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Levels of Fire Protection for Sustainable Forestry in Ontario

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Levels of Fire Protection for Sustainable Forestry in Ontario

FINAL REPORT

by

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Preface

This report describes our work on the Canada-Ontario Northern Ontario Development Agreement Sustainable Forestry Development/Decision Support Project entitled "Developing Analytical Procedures for Establishing the Level of Protection for Forest Fire Management to Support Sustainable Forestry in Ontario." It is one of a set of three documents that describe our work on the project.

"Levels of Fire Protection for Sustainable Forestry in Ontario", is a revised version of a discussion paper that we prepared to serve as background material for the participants in the Level of Protection Workshop that was held in Sault Ste. Marie in September of 1993. The revised version of the discussion paper reflects some of the comments and suggestions of the workshop participants and describes many of the basic principles of level of fire protection as they pertain to Ontario.

"**LANIK** User's Reference Manual", is a users manual which documents and describes the use of the level of protection decision support system computer software that was developed for the province of Ontario.

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F. M. Dunn of the Aviation, Flood and Fire Management Branch (AFFMB) of the Ontario Ministry of Natural Resources served as the scientific authority for the project. A. Tithecott of the AFFMB provided us with valuable insight into Ontario's forest fire management system and helpful suggestions. He also provided the data that was used to develop and test the models.

J.I. MacLellan developed and tested the database management system, and designed and tested the database query and data transformation software. B.M. Sakowicz helped with administrative support, the preparation and documentation of statistical analysis software. R. Saporta provided valuable advice concerning the development of the ESKER spreadsheet software and played a major role in documenting **LANIK**. All three assisted with the preparation of this final report and completed numerous other tasks that contributed significantly to the development of **LANIK**.

Table of Contents

Chapter 1: Introduction 2

Chapter 2: The Structure of LANIK 5
- **2.1 Design Philosophy** 6
- **2.2 The Decision Analysis Approach** 8
- **2.3 Pragmatic Systems Level Models Versus Refined Subsystem Models** 8
- **2.4 An Overview of the Basic Components of LANIK** 9

Chapter 3: Using LANIK to Identify and Evaluate Fire Management Program Alternatives 11
- **3.1 The Database Management System** 12
- **3.1 The Initial Attack Simulation Model** 12
- **3.3 The ESKER Spreadsheet Model** 13

Chapter 4: ESKER 15
- **4.1 Measuring the Impact of Fire on the People and Forests of Ontario** 15
- **4.2 Initial Attack Model Predictions** 18
- **4.3 The Impact of Fire on People that Live in and Near Forests** 18
- **4.4 Community Impacts** 19
  - 4.4.1 Damage to Buildings in Communities 19
  - 4.4.1 Community Smoke Problem Incidents 22
  - 4.4.2 Community Evacuation Alert Incidents 24
  - 4.4.3 Community Evacuation Incidents 25
- **4.5 Rural Residence Impacts** 25
- **4.6 Cottages** 26
- **4.7 Tourist Camps, Lodges and Resorts** 26
- **4.8 Recreation Sites** 26
- **4.9 Precious Heritage Sites** 26
- **4.10 Precious Heritage Areas** 27
- **4.11 Precious Biological Sites** 27
- **4.12 Precious Biological Areas** 27
- **4.13 Industrial Facilities Impacts** 27
- **4.14 Timber Production** 27

Chapter 5: Using LANIK to Evaluate the use of Foam by Fire Crews 29

Chapter 6: Discussion 32

Literature Cited 33

Chapter 1
Introduction

This report describes the development of **LANIK**, a forest fire management decision support system that can be used to help resolve decisions concerning the level of protection (e.g., how much area will be allowed to burn on average) and resource allocation (e.g., how the fire management budget will be allocated to fire management activities) in order to achieve specified forest fire management objectives.

Our primary objective, to help the OMNR develop a widely understood and acceptable means of selecting and achieving a level of protection for fire management programs, can be expressed in terms of three secondary objectives.

1. Improve the Ontario forestry community's understanding of the concept of level of fire protection.

2. Improve the degree of understanding within the forestry community, of the relationship between fire and forest management.

3. Develop analytical procedures based on level of protection measures, that can be used to help resolve decisions concerning the allocation of resources between components of the fire management program in such a way that those allocations are compatible with Ontario's forest management objectives.

In order to accomplish our task we consulted with fire managers and their clients and helped them identify and discuss issues they thought should be addressed when fire managers develop and implement their plans. We convened a workshop to facilitate consultation with fire management specialists and representatives of other OMNR programs that are influenced by fire management.

The workshop objectives were:

1. Education: To teach some basic principles of fire management planning to workshop participants so they could share a common body of knowledge and understanding.

2. Consultation: We asked the workshop participants to identify and discuss level of protection issues and measures that might be used to enhance forest fire management in Ontario.

We drew upon the discussion that occurred during the workshop and comments and suggestions some of the workshop participants subsequently submitted to us. We then developed a rough preliminary framework for level of protection planning which we discussed with OMNR representatives, and gradually developed **LANIK**, a comprehensive, flexible computer based decision support system that we judge to be a pragmatic, workable compromise to an exceedingly difficult problem. We then developed and tested computer software and related documentation that can be used to implement the system.

LANIK is a computer based decision support system that is designed to help forest fire managers and planners resolve level of protection decisions. We intentionally use the term "level of protection" in a broad and general sense, to refer to the very broad scope of decisions concerning the allocation of resources to forest fire management programs. It is designed to help resolve strategic decisions like:

1. how much money should be spent on forest fire management each year,

2. how many and what type of airtankers should be used, and where should they be based,

3. how many crews should be hired,

and tactical decisions like:

1. how should the available airtankers and fire crews be deployed tomorrow,

2. when and where should special prevention measures like restricted fire zones and restricted travel zones be invoked.

LANIK is not designed to help resolve operational decisions like:

1. what resources should be dispatched to a particular fire,

2. how should available suppression resources be deployed on the fire.

However, it can be used to help develop and evaluate operational guidelines like:

1. aerial detection planning procedures and

2. initial attack dispatch rules.

LANIK is a very flexible and comprehensive system that is designed to serve as a framework for evaluating level of protection decisions. It is, in many ways, what some might characterize as an Executive Information System (EIS) that can be adapted to help resolve a very broad range of level of protection decisions. In that sense, its primary strength is the relative ease with which it can be adapted to suit unforeseen decision support needs as they arise. Our hope is that users can modify **LANIK** to "suit the problem" and thereby avoid the all too common need to "modify the problem to fit the model."

Later in this report we describe how we used **LANIK** to evaluate the use of foam by fire crews in Ontario, to illustrate how **LANIK** can be adapted to specific problems. The ultimate test of its value will be the extent to which it can readily be adapted to address the needs of Ontario's forest fire managers and planners.

Chapter 2
The Structure of LANIK

LANIK is a computer based decision support system that includes many models of the components of a forest fire management system. It is embedded in a database management system that facilitates the storage and retrieval of data which describes the structure of the fire management system, the fireload that the fire management system must contend with, and data that describes alternative level of protection strategies. It is essentially a model management system or toolkit that makes it relatively easy for fire managers and planners to analyze what has occurred in the past, develop new fire management program options, and to test how well those proposed alternatives might satisfy fire management program objectives in the future.

LANIK includes:

1. a database management system that is used to store fire management system data (e.g., historical fire data), detailed descriptions of the land base under protection and the values at risk on that land base, descriptions of proposed fire management program alternatives (e.g., how many crews are hired and where they are based), and the predicted consequences of implementing specified fire management program alternatives in the future,

2. mathematical models of the major components of the fire management system (e.g., an initial attack system model (IA), a strategic assessment spreadsheet model (SANDBOX), and many small models that are incorporated in a very detailed scenario analysis spreadsheet model (ESKER)),

3. computer software that enables users to input data and describe fire management program alternatives and use the mathematical models to predict the consequences of implementing alternative level of protection strategies,

4. statistical analysis software that can be used to analyze both historical fire data and the predicted consequences of implementing specific fire management program alternatives.

LANIK predicts the consequences of alternative levels of protection by using a computer simulation model to fight historic fires and predict how many fires will escape initial attack, and incorporates those predictions in a large valuation model (ESKER) that projects the implications of those escaped fire levels for the people and forests of Ontario.

2.1 Design Philosophy

LANIK is a descriptive computer simulation model that predicts the consequences of implementing specified strategies. It is not a prescriptive optimization model that can be used to identify the optimal or best strategy. Many considerations led us to adopt this approach.

It is essential that fire management strategies, be they local (i.e., prevention measures in a small district) or global (how many airtankers should be purchased for the provincial fleet), be evaluated from an agency-wide perspective. For example, localized prevention measures may reduce fire occurrence in one part of the province and free up resources that can be used to enhance the performance of the initial attack system in other districts hundreds of miles away. Airtankers are very mobile resources and their efficient use can lead to reductions in extended attack suppression resources across the agency. Although it is possible to develop good prescriptive subsystem optimization models that are designed to optimize the performance of fire management subsystems (e.g., airtanker home basing), we need a comprehensive system level model in order to carry out system level evaluations of fire management programs. Forest fire management systems are sufficiently complicated that we simply cannot develop meaningful comprehensive optimization models that can be used to identify optimal strategies at the present time.

We therefore opted to develop a comprehensive descriptive system model that can be used to combine:

- the results of subsystem optimization models,
- predictions produced by very detailed descriptive simulation models,
- the experience and judgement of experienced fire managers and planners,

to facilitate the search for and evaluation of level of protection alternatives from a system level perspective. What follows is a list of some of the many factors and concerns that influenced the design of **LANIK**.

- There are no comprehensive detailed optimization or simulation models that can be used to assess level of protection strategies for large heterogeneous forest fire management agencies.
- There are some subsystem optimization models (e.g., airtanker home basing), but skilled fire managers must coordinate the interaction of such models with other subsystem models to ensure the subsystems are not optimized at the expense of system level objectives.
- Fire managers must deal with a great deal of uncertainty and their decision support systems should be designed to facilitate sensitivity analyses.

- Many aspects of forest fire management are not well understood and it will be many years before researchers can provide fire managers and planners with comprehensive and sufficiently accurate models of fire management systems. Fire managers and planners cannot postpone their decisions, and need the best decision support they can get in the time available.

- We decided to incorporate in **LANIK**, proven existing models like the initial attack model that Martell et al. (1984a, 1984b) developed to support airtanker acquisition decision making in Ontario. One of the most attractive features of the IA model is that it explicitly models the congestion that increases fire losses when fire arrival rates tax suppression resources and the resulting delays in suppression action can cause very significant increases in fire impact. Most published initial attack models assume fires occur one at a time and thereby ignore the congestion that makes fire management planning and — more importantly — fire management difficult.

- The initial attack model uses historical fire report data to generate fire load scenarios. Although this complicates the statistical analysis of the results, it ensures the small sample of fires that are fought are realistic representations of actual fireloads.

- We developed very simple models to fill the gaps. Those models are based on our understanding of fire management systems and are designed to make it easy for experienced fire managers to incorporate their subjective assessments of important system parameters where proven scientific knowledge is lacking.

- The subsystem models are linked in such a way that skilled planners can work with experienced fire managers to link subsystem inputs and outputs in a realistic fashion and thereby evaluate level of protection alternatives from a system level perspective.

Fire management decision support needs typically come and go far faster than researchers can design, build, and test models. Researchers often lag fire managers' practical needs by many years, and it not always possible to foresee what decisions will have to be resolved in the future, or even a short time in advance. Ontario's fire managers therefore need a relatively flexible decision support framework that:

- works "good enough for now",

- can be refined as they gain experience with its use and develop a better understanding of its limitations,

- can readily be modified to enable them to deal with important decisions and issues that have not been identified but might well emerge in the future.

2.2 The Decision Analysis Approach

We have drawn upon several disciplines and decision support methodologies to develop LANIK, including the very pragmatic decision analysis methodology that was developed and has been used extensively by R.A. Howard and others in the Engineering Economic Systems Department at Stanford University and at SRI International. The basic technique is described by Howard (1968).

The term decision analysis is commonly used to refer to a particular class of quantitative procedures that can be used to help describe decision making problems and evaluate alternatives for managing systems under uncertainty. Decision analysts work closely with decision makers to identify the decisions and the alternative courses of action the decision makers can choose to implement. They identify the outcomes (e.g., burned area) that might result from implementing alternative courses of action and describe them in terms of their suitability to the decision maker (e.g., value of timber consumed by fire, the value of the homes destroyed).

They then identify the system variables upon which the outcomes depend. Decision variables describe factors that are controlled by the decision maker (e.g., number of fire fighters hired for the season). State variables describe factors that are not controlled by the decision maker and can be viewed as being under the control of Nature (e.g., lightning fire occurrence). The approach includes the development of deterministic mathematical models (what Howard refers to as a structural model) that relate outcomes (e.g., area burned) to system variables. Our structural models are the Initial Attack simulation model and the ESKER spreadsheet model which is described later in this report. The iterative process produces successive improvements in the model until it is thought that it is "good enough" given the time and money available for resolving the decision, and the potential costs and benefits that might result.

2.3 Pragmatic Systems Level Models Versus Refined Subsystem Models

Our objective was to develop a level of protection decision support system that fire managers and planners can use to help identify and evaluate level of protection alternatives. A systems level perspective is essential to ensure alternatives are evaluated in terms of their impact on the people and forests of Ontario. A systems level perspective helps ensure the overall system is not degraded when some subsystem is improved at the expense of another. For example, we do not want to build up the initial attack subsystem at the expense of the prevention and detection subsystems to the extent that the prevention and detection subsystems are so impoverished the enhanced initial attack system cannot cope with the increased fireload, and overall system performance is degraded.

Fire managers and planners need comprehensive system level models that address all the important aspects of all the important fire management subsystems. As we noted earlier, there are no comprehensive fire management planning models that could be used to satisfy the needs of fire managers and planners in Ontario. We had to develop a comprehensive model that addressed many subsystems and their interactions. We were able to use a modified version of an existing subsystem model (the Initial Attack model developed by Martell et al. (1984a, 1984b)), but for the most part, we had to quickly develop many very simple models of complex subsystems that had seldom if ever been modelled in detail (e.g., the community evacuation subsystem). Our approach was to talk to fire management specialists, study the scientific literature, and use our own common sense to develop very simple models with small numbers of parameters that we believe can be subjectively assessed reasonably well by experienced fire managers and planners.

It would, of course, have been "nice" to devote many person-years of scientific research and software development resources to produce very refined models of the many subsystems that make up Ontario's forest fire managerial system. However, such an effort would have taken several years and the refined system would be of no help to fire managers and planners who must resolve many important decisions in the near future. We therefore developed a large system level model that includes complex detailed subsystem models (e.g., the initial attack system model) and many more very simple subsystem models (e.g., the community evacuation subsystem model).

2.4 An Overview of the Basic Components of LANIK

LANIK has several major components that are described in detail in subsequent sections of this report and in the User's Reference Manual.

- The database management system is used to store and manipulate basic historical fire report data and other aspects of the fire environment, descriptions of level of protection alternatives that are to be tested, and predicted measures of performance for those alternatives.

- An Initial Attack (IA) simulation model that predicts how the initial attack system will perform (i.e., how many fires will escape initial attack) under specified level of protection alternatives.

- Statistical analysis software that can be used to analyze historical and simulated fire report data.

- A strategy assessment spreadsheet model (SANDBOX) that makes it possible for fire managers and planners to quickly and easily vary a single decision variable over a specified range, and graphically illustrate the system level cost plus loss and escaped fire consequences of such measures.

- A large spreadsheet model (ESKER) that enables fire managers to examine in very fine detail, the impact of alternative levels of protection on the people and forests of Ontario, at both provincial and Fire Management Analysis Unit levels.

We believe **LANIK** is a scientifically sound and pragmatic compromise that will be of practical value to forest fire managers. Only time and extensive use by experienced fire managers and planners will reveal the extent to which we have met our objectives.

Chapter 3
Using LANIK to Identify and Evaluate Fire Management Program Alternatives

LANIK is a descriptive model that can be used to predict how well a specified fire management program will satisfy fire management program objectives. It is not a prescriptive model that specifies the best or optimal fire management program.

A forest fire management system is a very large and complex. It is possible to develop a mathematical model of a fire management system by using what are referred to as decision variables and state variables. Decision variables represent factors that are under the control of the decision-maker (e.g., how many fire fighters to hire for the fire season). State variables represent factors that are not controlled by the decision-maker (e.g., how often it rains throughout the course of the fire season).

The very simple Least Cost plus Damage (LCD) model of fire economics has only one decision variable (the amount of money to spend on presuppression), and a small number of state variables to specify the fire loss curve. It is relatively easy to identify the optimal solution to a simple decision variable LCD model. Any realistic model of a real forest fire management system would, however, have many decision and state variables. Many of the relationships between fire impact and the decision and state variables would be nonlinear. The problem of identifying an optimum solution would be compounded enormously by the high degree of uncertainty (e.g., the random processes that govern fire occurrence and behaviour) that is characteristic of forest fire management. Suffice it to state that it is not presently possible to develop a good prescriptive model that can be used to identify an optimum level of fire protection, nor do we expect it will be possible to do so in the near future.

Fire managers must therefore use descriptive models that predict how well proposed alternatives will perform. In effect, one must specify a level of protection by specifying a value for each of the many decision variables, and then running the descriptive model to see how well the proposed alternative will perform. Since there are many decision variables and most of them can be set to one of many possible values, there are so many alternatives that it is not possible to specify and evaluate all the feasible alternatives.

But the task is not as daunting as it might appear. Most forest fire management agencies have evolved over time and good managers and experience have in most cases, brought them to a point where they probably achieve their objectives reasonably well. Good managers and planners can usually gain valuable insight from relatively simple decision support system models that allow them to explore how they can improve upon their current practices. Furthermore, fire managers and planners can decompose large fire management planning problems into smaller "bite sized" chunks, and in some cases, use powerful optimization methods to help resolve issues concerning the smaller components of the system.

The mathematical programming optimization model which MacLellan and Martell (1993) developed for airtanker home basing is one such example. That decision support system was designed such that once a manager specified 1) how many airtankers were to be deployed, 2) what airtankers were to be considered, and 3) daily deployment rules, the airtanker home basing model could be used to specify a home basing strategy that was optimal given the conditions specified by the manager.

LANIK is a descriptive model that is designed to enable good managers and planners to predict how well specified levels of protection alternatives will perform. It has been developed and can be used on the assumption that fire managers and planners can identify good alternatives that are "in the ballpark." They can then specify incremental program changes and use **LANIK** to assess the potential of those changes. **LANIK** is therefore an exploratory tool that can be used to enhance the search for good but not necessarily optimal fire management program alternatives.

3.1 The Database Management System

LANIK is a comprehensive system level planning model that is embedded in a model management system which uses a powerful database management system to store data, descriptions of level of protection alternatives, and the predicted performance of specified level of protection alternatives. The database management system makes it possible to develop linkages between data, models, and predicted system performance relatively easily. That frees fire managers and planners from dealing with many complex computing and model administration tasks and makes it possible for them focus on fire management issues. Is a comprehensive database management system that is designed to manage the historical fire occurrence and fire weather data, detailed descriptions of the physical characteristics of the protected area stratified by Fire Management Analysis Unit (FMAU) and level of protection alternatives. It is described in detail in the **LANIK** Users Manual.

3.1 The Initial Attack Simulation Model

We needed a mathematical model that could be used to predict how well (e.g., number of escaped fires) each level of protection alternative would perform. Those physical measures could then be incorporated in a value model that expresses the predicted results in terms of the impact of fire on the people and forests of Ontario. Martell, Drysdale, Doan and Boychuk (1984a, 1984b) developed an initial attack system model that was used to help resolve decisions associated with the enhancement of the OMNR's airtanker fleet in the early 1980's. The Initial Attack model is a large computer simulation model that predicts the performance of alternative sets of fire fighters, transport helicopters, and airtankers when they are used to fight historical fires. It includes a set of initial attack dispatch rules that describe how many fire crews are required, and how they will be transported to each fire, and how many airtankers are required. The model assumes there are an unlimited number of fire fighters available for initial attack and it explicitly models the growth and suppression of historical fires and the congestion that occurs when the demand for transport helicopters and airtankers exceeds their supply and fires must queue for service. The model has several system performance measures including:

1. a cost plus loss figure that accounts for Extra Fire Fighting (EFF) expenditures, stumpage losses, and property losses,

2. initial attack dispatch delay (i.e., the elapsed time from the report of a fire until the last airtanker or fighter departs for the fire),

3. initial attack interval (i.e., the elapsed time from report until the first airtanker or fire fighter begins suppression action on the fire), and

4. the number of fires that escape initial attack each year.

The Ontario Initial Attack model has only been used to assess airtanker needs but is quite general. Given the time required to develop a new model and the remote possibility that it would constitute a significant improvement over the existing Initial Attack model, we opted to adapt the existing model to our current needs. That made it possible for us to devote more effort to the value model that transforms the relatively simple Initial Attack model measures of performance into comprehensive measures of the impact of level of protection alternatives on the people and forests of Ontario.

3.3 The ESKER Spreadsheet Model

ESKER is a mathematical model that is designed to enable fire management planners and their clients to assess the impact of level of fire protection in detail at both the provincial and FMAU levels. It draws upon the basic fire management environment data which is stored in the Fire Management Database (FMDB, which refers to all the FoxPro database and program files within the data management system), and the physical consequences (e.g., average number of escaped fires per year) of varying levels of fire protection as predicted by the Initial Attack (IA) simulation model.

ESKER is designed to allow fire managers to view the predicted impact of specified level of protection alternatives in great detail, and to use it interactively to search for possible improvements. This can be done as follows:

1. The user begins by partitioning the province into a large number of Fire Management Analysis Units (FMAU). We used a specific set of 43 FMAU's to develop and test

LANIK but users are free to develop other sets of FMAU's. The number and boundaries are arbitrary but should be designed so that planners and fire managers can treat each FMAU as a relatively homogeneous unit for planning and resource allocation purposes.

2. Historical fire report data for each FMAU is then stored in the FMDB.

3. The user specifies one or more level of protection alternatives that he or she wishes to consider, and describes them in such a way that they can be described in the FMDB.

4. The Initial Attack simulation model is run to predict how well the specified alternative will perform in terms of the number of escaped fires in each FMAU, and aggregate cost measures. The predicted performance data is stored in the FMDB.

The ESKER spreadsheet model is then loaded and the attributes of the FMAU's and the predicted performance of the specified alternative is loaded into relevant cells in the spreadsheet model.

5. ESKER is then used to view how the specified level of protection alternative will perform in terms of its potential impact on the people and forests of Ontario. ESKER displays the results for each FMAU and for the entire protected area. The many impact measures that are used are described in the following chapter.

6. ESKER can be used to identify troublesome aspects of the predicted impact of a specific level of protection alternative and search for improvements. Suppose for example, there were a relatively large number of escaped fires in several FMAU's. The user could arbitrarily decrease the number of escaped fires in each of those FMAU's, one at a time, and view the impact of those potential improvements on the FMAU's and the entire protected area[1].

7. He or she could draw upon his or her experience and develop a new level of protection alternative and describe it in such a way that it can be stored in the FMDB.

8. The Initial Attack simulation model could be run with the new alternative and the results imported into ESKER as described above.

9. The user could continue to search iteratively for improvements until he or she is satisfied with the predicted performance of some improved level of protection alternative.

We will now turn to ESKER and describe the many measures of system performance we developed. We will also describe the mathematical models we developed to transform the Initial Attack model predictions into comprehensive measures of system performance.

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[1]Note that this approach produces only a rough estimate of the impact of a tentative change as it would not reflect the impact of the interaction of those "eliminated" fires on the remaining fires.

Chapter 4
ESKER

The Fire Management Database (FMDB) contains information concerning the values at risk and other Fire Management Analysis Unit (FMAU) attributes. Most of the data in the current version of the database is hypothetical data that was used to develop and test LANIK and illustrate how it can be used for fire management planning purposes. However, the FMDB is designed such that as fire managers and their clients gather more and more data concerning the fire management environment and values at risk in each FMAU, that data can readily be incorporated in the FMDB.

4.1 Measuring the Impact of Fire on the People and Forests of Ontario

Fire can have very significant impacts on people and forests. We focused on the quality of peoples lives, the impact on commercial and industrial activity, and the impact on timber supply. We did not deal with the biological impact of fire on forest ecosystems as it is not well understood. That is of course, an important omission that should be addressed in the near future. However, our concern is somewhat diminished by the fact that fire is a natural component of most of Ontario's forest ecosystems and we do not believe fire has yet had a significant irreversible detrimental impact on Ontario's forest ecosystems. That of course, is based on an assumption that the potential long term ecological costs of enhanced fire management program effectiveness can be reversed, and fire can be more widely "re-introduced"[2] into Ontario's forests in a planned fashion.

We begin with the following cost, response, and burned area measures of performance produced by the IA model.[3] They are the predicted consequences of fighting the historical fires in the Historical Fire Database with the suppression resources available given some specified level of protection option.

Fire fighter hiring cost
Aircraft holding cost
Aircraft flying cost

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[2] We use the term "re-introduced" to describe the conscious decision to reduce the effectiveness of the fire organization in some areas due to economic and ecological factors. That is of course a misnomer as fire is already present in Ontario's forest ecosystems.

[3] The structure of the IA model is described in Martell et al. (1984a, 1984b).

Held fire loss
Escaped fire cost + loss
Total cost + loss
Initial attack crew dispatch delay: average (hours)
Initial attack crew dispatch delay: standard deviation (hours)
Initial attack response time: average (hours)
Initial attack response time: standard deviation (hours)

BURNED AREA:

Number of fires
Number of held fires
Number of escaped fires
Number of fires not attacked

We classified the impacts of fire on the people and forests of Ontario into the following categories and sub-categories:

COMMUNITY IMPACTS:

Community buildings burned
Community smoke problem incidents
Community evacuation alert incidents
Community evacuation incidents

RURAL RESIDENCE IMPACTS:

Rural buildings burned
Rural residence smoke problem incidents
Rural residence evacuation alert incidents
Rural residence evacuation incidents

COTTAGE IMPACTS:

Cottage buildings burned
Cottage smoke problem incidents
Cottage evacuation alert incidents
Cottage evacuation incidents

TOURIST CAMP, LODGE AND RESORT IMPACTS:

Resort buildings burned
Resort smoke problem incidents
Resort evacuation alert incidents
Resort evacuation incidents

RECREATION SITE IMPACTS:

Recreation sites burned
Recreation site smoke problem incidents
Recreation evacuation alert incidents
Recreation evacuation incidents

PRECIOUS HERITAGE SITE IMPACTS:

Number of precious heritage sites burned

PRECIOUS HERITAGE AREA IMPACTS:

Size of precious heritage area burned

PRECIOUS BIOLOGICAL SITE IMPACTS:

Number of biological sites burned

PRECIOUS BIOLOGICAL AREA IMPACTS:

Size of precious heritage area burned

INDUSTRIAL FACILITY IMPACTS:

Industrial buildings burned
Industrial evacuation alert incidents
Industrial evacuation incidents

TIMBER PRODUCTION:

Harvest volume reduction due to fire
Harvest value reduction due to fire

We will now describe the mathematical models we developed to the transform the IA model performance measures into those impact measures. Before we begin, it is important to note that there were no existing models that could suit our purposes. We therefore moved very quickly and pragmatically and developed simple intuitive models with parameters that can be subjectively assessed by experienced fire managers and planners that are familiar with the FMAU's. Our hope is that researchers will gradually replace these admittedly crude models with more accurate models over time.

4.2 Initial Attack Model Predictions

Most of the impacts of fire are caused by large escaped fires that burn over large areas and emit smoke over even larger areas. We use the Initial Attack model to predict how many fires will escape initial attack in each FMAU each year. We assume local fire managers and planners can review historical data concerning the area burned by escaped fires in each FMAU and subjectively estimated the average size of an escaped fire in each FMAU. We used this subjective approach to account for the following factors; very small escaped fire sample sizes for many FMAU's, the final size of escaped fires predicted by the IA model is probably not very accurate, and this approach makes it possible for a manager to incorporate possible policy changes and other important factors in his or her assessment.

4.3 The Impact of Fire on People that Live in and Near Forests

Fire has significant impacts on people that live in and near forests. We partitioned the impact on residents and residences into the following three categories: Communities, Rural Residents, and Cottagers. Within each of these categories we assess the potential impact of the level of fire protection on the number and value of structures damaged by fire, the number of people that experience smoke problems, the number of people that are put on alert for possible evacuation, and the number of people that are required to vacate their residences.

4.4 Community Impacts

4.4.1 Damage to Buildings in Communities

Forest fires can destroy villages, towns, and parts of large cities, and they can damage or destroy residences, business establishments, and other valuable structures. In this section we describe how we modeled the potential impact of forest fires on the buildings that lie within the boundaries of such communities.

We assume only escaped fires have the potential to burn communities. The area of the FMAU burned by escaped fires is the product of the number of escaped fires in the FMAU and the average size of an escaped fire in that FMAU. The average size of the area burned by escaped fires is divided by the area of the FMAU to estimate the fraction of the FMAU burned by escaped fires. For simplicity we then use that fraction to estimate the fraction of communities in the FMAU that *might* be burned by escaped fires.

Communities can range in size from small villages to large cities. Although each community occupies some defined area, we will assume that when we estimate the likelihood that a community is threatened by fire, it can be viewed as a single point which is located at the centre of the actual community. We use the term "threatened" to refer to the process of a fire burning up to the edge of a community. The extent to which such a fire actually destroys the community will depend upon the effectiveness of its fuel breaks and the fire suppression organization. We will assume all communities within a particular FMAU are identical and their characteristics are the averages of all the communities in that FMAU.

Given this assumption, it is reasonable to assume the probability that a community is threatened by fire is the area burned by escaped fires divided by the area of the FMAU. However, fuel management and natural vegetation can reduce the likelihood that fire will actually enter a community. We therefore assume the fraction of communities burned by fire (FCEEF) in a FMAU is given by the following expression.

FCEEF = (1 - CFBE) (area burned by escaped fires/area of the FMAU)

We define a fuel break effectiveness parameter (CFBE) which is 1 minus the probability that a fire which threatens a community will burn through the fuel break. The CFBE parameter ranges from 0.0 (natural and artificial fuel breaks are totally ineffective at preventing a fire from invading a community), to 1.0 (fuel breaks prevent all fires from invading the community).

We now describe how we modelled the damage to buildings incurred when fire threatens a community. Assume each community is circular as depicted in Figure 1.

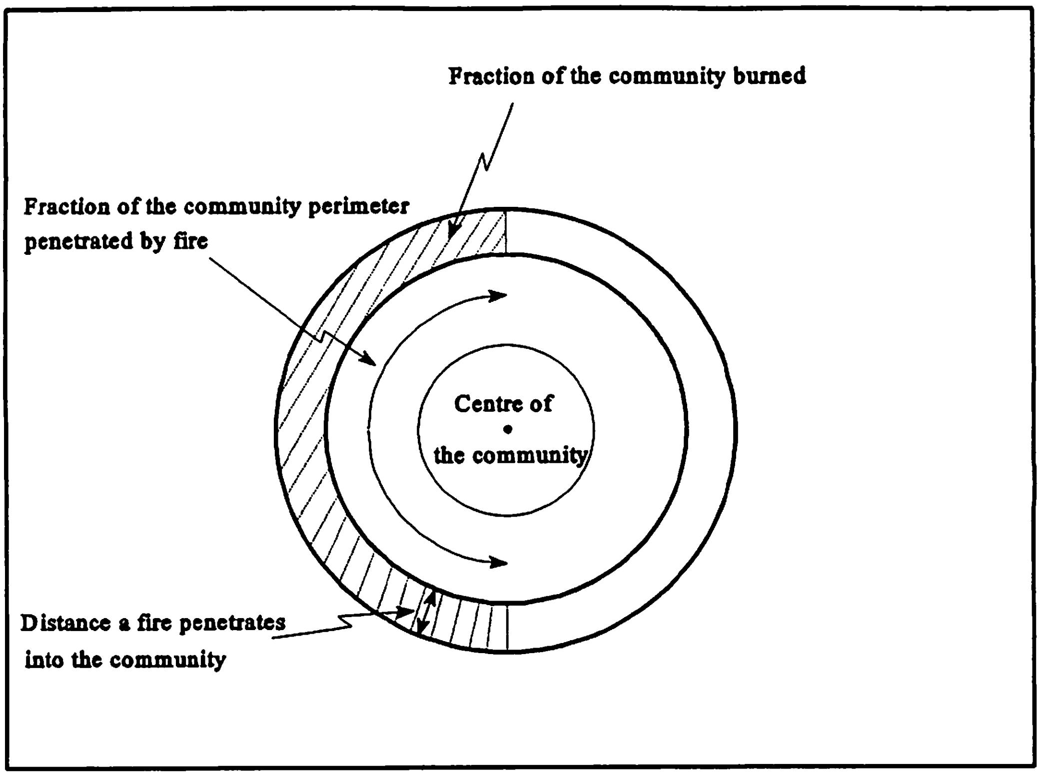

Figure 1. Fraction of a community destroyed when a fire first invades a circular community.

If an escaped fire breaks through the fuel break that surrounds a small village it might well destroy all the buildings in the village. However, if an escaped fire penetrates a large town, it is likely that it will be stopped before it burns the entire community.

We define the following variables.

ACOM = area of community

RCOM = radius of a circular community

Let DMAX = maximum distance a fire can burn into a community

DACT = actual distance a fire burns into a community

Then DACT = Min{DMAX,RCOM}

The resulting burned area will be a circular band on the outer edge of the community. Its width will be DACT and the radius of its inner edge will be RCOM-DACT.

If a fire threatens a community it will usually be driven into one side of the community by a strong wind. It is therefore reasonable to assume the entire perimeter of the community will not be threatened.

Let CPP = fraction of the community perimeter that is threatened by the fire

FCBURN = fraction of the area of the community that burns

Then $FCBURN = CPP\ (ACOM-\pi(RCOM-DACT)^2)/ACOM$

Let NBCOM = number of buildings in the community

NBBCOM = number of buildings burned in the community

Assuming the buildings are uniformly distributed over the area of the community, the number of buildings burned in the community is given by the following expression;

$$NBBCOM = FCBURN\ NBCOM$$

Let VBCOM = average monetary value of each building in a community

FVBBCOM = fraction of the monetary value of a building destroyed by fire that burns a building

Then the value of the buildings burned in the community (VBBCOM) is given by the following expression

$$VBBCOM = FVBBCOM\ VBCOM\ NBBCOM$$

The total number of buildings burned in the FMAU (NBB) and the value of the buildings burned in the FMAU (VBB) are;

$$NBB = NCOM\ NBBCOM$$

$$VBB = NCOM\ VBBCOM$$

Our very simple community building loss function has a number of limitations. We assume all communities are the same as the average community and that fires do not burn outside the FMAU in which they occur.

4.4.1 Community Smoke Problem Incidents

Large forest fires often emit smoke which can engulf communities as illustrated in Figure 2. Such incidents are generally short in duration and are not known to have any significant long-term detrimental impacts on human health. However, during the period of exposure, smoke can have a broad range of impacts on people ranging from diminished visibility to a significant health risk especially for selected individuals with respiratory or other health problems. Smoke from forest fires can force the evacuation of some or all the residents of small northern communities. However, people often opt to remain in their communities and suffer the consequences. We measure the impact of smoke problems in each FMAU by a Community Resident Smoke Index (CRSI) that is essentially an estimate of the number of person-days that people in communities are subject to smoke problems. That measure is of course highly subjective. We address that subjectivity by allowing the planner to describe potential smoke problems in such a way that he or she can implicitly represent the values of the people effected.

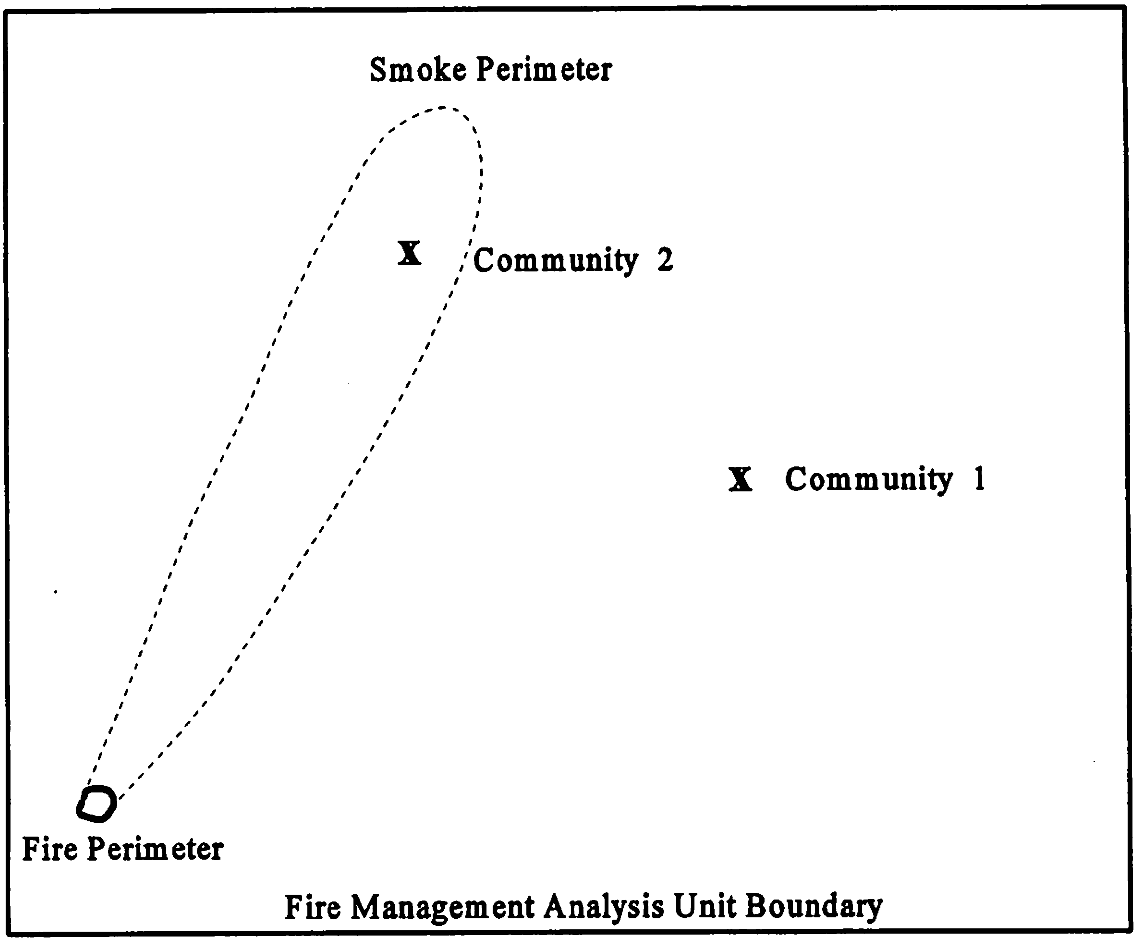

Figure 2. Community smoke problems caused by escaped fires

As was the case with threats to buildings in communities, we assume that only escaped fires have the potential to cause smoke problems. The average size of an escaped fire is divided by the area of the FMAU to estimate the fraction of the FMAU burned by an average escaped fire.

Most of the smoke produced by a fire is emitted from the active combustion zone which is typically less than the size of the actual fire. We will ignore the dynamic aspects of fire growth and smoke emission and use the final size of an escaped fire to model smoke emission.

Let AEF = area of an escaped fire

REF = radius of an escaped fire

MWSEZ = maximum width of the smoke emission zone

WSEZ = actual width of the smoke emission zone

Then WSEZ = Min{MWSEZ,WSEZ}

The smoke emission zone will be a circular band around the outside edge of the fire. Its inner radius (RSEZ) will be

$$RSEZ = REF - WSEZ$$

The size of the smoke emission zone (ASEZ) will be

$$ASEZ = AEF - \pi(REF-WSEZ)^2$$

The fire manager or planner estimates a smoke problem zone multiplier (SPZM) which is multiplied by the area of the smoke emission zone to estimate the size of the area that is covered by problem smoke (PSZA).

Then $PSZA = ASEZ\ SPZM$

The problem smoke zone area is divided by the area of the FMAU (FMAUA) to estimate the fraction of the FMAU is covered by problem smoke (FACPS).

$$FACPS = PSZA/FMAUA$$

That fraction is then multiplied by the community smoke problem multiplier to estimate the fraction of communities in the FMAU that experience smoke problems from each escaped fire.

That fraction is multiplied by the number of communities in the FMAU to estimate NCESP, the number of communities that experience smoke problems.

The NCESP is then multiplied by the number of escaped fires to estimate NCSPI, the number of community smoke problem incidents.

The NCSPI is multiplied by the average duration of a smoke problem to estimate NCSPD, the number of community smoke problem days which is in turn multiplied by the average population of each community to estimate CRSI, the number of community smoke person days which we refer to as the Community Resident Smoke Index (CRSI).

Our simple smoke model has a number of limitations. We ignore the potential smoke problems a fire might cause outside the FMAU in which it occurs. We also ignore double counting. A community that is subjected to smoke from two different escaped fires that are burning simultaneously within its FMAU will suffer two smoke problems rather than one. However, one might expect a "multiple" smoke problem incident to be more bothersome than a "single" smoke problem incident.

4.4.2 Community Evacuation Alert Incidents

Escaped fires can also initiate evacuation alerts. An evacuation alert occurs when the residents of a community are informed their community is threatened by an escaped fire but the threat is not yet considered sufficient to cause an evacuation. The residents are warned they might have to evacuate. Although an evacuation alert is not as troublesome, as an actual evacuation, is represents a significant cost to people that will worry about their well being.

We modelled the occurrence of evacuation alerts as follows. We assumed a community would be placed on evacuation alert when an escaped fire moves to within some specified distance from the community, which we refer to as the evacuation alert distance (EAD). Thus there is an evacuation alert zone (EAZ) around each escaped fire which is

$$EAZ = \pi \, EAD^2$$

The fraction of the FMAU covered by the evacuation alert zone (FCEAZ) is the size of the evacuation alert zone divided by the area of the FMAU.

$$FCAEZ = EAZ/FMAUA$$

That fraction is multiplied by the community evacuation alert zone multiplier (CEAZM) to estimate the fraction of communities in the FMAU that are put on evacuation alert due to an escaped fire (FCEA).

The FCEA is multiplied by the number of communities in the FMAU to estimate the number of communities that are put on evacuation alert for each escaped fire (NCEAEF).

The NCEA is multiplied by the number of escaped fires to estimate the number of communities that are put on evacuation alert (NCEA).

The NCEA is multiplied by the population of each community to estimate the number of people put on evacuation alert (NPEA).

The NPEA is multiplied by the average duration of an evacuation alert to estimate the number of person evacuation alert days (NPEAD).

The NPEAD is multiplied by the average population of a community to estimate the number of community person evacuation alert days.

4.4.3 Community Evacuation Incidents

Community evacuations are a significant detrimental impact on the residents of communities that are threatened by escaped fires. We model the occurrence of evacuations in the same way as we model the occurrence of evacuation alerts, but we use an evacuation distance which is less than an evacuation alert distance. In addition we estimate the monetary cost of evacuating and returning people to their communities, and the daily costs of food and accommodation for people that have been evacuated.

4.5 Rural Residence Impacts

Forest fires can damage or destroy rural residences and other buildings outside organized municipalities. In this sub-section we describe how we modelled the potential impact of forest fire on rural residences and associated structures. Note that cottages and rural industrial and business structures are addressed later.

The impact of fire on rural residents is similar to its impact on people that live in communities. The models we use are analogous to a single community with only one building. As was the case with communities, we use the term building to refer to any significant structure (e.g., a home or a store) and its associated structures (e.g., attached or detached garage and garden shed). We assume only escaped fires have the potential to burn rural buildings.

4.6 Cottages

The impact of fire on cottages is modelled in the same way as we modelled its impact on rural residences.

4.7 Tourist Camps, Lodges and Resorts

Tourist camps, lodges, and resorts are treated like small communities. Unlike communities they have employees that do not receive salaries while they are evacuated and they have guests that do not generate revenue while they are evacuated.[4]

4.8 Recreation Sites

Recreation sites are isolated points like campsites that can be damaged by fire. The fraction of recreation sites threatened by escaped fires is simply the fraction of the area of the FMAU that is burned by escaped fires. The fuel break effectiveness determines what fraction of those actually burn. In addition there are guests (but no employees) at those sites. They can suffer from smoke problems, evacuation alerts, and evacuations just like rural residents. There are potential lost revenues and evacuation and accommodation costs associated with evacuations.

We considered modelling recreation corridors (e.g., canoe routes) as separate entities but opted to model them as collections of individual sites. Recreation areas (e.g., small campgrounds that are small areas rather than points) can be modelled as small resorts.

4.9 Precious Heritage Sites

Ontario's forests contain some sites that are of immense intangible value. Although economists and others have developed procedures for quantifying many intangible values (e.g., wilderness recreation), we believe there are some very important intangible values that people will either be unwilling or unable to express in monetary terms. Some of these are associated with special cultural sites that are of very special importance to individuals or communities. We use the term "precious" to indicate that these sites are "in a class by themselves" and that we do not expect the people that treasure them or anyone else will be willing or able to assign monetary values to them. The only way to measure the impact of fire on such sites is to estimate how many of them burn.

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[4] Note that we did not model lost salaries or revenues for industrial facilities that are located *in* communities that are evacuated.

4.10 Precious Heritage Areas

Precious heritage areas are like precious heritage sites but are large enough to be classed as areas rather than points. The procedures we used to model the size of the area burned on precious heritage areas are similar to the methods we used to model the burned area that results when escaped fires threaten communities.

4.11 Precious Biological Sites

Precious biological sites are sites that have been classed as being of special importance for biological reasons. An example would be a nesting site of some endangered species. The procedures we used to model the impact of fire on precious biological sites are similar to the methods we used to model the impact of fire on precious heritage sites.

4.12 Precious Biological Areas

Precious biological areas are areas of special biological significance. An example is an area that contains some endangered plant species that might be damaged by fire. The procedures we used to model the impact of fire on precious biological areas are similar to the methods we used to model the impact of fire on precious heritage areas.

4.13 Industrial Facilities Impacts

Industrial facilities are assumed to be outside communities. The procedures we use to model the impact of fire on such facilities are similar to the procedures we used to model the impact of fire on resorts. They do not suffer smoke problems but they may be put on evacuation alert or be evacuated. They have no guests but there are revenue and lost salary costs associated with evacuations.[5]

4.14 Timber Production

Fire can have a significant impact on timber production. In order to assess the impact of fire on timber production it is necessary to develop a forest level timber harvest scheduling model that includes an average fire loss fraction. Reed and Errico (1986) developed such a model and Martell (1994) used a modified version of their model to assess the impact of fire on timber

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[5] Note that we did not account for the permanent loss of revenue and salary that might result if a fire caused the closure of resorts or industrial facilities.

supply in Ontario. The OMNR has developed an enhanced version of the Reed and Errico (1986) model which they refer to as the Strategic Forest Management Model (SFMM). In very simple terms, one can estimate how timber harvest volumes and revenues vary as the fraction of the forest burned varies.

We use the fraction of the FMAU burned as a measure of the area burned each year. We assume the fire manager or planner can allocate the burned area and determine what fraction of that area falls within each cover type. The FMDB contains tables that relate harvest levels and revenues to burn fraction by cover type within each FMAU. Those parameters are used to estimate the impact of fire on each of four cover types in each FMAU.

Chapter 5
Using LANIK to Evaluate the use of Foam by Fire Crews

LANIK is a decision support system that is designed to support a very broad array of forest fire management decision making. In this chapter we illustrate how we used it to carry out a "quick and dirty" evaluation of the use of foam by fire crews.

During the project G.T. Woods of the AFFMB indicated that he was faced with a decision concerning the use of foam by fire crews in Ontario. He asked us if it was possible to use **LANIK** to help resolve such decisions. We decided to carry out a simple evaluation of the use of foam to illustrate one way **LANIK** can be used to support forest fire management in Ontario. These results were subsequently presented at the International Wildland Fire Foam Symposium in Thunder Bay, Ontario, on May 3, 1994.

Fire managers and researchers have in the past, carried out "single fire" evaluations of new technology. The common practice is to evaluate proposed technological innovations by assessing how well they perform on a sample of representative fires, and projecting the apparent savings to the entire fire organization. The "single fire" approach is not valid as it 1) ignores the fact that fires are not independent of each other (they interact via fire suppression resources), and 2) you cannot assess savings by simply multiplying the area saved (i.e., not burned as a result of using foam) by a fixed dollar value per ha saved.

Forest fires often interact with each other via suppression resources, and that interaction makes it imperative to evaluate fire management strategies from a systems perspective. Consider for example, the following very simple cases.

Case 1:

A crew equipped with foam carries out initial attack action on one fire and then it moves and fights a second fire without foam. Let us suppose the crew uses foam when it attacks the first fire. Assume the effectiveness of foam is such that the first fire is declared as Being Held (BHE) earlier than it would have been declared BHE if the crew had not had foam. The crew's response time to the second fire will therefore be less than it would have been had they not used foam on the first fire. The use of foam on the first fire therefore enhances the productivity of the initial attack crew on the second fire as well as the first fire, but single fire evaluations ignore such interactions.

Case 2:

A crew with foam and airtankers without foam attack the first fire and a second crew and the same airtankers attack a second fire. Neither the crew nor the airtanker apply foam to the second fire. The effectiveness of foam is such that the first fire is declared BHE earlier than it would have been declared BHE if the crew had not had foam. The airtankers's response time to the second fire is therefore less than it would have been had the crew not used foam on the first fire. The use of foam on the first fire therefore enhances the productivity of the initial attack force (another crew and the same airtankers) on the second fire as well as the first fire. Single fire evaluations ignore such interactions.

Case 3:

A crew with foam fights a single potential "project fire" and crews without foam, but with airtankers fight several fires the following few days. Suppose the use of foam by the fire crew enables the crew to contain at 0.1 ha, the potential project fire that would have escaped to burn a large area. The existence of a large project fire may have drawn down the initial attack strength of the fire organization for several days. Thus the effective use of foam on the first fire has an important secondary beneficial impact that ripples through all the fires fought during the following few days. Single fire evaluations ignore such interactions.

A second error that analysts often commit, is to assess the value of innovations on the basis of a site specific assessment of the damage averted. Consider for example, the timber production implications of fire management. In the simplest case, they estimate the reduction in area burned that resulted and they multiply that saved area by some fixed value per unit area. That approach is incorrect as it ignores the important fact that one should assess the impact of fire on timber supply from a forest level perspective.

We used **LANIK** to conduct a "quick and dirty" assessment of the potential cost effectiveness of foam. The Initial Attack model has a fire crew productivity factor which is multiplied by the rate of line construction for sensitivity analysis purposes. The nominal value of that factor is 0.75. We assumed the impact of foam would be to increase the rate of line construction. We varied the crew productivity from 0.75 to 2.0 and plotted the results in Figure 3. The results indicate that reasonable improvements in fire crew productivity can result in significant cost reductions. We used the Initial Attack model and the SANDBOX model to complete this exploration analysis in a matter of hours.

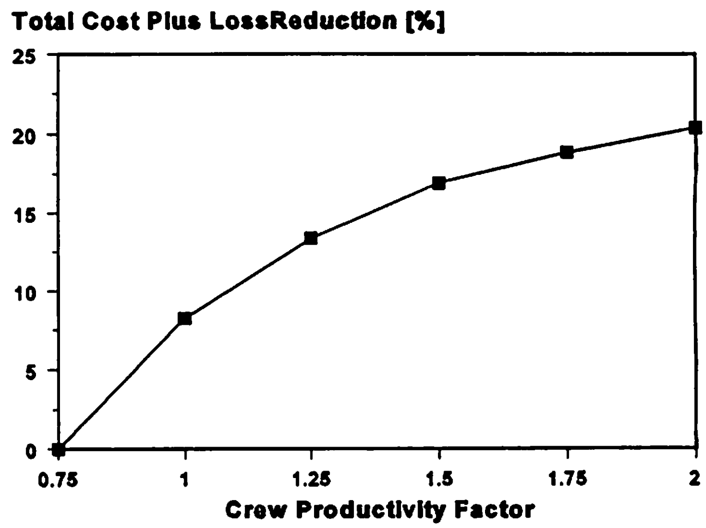

Figure 3. Cost Effectiveness of Ground Crew Foam

Chapter 6
Discussion

LANIK is a comprehensive decision support framework that is designed to evaluate level of protection alternatives in Ontario. It is very comprehensive but of necessity, it comprises many highly simplified models of the impact of fire on the people and forests of Ontario.

It calls for many subjective assessments on the part of fire managers and planners that are intimately acquainted with each FMAU. In that sense, it is designed to involve both local and provincial interests in the planning process.

It also calls for very detailed information about the values at risk in each FMAU. Since the required data is not yet available, we have designed the system such that fire managers and planners can start with simple yet representative estimates of those values (e.g., the number of rural residences and the average value of a rural residence in each FMAU). However, the OMNR is currently in the process of developing a comprehensive system for dealing with values at risk that may eventually be incorporated in its DFOSS information system As those data become available they can use LANIK to develop improved estimates of the impact of fire on the people and forests of Ontario.

In closing, it is important to note that LANIK is only the first step in a process that will gradually lead to improved forest fire management planning in Ontario. It was not our mandate, nor did we have the time, to develop, field test, and revise LANIK. We expect LANIK will be enhanced and improved as we and others learn from the experience that is gained as fire managers and planners implement Version 1.0 and the improved versions we expect will be developed. Readers should derive some consolation from the fact that although this may delay some needed improvements in forest fire management planning, we believe the OMNR's forest fire management program is presently reasonably well managed and cost effective.

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APPENDIX 1
Listing of *esker.wk3*

This is a portion of the spreadsheet that shows the variables which are used to assess alternative strategies. Variable values exist for each fmau and many are summed for a provincial total. An I indicates the estimated is produced by the Initail Attack system model, and an asterisk indicates those variables which are taken from the FoxPro database.

```
ESKER Version 1.0


Spreadsheet model for detailed analysis of fire management strategies
by Fire Management Analysis Unit (FMAU)

To IMPORT DATA from the LANIK database
go to cell  A360 and follow the data import instructions.

Scenario Name:
Scenario description:


Fire management analysis unit (FMAU)
Fire management analysis unit sequence number

Fire management analysis unit number                                   *
Fire management analysis unit name                                     *
Fire management analysis unit area (km**2)                             *


PERFORMANCE OF THE FIRE MANAGEMENT SYSTEM
 AS PREDICTED BY THE INITIAL ATTACK MODEL

Annual fire cost + loss predicted by the initial attack model:

Fire fighter hiring cost                                             I *
Aircraft holding cost                                                I *
Aircraft flying cost                                                 I *
Held fire loss                                                       I *
Escaped fire cost + loss                                             I *
Total cost + loss                                                    I *
Initial attack crew dispatch delay: average (hours)                  I *
Initial attack crew dispatch delay: standard deviation (hours)       I *
Initial attack response time: average (hours)                        I *
Initial attack response time: standard deviation (hours)             I *


BURNED AREA:

Number of fires                                                      I *
Average size of a fire (ha)                                            *
Standard deviation: size of a fire (ha)                                *
Area burned by fires (ha)
Fraction of the FMAU burned by fires

Number of held fires                                                 I *
Average size of a held fire (ha)                                       *
Standard deviation: size of held fires (ha)                            *
Area burned by held fires (ha)
Fraction of the FMAU burned by held fires

Number of escaped fires                                              I *
Average size of an escaped fire (ha)                                   *
Standard deviation: size of escaped fires (ha)                         *
Average radius of an escaped fire (m)
Fraction of FMAU burned by an average escaped fire
Area burned by all escaped fires (ha)
Fraction of the FMAU burned by all escaped fires

Number of fires not attacked                                         I *
```

COMMUNITY IMPACTS:

Number of communities in the FMAU	*
Average population of a community	*
Standard deviation: population of a community	*
Average number of buildings in each community	*
Standard deviation: buildings/community	*
Average monetary value of each building ($)	*
Standard deviation: value of each building ($)	*

Community buildings burned:

Average community fuel break effectiveness	*
Fraction of communities burned by escaped fires	
Average area of a community (ha)	*
Average radius of a community (m)	
Maximum distance fire can burn into a community (m)	*
Actual distance fire burns into a community (m)	
Average fraction of the community perimeter burned	*
Average fraction of the area of a community burned	
Average number of buildings burned in a community	
Fraction of value lost when a building burns	*
Avg. value of buildings burned in each community	
Number of community buildings burned in the FMAU	
Value of community buildings burned in the FMAU	

Community smoke problem incidents:

Maximum depth of the active smoke emission zone (m)	*
Radius of an average escaped fire (m)	
Actual depth of active smoke emission zone (m)	
Area of active smoke emission zone (ha)	
Smoke problem zone area multiplier	*
Area of problem smoke (ha)	
Area of problem smoke (km**2)	
Fraction of FMAU covered by problem smoke	
Community smoke problem multiplier	*
Fraction that experience problems from each esc fire	
Number of communities effected by each escaped fire	
Number of community smoke problem incidents	
Average length of a smoke problem incident (days)	*
Std. deviation: length of a smoke incident (days)	*
Number of community smoke problem days	
Number of smoke problem person days	

Community evacuation alert incidents:

Evacuation alert distance (km)	*
Evac. alert zone around each escaped fire (km**2)	
Fraction of FMAU covered by each alert zone	
Community evacuation alert zone multiplier	*
Fraction alerted due to each escaped fire	
Number alerted due to each escaped fire	
Average length of an evacuation alert (days)	*
Std. deviation: length of an evac. alert (days)	*
Number of community evacuation alerts	
Number of community evacuation alert days	
Number of community person evac. days	

Community evacuation incidents:

Evacuation distance (km)	*
Evacuation zone around each escaped fire (km**2)	
Fraction of FMAU covered by each evacuation zone	
Community evacuation zone multiplier	*
Fraction evacuated due to each escaped fire	
Number evacuated due to each escaped fire	
Average length of an evacuation (days)	*
Std. deviation: length of an evacuation (days)	*
Number of community evacuations	
Number of people evacuated	

Number of community evacuation days	
Number of community person evacuation days	
Cost to evacuate a person ($)	*
Total cost to evacuate people ($)	
Cost to accommodate an evacuee ($/day)	*
Total cost to accommodate evacuees ($)	

RURAL RESIDENCE IMPACTS:

Number of rural buildings in the FMAU	*
Average number of people in each building	*
Standard deviation: people in each building	*
Average monetary value of each rural building ($)	*
Standard deviation: value of each rural building ($)	*

Rural buildings burned:

Average rural residence fuel break effectiveness	*
Fraction of rural buildings burned by escaped fires	
Fraction of value lost by a building that burns	*
Number of rural buildings burned in the FMAU	
Value of rural buildings burned in the FMAU	

Rural residence smoke problem incidents:

Maximum depth of the active smoke emission zone (m)	*
Radius of an average escaped fire (m)	
Actual depth of active smoke emission zone (m)	
Area of active smoke emission zone (ha)	
Smoke problem zone area multiplier	*
Area of smoke problem (ha)	
Area of problem smoke (km**2)	
Fraction of FMAU covered by problem smoke	
Rural residence smoke problem multiplier	*
Fraction that experience problems from each esc fire	
Number of residences effected by each escaped fire	
Number of residence smoke problem incidents	
Average length of a smoke problem incident (days)	*
Std. deviation: length of a smoke incident (days)	*
Number of residence smoke problem days	
Number of smoke problem person days	

Rural residence evacuation alert incidents:

Evacuation alert distance (km)	*
Evac. alert zone around each escaped fire (km**2)	
Fraction of FMAU covered by each alert zone	
Rural residence evacuation alert zone multiplier	*
Fraction alerted due to each escaped fire	
Number alerted due to each escaped fire	
Average length of an evacuation alert (days)	*
Std. deviation: length of an evac. alert (days)	*
Number of rural residence evacuation alerts	
Number of residence evacuation alert days	
Number of residence person evacuation alert days	

Rural residence evacuation incidents:

Evacuation distance (km)	*
Evacuation zone around each escaped fire (km**2)	
Fraction of FMAU covered by each evacuation zone	
Rural residence evacuation zone multiplier	*
Fraction evacuated due to each escaped fire	
Number evacuated due to each escaped fire	
Average length of an evacuation (days)	*
Std. deviation: length of an evacuation (days)	*
Number of rural residence evacuations	
Number of people evacuated	
Number of rural residence evacuation days	
Number of rural residence person evacuation days	

Cost to evacuate a person ($)		*
Total cost to evacuate people ($)		
Cost to accommodate an evacuee ($/day)		*
Total cost to accommodate evacuees ($)		

COTTAGE IMPACTS:

Number of cottages in the FMAU		*
Average number of people in each cottage		*
Standard deviation: people in each cottage		*
Average monetary value of each cottage ($)		*
Standard deviation: value of each cottage ($)		*

Cottage buildings burned:

Average cottage fuel break effectiveness		*
Average fraction burned by escaped fires		
Average fraction of value lost by a burned cottage		*
Number of cottage buildings burned in the FMAU		
Value of cottage buildings burned in the FMAU		

Cottage smoke problem incidents:

Maximum depth of the active smoke emission zone (m)	*	
Radius of an average escaped fire (m)		
Actual depth of active smoke emission zone (m)		
Area of active smoke emission zone (ha)		
Smoke problem zone area multiplier	*	
Area of smoke problem (ha)		
Area of problem smoke (km**2)		
Fraction of FMAU covered by problem smoke		
Cottage smoke problem multiplier		*
Fraction that experience problems from each esc fire		
Number of cottages effected by each escaped fire		
Number of cottage smoke problem incidents		
Average length of a smoke problem incident (days)		*
Std. deviation: length of a smoke incident (days)	*	
Number of cottage smoke problem days		
Number of smoke problem person days		

Cottage evacuation alert incidents:

Evacuation alert distance (km)		*
Evac. alert zone around each escaped fire (km**2)		
Fraction of FMAU covered by each alert zone		
Cottage evacuation alert zone multiplier		*
Fraction alerted due to each escaped fire		
Number alerted due to each escaped fire		
Average length of an evacuation alert (days)		*
Std. deviation: length of an evac. alert (days)		*
Number of cottage evacuation alerts		
Number of cottage evacuation alert days		
Number of cottage person evacuation alert days		

Cottage evacuation incidents:

Evacuation distance (km)		*
Evacuation zone around each escaped fire (km**2)		
Fraction of FMAU covered by each evacuation zone		
Cottage evacuation zone multiplier		*
Fraction evacuated due to each escaped fire		
Number evacuated due to each escaped fire		
Average length of an evacuation (days)		*
Std. deviation: length of an evacuation (days)		*
Number of cottage evacuations		
Number of people evacuated		
Number of cottage evacuation days		
Number of cottage person evacuation days		
Cost to evacuate a person ($)		*
Total cost to evacuate people ($)		

Cost to accommodate an evacuee ($/day)	*
Total cost to accommodate evacuees ($)	
TOURIST CAMP, LODGE AND RESORT IMPACTS:	
Number of camps, lodges, and resorts in the FMAU	*
Average number of guests at each resort	*
Standard deviation: guests at each resort	*
Average daily revenue per guest ($)	*
Std. deviation: daily revenue per guest ($)	*
Average number of employees at each resort	*
Standard deviation: employees in each resort	*
Average daily salary per employee ($)	*
Std. deviation: daily salary per employee ($)	*
Average number of buildings in each resort	*
Standard deviation: buildings/resort	*
Average monetary value of each building ($)	*
Standard deviation: value of each building ($)	*
Resort buildings burned:	
Average resort fuel break effectiveness	*
Average fraction of resorts burned by escaped fires	
Average area of a resort (ha)	*
Average radius of a resort (m)	
Maximum distance fire can burn into a resort (m)	*
Actual distance fire burns into a resort (m)	
Average fraction of resort perimeter burned	*
Average fraction of the area of a resort burned	
Average number of buildings burned in a resort	
Average fraction of value destroyed by a resort building burned	*
Average value of resort buildings burned in each com	
Number of resort buildings burned in the FMAU	
Value of resort buildings burned in the FMAU	
Resort smoke problem incidents:	
Maximum depth of the active smoke emission zone (m)	*
Radius of an average escaped fire (m)	
Actual depth of active smoke emission zone (m)	
Area of active smoke emission zone (ha)	
Smoke problem zone area multiplier	*
Area of smoke problem (ha)	
Area of problem smoke (km**2)	
Fraction of FMAU covered by problem smoke	
Resort smoke problem multiplier	*
Fraction that experience problems from each esc fire	
Number of resorts effected by each escaped fire	
Number of resort smoke problem incidents	
Average length of a smoke problem incident (days)	*
Std. deviation: length of a smoke incident (days)	*
Number of resort smoke problem days	
Number of smoke problem person days	
Resort evacuation alert incidents:	
Evacuation alert distance (km)	*
Evac. alert zone around each escaped fire (km**2)	
Fraction of FMAU covered by each alert zone	
Resort evacuation alert zone multiplier	*
Fraction alerted due to each escaped fire	
Number alerted due to each escaped fire	
Average length of an evacuation alert (days)	*
Std. deviation: length of an evac. alert (days)	*
Number of resort evacuation alerts	
Number of resort evacuation alert days	
Number of resort person evacuation alert days	

Resort evacuation incidents:

Evacuation distance (km)	*
Evacuation zone around each escaped fire (km**2)	
Fraction of FMAU covered by each evacuation zone	
Rural residence evacuation zone multiplier	*
Fraction evacuated due to each escaped fire	
Number evacuated due to each escaped fire	
Average length of an evacuation (days)	*
Std. deviation: length of an evacuation (days)	*
Number of resort evacuations	
Number of people evacuated	
Number of resort evacuation days	
Number of resort person evacuation days	
Cost to evacuate a person ($)	*
Total cost to evacuate people ($)	
Cost to accommodate an evacuee ($/day)	*
Total cost to accommodate evacuees ($)	
Total daily revenue lost due to evacuation ($)	
Total salary lost due to evacuation ($)	

RECREATION SITE IMPACTS:

Number of recreation sites	*
Average monetary value of each site	*
Standard deviation: value of each site	*
Average number of guests at each site	*
Standard deviation: guests at each site	*
Average daily revenue per guest	*
Std. deviation: daily revenue per guest	*

Recreation sites burned:

Average recreation site fuel break effectiveness	*
Average fraction of recreation sites burned by escaped fire	
Average fraction of value destroyed by a recreation	*
Number of recreation sites burned in the FMAU	
Value of recreation sites burned in the FMAU	

Recreation site smoke problem incidents:

Maximum depth of the active smoke emission zone (m)	*
Radius of an average escaped fire (m)	
Actual depth of active smoke emission zone (m)	
Area of active smoke emission zone (ha)	
Smoke problem zone area multiplier	*
Area of smoke problem (ha)	
Area of problem smoke (km**2)	
Fraction of FMAU covered by problem smoke	
Recreation site smoke problem multiplier	*
Fraction that experience problems from each esc fire	
Number of recreation sites effected by each escaped fire	
Number of recreation site smoke problem incidents	
Average length of a smoke problem incident (days)	*
Std. deviation: length of a smoke incident (days)	*
Number of recreation site smoke problem days	
Number of smoke problem person days	

Recreation evacuation alert incidents:

Evacuation alert distance (km)	*
Evac. alert zone around each escaped fire (km**2)	
Fraction of FMAU covered by each alert zone	
Recreation site evacuation alert zone multiplier	*
Fraction alerted due to each escaped fire	
Number alerted due to each escaped fire	
Average length of an evacuation alert (days)	*
Std. deviation: length of an evac. alert (days)	*
Number of recreation site evacuation alerts	
Number of recreation site evacuation alert days	

Number of recreation site person evacuation alert days	
Recreation evacuation incidents:	
Evacuation distance (km)	*
Evacuation zone around each escaped fire (km**2)	
Fraction of FMAU covered by each evacuation zone	
Recreation evacuation zone multiplier	*
Fraction evacuated due to each escaped fire	
Number evacuated due to each escaped fire	
Average length of an evacuation (days)	*
Std. deviation: length of an evacuation (days)	*
Number of recreation site evacuations	
Number of people evacuated	
Number of recreation site evacuation days	
Number of recreation site person evacuation days	
Cost to evacuate a person ($)	*
Total cost to evacuate people ($)	
Cost to accommodate an evacuee ($/day)	*
Total cost to accommodate evacuees ($)	
PRECIOUS HERITAGE SITE IMPACTS:	
Number of precious heritage sites in the FMAU	*
Average monetary value of each heritage site ($)	*
Std. deviation: value of each heritage site ($)	*
Average fuel break effectiveness	*
Fraction of sites burned by escaped fires	
Number of precious heritage sites burned	
Monetary value of heritage sites burned ($)	
PRECIOUS HERITAGE AREA IMPACTS:	
Number of precious heritage areas in the FMAU	*
Average heritage area fuel break effectiveness	*
Fraction of heritage areas burned by escaped fires	
Number of precious heritage areas burned	
Average size of a heritage area (ha)	*
Std. deviation: size of each heritage area (ha)	*
Average radius of a heritage area (m)	
Maximum distance fire can burn into an area (m)	*
Actual distance fire burns into an area (m)	
Average fraction of the perimeter burned	*
Average fraction of each area burned	
Avg. monetary value: each heritage area ($/ha)	*
Std. deviation: value of heritage areas ($/ha)	*
Size of precious heritage area burned (ha)	
Monetary value of precious heritage area burned ($)	
PRECIOUS BIOLOGICAL SITE IMPACTS:	
Number of precious biological sites in the FMAU	*
Average monetary value of each biological site ($)	*
Std. deviation: value of each biological site ($)	*
Average fuel break effectiveness	*
Fraction of sites burned by escaped fires	
Number of biological sites burned	
Monetary value of biological sites burned ($)	
PRECIOUS BIOLOGICAL AREA IMPACTS:	
Number of precious biological areas in the FMAU	
Average heritage area fuel break effectiveness	*
Fraction of heritage areas burned by escaped fires	
Number of precious heritage areas burned	

Average size of a heritage area (ha)	*
Std. deviation: size of each heritage area (ha)	
Average radius of a heritage area (m)	
Maximum distance fire can burn into an area (m)	*
Actual distance fire burns into an area (m)	
Average fraction of the perimeter burned	*
Average fraction of each area burned	
Avg. monetary value: each precious biological area ($/ha)	*
Std. deviation: value of precious biological areas ($/ha)	*
Size of precious heritage area burned (ha)	
Monetary value of precious heritage area burned ($)	

INDUSTRIAL FACILITY IMPACTS:

Number of industrial facilities in the FMAU	*
Average number of employees at each facility	*
Standard deviation: employees at each facility	*
Average daily salary per employee ($)	*
Std. deviation: daily salary of an employee ($)	*
Average revenue per day ($)	*
Standard deviation: revenue per day ($)	*
Average number of buildings at each facility	*
Standard deviation: buildings/facility	*
Average monetary value of each building	*
Standard deviation: value of each building	*

Industrial buildings burned:

Average facility fuel break effectiveness	*
Fraction of facilities burned by escaped fires	
Average area of a facility (ha)	*
Average radius of a facility (m)	
Maximum distance fire can burn into a facility (m)	*
Actual distance fire burns into a facility (m)	
Average fraction of facility perimeter burned	*
Average fraction of the area of a facility burned	
Average number of buildings burned at a facility	
Fraction of value lost when a building burns	*
Average value of buildings burned at each facility	
Number of industrial buildings burned in the FMAU	
Value of industrial buildings burned in the FMAU	

Industrial evacuation alert incidents:

Evacuation alert distance (km)	*
Evac. alert zone around each escaped fire (km**2)	
Fraction of FMAU covered by each alert zone	
Industrial facility evacuation alert zone multiplier	*
Fraction alerted due to each escaped fire	
Number alerted due to each escaped fire	
Average length of an evacuation alert (days)	*
Std. deviation: length of an evac. alert (days)	*
Number of industrial facility evacuation alerts	
Number of industrial facility evacuation alert days	
Number of industrial person evacuation alert days	

Industrial evacuation incidents:

Evacuation distance (km)	*
Evacuation zone around each escaped fire (km**2)	
Fraction of FMAU covered by each evacuation zone	
Industrial facility evacuation zone multiplier	*
Fraction evacuated due to each escaped fire	
Number evacuated due to each escaped fire	
Average length of an evacuation (days)	*
Std. deviation: length of an evacuation (days)	*
Number of industrial facility evacuations	
Number of people evacuated	
Number of industrial facility evacuation days	
Number of industrial person evacuation days	

Cost to evacuate a person ($) *
Total cost to evacuate people ($)
Cost to accommodate an evacuee ($/day) *
Total cost to accommodate evacuees ($)
Total daily revenue lost due to evacuation ($)
Total salary lost due to evacuation ($)

TIMBER PRODUCTION:

Cover type number *
Cover type name *
Fraction of the FMAU burned area that is in this cover type *
Size of the cover type (ha) *
Fraction of the area burned each year *
Harvest volume with no fire (m**3/year) *
Harvest volume with fire (m**3/year) *
% reduction due to fire
Harvest value with no fire ($/year) *
Harvest value with fire ($/year) *
% reduction due to fire

Cover type number *
Cover type name *
Fraction of the FMAU burned area that is in this cover type *
Size of the cover type (ha) *
Fraction of the area burned each year *
Harvest volume with no fire (m**3/year) *
Harvest volume with fire (m**3/year) *
% reduction due to fire
Harvest value with no fire ($/year) *
Harvest value with fire ($/year) *
% reduction due to fire

Cover type number *
Cover type name *
Fraction of the FMAU burned area that is in this cover type *
Size of the cover type (ha) *
Fraction of the area burned each year *
Harvest volume with no fire (m**3/year) *
Harvest volume with fire (m**3/year) *
% reduction due to fire
Harvest value with no fire ($/year) *
Harvest value with fire ($/year) *
% reduction due to fire

Cover type number *
Cover type name *
Fraction of the FMAU burned area that is in this cover type *
Size of the cover type (ha) *
Fraction of the area burned each year *
Harvest volume with no fire (m**3/year) *
Harvest volume with fire (m**3/year) *
% reduction due to fire
Harvest value with no fire ($/year) *
Harvest value with fire ($/year) *
% reduction due to fire