WINDTHROW ECONOMICS AT THE FOREST LEVEL IN THE CANTERBURY REGION, NEW ZEALAND

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We manage natural systems that are inherently unstable and unpredictable,
yet seek to impose on them something they cannot be.

— Mike Dombrek
Chief, US Forest Service
8 April, 1997

ABSTRACT. -- The problems of forest estate valuation and harvest scheduling under risk of occurrence of catastrophic events were examined. An optimization and simulation model were used sequentially to test the robustness of management strategies. The optimization model provides an optimal harvest pattern under deterministic conditions. The simulation model modifies the optimal harvest pattern according to a function of random risk assessing the robustness of the strategy through net present value (NPV). A large number of runs provides estimates of mean, standard deviation and a frequency distribution for NPV.

The model is demonstrated using data from a plantation forest estate of 8 412 ha located in Canterbury, New Zealand which has been subject to periodic catastrophic windthrow.

Findings were that incorporating wind risk reduced the NPV after taxes of the Canterbury forest estate by 11 percent on average, compared with a deterministic solution. Estate value was not highly sensitive to moderate changes in windthrow frequency. The results of the stochastic simulation were not greatly different than an optimised solution under risk, sub-optimising by no more than 3 percent.

Forestry is important to New Zealand currently accounting for 6.9 percent of New Zealand's GDP (New Zealand Forest Owners' Association, 1996). Plantation forests account for 99.3 percent of the roundwood removals in New Zealand (Ministry of Forestry, 1996). Harvests are currently at 17.2 million m^3 (Ministry of Forestry, 1996) and are projected to increase to 25 million m^3 by the year 2010[2] (New Zealand Forest Owners' Association, 1996). Risks affecting the plantations affect the entire forest industry.

Wind is the most important risk factor affecting New Zealand's plantations. Wind damage is far more important than fire which accounts for only a small proportion of the total annual damage in New Zealand' plantations (Somerville, 1989). Windthrow, in contrast, has accounted for at least 50 000 ha of catastrophic damage to stands over five years-old since the turn of the century (Somerville, 1995).

The nature of the impact of wind on the plantations varies by region within New Zealand. While windthrow and stem breakage have occurred over a high proportion of New Zealand, wind damage has been more accentuated in the Wellington, Canterbury, North Auckland, and Manawatu regions. Of these, Canterbury has suffered the most serious damage due to catastrophic loss (Sommerville, 1989).

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2 This forecast is conservative since it assumes no new planting. If an additional 50 000 ha/year are planted, then the predicted annual harvest will increase to about 30 million m^3. New land is currently being planted at a rate of about 74 000 ha/year (Ministry of Forestry, 1996, p.1).

New Zealand lies within a belt of westerly winds circling the globe (Wards, 1976). The most damaging winds in Canterbury come from the northwest. These are warm, dry (föhn) winds which, reinforced by the blocking effect of the Southern Alps, reach gale speeds (New Zealand Meteorological Service, 1986). In August 1975, a 170 km/hr gust contributed to the blowdown of 6000 ha. Northwest gales, often preceded by heavy rain, have caused damage in Canterbury in 1914, 1930, 1945, 1956, and 1975. In addition in 1968, a tropical cyclone producing strong south-westerly winds, resulted in 1000 ha of windthrow (Thompson, 1976).

Such storms can flatten forests and cause large management and logistical problems. Due to a lack of suitable infrastructure, the timber blown down in the 1945 storm was only partially recovered. The timber blown down in 1975 resulted in special marketing strategies to export to Japan and China. In addition, domestic sawlogs and poles were stockpiled under sprinklers for over two years (Turner, 1989).

To give some idea of the magnitude of the problem, one local company reported that since the turn of the century, 90 percent of all timber harvested in the Canterbury plains has been following windthrow (Studholme, 1995). The impact of a major storm can be illustrated by examining the age class distribution of that company's estate in the early morning and then in the afternoon of August 1, 1975 (Fig. 1).

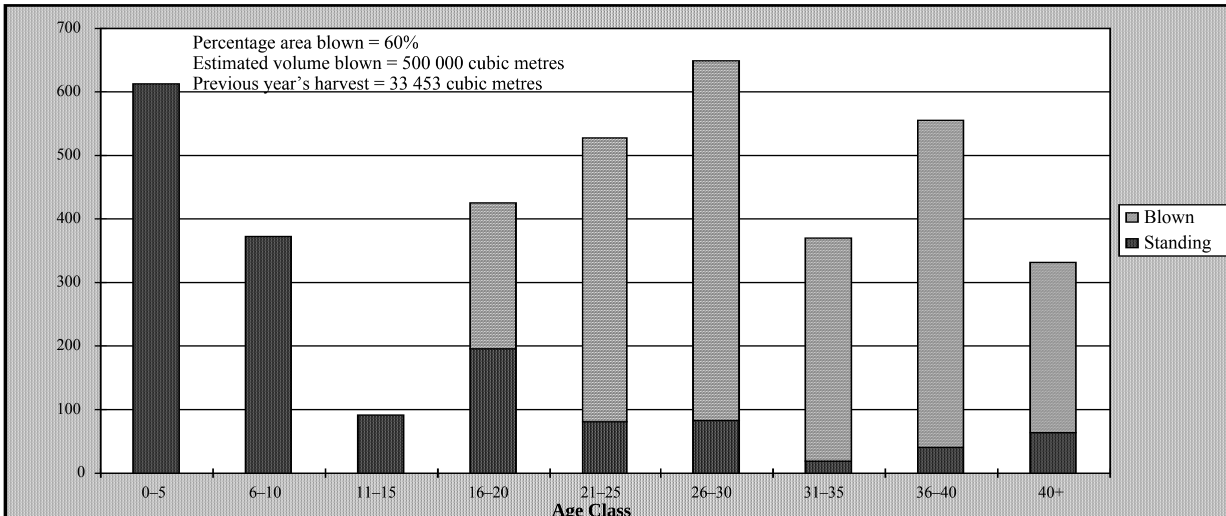

Figure 1. Selwyn Plantation Board forest estate on August 1, 1975

Source: Selwyn Plantation Board Limited, Unpublished Data.

Note that stands under 15 years-old were not windblown and that generally the proportion of forest being windblown increases by age class. Stands 30 years and older were almost completely windblown. Wendelken (1966) reported scarce damage to plantations younger than 18 years after a 1964 storm in New Zealand. Similar trends have also been observed in the UK (Miller and Quine, 1991).

Current models planning the evolution of forest estates usually address risk in a deterministic fashion (Somerville 1995). Risk is recognised through a constant average annual reduction in net stocked volume. Therefore each year the forest area is reduced by a constant attritional factor representing the forest area which is partially or completely affected over the long term. Reed and Errico (1986) used this approach when dealing with fire risk in Canada. New (1989) reports that a 0.6 percent loss per annum due to wind has been used to account for windthrow in a New Zealand growth model. Sommerville (1995, p.463) notes:

> "With the exception of Canterbury, the regional average losses as catastrophic damage are quite similar at 0.20-0.26 percent of net stocked area lost per annum. Canterbury, however, has been subjected to very high levels of catastrophic damage."

Generalisations may be appropriate over the entire country, or over a long enough time period, or where wind losses are endemic, affecting a constantly small, predictable portion of the forest each year. However, such generalisations are not adequate in all regions. Nor are they adequate to assess the impact of major catastrophic events on the financial or operational position of an organisation over time. Because windthrow can result in large sudden economic losses, and disrupt woodflows and harvest scheduling, tools are required which can aid decision makers in understanding and managing such risks.

This paper examines the harvest scheduling problem at the forest estate level by including random risk, and compares the results with a deterministic solution in a case study.

MODELING METHODOLOGY

The methodology is divided in two parts: estate modelling and stochastic modelling. Estate modelling refers to the development of a mathematical model able to represent a forest estate over time. The stochastic component refers to a probability distribution function able to randomly represent the windthrow occurrence. Both components are integrated in order to achieve the research objectives. The system is shown (Fig. 2).

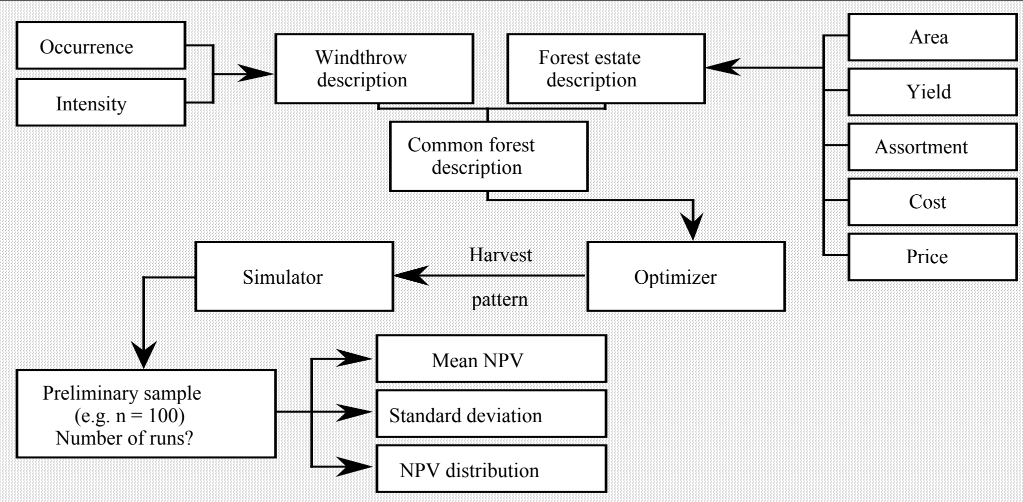

Figure 2. Description of a proposed system to address catastrophic risk at the forest level

The models are compatible and use a common forest description. This description has two components: a forest estate description (areas by age class within croptypes, yield and log assortment, costs, prices and some financial parameters); and a probability distribution function regarding windthrow damage (occurrence and intensity).

Forest Estate Modelling

The forest description is used in a linear programming model in order to find an optimal solution, maximising NPV. Standard constraints relating to conservation of area, as well as volume constraints and ending inventory constraints ensure that the resulting solution is believable. However, the LP model is deterministic. That is, it does not incorporate the random element of risk of a major wind storm.

Stochastic modelling

The simulation model reshapes the solution from the optimiser according to “proportional rates” regarding the distribution of storm damage. That is, if a random storm occurs in simulation, we assume stands will be damaged according to their age and in the same proportions that Selwyn Plantation Board’s age classes were damaged in 1975.

We used historical data from Canterbury to create a probability distribution function representing the damage caused by windthrow at the forest level. The function describes frequency of occurrence and intensity of windthrow over time. The development of this function was based on the approaches followed by Reed and Errico (1986) in Canada and Manley and Wakelin (1989) in New Zealand.

Occurrence is the time interval between two successive catastrophic windthrow events. This time span is obviously not a constant behaving as a random variable. However, we assume an average return period in order to represent the phenomenon in the long term.

Data recording gust speeds for New Zealand extends back only to 1919. Therefore, we cannot statistically estimate an average return period for major wind events. Selwyn Plantation Board Limited, a major forest owner in Canterbury, uses a 28 year return period for its silvicultural planning (Studholme, 1996. Pers. comm.), so we chose this for an average return period of major storms, testing it later in a sensitivity analysis.

Buongiorno and Gilles (1987) proposed an exponential probability distribution function to represent the occurrence of catastrophic events which have the same chance of occurring, regardless of when the previous event happened. If T is the time interval between two wind storms, and m is the mean rate of catastrophic wind storms, then the probability p of having a storm during a time period t is:

$$P(T \leq t) = 1 - \exp(-mt) \tag{1}$$

The function is used to generate random time intervals between two successive catastrophic events which, after a large number of observations, are equal to the average return period. This is accomplished by adding a random number, R, and rearranging (1) to solve for the time period:[3]

$$t = -ln\frac{(1-R)}{m} \tag{2}$$

In any given year, the probability of a major wind storm is a small constant. However, as the time span to be considered increases, the probability of a major wind storm occurring during that time span also increases. This relationship may be seen (Fig. 2):

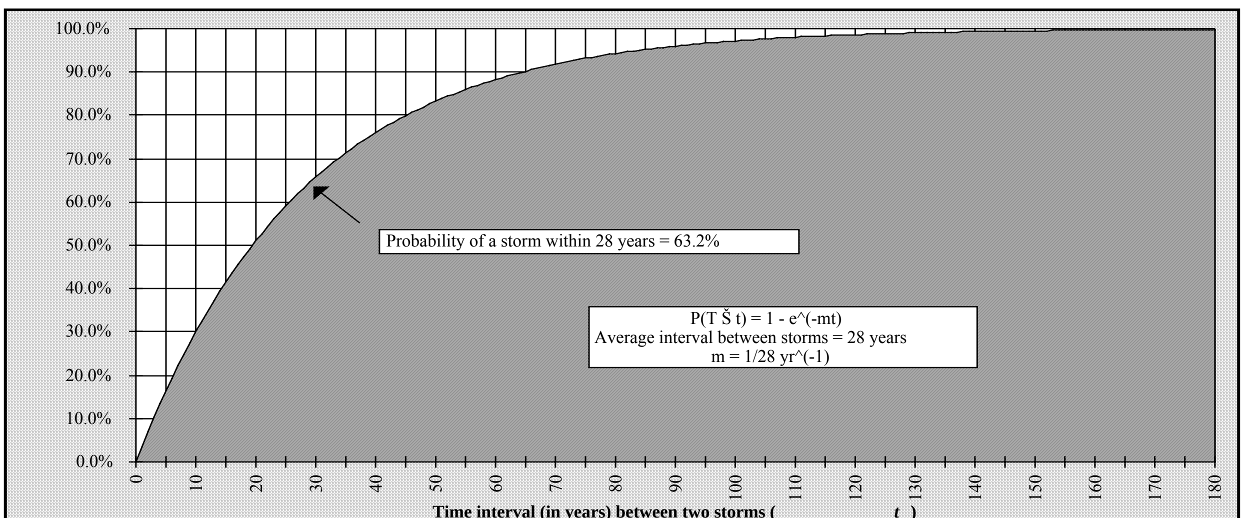

Figure 2. Probability of having a storm within *t* years, given an average storm incidence of once every 28 years

Function (2) is used as many times as necessary over the planning horizon in order to provide a frequency distribution for the desired planning variable. For this analysis, we chose net present value as the planning variable. As a result we can foresee not only the expected value of the decision criterion but also the likelihood of realising a much higher or a much lower value. If the calculated NPV_i's are normally distributed or symmetrical about the mean, then a ***t***-distribution may be used to approximate the distribution (Gottfried, 1984).

3 See Buongiorno and Gilles (1987) pp.216-217 for full details.

$$\text{Number of observations required} \qquad n = \left(\frac{t * s}{x * \overline{Y}}\right)^2 + 1$$

Determining the number of random events required for the desired confidence level is a two-step process. First a trial is run with 100 simulations and its mean and standard deviation are calculated. Then, based on these statistics the desired confidence interval for the mean and the number of simulations required to achieve this may be estimated based on the t-distribution (Gottfried, 1984).

where:

t	=	the t-statistic based on the desired confidence level
s	=	the calculated standard deviation for the NPV in the trial run
x	=	desired percentage range for the mean (e.g. 0.01 is ± 1 percent)
$\overline{Y}$	=	the calculated mean for the NPV in the trial run

While our distribution is not symmetrical about the mean, we took the results of this formula and arbitrarily doubled the number of simulations to ensure we had an adequate number of runs.

CASE STUDY

We ran the model using a data for a portion (8412 ha) of the forest estate owned by Selwyn Plantation Board Limited (SPBL). SPBL is a local authority trading enterprise, essentially a limited liability company owned by local government organisations. SPBL's estate is mostly *Pinus radiata D.Don* (radiata pine) planted largely in the Canterbury Plains.

We made several assumptions to simplify the study:[4]

- all simulations were over a 50-year planning horizon;
- time was aggregated into 5-year-periods in order to reduce the number of decision variables and because the model assumes that the period of recovery is the same as the aggregation of time;
- no price penalty was assumed for timber blown down and harvested in relation to unblown harvested timber.
- twenty percent of the timber volume was assumed to be lost due to windthrow;
- we only attempted to model Spell's radiata pine. This species makes up 90 percent of Spell's estate.
- costing was kept constant.

We used volume and regulation constraints in optimising the harvesting scheduling problem. We constrained volume so that from one period to the next, it did not vary more than 10 percent. We set up regulation constraints to achieve at least 1500 ha in each of the first four age classes at the end of the planning horizon. The optimised solution produced a NPV after taxes of $43.208 million. However, this value does not include windthrow risk.

We used preliminary sample of 100 runs to estimate that approximately 550 runs were required to return a 95 percent confidence interval. We arbitrarily doubled this to ensure that we achieved an adequate confidence level. The average NPV after taxes under stochastic conditions was $38.278 million, an average reduction of 11 percent over the deterministic case. The minimum value was $24.152 million and the maximum was $43.301 million.

The frequency distribution of these stochastic NPVs by $2 million classes is shown (Fig. 3). This does not follow a normal distribution. The overall trend is increasing in relative frequency (probability) from left to right which means that there are better chances in getting NPVs closer to the stochastic maximum than to the stochastic minimum.

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[4] These costing, price, and timber recovery assumptions were based on personal communications with staff from Selwyn Plantation Board Limited.

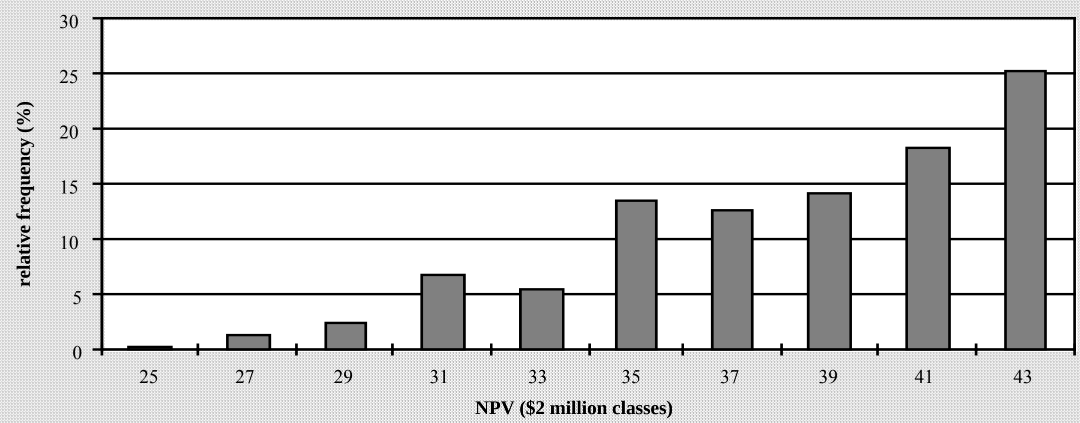

Figure 3. NPV distribution for Selwyn Plantation Board Limited under windthrow risk

The lowest NPVs relate to cases in which there are frequent windthrows early in the planning horizon. In the case where no windthrow takes place, the stochastic solution is identical to the deterministic solution. Curiously, there are cases where the stochastic NPV is higher than the deterministic NPV. This is due to the regulation constraints in the optimization and to the way NPV is calculated in the objective function. Cash flows only are included in the formulation and the residual forest area is not valued. There are simulation runs in which the only windthrow occurs late in the planning horizon. These cases allow more fallen timber to be recovered in the final periods than would be allowed under deterministic conditions.

SENSITIVITY ANALYSIS

We ran sensitivity analyses on the significant variables in the analysis, that is establishment costs, prices, recovery assumptions, and return period for the wind storms. Changes in NPV due to changes in the first three variables are shown (Table 1).

Table 1. Decrease in NPV due to a one percent change in selected variables

Variable	Percentage decrease in NPV
Establishment cost increases	0.22%
Log price decreases	0.40%
Recovery factor decreases	0.50%

We also analysed the sensitivity of the solution in relation to the return period. We varied the average return period by five years and by ten years. Varying the return period by five years had little impact on NPV. NPV decreased by 1.8 percent given a 23 year return period and increased by 1.7 percent given a 28 year return period. Varying the return period by ten years had more of an impact. NPV decreased by 4.6 percent given an 18 year return period and increased by 3.0 percent given a 38 year return period.

COMPARISON BETWEEN SIMULATION AND OPTIMIZATION

While simulations are useful to illustrate the risk associated with forestry, they do not produce an optimal solution. In order to test the degree of sub-optimality, the sub-optimal solution provided by the simulator was compared with a re-optimised solution following simulated windthrows in two selected runs. Both had only one windthrow in the planning horizon. In the first run, the windthrow occurred early. In the second, the windthrow happened more towards the middle of the planning period. There was very little difference in the resulting net present values.

Table 2. Difference in NPV between a sub-optimal simulation and an optimization in two selected stochastic runs

Year of windthrow	Simulation ($ million)	Optimization ($ million)	Percent difference
2	$30.322	$31.009	2.2
18	$38.627	$38.639	0.003

Where windthrow occurs early, the difference between the two methodologies is greater. However, even if the windthrow occurs early, the difference between the simulation results and re-optimised results is small.

DISCUSSION

This study demonstrated a methodology for examining the wind risk associated with a forest estate. It is a relatively simple combination of models. A model able to re-optimise between windthrow events would be more accurate than the model proposed here. However, such a problem becomes more complex and takes much longer to solve. We do not feel that the added complexity is justified by the added accuracy.

There were not large differences between the NPV produced by optimization and the average NPV produced by simulation incorporating windthrow risk. Part of the reason for this is the assumptions regarding recovery and the length of time over which fallen trees may be recovered. Canterbury has relatively high recovery rates and blown over trees remain harvestable for a relatively long time. Silviculture in Canterbury has been adapted to accommodate the northwest winds.[5] Trees are planted and roading designed with the expectation that the trees will be blown over during the rotation. There is no deep ripping and no high pruning in the plains because when the wind does come, it is preferable that the trees blow over, rather than snap off. If they blow over and take a root plate with them, they can stay alive for up to five years.

Although there were not large differences between the deterministic and average stochastic NPVs, that does not mean that the simulation is a waste of time. The simulations do provide decision makers with an idea of the range of NPVs which might be achieved and also provide a quantification of the degree of risk which the enterprise is bearing. Simulation can be used to give an idea of the magnitude of the events.

The simulations can also provide decision makers with an idea of the importance of various factors in the profitability of their operation following windthrow. For example, in these runs we found that while NPV was not very sensitive to the average return period of the wind, NPV was highly sensitive to the recovery factor and to establishment costs. Two ways to increase NPV would be to improve the recovery factor by finding suitable use for broken trees (chips, poles, pulplogs, small sawlogs, etc), or to adopt new establishment techniques aimed to reduce costs.

This is a first step in modelling wind risk at the estate level. The modeling system could be modified and improved. Additional species could be incorporated along with their relative susceptibility to wind. Trees which have just been thinned tend to be very susceptible to wind for a few years until they become windfirm. Impacts of defects later appearing in trees which were not blown over could be incorporated. Further study of the conditions under which trees blow down could lead to more accurate predictive models of which stands will blow down and under what conditions. The goal of this model and any future improvements is to provide managers and investors with tools which can help them to better understand and manage the risks they take in forestry.

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5 See Studholme (1995) for a detailed description of the silviculture adopted.

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