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 Dombeck
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 uses data from a plantation forest estate of 8,412 ha located in Canterbury, New Zealand that has been subject to periodic catastrophic windthrow. 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 similar to those in an optimized solution under risk, suboptimizing by no more than 3 percent.

INTRODUCTION

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 cubic meters (m^3) (Ministry of Forestry 1996) and are projected to increase to 25 million m^3 by the year 2010 (New Zealand Forest Owners' Association 1996).[2] 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's 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 within New Zealand varies by region. While windthrow and stem breakage have occurred over a high proportion of the country, wind damage has been more accentuated in the

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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).

Wellington, Canterbury, North Auckland, and Manawatu regions. Of these, Canterbury has suffered the most serious damage due to catastrophic loss (Sommerville 1989).

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 6,000 ha. Northwest gales, often preceded by heavy rain, have caused damage in Canterbury in 1914, 1930, 1945, 1956, and 1975. In 1968, a tropical cyclone producing strong southwesterly winds resulted in 1,000 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).

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 events (Studholme 1995). An examination of the age class distribution of a company's estate in the early morning and then in the afternoon of August 1, 1975 illustrates the impact of a major storm (Fig. 1).

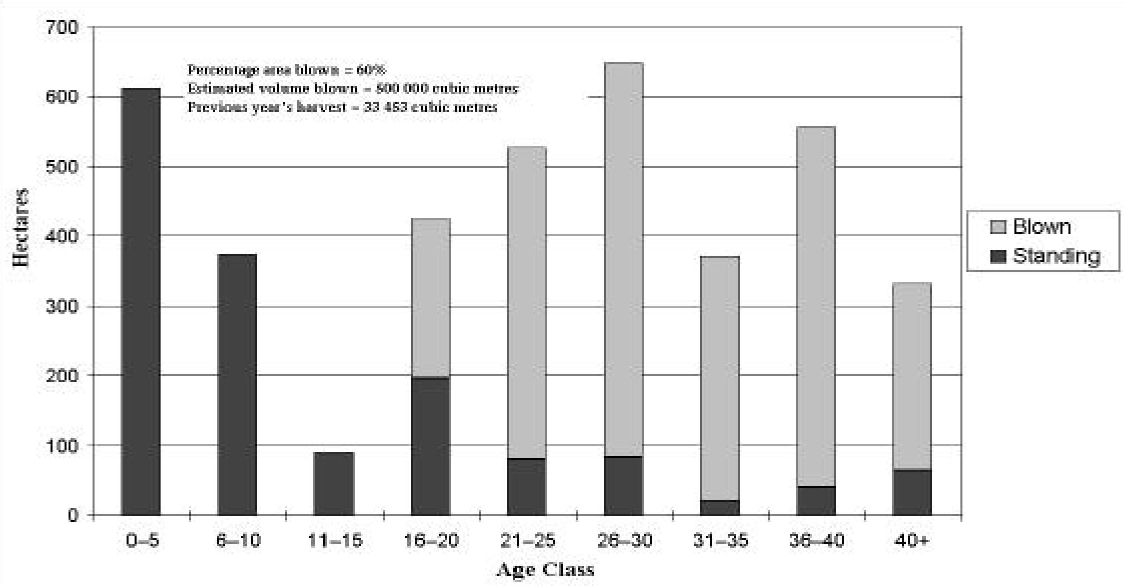

Figure 1. Selwyn Plantation Board forest estate on August 1, 1975

Source: Selwyn Plantation Board Limited, Unpublished Data.

Note that stands under 15 years old were not windblown, but that stands 30 years and older were almost completely windblown. The proportion of forest being windblown generally increases by age class. 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 recognized 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 that 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.

Generalizations may be appropriate either 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 generalizations are not adequate in all regions. Nor are they adequate to assess the impact of major catastrophic events on an organization's financial or operational position over time. Because windthrow can result in sudden large economic losses and disrupt wood flows and harvest scheduling, tools are required that 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 modeling and stochastic modeling. Estate modeling 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 in figure 2.

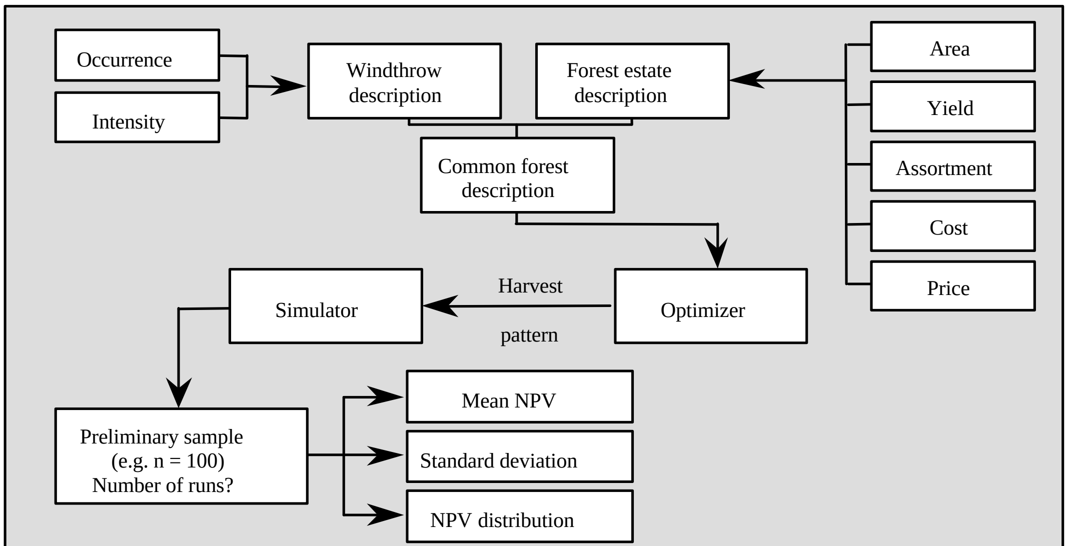

Figure 2.— Description of a proposed system to address catastrophic risk at the forest level

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

Forest Estate Modeling

We used the forest description in a linear programming (LP) model in order to find an optimal solution, maximizing net present value (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 risk element of a major windstorm.

Stochastic Modeling

The simulation model reshapes the solution from the optimizer 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 age classes of Selwyn Plantation Board Limited (SPBL) 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. We developed this function 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. SPBL, 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 Gilless (1987) proposed an exponential probability distribution function to represent the occurrence of catastrophic events that 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:

$$P(T^2\ t) = 1 - \exp(-mt) \tag{1}$$

We used this function to generate random time intervals between two successive catastrophic events that, 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 windstorm is a small constant. However, as the time span to be considered increases, the probability of a major windstorm occurring during that time span also increases. This relationship may be seen in figure 3:

[3] See Buongiorno and Gilless (1987) pp. 216–17 for full details.

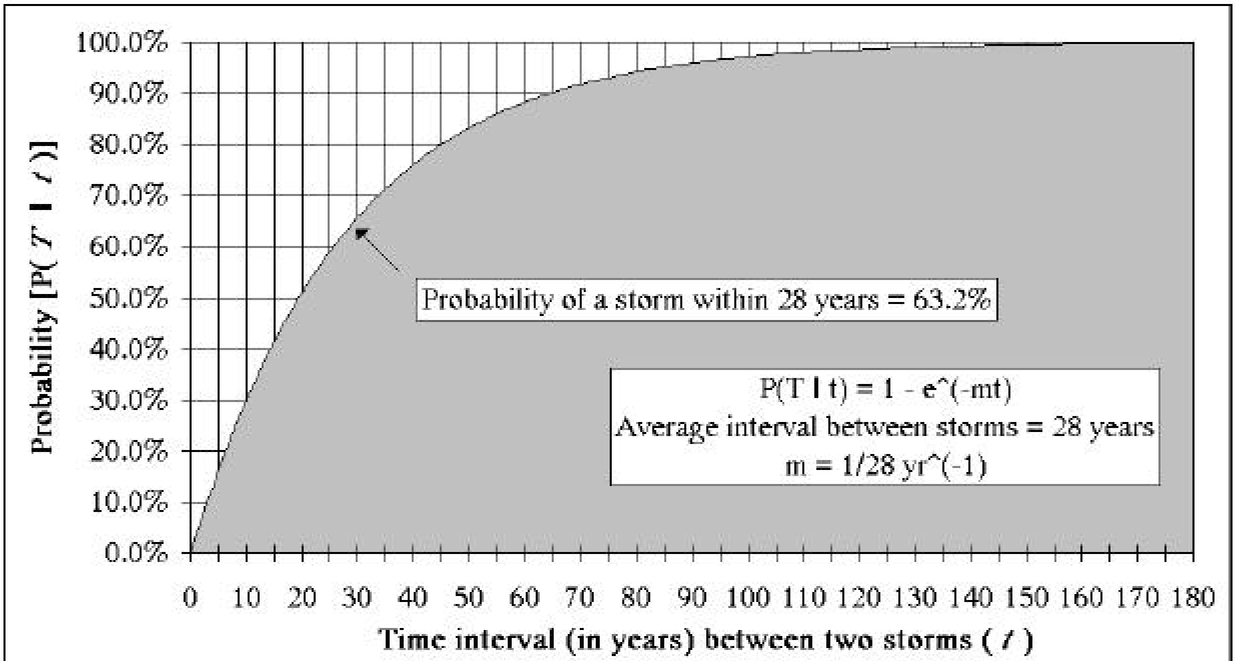

Figure 3. Probability of having a storm within t years, given an average storm incidence of once every 28 years

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 NPV as the planning variable. As a result we can foresee not only the expected value of the decision criterion but also the likelihood of realizing a much higher or a much lower value. If the calculated NPV's are normally distributed or symmetrical about the mean, then a t-distribution may be used to approximate the distribution (Gottfried 1984).

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).

Number of observations required $$n = \left(\frac{t * s}{x * \bar{Y}}\right)^2 + 1 \quad (3)$$

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)
$\bar{Y}$	=	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 data for a portion (8,412 ha) of the forest estate owned by SPBL. SPBL is a local authority trading enterprise, which is essentially a limited liability company owned by local government organizations. 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:

- 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;
- There is no price penalty 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 SPBL's radiata pine. This species makes up 90 percent of SPBL's estate.
- Costing was kept constant.[4]

We used volume and regulation constraints in optimizing 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 1,500 ha in each of the first four age classes at the end of the planning horizon. The optimized 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 in figure 4. 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.

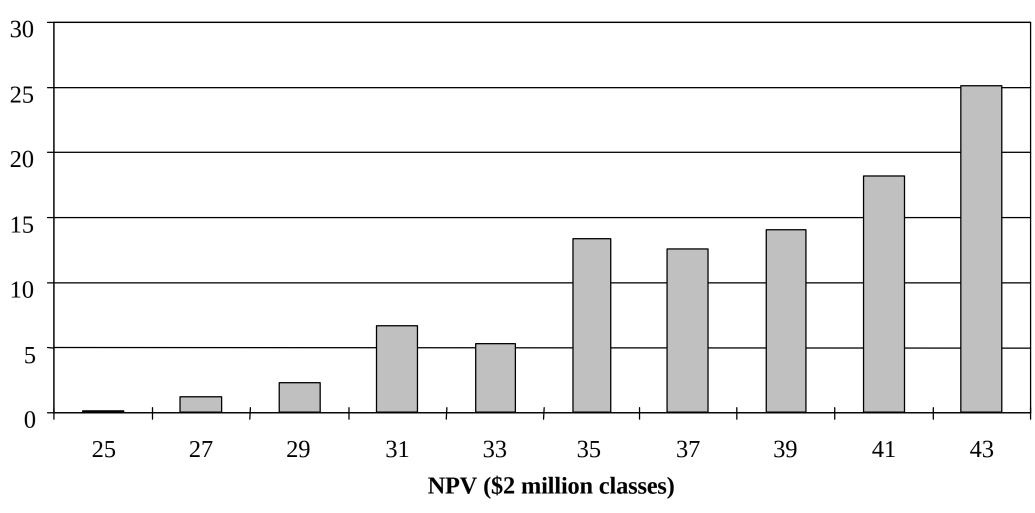

Figure 4. —NPV distribution for Selwyn Plantation Board Limited under windthrow risk

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

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 we have calculated NPV in the objective function. We have included only cash flows in the formulation and a value for the residual forest area. 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 windstorms. Changes in NPV due to changes in the first three variables are shown in 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 analyzed the sensitivity of the solution in relation to the return period. We varied the average return period by 5 years and by 10 years. Varying the return period by 5 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 10 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 suboptimality, we compared the suboptimal solution provided by the simulator with a reoptimised 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	Optimization	Percent difference
	- - - - - - - - - - -*million dollars*- - - - - - - - - -		
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 reoptimized 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 reoptimize 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 is 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.

There were not large differences between the deterministic and average stochastic NPVs, but this does not mean that the simulation is a waste of time. The simulations do provide decision-makers with an idea of the range of achievable NPVs and also provide a quantification of the degree of risk that 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 operations following windthrow. For example, in these runs we found that while NPV was not very sensitive to the average return period of the wind, it 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 modeling 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. Models could consider tree thinning since trees that 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 that were not blown over could be incorporated. Further study of the conditions under which trees are blown 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 that 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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