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PROFESOR RESPONSABLE	:	HORACIO BOWN
E-MAIL	:	hbown@uchile.cl
Fono	:	978 5872

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Windthrow Economics at the Forest Level in the Canterbury Region, New Zealand

H. Bown and E.M. Bilek

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Windthrow Economics - Introduction

1. Risks affecting plantations affect the entire forest industry.
2. Wind is the most important risk factor affecting New Zealand's plantations.
3. Wind damage is far more important than fire in New Zealand
4. 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).
5. The nature of the impact of wind on the plantations varies by region within New Zealand.
6. Canterbury has suffered the most serious windthrow damage

Windthrow Economics - Introduction

1. In August 1975, a 170 km/hr gust blew down 6000 ha.

2. Northwest gales, often preceded by heavy rain, have caused damage in Canterbury in 1914, 1930, 1945, 1956, and 1975.

3. Also in 1968, a tropical cyclone brought about strong south-westerly winds, resulting in 1000 ha windblown.

4. Such storms can flatten forests and cause large management and logistical problems.

5. For instance, due to a lack of suitable infrastructure, the timber blown down in the 1945 storm was only partially recovered.

Windthrow Economics - Introduction

1. The timber blown down in 1975 resulted in high volumes being exported to Japan and China.

2. In addition, domestic sawlogs and poles were stockpiled under sprinklers for over two years.

3. To give some idea of the magnitude of the problem, one local company reported that since the turn of the century, 90 % of all timber harvested in the Canterbury plains was a consequence of windthrow.

4. 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).

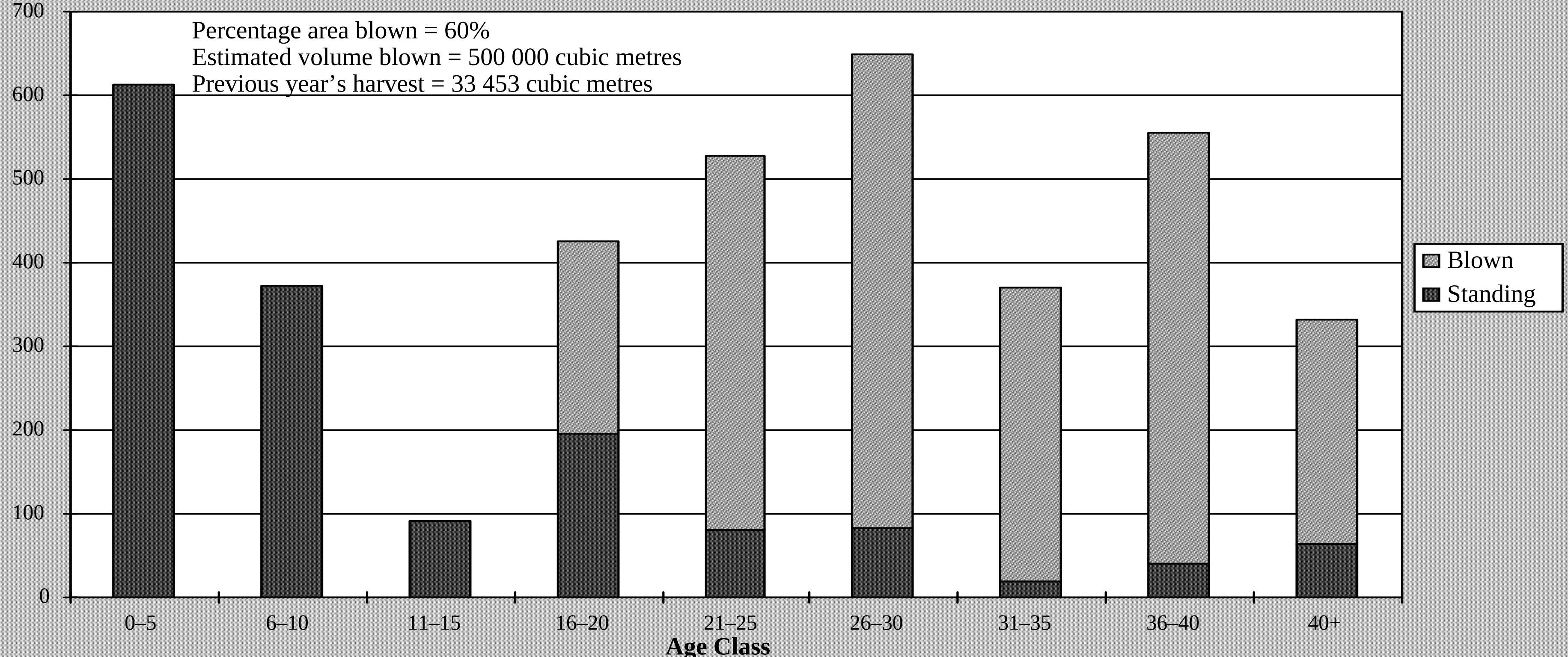


Figure 1. Selwyn Plantation Board forest estate on August 1, 1975

Source: Selwyn Plantation Board Limited, Unpublished Data.

Chance of windthrow occurrence as a function of age class.
Source: ***Selwyn Plantation Board Ltd***.

Age class number	*Age class*	*chance of occurrence*
1	0-5	0
2	6-10	0
3	11-15	0
4	16-20	.53
5	21-25	.85
6	26-30	.87
7	31-35	.95
8	36-40	.93
9	40+	.80

Windthrow Economics - Introduction

1. Note that stands under 15 years-old were not windblown and that generally the proportion of forest being windblown increases by age class.

2. Stands 30 years and older were almost completely windblown.

3. Wendelken (1966) reported scarce damage to plantations younger than 18 years after a 1964 storm in New Zealand.

4. Similar trends have also been observed in the UK (Miller and Quine, 1991).

Windthrow Economics - Introduction

1. Current models planning the evolution of forest estates usually address risk in a deterministic fashion (Somerville 1995).

2. Risk is recognized through a constant average annual reduction in net stocked volume or area, which is partially or completely affected

3. Reed and Errico (1986) used this approach when dealing with fire risk in Canada.

4. 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.

Windthrow Economics - Introduction

1. Windthrow can result in large sudden economic losses
2. That disrupt woodflows and harvest scheduling
3. Therefore tools are required which can aid decision makers in understanding and managing such risks.
4. 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.

Windthrow Economics - Methods

1. The methodology is divided in two parts: estate modelling and stochastic modelling.

2. Estate modelling refers to the development of a mathematical model able to represent a forest estate over time.

3. The stochastic component refers to a probability distribution function able to randomly represent the windthrow occurrence.

4. Both components are integrated in order to achieve the research objectives.

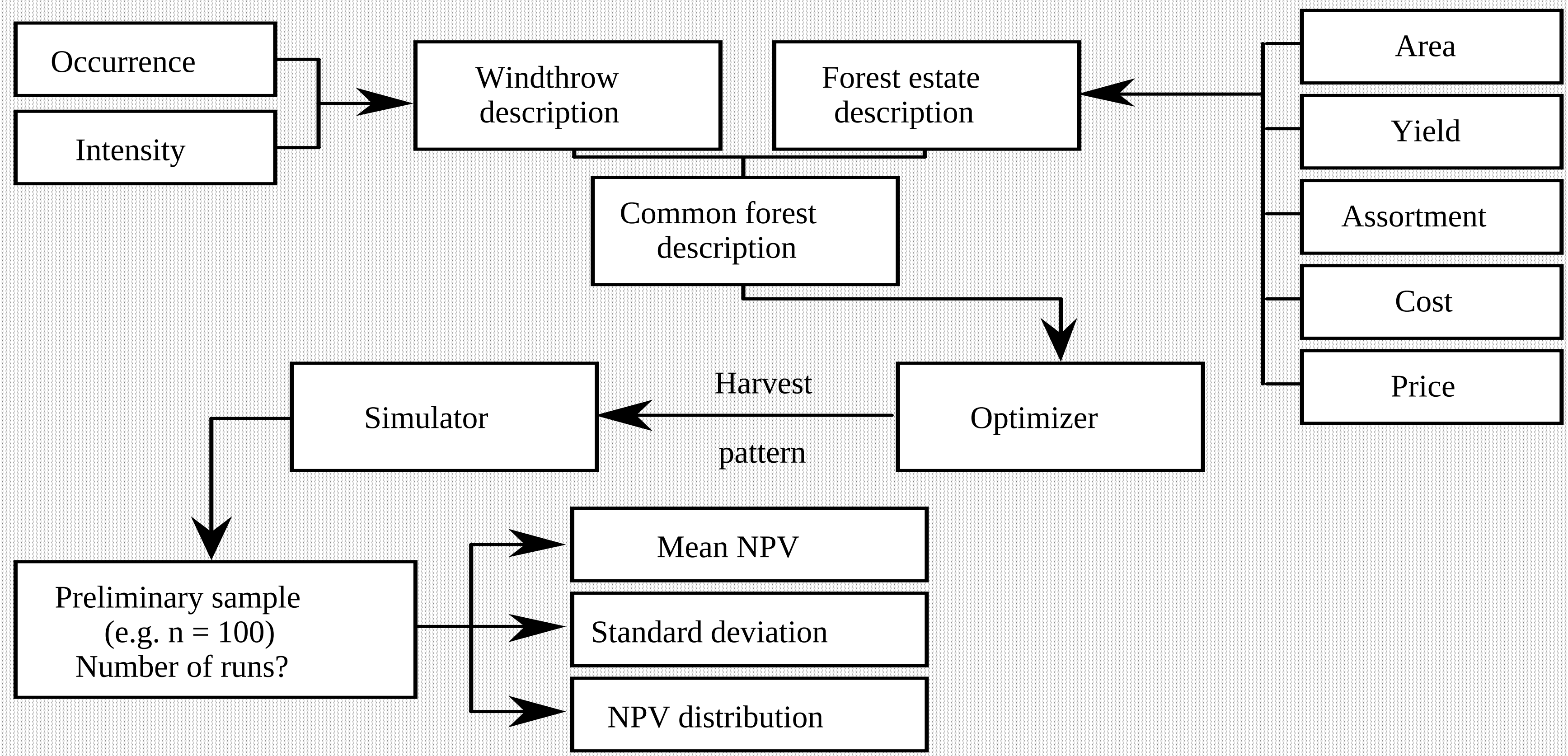


Figure 2. Description of a proposed system to address catastrophic risk at the forest level

Windthrow Economics - Methods

1. The models are compatible and use a common forest description.

2. This description has two components:

    a. a forest estate description (areas by age class within croptypes, yield and log assortment, costs, prices and some financial parameters); and a

    b. probability distribution function regarding windthrow damage (occurrence and intensity).

Windthrow Economics - Forest Estate Modelling

1. The forest description is used in a linear programming model in order to find an optimal solution, maximising NPV.

2. Standard constraints: conservation of area, non-declining yield, and ending inventory constraints, ensuring that the resulting solution is believable.

3. However, the LP model is deterministic.

4. That is, it does not incorporate the random element of risk of a major wind storm.

Windthrow Economics - Stochastic Modelling

1. The simulation model reshapes the solution from the optimiser according to "proportional rates" regarding the distribution of storm damage.

2. 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.

3. We used historical data from Canterbury to create a probability distribution function representing the damage caused by windthrow at the forest level.

4. The function describes frequency of occurrence and intensity of windthrow over time.

Windthrow Economics - Stochastic Modelling

1. Occurrence is the time interval between two successive catastrophic windthrow events.

2. This time span is obviously not a constant behaving as a random variable.

3. Data recording gust speeds for New Zealand extends back only to 1919 (Canterbury gusts 1914, 1930, 1945, 1956, and 1975)

4. Selwyn Plantation Board Limited, a major forest owner in Canterbury, uses a 28 year return period for its silvicultural planning (Studholme, 1996. Pers. comm.),

5. so we chose this for an average return period of major storms, testing it later in a sensitivity analysis.

Windthrow Economics - Stochastic Modelling

1. 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.

2. 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:

$$P(0 \le t \le T) = 1 - \exp(-m\, T)$$

$$P(0 \le t \le T) = 1 - \exp(-0.0357\ T)$$

3. 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.

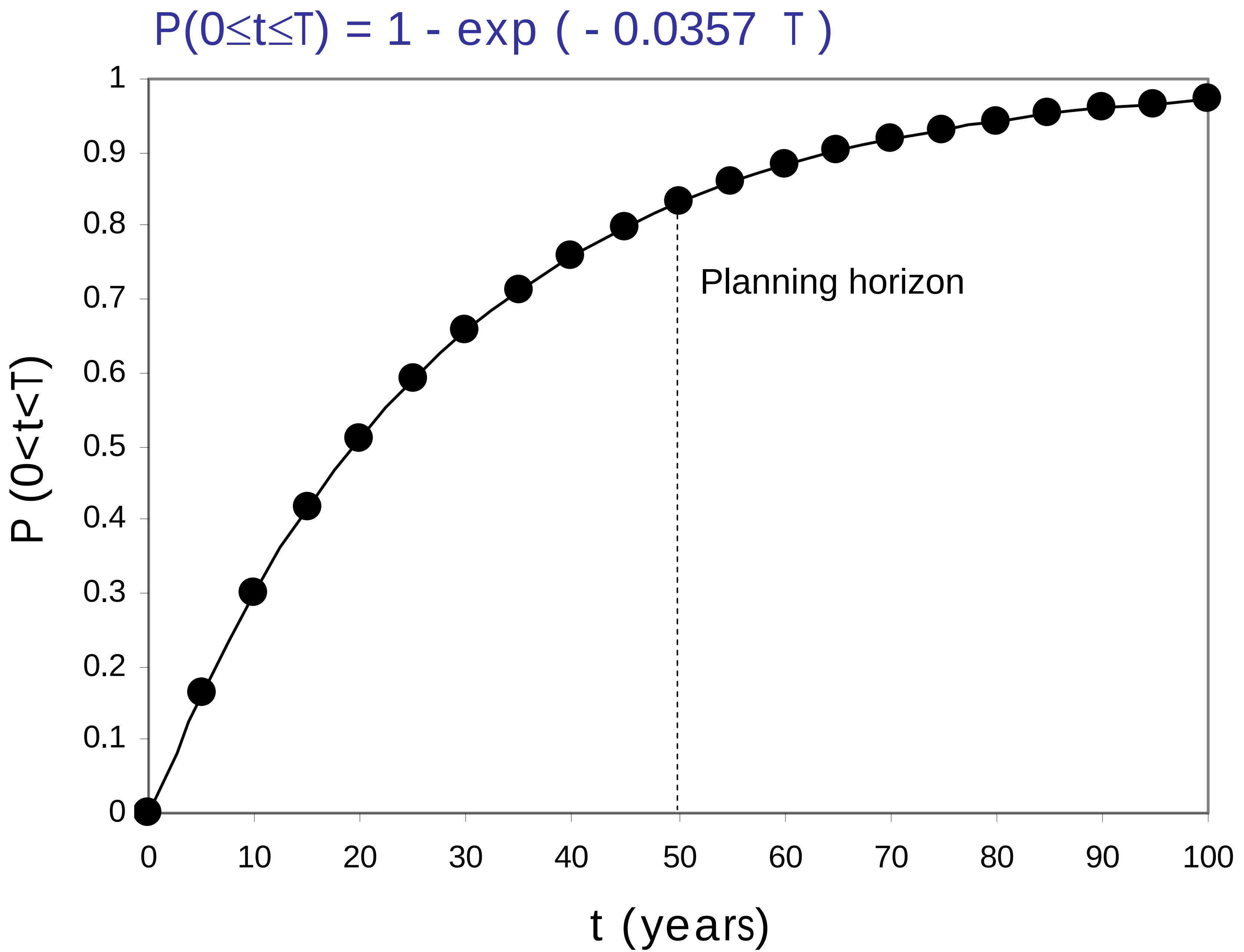
Windthrow Economics - Stochastic Modelling

1. This is accomplished by adding a random number, R, and rearranging (1) to solve for the time period:

2. In any given year, the probability of a major wind storm is a small constant.

$$t = [\ -\ln\ (1-R)\ ]\ /\ 0.0357$$

3. However, as the time span to be considered increases, the probability of a major wind storm occurring during that time span also increases.



P(0≤t≤T) = 1 - exp (- 0.0357 T)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
P (0<t<T)
Planning horizon
0
10
20
30
40
50
60
70
80
90
100
t (years)

Windthrow Economics - Stochastic Modelling

1. 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.

2. For this analysis, we chose net present value as the planning variable.

3. 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.

4. If the calculated NPVi's are normally distributed or symmetrical about the mean, then a t-distribution may be used to approximate the distribution (Gottfried, 1984).

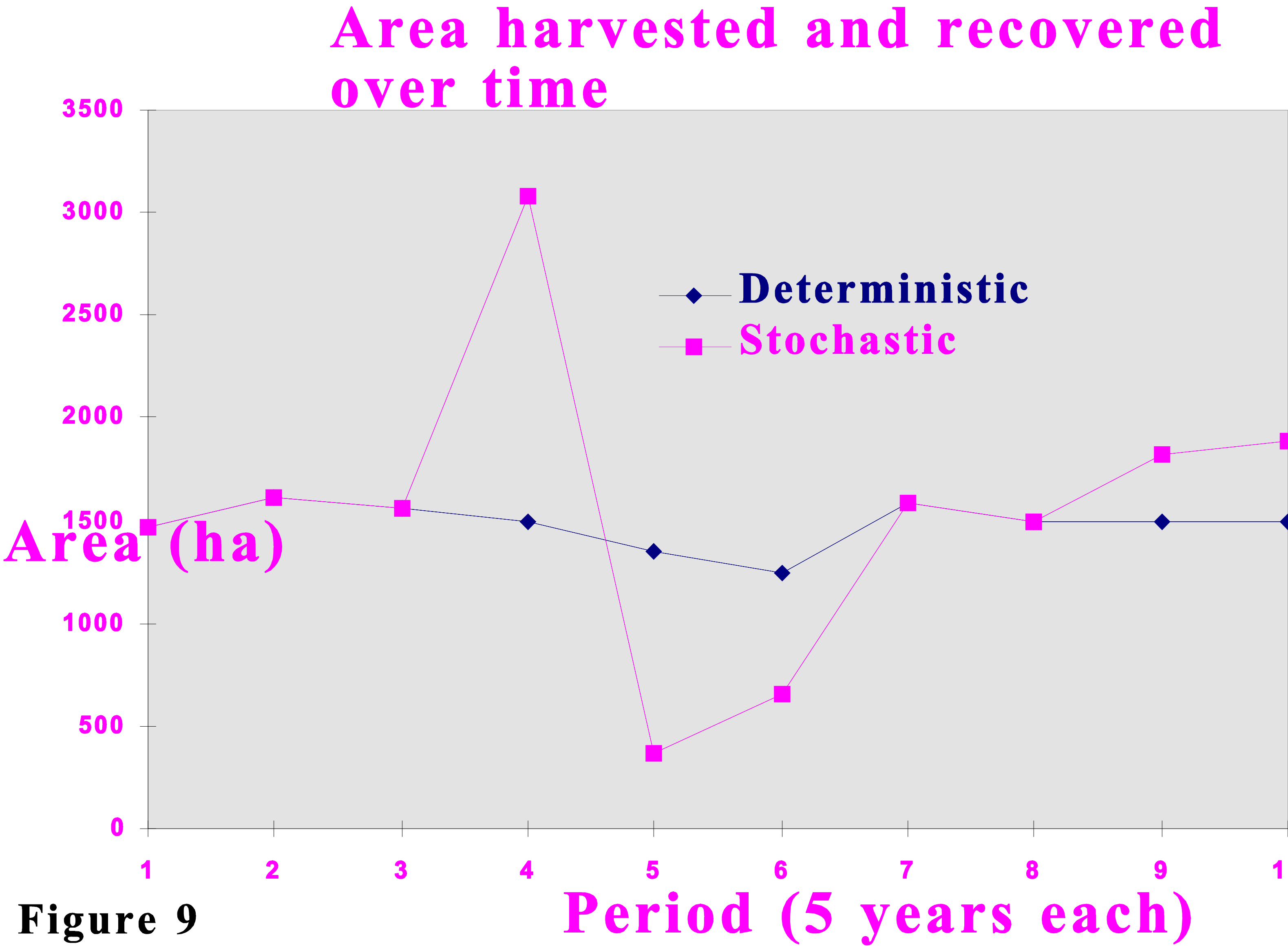

Area harvested and recovered over time
Area (ha)
3500
3000
2500
2000
1500
1000
500
0
Deterministic
Stochastic
1
2
3
4
5
6
7
8
9
10
Period (5 years each)

Figure 9

Windthrow Economics – Case Study

1. We ran the model using a data for a portion (8412 ha) of the forest estate owned by Selwyn Plantation Board Limited (SPBL).

2. SPBL is a local authority trading enterprise, essentially a limited liability company owned by local government organisations.

3. SPBL's estate is mostly Pinus radiata D.Don (radiata pine) planted largely in the Canterbury Plains.

Windthrow Economics – Case Study

Age (years)	Area by croptype Radiata Pine (ha)									Total
	Hills			Plains			Sands			
	Tended	Untended	Sub	Tended	Untende	Sub total	Tended	Untende	Sub	
1-5		**694.3**	**694.3**		**288.0**	**288.0**		**135.5**	**135.5**	**1117.8**
6-10		**1269.9**	**1269.9**		**482.4**	**482.4**		**158.9**	**158.9**	**1911.2**
11-15	**0.9**	**206.6**	**207.5**	**953.7**	**56.8**	**1010.5**	**43.2**	**49.6**	**92.8**	**1310.8**
16-20	**354.9**	**207.7**	**562.6**	**1799.1**	**54.5**	**1853.6**	**256.9**	**97.7**	**354.6**	**2770.8**
21-25	**27.6**	**51.8**	**79.4**	**498.1**	**159.4**	**657.5**	**139.3**	**22.2**	**161.5**	**898.4**
26-30		**6.1**	**6.1**	**195.4**	**48.3**	**243.7**	**90.1**		**90.1**	**339.9**
31-35							**10.7**	**3.1**	**13.8**	**13.8**
36-40				**0.6**		**0.6**	**1.5**		**1.5**	**2.1**
40 +		**0.5**	**0.5**	**24.9**	**0.3**	**25.2**	**4.3**	**17.8**	**22.1**	**47.8**
Sub	**383.4**	**2436.9**	**2820.3**	**3471.8**	**1089.7**	**4561.5**	**546.0**	**484.8**	**1030.8**	**8412.6**

Table 5. *Area of forest by site, historical management and age class used in the case study. Source: Studholme (no date).*

Windthrow Economics – Case Study

Age (years)	Volume by croptype Radiata Pine (m3/ha)					
	Hills		Plains		Sands	
	Tended	Untended	Tended	Untende	Tended	Untende
1-5	**0**	**0**	**0**	**0**	**0**	**0**
6-10	**0**	**0**	**0**	**0**	**0**	**0**
11-15	**145**	**124**	**111**	**127**	**189**	**213**
16-20	**266**	**310**	**198**	**227**	**291**	**314**
21-25	**419**	**612**	**306**	**351**	**403**	**420**
26-30	**603**	**787**	**434**	**495**	**523**	**540**
31-35	**678**	**862**	**496**	**558**	**598**	**615**
36-40	**753**	**937**	**559**	**620**	**673**	**690**
40 +	**828**	**1012**	**621**	**683**	**748**	**765**

Table 6. Prediction of yield by site, historical management and age class used in the case study. Source : Prediction of Yield based on data provided by Selwyn Plantation Board and suggested revision of the national exotic forest description by Keer-Keer (1995)

Windthrow Economics – Case Study

1. SPB frequently deals with windthrow that brings about significant financial losses.

2. Windthrow has a negative influence on a cash flow because it increases costs and depress revenues.

3. Since most trees are lying on the ground, recovery operations are more expensive.

4. Moreover, a high volume of waste brings about higher establishment costs (site preparation, planting, weed control, etc).

5. Revenues decrease as a result of smaller volume recovered, smaller logs, smaller products, appearance of products, lack of markets able to absorb a large production in a short time, etc.

Windthrow Economics – Case Study

1. the management problem is complex because it is not possible to predict:

    a. when the next windthrow would strike
    b. Its magnitude
    c. how it would affect the future supply of timber and age class distribution of the forest estate.

2. However, the phenomenon is not completely uncertain and some empirical knowledge has been collected over the years.

3. In affected areas, trees can be either blown down or broken.

4. Blown down trees are usually not damaged and they can be recovered in a period of less than five years.

Windthrow Economics – Case Study

1. Historically, most broken trees were not susceptible to economical utilization but they needed to be felled in order to decrease the risk of harvesting operations and for establishment purposes.

2. It has been estimated that approximately 1 of each 5 trees was broken during the 1975 storm at Canterbury (Selwyn Plantation Board, pers. comm., 1995).

Windthrow Economics – Case Study - Assumptions

1. all simulations were over a 50-year planning horizon;
2. time was aggregated into 5-year-periods (recovery period)
3. no price penalty was assumed for timber blown down and harvested in relation to unblown harvested timber.
4. twenty percent of the timber volume was assumed to be lost due to windthrow;
5. we model SPB's radiata pine only. This species makes up 90 percent of SPB's estate.
6. costing was kept constant.

Windthrow Economics – Case Study

1. We used volume and regulation constraints in optimizing the harvesting scheduling problem.

2. We constrained volume so that from one period to the next, it did not vary more than 10 percent.

3. 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.

Windthrow Economics – Results

1. The optimized solution produced a NPV after taxes of $43.208 million.

2. This value does not include windthrow risk.

3. We used preliminary sample of 100 runs to estimate that approximately 550 runs were required to return a 95 percent confidence interval.

4. We arbitrarily doubled this to ensure that we achieved an adequate confidence level.

Windthrow Economics – Results

1. The average NPV after taxes under stochastic conditions was $38.278 million, an average reduction of 11 percent over the deterministic case.

2. The minimum value was $24.152 million and the maximum was $43.301 million.

3. The frequency distribution of these stochastic NPVs by $2 million classes is shown (Fig. 3).

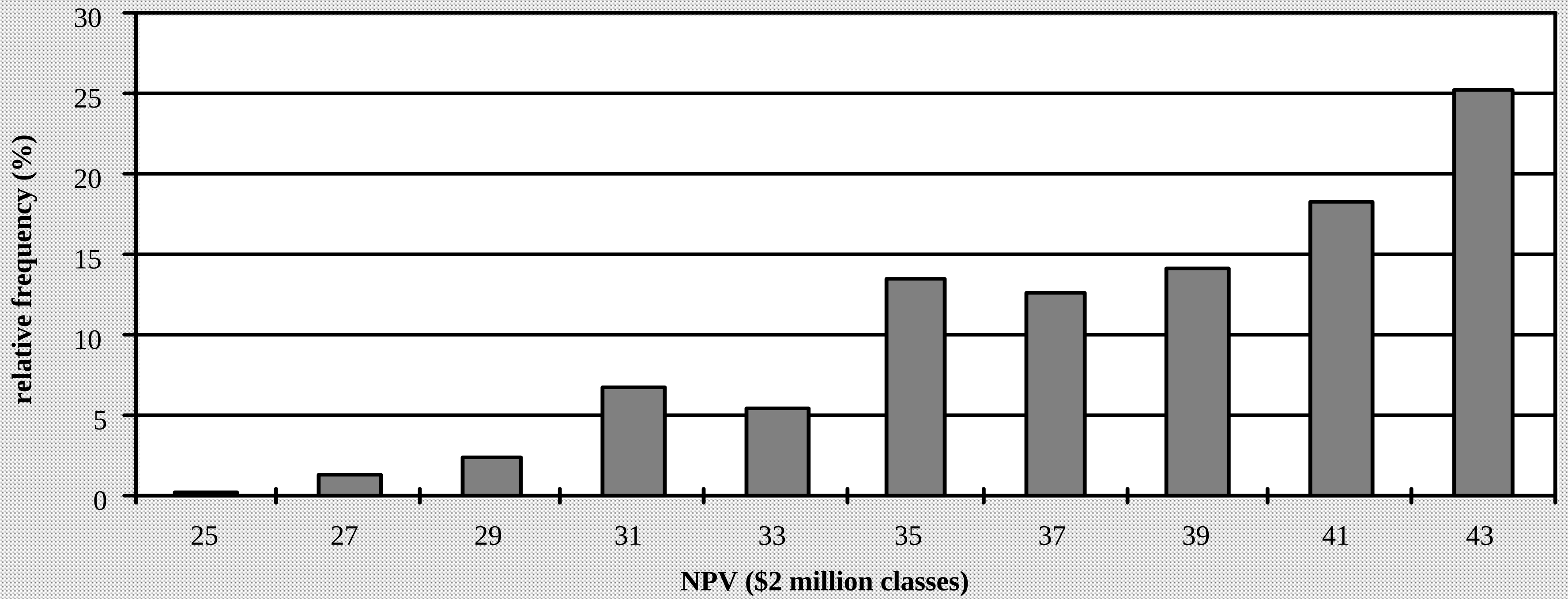


Figure 3. NPV distribution for Selwyn Plantation Board Limited under windthrow risk

Windthrow Economics – Results

1. This does not follow a normal distribution.

2. 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.

3. The lowest NPVs relate to cases in which there are frequent windthrows early in the planning horizon.

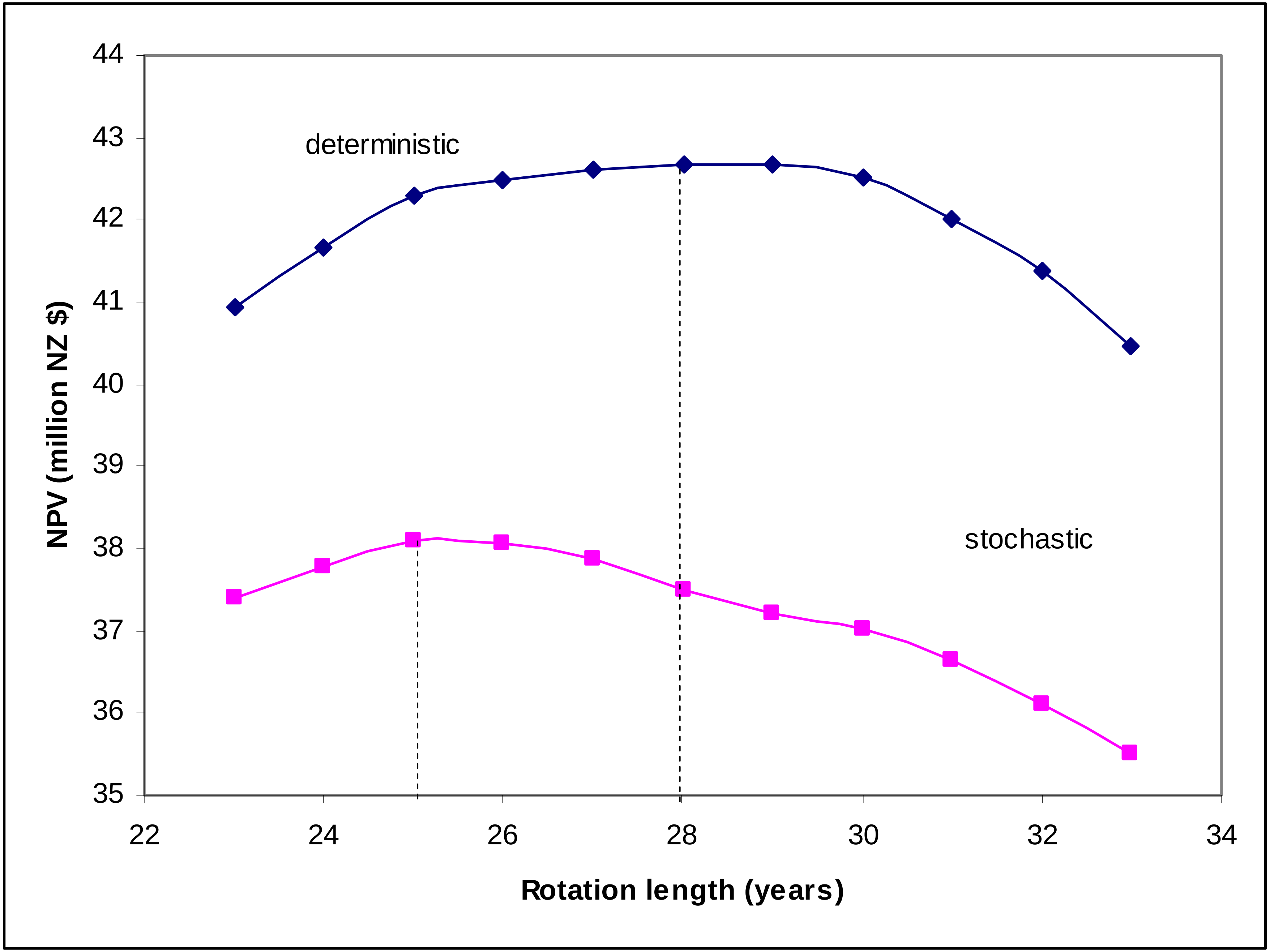
4. In the case where no windthrow takes place, the stochastic solution is identical to the deterministic solution.

5. Curiously, there are cases where the stochastic NPV is higher than the deterministic NPV.

6. This is due to the regulation constraints in the optimization and to the way NPV is calculated in the objective function.

Windthrow Economics – Results

Target rotation	NPV under deterministic conditions after tax (million $)	NPV under stochastic conditions		
		Average after tax (million $)	Standard Deviation (million $)	Range of variation (million $)
23	40.95	37.39	3.66	25.53 - 40.95
24	41.65	37.77	3.84	25.53 - 41.65
25	42.29	38.09	4.00	25.57 - 42.29
26	42.49	38.05	4.11	25.46 - 42.49
27	42.62	37.88	4.29	24.09 - 42.62
28	42.66	37.50	4.52	22.99 - 42.66
29	42.66	37.22	4.66	22.58 - 42.66
30	42.51	37.01	4.70	22.17 - 42.51
31	42.02	36.63	4.73	21.36 - 42.02
32	41.37	36.11	4.74	20.56 - 41.37
33	40.46	35.49	4.60	20.05 - 40.46



deterministic
stochastic
NPV (million NZ $)
44
43
42
41
40
39
38
37
36
35
22
24
26
28
30
32
34
Rotation length (years)

Windthrow Economics – Results

1. Risk averse decision makers who require an increase in return for an increase in risk would probably choose a rotation age of 25 years because it maximizes profit at the least risk.

2. Risk neutral decision makers who do not require an increase in returns for an increase in risk would probably select a rotation age of 28 years because it maximizes profit regardless of the level of risk.

3. Risk takers would probably choose a rotation age between 25 and 28 years.

Windthrow Economics – Sensitivity Analysis

1. We ran sensitivity analyses on significant variables:

   a. establishment costs
   b. pricesrecovery assumptions
   c. return period for the wind storms

2. 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%

Windthrow Economics – Sensitivity Analysis

1. We also analysed the sensitivity of the solution in relation to the return period.

2. We varied the average return period by five years and by ten years.

3. Varying the return period by five years had little impact on NPV.

4. NPV decreased by 1.8 percent given a 23 year return period and increased by 1.7 percent given a 33 year return period.

5. NPV decreased by 4.6 percent given an 18 year return period and increased by 3.0 percent given a 38 year return period.