Cable logging (Yarder)	5.35	38,519.83	49,388.50	35,802.67	18,221.00	40,917.33	34,843.67	217,693.00

APPENDIX F (Continued)

		hij	klm	nopq	rst	uvw	xyz	Total
		24,100.00	30,900.00	22,400.00	11,400.00	25,600.00	21,800.00	136,200.00
	Variable			Fixed Costs				
HAULING								
Extraction road	$/m³/km			$/System				
Tractor & trailer manual	0.70	46,794.90	59,998.44	43,494.02	22,135.35	49,707.45	42,329.00	264,459.16
Tractor & trailer winch	0.70	68,446.28	87,758.92	63,618.12	32,377.08	72,706.42	61,914.06	386,820.86
Straight truck manual	0.36	46,096.47	59,102.94	42,844.85	21,804.97	48,965.55	41,697.22	260,512.01
Straight truck loader	0.36	73,335.30	94,027.41	68,162.27	34,689.72	77,899.73	66,336.49	414,450.92
Cable (Swing) /m³	5.35	95,685.10	122,683.39	88,935.53	45,261.83	101,640.60	86,553.33	540,759.78
Access Road	$/m³/km							
Tractor & trailer manual	0.47	46,794.90	59,998.44	43,494.02	22,135.35	49,707.45	42,329.00	264,459.16
Tractor & trailer winch	0.47	68,446.28	87,758.92	63,618.12	32,377.08	72,706.42	61,914.06	386,820.86
Straight truck manual	0.14	46,096.47	59,102.94	42,844.85	21,804.97	48,965.55	41,697.22	260,512.01
Straight truck loader	0.14	73,335.30	94,027.41	68,162.27	34,689.72	77,899.73	66,336.49	414,450.92
Truck & Trailer	0.05	91,494.51	117,310.39	85,040.54	43,279.56	97,189.19	82,762.67	517,076.87
Semi Trailer	0.05	97,081.96	124,474.38	90,233.86	45,922.59	103,124.41	87,816.88	548,654.08

APPENDIX G

NETWORK LINK, SALE AND BOUND FILES

Current date: 13-May-97
Current time: 12:10 pm

Listing of NETWORK link file: "FINOL.LNK"

Line (status)	From node label	To node label	Variable cost ($/unit/link)	Fixed cost ($/link)
1:*	h	FELL1	0.00	0
2:*	i	FELL1	0.00	0
3:*	j	FELL1	0.00	0
4:*	FELL1	HSAW1	2.13	5391
5:*	FELL1	PSAW1	1.28	10781
6:*	HSAW1	FARM1	2.86	30085
7:*	HSAW1	FORE1	2.66	33740
8:*	HSAW1	SKID1	2.85	37395
9:*	HSAW1	FRWD1	3.07	39645
10:*	HSAW1	STruk1	3.74	35427
11:*	PSAW1	FARM1	2.86	30085
12:*	PSAW1	FORE1	2.66	33740
13:*	PSAW1	SKID1	2.85	37395
14:*	PSAW1	FRWD1	3.07	39645
15:*	PSAW1	STruk1	3.74	35427
16:*	FARM1	C	0.00	0
17:*	FORE1	C	0.00	0
18:*	SKID1	C	0.00	0
19:*	FRWD1	C	0.00	0
20:*	STruk1	C	0.00	0
21:*	k	FELL2	0.00	0
22:*	l	FELL2	0.00	0
23:*	m	FELL2	0.00	0
24:*	FELL2	HSAW2	2.13	6912
25:*	FELL2	PSAW2	1.28	13823
26:*	HSAW2	FARM2	2.86	38574
27:*	HSAW2	FORE2	2.66	43260
28:*	HSAW2	SKID2	2.85	47847
29:*	HSAW2	FRWD2	3.07	50831
30:*	HSAW2	STruk2	3.74	45423
31:*	PSAW2	FARM2	2.86	38574
32:*	PSAW2	FORE2	2.66	43260
33:*	PSAW2	SKID2	2.85	47847
34:*	PSAW2	FRWD2	3.07	50831
35:*	PSAW2	STruk2	3.74	45423
36:*	FARM2	A	0.00	0
37:*	FORE2	A	0.00	0
38:*	SKID2	A	0.00	0
39:*	FRWD2	A	0.00	0
40:*	STruk2	A	0.00	0
41:*	n	FELL3	0.00	0
42:*	o	FELL3	0.00	0
43:*	p	FELL3	0.00	0
44:*	q	FELL3	0.00	0
45:*	FELL3	HSAW3	2.13	5010
46:*	FELL3	PSAW3	1.28	10021
47:*	HSAW3	FARM3	2.86	27963
48:*	HSAW3	FORE3	2.66	31360
49:*	HSAW3	SKID2	2.85	34757
50:*	HSAW3	FRWD2	3.07	36848

APPENDIX G (Continued)

51:*	HSAW3	STruk3	3.74	32928
52:*	PSAW3	FARM3	2.86	27963
53:*	PSAW3	FORE3	2.66	31360
54:*	PSAW3	SKID3	2.85	34757
55:*	PSAW3	FRWD3	3.07	36848
56:*	PSAW3	STruk3	3.74	32928
57:*	FARM3	B	0.00	0
58:*	FORE3	B	0.00	0
59:*	SKID3	B	0.00	0
60:*	FRWD3	B	0.00	0
61:*	STruk3	B	0.00	0
62:*	r	FELL4	0.00	0
63:*	s	FELL4	0.00	0
64:*	t	FELL4	0.00	0
65:*	FELL4	HSAW4	2.13	2550
66:*	FELL4	PSAW4	1.28	5100
67:*	HSAW4	FARM4	2.86	14231
68:*	HSAW4	FORE4	2.66	15960
69:*	HSAW4	SKID4	2.85	17689
70:*	HSAW4	FRWD4	3.07	18753
71:*	HSAW4	STruk4	3.74	16758
72:*	PSAW4	FARM4	2.86	14231
73:*	PSAW4	FORE4	2.66	15960
74:*	PSAW4	SKID4	2.85	17689
75:*	PSAW4	FRWD4	3.07	18753
76:*	PSAW4	STruk4	3.74	16758
77:*	FARM4	D	0.00	0
78:*	FORE4	D	0.00	0
79:*	SKID4	D	0.00	0
80:*	FRWD4	D	0.00	0
81:*	STruk4	D	0.00	0
82:*	A	TTLer1	0.00	46795
83:*	A	Truk1	0.00	46096
84:*	A	FWD1	0.00	39645
85:*	B	TTLer2	0.00	59998
86:*	B	Truk2	0.00	59103
87:*	B	FWD2	0.00	50831
88:*	C	TTLer3	0.00	43494
89:*	C	Truk3	0.00	42845
90:*	C	FWD3	0.00	36848
91:*	C	CABLE1	0.00	352566
92:*	D	TTLer4	0.00	22135
93:*	D	Truk4	0.00	21805
94:*	D	FWD4	0.00	18753
95:*	TTLer1	BH	2.38	0
96:*	TTLer2	BH	2.16	0
97:*	TTLer3	BH	2.65	0
98:*	TTLer4	BH	1.84	0
99:*	Truk1	BH	1.28	0
100:*	Truk2	BH	1.16	0
101:*	Truk3	BH	1.42	0
102:*	Truk4	BH	0.99	0
103:*	FWD1	BH	1.36	0
104:*	FWD2	BH	1.24	0
105:*	FWD3	BH	1.52	0
106:*	FWD4	BH	1.05	0
107:*	TTLer1	CG	1.08	0
108:*	TTLer2	CG	1.68	0
109:*	TTLer3	CG	0.81	0
110:*	TTLer4	CG	1.62	0

APPENDIX G (Continued)

111:*	Truk1	CG	0.58	0
112:*	Truk2	CG	0.70	0
113:*	Truk3	CG	0.44	0
114:*	Truk4	CG	0.87	0
115:*	FWD1	CG	0.62	0
116:*	FWD2	CG	0.74	0
117:*	FWD3	CG	0.47	0
118:*	FWD4	CG	0.93	0
119:*	BH	RoadBH	0.00	20000
120:*	CG	RoadCG	0.00	30000
121:*	RoadBH	H	0.00	0
122:*	RoadCG	G	0.00	0
123:*	CABLE1	H	4.08	0
124:*	CABLE1	G	4.08	0
125:*	u	FELL5	0.00	0
126:*	v	FELL5	0.00	0
127:*	w	FELL5	0.00	0
128:*	FELL5	HSAW5	1.13	5726
129:*	FELL5	PSAW5	1.28	11452
130:*	HSAW5	FARM5	2.86	31957
131:*	HSAW5	FORE5	2.66	35840
132:*	HSAW5	CABLE2	5.35	40917
133:*	PSAW5	FARM5	2.86	31957
134:*	PSAW5	FORE5	2.66	35840
135:*	PSAW5	CABLE2	4.08	40917
136:*	CABLE2	TTLer5	0.00	49707
137:*	FARM5	E	0.00	5000
138:*	FORE5	E	0.00	7000
139:*	TTLer5	E	0.27	5000
140:*	TTLer5	F	0.87	5000
141:*	E	SCABLE2	0.00	0
142:*	x	FELL6	0.00	0
143:*	y	FELL6	0.00	0
144:*	z	FELL6	0.00	0
145:*	FELL6	HSAW6	2.13	4876
146:*	FELL6	PSAW6	1.28	9752
147:*	HSAW6	FARM6	2.86	27213
148:*	HSAW6	FORE6	2.66	30520
149:*	HSAW6	CABLE3	4.08	34844
150:*	PSAW6	FARM6	2.86	27213
151:*	PSAW6	FORE6	2.66	30520
152:*	PSAW6	CABLE3	4.08	34844
153:*	CABLE3	TTLer6	0.00	42329
154:*	FARM6	E	0.00	5000
155:*	FORE6	E	0.00	7000
156:*	TTLer6	F	0.54	5000
157:*	F	SCABLE3	0.00	0
158:*	F	STruk8	0.00	144236
159:*	STruk8	RoadFM	0.41	0
160:*	TTLer5	RoadFM	1.35	0
161:*	SCABLE2	J	4.08	2000
162:*	SCABLE3	L	4.08	2000
163:*	RoadFM	M	0.00	25000
164:*	G	TRACT1	0.00	252200
165:*	G	TRUCK1	0.00	270215
166:*	G	TTLER1	0.00	337123
167:*	G	COMBI1	0.00	357713
168:*	G	TRACT2	0.00	252200
169:*	H	TRUCK2	0.00	169849
170:*	H	TTLER2	0.00	337123

APPENDIX G (Continued)

171:*	H	COMBI2	0.00	357713
172:*	J	TRACT3	0.00	134621
173:*	J	TRUCK3	0.00	144236
174:*	J	TTLER3	0.00	179952
175:*	J	COMBI3	0.00	190941
176:*	L	TRACT4	0.00	134621
177:*	L	TRUCK4	0.00	144236
178:*	L	TTLER4	0.00	179952
179:*	L	COMBI4	0.00	190941
180:*	M	TRACT5	0.00	134621
181:*	M	TRUCK5	0.00	144236
182:*	M	TTLER5	0.00	179952
183:*	M	COMBI5	0.00	190941
184:*	TRACT1	MILKHA	2.84	0
185:*	TRACT1	SUA	2.05	0
186:*	TRACT1	MILLS	6.37	0
187:*	TRACT1	FAL	11.20	0
188:*	TRACT2	MILKHA	2.09	0
189:*	TRACT2	SUA	4.10	0
190:*	TRACT2	MILLS	8.06	0
191:*	TRACT2	FAL	12.89	0
192:*	TRACT3	MILKHA	1.66	0
193:*	TRACT3	SUA	3.67	0
194:*	TRACT3	MILLS	7.63	0
195:*	TRACT3	FAL	12.46	0
196:*	TRACT4	MILKHA	0.86	0
197:*	TRACT4	SUA	2.88	0
198:*	TRACT4	MILLS	6.84	0
199:*	TRACT4	FAL	11.66	0
200:*	TRACT5	MILKHA	0.40	0
201:*	TRACT5	SUA	2.41	0
202:*	TRACT5	MILLS	6.37	0
203:*	TRACT5	FAL	11.20	0
204:*	TRUCK1	MILKHA	0.47	0
205:*	TRUCK1	SUA	0.34	0
206:*	TRUCK1	MILLS	1.06	0
207:*	TRUCK1	FAL	1.87	0
208:*	TRUCK2	MILKHA	0.35	0
209:*	TRUCK2	SUA	0.68	0
210:*	TRUCK2	MILLS	1.34	0
211:*	TRUCK2	FAL	2.15	0
212:*	TRUCK3	MILKHA	0.28	0
213:*	TRUCK3	SUA	0.61	0
214:*	TRUCK3	MILLS	1.27	0
215:*	TRUCK3	FAL	2.08	0
216:*	TRUCK4	MILKHA	0.14	0
217:*	TRUCK4	SUA	0.48	0
218:*	TRUCK4	MILLS	1.14	0
219:*	TRUCK4	FAL	1.94	0
220:*	TRUCK5	MILKHA	0.07	0
221:*	TRUCK5	SUA	0.40	0
222:*	TRUCK5	MILLS	1.06	0
223:*	TRUCK5	FAL	1.87	0
224:*	TTLER1	MILKHA	0.32	0
225:*	TTLER1	SUA	0.23	0
226:*	TTLER1	MILLS	0.71	0
227:*	TTLER1	FAL	1.24	0
228:*	TTLER2	MILKHA	0.23	0
229:*	TTLER2	SUA	0.46	0
230:*	TTLER2	MILLS	0.90	0

APPENDIX G (Continued)

231:*	TTLER2	FAL	1.43	0
232:*	TTLER3	MILKHA	0.18	0
233:*	TTLER3	SUA	0.41	0
234:*	TTLER3	MILLS	0.85	0
235:*	TTLER3	FAL	1.38	0
236:*	TTLER4	MILKHA	0.10	0
237:*	TTLER4	SUA	0.32	0
238:*	TTLER4	MILLS	0.76	0
239:*	TTLER4	FAL	1.30	0
240:*	TTLER5	MILKHA	0.04	0
241:*	TTLER5	SUA	0.27	0
242:*	TTLER5	MILLS	0.71	0
243:*	TTLER5	FAL	1.24	0
244:*	COMBI1	MILKHA	0.32	0
245:*	COMBI1	SUA	0.23	0
246:*	COMBI1	MILLS	0.71	0
247:*	COMBI1	FAL	1.24	0
248:*	COMBI2	MILKHA	0.23	0
249:*	COMBI2	SUA	0.46	0
250:*	COMBI2	MILLS	0.90	0
251:*	COMBI2	FAL	1.43	0
252:*	COMBI3	MILKHA	0.18	0
253:*	COMBI3	SUA	0.41	0
254:*	COMBI3	MILLS	0.85	0
255:*	COMBI3	FAL	1.38	0
256:*	COMBI4	MILKHA	0.10	0
257:*	COMBI4	SUA	0.32	0
258:*	COMBI4	MILLS	0.76	0
259:*	COMBI4	FAL	1.30	0
260:*	COMBI5	MILKHA	0.04	0
261:*	COMBI5	SUA	0.27	0
262:*	COMBI5	MILLS	0.71	0
263:*	COMBI5	FAL	1.24	0
264:*	MILKHA	SUPERMILL	0.00	0
265:*	SUA	SUPERMILL	0.00	0
266:*	MILLS	SUPERMILL	0.00	0
267:*	FAL	SUPERMILL	0.00	0

APPENDIX G (Continued)

Current date: 13-May-97
Current time: 12:11 pm

Listing of NETWORK sale file: "FINOL.SLS"

Line (status)	Network entry node label	Destination node label	Timber volume (units)	Harvest year (years from now)
1:*	h	SUPERMILL	4000	0.0
2:*	i	SUPERMILL	5500	0.0
3:*	j	SUPERMILL	14600	0.0
4:*	k	SUPERMILL	10800	0.0
5:*	l	SUPERMILL	14600	0.0
6:*	m	SUPERMILL	5500	0.0
7:*	n	SUPERMILL	7300	0.0
8:*	o	SUPERMILL	5200	0.0
9:*	p	SUPERMILL	1800	0.0
10:*	q	SUPERMILL	8100	0.0
11:*	r	SUPERMILL	4600	0.0
12:*	s	SUPERMILL	900	0.0
13:*	t	SUPERMILL	5900	0.0
14:*	u	SUPERMILL	7600	0.0
15:*	v	SUPERMILL	12800	0.0
16:*	w	SUPERMILL	5200	0.0
17:*	x	SUPERMILL	8700	0.0
18:*	y	SUPERMILL	8800	0.0
19:*	z	SUPERMILL	4300	0.0

Listing of Bounds File: Finol.bnd

```
3
MILKHA, SUPERMILL, 20000, 25000, 0
SUA,    SUPERMILL, 15000, 20000, 0
MILLS,  SUPERMILL, 35000, 40000, 0
```

APPENDIX H

PROBLEM FORMULATION FOR LINDO

Objective Function:
MINIMIZATION:
(i) *Fixed Costs*:
5391 HSAW1 + 10781 PSAW1 + ... + 179952 TTLER5 + 190941 COMBI5

(ii) *Variable Costs*
+ 2.13 HSAW1 + 1.28 PSAW1 + ... + 1.24TTLER5-FAL + 1.24COMBI5-FAL

Constraints:

SUBJECT TO
(i) *Polygon (Unit) Capacity*
h = 4000; *i* = 5500; ...; *z* = 4300

(ii) *Conservation of Flow*
3) - h + HSAW1 + PSAW1 = 0;
7) - PSAW1 + FARM1 + FORE1 + SKID1 + FRWD1 = 0;
91) - TRACT5 + MILKHA + SUA + FAL = 0

(iii) *Trigger Variables*
360) - 136300 ROAD C-G + TTLER1 + TRUCK1 + FWD1 <= 0
424) - 136300 SCABLE2 + TTLER5 + FARM5 + FORE5 <= 0
425) - 136300 COMBI1 + LANDN-G + LANDN-H + ... + LANDN-M <= 0

(iv) *Mill Requirements*
MILKHA ≤ 25000
SUA ≤ 20000
MILLS ≤ 40000
FAL ≤ 50000
END
GIN 79

OBJECTIVE FUNCTION VALUE

1) 1,814,647.00

APPENDIX I

OPTIMUM PATH DERIVED FROM LINDO ANALYSIS

This run was made on 9-May-97 at 1:36:13 pm.

Number of links: 267
Number of nodes: 122
Number of sales: 21

Total volume: 136,200 units   Discount rate: 0.0%
Time periods: 1   Year 0.0

Objective Function:		
Total discounted variable costs:	900,635	(6.61 $/unit)
Total discounted fixed costs:	914,012	(6.71 $/unit)
Total disc variable+fixed costs:	1,814,647	(13.32 $/unit)

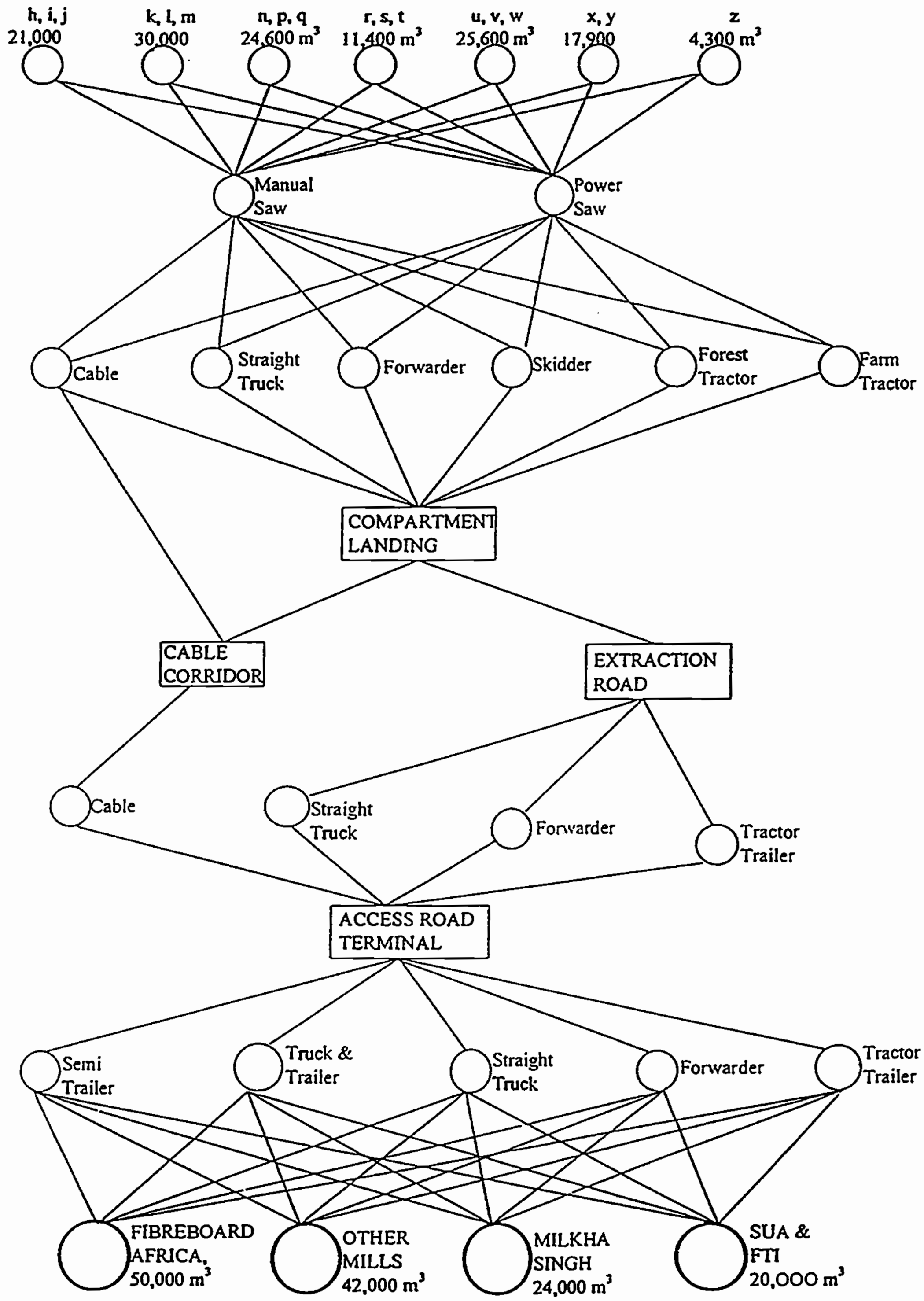
*** SALE PATHS ***

Sorted by the alphanumeric sale node

Node	Volume	Path
h	4,000	h-FELL1-PSAW1-FORE1-C-FWD3-CG-RoadCG-G-TTLER1-FAL
i	5,500	i-FELL1-PSAW1-FORE1-C-FWD3-CG-RoadCG-G-TTLER1-FAL
j	14,600	j-FELL1-PSAW1-FORE1-C-FWD3-CG-RoadCG-G-TTLER1-MILLS
k	10,800	k-FELL2-PSAW2-FORE2-A-FWD1-CG-RoadCG-G-TTLER1-FAL
l	14,600	l-FELL2-PSAW2-FORE2-A-FWD1-CG-RoadCG-G-TTLER1-FAL
m	5,500	m-FELL2-PSAW2-FORE2-A-FWD1-CG-RoadCG-G-TTLER1-FAL
n	7,300	n-FELL3-PSAW3-FORE3-B-FWD2-CG-RoadCG-G-TTLER1-MILLS
o	5,200	o-FELL3-PSAW3-FORE3-B-FWD2-CG-RoadCG-G-TTLER1-MILLS
p	1,800	p-FELL3-PSAW3-FORE3-B-FWD2-CG-RoadCG-G-TTLER1-FAL
q	8,100	q-FELL3-PSAW3-FORE3-B-FWD2-CG-RoadCG-G-TTLER1-FAL
r	4,600	r-FELL4-PSAW4-FORE4-D-FWD4-CG-RoadCG-G-TTLER1-MILLS
s	900	s-FELL4-PSAW4-FORE4-D-FWD4-CG-RoadCG-G-TTLER1-FAL
t	5,900	t-FELL4-PSAW4-FORE4-D-FWD4-CG-RoadCG-G-TTLER1-MILLS
u	7,600	u-FELL5-HSAW5-FORE5-E-SCABLE2-J-TRUCK3-SUA
v	12,800	v-FELL5-HSAW5-FORE5-E-SCABLE2-J-TRUCK3-MILKHA
w	3,600	w-FELL5-HSAW5-FORE5-E-SCABLE2-J-TRUCK3-SUA
w	1,600	w-FELL5-HSAW5-FORE5-E-SCABLE2-J-TRUCK3-MILLS
x	8,700	x-FELL6-PSAW6-FARM6-E-SCABLE2-J-TRUCK3-MILKHA
y	8,800	y-FELL6-PSAW6-FARM6-E-SCABLE2-J-TRUCK3-SUA-SUPERMILL
z	3,500	z-FELL6-PSAW6-FARM6-E-SCABLE2-J-TRUCK3-MILKHA
z	800	z-FELL6-PSAW6-FARM6-E-SCABLE2-J-TRUCK3-MILLS

APPENDIX J (A)

NETWORK OF ALL POSSIBLE SYSTEMS



APPENDIX J (B)

NETWORK OF OPTIMUM HARVESTING SYSTEM