Forest and wind risk in Tasmania

A guide for foresters, landowners and planners

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Private Forests Tasmania
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Preface

This document has sections that are based on the previous work of a few dedicated forestry professionals, to whom we are ever indebted. Their following work forms the basis of the subject of ‘Forests & wind risk’:


Without these seminal texts this document would not exist.

Forest wind risk calculator

This document also serves as the background information for the Excel based ‘Forest wind risk calculator’. Before attempting to complete the ‘Forest wind risk calculator’ it is necessary to read and fully understand the contents of this document.

By using the 'Forest wind risk calculator', you acknowledge that results may be inaccurate for your site. Results are based on assumptions and may be indicative only.

NB - Wind risk within forests is dependent upon the interaction of a number of individual factors, including the windthrow stand and treatment hazards. The importance of which will vary from place to place and time to time.

The forest wind risk indicates the likelihood of forests being damaged by winds and trees suffering from windthrow and/or breakage.
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<th>Page</th>
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</thead>
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<td>11</td>
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</tbody>
</table>
Introduction

Within Tasmania the forest wind risk must not be underestimated. The establishment and management of forests, plantation and native, can be severely affected by wind if it is not assessed as part of the strategic forest planning process, failure to assess this could result in commercial failure.

Wind risk within forests is dependent upon the interaction of a number of factors. The importance of individual factors will vary from place to place and time to time. As foresters, landowners and planners within Tasmania we are not able to control many of the environmental and biophysical factors affecting our forests; however, via our planning, silvicultural and harvesting operations we can dramatically influence the forest wind risk. This guide is intended to introduce Tasmanian foresters, landowners and planners to:

- the concepts of forest wind risk;
- develop a method of determining the level of wind risk for an individual operation, a single coupe, a whole forest or an entire property;
- provide a planning framework for wind risk; and
- windthrow management strategies to reduce forest wind risk.

The forest wind risk is the combination of the forest wind hazards: windthrow hazard, forest stand hazard and the treatment hazard (Figure 1). It can be used to plan operations in existing forests, and also to design and plan future forests, for example: the strategic positioning of shelterbelts. The following sections deal individually with each component of forest wind risk and combine the hazard ratings to achieve a Forest Wind Risk Class (FWRC). These classes indicate the likelihood of a forest wind damage event resulting in both windthrow and wind breakage.
The scoring system used throughout this guidebook was initially developed by K. Miller (UK Forestry Commission) in 1985 and revisions as cited, as an attempt to objectify and quantify windthrow hazard classification (WHC). However, the scoring system itself was subjective and scores were assigned to values with little objectivity. The scoring method has been retained for WHC and also used for forest treatment hazard class (FTHC), forest stand hazard class (FSHC) and forest wind risk class (FWRC) with the acceptance of its limitations and ease of implementation. The scoring system should be interpolated with relation to experience, local knowledge and common sense.

It should be noted that this guidebook is not intended to be a 'stand-alone' document, it presupposes a knowledge of the foundations on which silviculture is based and forest surveying techniques.

The subject has been more recently revisited by the UK Forestry Commission resulting in ForestGALES (Gardiner et al 2004), a PC-based decision support tool for forest managers to estimate the probability of wind damage (www.forestresearch.gov.uk/forestgales); and the British Columbia Ministry of Forests (http://www.for.gov.bc.ca/hfp/training/00015/). Both are excellent sources for anyone further interested in forests and wind risk.

It should be noted that this is a guidebook – not a rule book. The information should be interpreted and interpolated with relation to experience and local knowledge.
**Forest wind hazard classes**

1. **Windthrow hazard**

The following section is largely derived from the Miller (1985) leaflet, to which further reference should be made (www.forestry.gov.uk). The leaflet sets out a simple ground-based approach of quantifying and mapping the windthrow hazard, although it was written primarily for use in the UK it can be adapted to Tasmania and utilized by Tasmanian foresters, landowners and planners.

In general, trees can adapt to endemic winds, but trees are not usually adapted to peak and/or irregular wind events. A lack of windfirmness is due to a site/stand limitation caused by environmental factors: windiness, elevation, exposure and soil. The combined scores of the environmental factors determine a windthrow hazard class (WHC):

### a. Windiness

The windiness of a site can be determined with access to local knowledge – how severe are the winds in the area?

<table>
<thead>
<tr>
<th>Score</th>
<th>High</th>
<th>Moderate</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>13</td>
<td>7.5</td>
<td>0</td>
</tr>
</tbody>
</table>

Alternatively, without local knowledge, the generalized windiness of a site can be gathered from the windzone map of Tasmania (see Appendix 1)

<table>
<thead>
<tr>
<th>Score</th>
<th>Extra Heavy</th>
<th>Heavy</th>
<th>Moderate</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>13</td>
<td>7.5</td>
<td>4</td>
<td>0</td>
</tr>
</tbody>
</table>

In addition, the Bureau of Meteorology produces a series of Wind Frequency Analyses (aka Wind Roses) that are also useful in determining windiness (see Appendix 1).

### b. Elevation

The elevation above sea level is best determined from published Tasmaps or GIS data.

<table>
<thead>
<tr>
<th>Elevation (m)</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>541+</td>
<td>10</td>
</tr>
<tr>
<td>406 – 540</td>
<td>8</td>
</tr>
<tr>
<td>316 – 405</td>
<td>6</td>
</tr>
<tr>
<td>256 – 315</td>
<td>4</td>
</tr>
<tr>
<td>191 – 256</td>
<td>2</td>
</tr>
<tr>
<td>61 – 190</td>
<td>.5</td>
</tr>
<tr>
<td>0 – 60</td>
<td>0</td>
</tr>
</tbody>
</table>

### c. Exposure

The degree of exposure is influenced by the topographic features surrounding the site and should be ascertained from surveys in the field and maps. Topex readings (sum of angles of inclination to the horizon at the eight compass points) are an assessment of exposure, however it is also possible to subjectively determine site exposure using the following table:

<table>
<thead>
<tr>
<th>Exposure</th>
<th>Topex Total</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Severely exposed</td>
<td>0 – 10</td>
<td>10</td>
</tr>
<tr>
<td>Very exposed</td>
<td>11 – 30</td>
<td>7</td>
</tr>
<tr>
<td>Moderately exposed</td>
<td>31 – 60</td>
<td>3</td>
</tr>
<tr>
<td>Moderately sheltered</td>
<td>61 – 100</td>
<td>1</td>
</tr>
<tr>
<td>Very sheltered</td>
<td>100+</td>
<td>0</td>
</tr>
</tbody>
</table>
Where possible the Topex readings should be distance-limited at .5km (Quine & White 1998), the use of a distance threshold can lead to improved estimates for these sites. See also PFT’s ‘Forests and wind risk’ webpage for a TOPEX map of Tasmania (www.pft.tas.gov.au).

d. Soil
Soils vary greatly between and within forests, site observations are therefore important to ascertain the possible restriction to root development.

<table>
<thead>
<tr>
<th>Root Development</th>
<th>Score</th>
<th>Soil Character</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unrestricted rooting in excess of 100cm</td>
<td>0</td>
<td>Deep brown earths, podzols, loams</td>
</tr>
<tr>
<td>Restricted rooting but some structural root penetration in excess of 45cm</td>
<td>5</td>
<td>Moderate depth peats, gleys</td>
</tr>
<tr>
<td>Very restricted rooting under 45cm deep</td>
<td>10</td>
<td>Shallow, indurated, waterlogged</td>
</tr>
</tbody>
</table>

e. Derivation of WHC
The scores for windiness, elevation, exposure and soil are added to give total score for windthrow hazard.

<table>
<thead>
<tr>
<th>Total Score</th>
<th>Windthrow Hazard Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to 8.0</td>
<td>1</td>
</tr>
<tr>
<td>8.0 – 13.5</td>
<td>2</td>
</tr>
<tr>
<td>14.0 – 19.0</td>
<td>3</td>
</tr>
<tr>
<td>19.5 – 24.5</td>
<td>4</td>
</tr>
<tr>
<td>25.0 – 30.0</td>
<td>5</td>
</tr>
<tr>
<td>&gt; 30.5</td>
<td>6</td>
</tr>
</tbody>
</table>

The simple WHC system can be used in general forest management planning recommendations and it is a useful tool when establishing plantations and their proposed regimes:

**Areas with a low WHC (1 – 2)** Plantations can generally be thinned selectively, systematically or a combination selective/systematic; they should be thinned ‘on-time’ and can withstand a heavy thinning intensity. Native forests can have both clearfall and non-clearfall silvicultural systems implemented. Wind damage is likely to be minimal and should be considered a low priority.

**Areas with a medium WHC (3 – 4)** Plantations can generally be thinned selectively (on-time), systematically (early, light thinning) or a combination selective/systematic (on-time or early). Native forests can have both clearfall and partial harvest silvicultural systems implemented. Wind damage could affect the outcome of operational treatments and should be considered.

**Areas with a high WHC (5 – 6)** Plantations should generally not be thinned for risk of severe windthrow. Native forests should be managed with extreme caution. Wind damage must be considered a high priority.

However, a detailed analysis is necessary to gain a more objective evaluation of potential effects of wind events on existing forests. The WHC should be combined with the forest stand hazard class (FSHC) and the forest treatment hazard class (FTHC).
2. Forest stand hazard

The endemic characteristics of stands of trees and forests that affect windfirmness.

The combined scores of the biophysical factors: canopy roughness and uniformity, prevailing wind and topography, tree height, diameter and crown ratio, plus forest stand shape & size determine a forest stand hazard class (FSHC):

a. Canopy roughness and uniformity

The canopy roughness and stand uniformity combine to affect the windfirmness:
Figure 3 - A comparison of distributions of the relative windfirmness of individual trees comprising stands with different characteristics (Strathers et al, 1994)

<table>
<thead>
<tr>
<th>Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Even, dense eg. unthinned plantation or regrowth / unstable, thinned plantation</td>
</tr>
<tr>
<td>5</td>
<td>Even, dense with emergents eg. mixed forest or stabilised, thinned plantation</td>
</tr>
<tr>
<td>0</td>
<td>Uneven, open eg. dry sclerophyll or multi-age plantation</td>
</tr>
</tbody>
</table>

b. Prevailing wind and topography
The orientation of the forest stand in relation to the prevailing wind and the topography influences the wind acceleration and turbulence of a location.
Figure 4 - The effects of topography on wind speed. When the wind direction is perpendicular to a ridge the wind speed is relatively low in the valley bottom and increases to a maximum at the ridge top. When the wind direction is parallel to a ridge higher wind speeds occur in the bottom of the valley and near the ridge crest (Alexander, 1987)

<table>
<thead>
<tr>
<th>Score</th>
<th>Low</th>
<th>Moderate</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>5</td>
<td>10</td>
</tr>
</tbody>
</table>

In addition, the Bureau of Meteorology produce a series of Wind Frequency Analysis’s (aka Wind Roses) that are also useful in determining prevailing wind directions and the effect of the landscape characters zones (see Appendix 1).

c. Tree height, diameter and crown ratio

At the individual tree level the height, diameter and crown of a tree will influence a tree’s stability. The height-to-diameter ratio and crown depth ratio are good indicators of likely windthrow and stem breakage.

<table>
<thead>
<tr>
<th>Height-to-Diameter</th>
<th>Score</th>
<th>Crown-Depth-Ratio</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height-to-diameter ratio &lt;60</td>
<td>0</td>
<td>Crown depth ratio &gt;35%</td>
<td>0</td>
</tr>
<tr>
<td>Height-to-diameter ratio 61-9</td>
<td>3</td>
<td>Crown depth ratio 20-35%</td>
<td>3</td>
</tr>
<tr>
<td>Height-to-diameter ratio 91+</td>
<td>5</td>
<td>Crown depth ratio &lt;20%</td>
<td>5</td>
</tr>
</tbody>
</table>
Figure 5 - Example of height-to-diameter ratio

<table>
<thead>
<tr>
<th>a. Crown depth ratio = 50%</th>
<th>b. Crown depth ratio = 30%</th>
<th>c. Crown depth ratio = 20%</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Height (h) = 25m</td>
<td>b. Height (h) = 13.75m</td>
<td>c. Height (h) = 12.5m</td>
</tr>
<tr>
<td>Crown depth (d) = 12.5m</td>
<td>Crown depth (d) = 7.5m</td>
<td>Crown depth (d) = 6.25m</td>
</tr>
<tr>
<td>= 50%</td>
<td>= 30%</td>
<td>= 20%</td>
</tr>
<tr>
<td>Crown depth score = 0</td>
<td>Crown depth score = 1</td>
<td>Crown depth score = 0</td>
</tr>
</tbody>
</table>

Figure 6 - Comparisons of crown depth ratios (Crown depth ratio = d/h) (Smith, 2002)

d. Shape and size of a stand of trees

The shape and size of a forest will influence its windfirmness. In particular, the width of the stand of trees and therefore the ability of the trees to support each other is of great importance. For example: if narrow streamside reserves are left during a clearfall harvest operation in an area with a high Wind Hazard Class, is it likely that the retained reserve will remain standing or will it be liable to windthrow?

<table>
<thead>
<tr>
<th>Stand size</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 50m wide</td>
<td>10</td>
</tr>
<tr>
<td>50 – 100m wide</td>
<td>5</td>
</tr>
<tr>
<td>Greater than 100m wide</td>
<td>0</td>
</tr>
</tbody>
</table>
e. Derivation of FSHC
The scores for canopy roughness, prevailing wind, height/crown depth and size are added to give a total score for forest stand hazard class.

<table>
<thead>
<tr>
<th>Total Score</th>
<th>Forest Stand Hazard Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to 8.0</td>
<td>1</td>
</tr>
<tr>
<td>8.0 – 13.5</td>
<td>2</td>
</tr>
<tr>
<td>14.0 – 19.0</td>
<td>3</td>
</tr>
<tr>
<td>19.5 – 24.5</td>
<td>4</td>
</tr>
<tr>
<td>25.0 – 30.0</td>
<td>5</td>
</tr>
<tr>
<td>Over 30.5</td>
<td>6</td>
</tr>
</tbody>
</table>

3. Treatment hazard
The wind load on an individual tree caused by an operation.

It has already been asserted that trees can adapt to endemic winds, but how will a forest operation and conditions affect the wind loading of individual trees? The combination of the operational and condition factors - operation intensity, scale of operation, forest operation orientation and waterlogging will determine a forest treatment hazard class (FTHC):

a. Intensity of proposed operation
In general, if a forest operation alters the canopy roughness and stand uniformity it will affect the windfirmness - the greater the intensity of the operation, the greater the treatment hazard. This includes operations such as thinning, selective harvests, fertilising and roading.

<table>
<thead>
<tr>
<th>Intensity</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low (eg. respacing, chemical thinning)</td>
<td>0</td>
</tr>
<tr>
<td>Moderate (eg. fertilising, light thinning)</td>
<td>5</td>
</tr>
<tr>
<td>High (eg. heavy thinning, clearfall)</td>
<td>10</td>
</tr>
</tbody>
</table>

NB – fertilising has the effect of encouraging rapid crown growth without a corresponding root development, resulting in reduced windfirmness due to an increased sail-area of the crown. It is recommended that plantations should not be fertilised for at least 3 years following a conventional thinning operation to reduce the chance of windthrow on high risk sites.

The intensity of operations will also need to be considered during establishment as different ground preparation techniques have a profound effect on subsequent windfirmness. For example: deep ploughing and mounding encourages lineal root development and reduces windfirmness (high intensity – score 10), whereas individual spot cultivation encourages a more radiant pattern of root development that increases windfirmness (low intensity – score 0).
**b. Scale of operation**
Overseas research has shown that the size of a forest opening caused by a harvesting event does not seem to have a significant effect on the amount of windthrow as there may be more opportunity to find windfirm boundary locations. In some areas, very small openings (<1ha) have proven to be relatively windfirm (Strathers et al, 1994).

Turbulence resulting from accelerated wind flow over the edge of the stand causes zones of very high turbulence a few tree heights downwind. This turbulence increases the risk of windthrow in this zone (Strathers et al, 1994) especially when the trees are not adapted to a rapid increase in individual wind loading, for example, during a clearfall harvest operation (Cremer et al, 1974). Therefore new openings to the prevailing wind must be minimised to reduce the risk of windthrow.

<table>
<thead>
<tr>
<th>Score</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low &lt;1Ha</td>
<td>0</td>
</tr>
<tr>
<td>Moderate 1 – 5ha</td>
<td>5</td>
</tr>
<tr>
<td>High &gt;5ha</td>
<td>10</td>
</tr>
</tbody>
</table>

**c. Orientation to prevailing wind**
The orientation of the forestry operation to the prevailing wind, especially lineal operations such as: outrows, roads, plough direction, clearfall boundaries etc, will have an effect on the windfirmness of the forest. Less wind damage can be expected from operational boundaries that are orientated parallel to the prevailing wind directions, compared to potential high wind damage from operational boundaries that are orientated perpendicular to prevailing wind directions.
Forests and Wind Risk in Tasmania

**Score**

- Low - parallel to prevailing wind: 0
- Moderate - 45° to prevailing wind: 5
- High - perpendicular to prevailing wind: 10

In addition, the Bureau of Meteorology produce a series of Wind Frequency Analysis (aka Wind Roses) that are also useful in determining prevailing wind direction (see Appendix 1).

d. **Soil saturation and strong winds**
   The scheduling of specific forestry operations, especially harvesting, to occur during wet seasons and predictable seasonal strong wind events can have a marked influence on the windfirmness of the forest. A saturated soil has significantly lower soil shear strength, if this is combined with strong winds the treatment hazard is greatly increased.

   **Score**
   - Low - soil not prone to saturation: 0
   - Moderate - soil prone to saturation operations scheduled for dry season only: 5
   - High - soil prone to saturation and operations poorly scheduled: 10

e. **Derivation of FTHC**
   The scores for operation intensity, scale of operation, forest openings orientation and soil saturation are added to give a total score for forest treatment hazard class (FTHC).

<table>
<thead>
<tr>
<th>Total score</th>
<th>Forest treatment hazard class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to 8.0</td>
<td>1</td>
</tr>
<tr>
<td>8.0 – 13.5</td>
<td>2</td>
</tr>
<tr>
<td>14.0 – 19.0</td>
<td>3</td>
</tr>
<tr>
<td>19.5 – 24.5</td>
<td>4</td>
</tr>
<tr>
<td>25.0 – 30.0</td>
<td>5</td>
</tr>
<tr>
<td>Over 30.5</td>
<td>6</td>
</tr>
</tbody>
</table>

4. **Forest wind hazard assessment process - windthrow hazard (WHC), forest stand hazard (FSHC) and forest treatment hazard (FTHC)**

Now that we have introduced the 3 components of forest wind risk: windthrow hazard, forest stand hazard and forest treatment hazard, we need to identify an assessment process for an individual operation, a single coupe, a whole forest or an entire property.

A simple method of systematically laid-out sample points within striplines parallel to the prevailing winds will collect the necessary data. The distance between plots within a stripline and the distance between striplines will be determined to ensure that at least the minimum number of points is installed across the area, the minimum number of points will depend on the area and uniformity of the forest.

Table 1 gives a guide to the number of points needed:

<table>
<thead>
<tr>
<th>Area</th>
<th>Uniform conditions</th>
<th>Variable conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>.5 – 2</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>2 - 10</td>
<td>8</td>
<td>12</td>
</tr>
<tr>
<td>&gt; 10</td>
<td>10</td>
<td>16</td>
</tr>
</tbody>
</table>

**Table 1 - A guide to the number of sample points necessary**
NB – if the topography or ground conditions vary greatly within the area it is necessary to locate extra plot points, in addition to the striplines, to represent the variances.

At each point the WHC should be assessed, however it will only be necessary to reassess the FSHC and FTHC when variances in stand characteristics and operations occur. An example of a “Windthrow hazard (WHC), forest stand hazard (FSHC) and the forest treatment hazard (FTHC) assessment proforma” is shown in Appendix 2.

It should be noted that the scores for the variables within wind hazard, stand hazard and treatment hazard are generally grouped into Low, Moderate or High. These scores should be interpolated with relation to local knowledge and common sense.

Figure 8 - An example of a well laid-out wind risk assessment exercise. (map from www.thelist.tas.gov.au)

NB - The striplines have been set at approximately 100m apart and sample points will be at 150m intervals along the stripline to ensure the minimum number of points are captured

Eg >10ha & Variable conditions = minimum 16 plots necessary.

Additional points have been added (marked as stars) along a steep slope to gain additional information.
**Forest wind risk**

The forest wind risk is the combination of the windthrow hazard (WHC), forest stand hazard (FSHC) and the forest treatment hazard (FTHC).

*Figure 9 - A diagrammatical representation of the components of forest wind risk.*

As previously discussed in the Windthrow hazard section, the WHC can be used as a simple stand-alone tool to plan forestry operations. However, when the WHC is combined with FSHC and FTHC it becomes a much more powerful tool that can help to predict forest wind risk.

The importance of the WHC in the forest wind risk assessment is reflected in the weighting (2X) of the WHC score.
Derivation of forest wind risk class

The scores for windthrow hazard (WHC X2), forest stand hazard (FSHC) and the forest treatment hazard (FTHC) are added to give a total score for forest wind risk class (FWRC).

<table>
<thead>
<tr>
<th>Total score</th>
<th>Forest wind risk class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to 9 points</td>
<td>Low</td>
</tr>
<tr>
<td>10 – 13 points</td>
<td>Moderate</td>
</tr>
<tr>
<td>Greater than 13 points</td>
<td>High</td>
</tr>
</tbody>
</table>

- **High forest wind risk** - high wind force and low resistance to overturning. Located where poor root anchorage occurs, where high wind speeds and turbulence are more likely to occur and where the stand structure, composition and tree form make it more liable to wind damage if openings are made. Wind damage is likely to occur at some time during the rotation and must be considered carefully during the formulation of strategic plans and site-specific prescriptions.

- **Moderate forest wind risk** - moderate wind force and a moderate resistance to overturning. Located where either poor anchorage and low wind force, or good anchorage and a high wind force are present. Wind damage could affect the outcome of operational treatments and should be considered.

- **Low forest wind risk** – low wind force and high resistance to overturning. Located where good root anchorage occurs as a result of soil conditions, where topographic shelter reduces the windspeed and turbulence and where the stand and individual tree characteristics makes trees less susceptible to windthrow after openings are made. Wind damage is unlikely to occur over a rotation and management for windthrow can be considered as a relatively low priority (Strathers et al, 1994).

Alternatively, when a more sensitive indication of forest wind risk is needed the initial forest wind risk score (1 – 24) can be used to replace the broad Low, Moderate and High classes. Conversely, when a very quick forest wind risk assessment is necessary and/or acceptable a simple wind risk calculator could be used:

<table>
<thead>
<tr>
<th>Wind Force</th>
<th>Low Score 1</th>
<th>Medium Score 2</th>
<th>High Score 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resistance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low Score 3</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Medium Score 2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>High Score 1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

*Table 2 - An example of a simple wind risk calculator*

*Total score 2/3 = Low Risk   4/5 = Moderate Risk 6 = High Risk*
**Principles to reduce forest wind risk**

As foresters, landowners and planners within Tasmania we are not able to control many of the environmental and biophysical factors affecting our forests. However, via our planning, silvicultural and harvesting operations we can dramatically influence the forest wind risk for an individual operation, a single coupe, a whole forest or an entire property.

The objective of forest wind risk management is to reduce the potential of wind damage (windthrow and breakage) by reducing the wind force on crowns and improving the root anchorage strength of retained and boundary trees ie, reduced wind-loading and increased root-soil resistance.

The following section is largely derived from p.18-23 Strathers et al (1994), to which further reference should be made. The handbook recommends windthrow management strategies for forests. Although it was written primarily for use in British Columbia it can be adapted to Tasmania and utilized by Tasmanian foresters, landowners and planners.

**Windthrow management strategies**

Using a combination of the following strategies should reduce the wind risk:

**a. Clearfall operations**

1. Downwind boundaries (windward) should be located on sites at least risk.
2. Utilize natural landscape boundaries to create windfirm edges eg. rock bluffs, bogs, etc.
3. Avoid locating boundaries in areas of previous windthrow.
4. If a windward boundary proves to be windfirm, ensure it is not harvested in the short-term. Replicate the conditions to create additional windfirm boundaries.*
5. Boundaries that are exposed to wind should be left uniform and smooth.
6. Avoid damage to tree roots along boundaries.
7. Boundary edges may need to be feathered on moderate and high risk sites.
8. Include poorly drained areas, shallow soils and high risk areas within an opening.
9. If windthrow occurs along a boundary, do not salvage and create a similar new boundary. Retain windthrow as a windfirm buffer or create a new windfirm boundary (see above*).
10. Create a windfirm boundary and then harvest progressively into the wind.
11. Extensive high wind risk areas may require progressive development of coupes to minimize exposure and facilitate windthrow salvage operations.
12. Openings, roads etc should be located so that potential windthrow salvage operations create little damage to retained trees.
13. Narrow reserves are prone to windthrow, their siting and width need careful planning.
14. The shape of the coupe will have a marked effect on the stability of the retained forest. In high risk areas strip systems appear to be more stable.
15. Plan clearfalls adjacent to stabilized forest areas, not next to recently thinned coupes.
16. Clearfall or no falling may be appropriate treatments for high risk areas that contain endemic windthrow. Other silvicultural systems may be implemented if the stands are thinned at an early age.
Figure 10 - Cutting is done progressively in strips, into the wind to develop a windfirm stand border.

1 - Situation shown is a stand of a naturally windfirm border.
2 – The first strip is cut as close to the more windfirm stand as economics will allow.
3 – The second strip is cut windward of first strip. Any blowdown that has occurred at the leeward edge of the uncut stand is salvaged.
4. Strips are cut to the windward; blowdown on the windward edge of uncut stand is salvaged.
5 – As strip cutting continues to windward, the increasing height of the developing stand helps to lift the wind gradually, thereby eliminating an abrupt windward edge. (Strathers et al (1994))

b. Edge Stabilisation

1. Edge feathering will reduce wind-loading on boundary trees. Trees in the edge buffer should be removed in the following order of preference:
   - Unsound trees with a large crown, including: diseased, deformed, forked, scarred, root rot infested etc.
   - Trees with asymmetric or stilt roots.
   - Trees on unstable substrates, e.g. rocky knolls, large boulders, poorly drained depressions, etc.
   - Tall non-veteran trees, especially with above features or large crowns.
2. Residual trees should be left in the following order of preference:
   - Sound, well-rooted veterans.
   - Sound trees (strong roots and good taper) with relatively small, open crowns.
   - Sound hung-up trees, where safety is not comprised.
3. Stem removal should not exceed 15-20% of the trees in a strip 20-30m from the boundary (not recommended at all in single-story, dense stands).
4. Topping and/or pruning of vulnerable trees may be necessary along boundaries to protect critical areas eg. reserves, wildlife habitat, etc.
5. 20-30% crown reduction appears to reduce wind risk.
6. Combination of edge-feathering, topping and pruning should be effective in high risk areas.

c. Partial cutting and thinning

1. Group selection, thinning, shelterwood and strip falling must be used with caution in high hazard areas.
2. Reserves should be located on low hazard areas.
3. Thin from below in shelterwood and thinning operations. Avoid gaps greater than half tree length.
4. Avoid selective, shelterwood and thinning harvests at clearfall edges, leave a buffer.
5. Trees with damaged roots should be removed.
6. If windthrow occurs, re-evaluate the wind risk of the remaining trees and decide to:
   ➢ clearfall,
   ➢ salvage windthrow and remaining trees, or
   ➢ leave the windthrow.
7. Relative spacing (Average tree spacing ÷ Mean dominant height) should be kept around the optimum value of .33.
8. Relative height (Mean dominant height ÷ Average diameter at breast height) should be kept around 40.

d. Regeneration and forest maintenance

1. Early respacing on moderate-to-high hazard sites, or maintain a dense stand for the rotation.
2. A series of light respacing’s or thinnings on high hazard sites.
3. Delay fertilising after respacing or thinning.
4. Draining wet sites will improve root-soil resistance.
5. In high hazard areas where immature forests are windthrown by endemic winds, consider developing harvesting schedules based on mean dominant height. NB - The determination of threshold tree heights for Tasmanian species and conditions is currently under investigation.

**Basic strategies for regenerating windfirm stands on moderate-to-high hazard sites includes:**

1. Grow trees at wide spacing and no thinning.
2. Grow trees at medium spacing by planting at medium spacing or using early thinning.
3. Grow trees at close spacing and harvesting at onset of windthrow or at a predetermined height.
4. Relative height (Mean dominant height ÷ Average diameter at breast height) should be kept around 40.
5. Relative spacing (Average tree spacing ÷ Mean dominant height) should be kept around the optimum value of .33

e. Windthrow monitoring and remedial treatments

Windthrow monitoring will provide information for foresters, landowners and planners to improve hazard classification, treatment techniques and windthrow management strategies.

The broad scale map produced to evaluate wind hazard class (see Windthrow Hazard Class section) should be updated annually and major windthrow events documented (intensity & scale), mapped and, ideally, photographically recorded.

Appropriate remedial treatment techniques, when necessary, can then be identified and implemented, for example:
1. edge stabilisation;
2. re-evaluate the wind risk of the remaining trees and decide to: clearfall,
3. salvage windthrow or leave the windthrow; or
4. if windthrow occurs along a boundary, do not salvage and create a similar new boundary.
   Retain windthrow as a windfirm buffer or create a new windfirm boundary (see also Windthrow Management Strategies).

An example of a Windthrow Monitoring and Windthrow Hazard Evaluation proforma is included in Appendix 3.

**Figure 11 -** Typical windthrow damage in a spruce plantation in Germany (left) and Northern England (right)

Case study 1
Stoodley plantation, Sheffield
Timberlands Pacific

The Stoodley plantation consists primarily of second rotation *Pinus radiata* planted 1980 – 84 and have been managed on a sawlog (2 thin) regime. The plantations include significant recreational, landscape and heritage values (58m tall pines and *E.globulus* planted 1939)

The forest wind risk assessment process concentrated on areas that were to be harvested in the next 5 years

*Figure 12* - Initial planning (left) identifies the Stoodley forest areas and plot points (yellow markers), the imminent harvest areas were targeted for wind risk assessment (right).

*Figure 13* - The majority of the plantation areas were classed as moderate wind risk (orange) with the exception of the *E.globulus* component of 202/1 and the exposed ridgeline in 202/3 that were classed as high risk (red).
Due to the Moderate wind risk of Stoodley plantation, the assessment did not have any effect on the planned harvesting operations - the retained plantation shall also be Moderate risk, younger and more windfirm. The *E.globulus* were assessed as High risk highlighting the potential effect of removing the pines from around them.

The process identified the practical issues of the assessment procedure, in particular the acquisition of the topex reading at each plot was often difficult due to the density of the plantation and therefore the more subjective evaluation (Severely exposed - Very sheltered) was used where necessary.

**Figure 14** - The density of plantations makes the determination of exposure more difficult as views to the horizon are severely limited.

Timberlands Pacific staff did note that the process is ideally suited for implementation during the planning phase of forest operations to help determine relevant silvicultural regimes.

**Figure 15** - Chris Ringk (Timberlands Pacific) conducts a wind risk assessment plot at Stoodley plantation.
Case Study 2
Willow Bend Farm, Wattle Grove
The White family

The White’s family property is 67 hectares (ha) of which 59 ha are currently non-forest, managed for grazing. Due to a reduction in cattle and a desire to improve the property the family has committed themselves to:

- establish and manage eucalypt and blackwood plantations for high value products such as veneer and sawlog;
- exclude livestock, establish streamside revegetation plantings to improve soil, water and visual amenity values;
- maintain native forest.

These operations are to be integrated with the pastoral activities on the property.

The 8ha of native forest is dry sclerophyll and young wattle regrowth, due to their composition and access they shall remain predominantly unmanaged but maintained.

Figure 16 - Views of Willow Bend property looking North from Plot 1 (above) and looking South from Plot 5 (below).

The forest wind risk assessment process was conducted across the whole property. During the assessment process it was noted that although the riparian plantings had not yet grown, assumptions could be made with regard to canopy structures, treatments, etc to ascertain the potential Forest Stand and Treatment Hazard classes.
Figure 17 - Initial planning identifies the property and plot points (yellow markers).

Figure 18 - The majority of the property was classed as moderate wind risk (orange) with the exception of the elevated native forest that was classed as high risk (red) and a small, sheltered area that was classed as low risk (green).

Note the establishment (2007/08) of riparian plantings that should also provide additional shelter for livestock and crops.
High forest wind risk areas - high wind force and low resistance to overturning indicates wind damage is likely to occur at some time. However, as it is located within the elevated native forest area that is planned to remain unmanaged (but maintained) it will not impact on the property plans.

Moderate forest wind risk areas - moderate wind force and a moderate resistance to overturning indicates wind damage could affect the outcome of operational treatments and should be considered. The planned riparian plantings and their management (thinning, non-clearfall, semi-natural) shall be compatible with the predicted wind risk.

Low forest wind risk – low wind force and high resistance to overturning, indicates that wind damage is unlikely to occur and management for windthrow can be considered as a relatively low priority.

2016 update
Chris and Giuliana White prepared a property management plan to integrate trees into their 60 hectare farm. A main aim was to provide windbreak shelter for livestock and pasture. They planned and planted 3 hectares of trees in 2007 and 2008 (Figure 17).

![Willow Bend 2007](image1)

![Willow Bend 2012](image2)

Chris commented that “The trees are benefiting the farm. Cattle tend to gather to find shelter in the lee of the trees. Pastures appear to be far healthier. I expect these benefits to increase as the trees grow.”

![2007 – Cattle had access to streams](image3)

![2013 – Cattle have healthy pasture and shelter. Streams are well protected by trees](image4)
Following the pruning and thinning operations the trees are more susceptible to windthrow due to the raising of centre of gravity and increased exposure. In December 2015 a single *Eucalyptus nitens* blew over in a peak wind event combined with high groundwater levels (reduced soil tear strength):

However, the remaining trees continue to grow healthily and provide greater shelter from the wind.
Case study 3
Norske Skog

During the winter and early spring of 2009 Tasmania had some of the highest rainfall on record; in addition, in late-September Southern Tasmania experienced a series of peak wind events resulting in windthrow throughout the region.

1. Joint venture plantation, Lucaston
   The joint venture plantation at Lucaston consisted primarily of first rotation *Pinus radiata* planted circa 1994 and had been managed for a sawlog (2 thin) regime.

![Figure 19](image1)

*Figure 19* - Satellite imagery identifies the 15 hectares of pine plantation, the plantation was thinned (1:5 outrows, 500sph) in summer 2008-'09.

![Figure 20](image2)

*Figure 20* - The plantation was subject to severe windthrow following the atypical weather events in winter 2009.
Figure 21 - The plantation was classed as moderate wind risk, however the combination of a harvesting event, excessive soil moisture and peak winds has resulted in windthrow that will have to be entirely cleared.

The plantation received the scheduled first thinning operation in summer 2008-'09 following the standard prescription of 1:5 outrows and retention of 500sph. However the combination of a standard harvesting event (creating gaps that wind could access and a reduction in stability of the retained trees), a reduction in soil shear strength (due to excessive soil moisture and poor rooting due to mudstone soils) and peak winds has resulted in a degree of windthrow that shall dictate that the entire plantation shall have to be prematurely harvested.

The wind and stand hazards were assessed as low-moderate, however the peak weather events and a heavy thinning operation (treatment hazard) created a situation of high wind risk.

Radiata pine plantation, Pelham

Figure 22 - Satellite imagery identifies the >1,000 hectares of pine plantation, the recent thinning operations (summer 2008-'09) are clearly evident (1:5 outrows, 500sph).
The joint venture plantation at Lucaston consisted primarily of first rotation *Pinus radiata* planted circa 1994 and had been managed for a sawlog (2 thin) regime.

**Figure 23** - The plantation was subject to sporadic windthrow following the atypical weather events in winter 2009. Note the soil saturation indicated by a very high water table in the hole left by the butt plate (left).

**Figure 24** - The plantation was classed as moderate wind risk, however the combination of a harvesting event, excessive soil moisture and peak winds has resulted in sporadic windthrow that should be retained to maintain crop stability.

The plantation received the scheduled first thinning operation in summer 2008-'09 following the standard prescription of 1:5 outrows and retention of 500sph. However the combination of a standard harvesting event (creating gaps that wind could access and a reduction in stability of the retained trees), a reduction in soil shear strength (due to excessive soil moisture) and peak winds has resulted in sporadic windthrow that should be retained to maintain crop stability.

The wind and stand hazards were assessed as low-moderate, however the peak weather events and a heavy thinning operation (treatment hazard) created a situation of high wind risk.
Operational notes

Although the winter weather of 2009 was not typical and was largely responsible for the windthrow, it was also evident in other Norske Skog plantations eg. Boyer, that where there were adjacent crops of pines that had not been thinned, the level of windthrow was endemic, indicating that the treatment had been the deciding factor of the windthrow.

Future management of the pine plantations should include consideration of the wind risk:

In areas of low wind risk the standard thinning prescriptions should be implemented. In areas of moderate wind risk the standard thinning prescriptions should be heavily scrutinized and should only be implemented with regard to local knowledge and acceptance of the likelihood of windthrow. Alternative lower impact thinning regimes should be considered and attempts to mitigate the effects of wind should be implemented (see ‘Principles to reduce forest wind risk’).

In areas of high wind risk no-thin prescriptions should be considered and low impact thinning regimes should only be implemented with regard to local knowledge and acceptance of the likelihood of windthrow. Attempts to mitigate the effects of wind should be implemented (see ‘Principles to reduce forest wind risk’).
Case study 4
Notley Hills Road, Notley Hills
The McCutchan’s property

The McCutchan’s property is 23 hectares (ha) of which 5ha are native forest and 18ha are mainly pine plantation.

The native forest, due to their composition and structure they are planned for a selective harvest in 2012.

Figure 25 - Satellite imagery of the property showing the harvest boundary (blue line) and the combination of native forest and pine plantation forest types.

Figure 26 - The Forest Practices Plan (FPP) map identifying the various harvesting operations.

Approximately 8ha of the pines are planned for a combination of a clearfall and a thinning operation. The pines are 31 years old, approximately 35-40m tall, 350-380 stems per hectare (sph) and an average diameter at breast height (dbh) range of 40-50cm; due to these characteristics and a
predicted high risk of windthrow, the thinning operation is atypical as most landowners would probably
be advised to, and choose to, clearfall. Gordon, as an ex-forestry professional, is aware of the risks of
thinning the pines, but is willing to take the risk to achieve a higher return from the anticipated growth
of the retained trees.

### Figure 27 - A copy of the completed wind risk assessment form for Gordon’s pines at Notley Hills.

| Appendix 1 |
| Windthrow hazard (WHC), forest stand hazard (FSHC), forest treatment
| hazard (FTHC) and forest wind risk (FWRC) assessment proforma |
| Name: G. M. Curnow
| Location: Notley Hills |
| Tenure: Private |
| Landowner: G. M. Curnow |
| Total area: 120 ha |
| Number of plots: 8 |
| Map Sheet: TAC 1001 |
| Grid Reference: 418399 m E, 522129 m N |
| WHC | Plot 1 | Plot 2 | Plot 3 | Plot 4 | Plot 5 | Plot 6 | Plot 7 | Plot 8 |
| Windiness | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 |
| Elevation | 2 | 2 | 2 | 2 | 4 | 4 | 4 | 3 |
| Exposure | 3 | 3 | 3 | 4 | 6 | 6 | 5 | 4 |
| Soil | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WHC | 14 | 14 | 15 | 19 | 19 | 14 | 16 | 
| FSHC | | | | | | | | 
| Canopy | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| Topography | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Ft/DBH/crown | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Size | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Total score | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 |
| FSHC | | | | | | | | 
| FTHC | | | | | | | | 
| Intensity | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| Scale | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Orientation | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Soil Saturation | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Total score | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 |
| FTHC | | | | | | | | 
| FWRC | | | | | | | | 
| WHC x2 | | | | | | | | 
| FSHC | 5 | | | | | | | 
| FTHC | 4 | | | | | | | 
| Total score | 15 | | | | | | | 
| FWRC | | | | | | | | 

- Forests and Wind Risk in Tasmania www.pft.tas.gov.au
The forest wind risk assessment process was conducted across the whole property in February, 2012 prior to the commencement of the planned harvesting operations. Unsurprisingly, the entire property, stand and treatment were assessed as being high risk. However, Gordon has still continued with his planned harvest operation and harvesting began in March 2012.

It is planned that the harvest operations, climatic events and stand responses shall be monitored and compared to the predicted windthrow, this will help to add a quantitative evaluation to the wind risk assessment process.
Case Study 5
Adam Culley, Frankford

Frankford landowner Adam Culley established a plantation for timber production in 1999, with the assistance and guidance of Private Forests Tasmania staff.

<table>
<thead>
<tr>
<th>Property Facts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name:</td>
</tr>
<tr>
<td>Location:</td>
</tr>
<tr>
<td>Enterprise:</td>
</tr>
<tr>
<td>Property size:</td>
</tr>
<tr>
<td>Average rainfall:</td>
</tr>
<tr>
<td>Soil types:</td>
</tr>
<tr>
<td>Project undertaken:</td>
</tr>
</tbody>
</table>

The plantations have been maintained and managed using standard plantation prescriptions for a quality sawlog regime, including high-lift pruning but no thin-to-waste operation.

In 2013 it was decided that the trees had reached a size that a commercial thinning operation could be carried-out and that the potential final-crop trees would benefit from a reduction in competition.

![Figure 28 - A topographical map of Adam’s property and species layout](image-url)
During autumn-early winter 2013:
1. the pines were first thinned from 1,000 to 550 trees per hectare;
2. the eucalypts were thinned from 550 to 250-300 SPH having been non-commercially thinned at age 4 from 1,200 to 550 SPH.

Thinning operations were suspended in their final stages due to excessive rainfall causing soil saturation and difficult ground conditions. The harvesting was completed when the ground was trafficable.

During late-winter and early spring the thinned plantation experienced some peak wind events that resulted in both windthrow and windsnap of the pines.

Whereas, the eucalypts and cypresses suffered relatively very minor windblow because they were more stable having been thinned earlier and their larger root plates provided anchorage to the ground.
Figure 31 - Adam Culley next to a nice cypress. A few leaning cypress can be seen in the background.

Figure 32 - 8 plots were installed across the property to gain a reasonable Wind Risk assessment of the area.
The majority of the area is classed as Moderate FWRC, with the southern ridgeline being High FWRC:

![Forest Wind Risk Assessment Form](image)

**Figure 33** - The completed Forest Wind Risk assessment form for Adam’s property

![Wind Risk Areas Map](image)

**Figure 34** – Wind Risk Areas
The potential reasons for the pattern and intensity of the windthrow include:

1. The intensity of the thinning operation created a rapid opening of the canopy (high roughness);
2. Inherent morphology of pines renders them more susceptible to catching the wind, whereas the eucalypts are inherently more windfirm;
3. The pines relatively high height/crown/dbh ratio and the cypresses more favourable relative height/spacing;
4. The lack of a thin-to-waste operation;
5. Very high rainfall causing soil saturation, leading to a much reduced soil tear strength; and
6. A peak wind event.

The concentration of the significant windthrow in the south-east is probably due to:

1. The shelter afforded to the pines in the north by the roadside native trees;
2. Maximum soil saturation; and
3. Possible wind funnelling by the power-line easement on the leeward side of the ridge through the property.

Recommendations:

1. Any follow-up operations should not decrease the windfirmness of the remaining trees;
2. Where practicable and viable, the leaning trees should be retained; and
3. Operations should be light and gradual to allow the retained trees to regain their windfirmness, usually over a period of 18 months – 2 years.

Basic strategies for regenerating windfirm stands on moderate-to-high hazard sites includes:

1. Grow trees at wide spacing and no thinning.
2. Grow trees at medium spacing by planting at medium spacing or using early thinning.
3. Grow trees at close spacing and harvesting at onset of windthrow or at a predetermined height.
4. Relative height (Mean dominant height ÷ Average diameter at breast height) should be kept around 40.
5. Relative spacing (Average tree spacing ÷ Mean dominant height) should be kept around the optimum value of .33.
Appendix 1 – BURNIE 9:00am

WIND FREQUENCY ANALYSIS (in km/h)
BURNIE (ROUND HILL) STATION NUMBER 091009
Latitude: -41.08° Longitude: 145.94°

9 am
15209 Total Observations (1965 to 2004)

Calm: 4%

Wind directions are divided into eight compass directions. Calm has no direction.
An asterisk (*) indicates that calm is less than 1%.
An observed wind speed which falls precisely on the boundary between two divisions (eg 10km/h) will be included in the lower range (eg 1-10 km/h). Only quality controlled data have been used.

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Appendix 1 – BURNIE 3:00pm

WIND FREQUENCY ANALYSIS (in km/h)
BURNIE (ROUND HILL) STATION NUMBER 091009
Latitude: -41.68° Longitude: 145.94°

3 yrs
11,502 Total Observations (1955 to 2004)

Calm 1%

Wind directions are divided into eight compass directions. Calm has no direction.
An asterisk (*) indicates that calm is less than 1%.
An observed wind speed which falls precisely on the boundary between two divisions (eg 10 km/h) will be included in the
lower range (eg 1-10 km/h). Only quality controlled data have been used.

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Appendix 1 – ST HELENS 9:00am

WIND FREQUENCY ANALYSIS (in km/h)
ST HELENS POST OFFICE STATION NUMBER 092333
Latitude: 41.32° Longitude: 146.25°

9 June
13340 Total Observations (1957 to 2001)

Calm 22%

Wind directions are divided into eight compass directions. Calm has no direction.
An asterisk (*) indicates that calm is less than 1%.
An observed wind speed which falls precisely on the boundary between two divisions (eg. 10km/h) will be included in the lower range (eg 1-10 km/h). Only quality controlled data have been used.

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Appendix 1 – ST HELENS 3:00pm

WIND FREQUENCY ANALYSIS (in km/h)
ST HELENS POST OFFICE STATION NUMBER 692033
Latitude: -11.12° Longitude: 148.25°

3 pm
11986 Total Observations (1957 to 2001)

Calm 5%

Wind directions are divided into eight compass directions. Calm has no direction.
An asterisk (*) indicates that calm is less than 1%.
An observed wind speed which falls precisely on the boundary between two divisions (eg. 10 km/h) will be included in the lower range (eg. 1-10 km/h). Only quality controlled data have been used.

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Appendix 1 – LAUNCESTON 9:00am

WIND FREQUENCY ANALYSIS (in km/h)
LAUNCESTON AIRPORT COMPARISON STATION NUMBER 091104
Latitude: 41.54°  Longitude: 147.20°

9am
22769 Total Observations (1939 to 2004)

Calm 16%

Wind directions are divided into eight compass directions. Calm has no direction.
An asterisk (*) indicates that calm is less than 1%.
An observed wind speed which falls precisely on the boundary between two divisions (eg 10km/h) will be included in the lower range (eg 0-10 km/h). Only quality controlled data have been used.

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Appendix 1 – LAUNCESTON 3:00pm

WIND FREQUENCY ANALYSIS (in km/h)
LAUNCESTON AIRPORT COMPARISON  STATION NUMBER 091104
Latitude: -41.64° Longitude: 147.20°

3 pm: 2274 Total Observations (1939 to 2004)

Calm 5%

Wind directions are divided into eight compass directions. Calm has no direction.
An asterisk (*) indicates that calm is less than 1%.
An observed wind speed which falls precisely on the boundary between two divisions (eg 10km/h) will be included in the lower range (eg 1-10 km/h). Only quality controlled data have been used.

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Forests and Wind Risk in Tasmania www.pft.tas.gov.au
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Appendix 1 – HOBART 9:00am

WIND FREQUENCY ANALYSIS (in km/h)
HOBART AIRPORT STATION NUMBER 094008
Latitude: 42.84 Longitude: 147.60

9 am
16027 Total Observations (1938 to 2004)

Calm 8%

Wind directions are divided into eight compass directions. Calm has no direction.
An asterisk (*) indicates that calm is less than 1%.
An observed wind speed which falls precisely on the boundary between two divisions (eg. 10km/h) will be included in the lower range (eg 0-10 km/h). Only quality controlled data have been used.

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Appendix 1 – HOBART 3:00pm

WIND FREQUENCY ANALYSIS (in km/h)
HOBART AIRPORT  STATION NUMBER 094008
Latitude: -42.84°  Longitude: 147.50°

3 pm
16024 Total Observations (1958 to 2004)

Calm 3%

Wind directions are divided into eight compass directions. Calm has no direction.
An asterisk (*) indicates that calm is less than 1%.
An observed wind speed which falls precisely on the boundary between two divisions (eg 10km/h) will be included in the lower range (eg 1-10 km/h). Only quality controlled data have been used.

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Appendix 1 – CAPE SORRELL 9:00am

WIND FREQUENCY ANALYSIS (in km/h)
CAPE SORRELL  STATION NUMBER 097000
Latitude: -42.50° Longitude: 145.17°

9 km
8020 Total Observations (1957 to 2004)

Calm 2%

Wind directions are divided into eight compass directions. Calm has no direction.
An asterisk (*) indicates that calm is less than 1%.
An observed wind speed which falls precisely on the boundary between two divisions (eg 10km/h) will be included in the lower range (eg 1-10 km/h). Only quality controlled data have been used.

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Appendix 1 – CAPE SORRELL 3:00pm

WIND FREQUENCY ANALYSIS (in km/h)
CAPE SORRELL STATION NUMBER 097000
Latitude: -42.20° Longitude: 145.17°

3 pm
7923 Total Observations (1957 to 2004)

Calm 1%

Wind directions are divided into eight compass directions. Calm has no direction.
An asterisk (*) indicates that calm is less than 1%.
An observed wind speed which falls precisely on the boundary between two divisions (eg. 10km/h) will be included in the
closer range (eg. 0-10 km/h). Only quality controlled data have been used.

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provide any warranty nor accept any liability for this information.
Appendix 1 – STRATHGORDON 9:00am

Wind directions are divided into eight compass directions. Calm has no direction.
An asterisk (*) indicates that calm is less than 1%.
An observed wind speed which falls precisely on the boundary between two divisions (eg 10km/h) will be included in the lower range (eg 1-10km/h). Only quality controlled data have been used.
Appendix 1 – STRATHGORDON 3:00pm

WIND FREQUENCY ANALYSIS (in km/h)
STRATHGORDON VILLAGE STATION NUMBER 697053
Latitude: -42.77° Longitude: 146.04°

3003 Total Observations (1970 to 2003)
Calm 10%

Wind directions are divided into eight compass directions. Calm has no direction.
An asterisk (*) indicates that calm is less than 1%.
An observed wind speed which falls precisely on the boundary between two divisions (eg. 10km/h) will be included in the lower range (eg. 5-10 km/h). Only quality controlled data have been used.

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Landscape character and wind zones of Tasmania

NB- due to familiarity and relevance, the following section has been largely adapted from the classification of landscape types within 'A Manual for Forest Landscape Management', Forest Practice Authority, 2006; to which further reference should be made.

Tasmania was divided into broad landscape regions, each having an identifiable landscape character. Each region (Figure 35) is an "area of land with common distinguishing (visual) characteristics of landform, rock formations, water forms and vegetative patterns" and elevation. These distinct landscape characters have a direct influence on the exposure, wind patterns and wind zones of Tasmania.

The landscape character helps to develop the generic wind zones across Tasmania. The landscape character should be reassessed where local knowledge indicates that the description is too broad, diverse or where local variances are known to influence wind patterns, for example: coastlines including lakes, >500m altitude, localised funnelling, flat even land with few or no obstacles, etc.

Figure 35 - Landscape character regions

North-west Plains and Slopes:
This is a sloping plateau, which rises from the coastal plains in the north and west up to 600m hills in the south-east. Rivers cut deeply into the slopes, creating gorges towards the west.

North-west Hills and Plains:
In the north, there are rolling coastal plains isolated hills throughout. Inland, the foothills rise towards the mountains in the south. A small plateau at 700m occurs in the south-west. The Forth River flows northward through a deeply incised valley, where it has been dammed to form three elongated lakes.
Northern Plains:
The area is characterized by the dry grasslands of extensive low (0-200m) plains of the Northern Midlands that have flat even land with few obstacles to reduce the effects of the wind, resulting in an area often subjected to high exposure.
In addition, the broad river drainages and flooded estuary of the Tamar that is indented deeply into the coastline create localised sites subject to funnelling that can require special consideration.

North-east Coastal Hills:
This coastal region with flat to undulating terrain. Coastal sclerophyll woodlands and heathlands, with native-grassland openings throughout the woodlands. Clearings have been made for grazing along most of the coastline.

North-east Highlands & Eastern Hills:
This is a region of steep to undulating hills and mountains, some with rocky mountain peaks. Clifflined mountains, some rising to 1,400m, are features in the west. Rivers and streams are numerous.
The Eastern Hills are dominated dry, regularly burnt, woodlands and forests on mountain tiers and sugarloaves.

Southern & Eastern Plains and Hills:
The area is characterized by the dry grasslands of extensive low-moderate (0-400m) plains of the Southern Midlands and East Coast that have flat, even land with few obstacles to reduce the effects of the wind, resulting in an area often subjected to high exposure.
In addition, the broad river drainages and flooded estuary of the Derwent that is indented deeply into the coastline, create localised sites subject to funnelling that can require special consideration.
There are isolated mountain peaks and ranges, that influence the wind patterns, creating funnelling, shelter and exposure, dictates that the very diverse landscape should be critically evaluated to assess the influence of local variances.

Central Plateau:
This plateau drops from 1,200m in the north through a series of steps to 800m in the south. There are major peaks in the northwest of the plateau and distinctive cliff-lined escarpments form the boundaries in the west, north and east.
The combination of the extreme altitude and the predominant exposed, undulating rock across the whole area with few major obstacles, results in an area that is subjected to high exposure. Lake edges with a length exposed to the wind of at least 5km are particularly prone to high exposure.

High Mountains:
This is a continuous elongated area of rugged highland landscape running north-south through the centre of the State. It is typified by highly glaciated mountain peaks, ranges and highland lakes. This area is a very diverse landscape and should be critically evaluated to assess the influence of local variances.

South-east Coastal Hills:
This coastal region is centred on Storm Bay and the Huon and Derwent estuaries. Steep, isolated hills and foothills rise to the mountain ranges to the west.
This area is a very diverse landscape that is heavily affected by coastal wind patterns and should be critically evaluated to assess the influence of local variances.

Coastlines:
This is the coastal zone encircling the State. It varies considerably in width and landforms, from extensive sand beaches and dunes, rocky headlands and capes, to sandy bays and sheltered water bodies and coastal lagoons.
Due to the potential of all coastal sites to be subjected to high exposure, all sites within 5km of the coast will require special consideration.
Figure 36 – Mean annual wind speed and frequency
Figure 37 – Wind Zones of Tasmania
Figure 38 – Wind Zone Map of Tasmania

Green = Moderate
Yellow = Heavy
Red = Extra heavy
Appendix 2

Windthrow hazard (WHC), forest stand hazard (FSHC), forest treatment hazard (FTHC) and forest wind risk (FWRC) assessment proforma

<table>
<thead>
<tr>
<th>WHC</th>
<th>Plot 1</th>
<th>Plot 2</th>
<th>Plot 3</th>
<th>Plot 4</th>
<th>Plot 5</th>
<th>Plot 6</th>
<th>Plot 7</th>
<th>Plot 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Windiness</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elevation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exposure</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total score</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WHC =</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| FSHC         |        |        |        |        |        |        |        |        |
| Canopy       |        |        |        |        |        |        |        |        |
| Topography   |        |        |        |        |        |        |        |        |
| Ht/DBH/crown |        |        |        |        |        |        |        |        |
| Size         |        |        |        |        |        |        |        |        |
| Total score  |        |        |        |        |        |        |        |        |
| FSHC =       |        |        |        |        |        |        |        |        |

| FTHC         |        |        |        |        |        |        |        |        |
| Intensity    |        |        |        |        |        |        |        |        |
| Scale        |        |        |        |        |        |        |        |        |
| Orientation  |        |        |        |        |        |        |        |        |
| Soil Saturation |    |        |        |        |        |        |        |        |
| Total score  |        |        |        |        |        |        |        |        |
| FTHC =       |        |        |        |        |        |        |        |        |

| FWRC         |        |        |        |        |        |        |        |        |
| WHC x2       |        |        |        |        |        |        |        |        |
| FSHC         |        |        |        |        |        |        |        |        |
| FTHC         |        |        |        |        |        |        |        |        |
| Total score  |        |        |        |        |        |        |        |        |
| FWRC =       |        |        |        |        |        |        |        |        |
WHC (Windthrow Hazard)

1. Windiness

<table>
<thead>
<tr>
<th>Score</th>
<th>High</th>
<th>Moderate</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>13</td>
<td>7.5</td>
<td>0</td>
</tr>
</tbody>
</table>

2. Elevation (m)

<table>
<thead>
<tr>
<th>Elevation</th>
<th>Score</th>
<th>Elevation</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>541 +</td>
<td>10</td>
<td>191 – 256</td>
<td>2</td>
</tr>
<tr>
<td>406 – 540</td>
<td>8</td>
<td>61 – 190</td>
<td>.5</td>
</tr>
<tr>
<td>316 – 405</td>
<td>6</td>
<td>0 – 60</td>
<td>0</td>
</tr>
<tr>
<td>256 - 315</td>
<td>4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. Exposure

<table>
<thead>
<tr>
<th>Topex Total</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Severely exposed</td>
<td>0 – 10</td>
</tr>
<tr>
<td>Very exposed</td>
<td>11 – 30</td>
</tr>
<tr>
<td>Moderately exposed</td>
<td>31 - 60</td>
</tr>
<tr>
<td>Moderately sheltered</td>
<td>61 – 100</td>
</tr>
<tr>
<td>Very sheltered</td>
<td>100 +</td>
</tr>
</tbody>
</table>

4. Soil

<table>
<thead>
<tr>
<th>Root Development</th>
<th>Score</th>
<th>Soil Character</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unrestricted rooting in excess of 100cm</td>
<td>0</td>
<td>Deep brown earths, podzols, loams</td>
</tr>
<tr>
<td>Restricted but some penetration in excess of 45cm</td>
<td>5</td>
<td>Moderate depth peats, gleys</td>
</tr>
<tr>
<td>Very restricted rooting under 45cm deep</td>
<td>10</td>
<td>Shallow, indurated, waterlogged</td>
</tr>
</tbody>
</table>

5. Derivation of WHC

<table>
<thead>
<tr>
<th>Total Score</th>
<th>Windthrow Hazard Class</th>
<th>Total Score</th>
<th>Windthrow Hazard Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to 8.0</td>
<td>1</td>
<td>19.5 – 24.5</td>
<td>4</td>
</tr>
<tr>
<td>8.0 – 13.5</td>
<td>2</td>
<td>25.0 - 30.0</td>
<td>5</td>
</tr>
<tr>
<td>14.0 – 19.0</td>
<td>3</td>
<td>Over 30.5</td>
<td>6</td>
</tr>
</tbody>
</table>

FSHC (Forest Stand Hazard)

1. Canopy roughness and uniformity

<table>
<thead>
<tr>
<th>Canopy</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Even, dense (eg unthinned plantation)</td>
<td>10</td>
</tr>
<tr>
<td>Even, dense with emergents (eg mixed forest)</td>
<td>5</td>
</tr>
<tr>
<td>Uneven, open (eg dry sclerophyll)</td>
<td>0</td>
</tr>
</tbody>
</table>

2. Prevailing wind and topography

<table>
<thead>
<tr>
<th>Prevailing Wind and topography</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>0</td>
</tr>
<tr>
<td>Moderate</td>
<td>5</td>
</tr>
<tr>
<td>High</td>
<td>10</td>
</tr>
</tbody>
</table>
3. Height, diameter & crown

<table>
<thead>
<tr>
<th>Height to Diameter</th>
<th>Score</th>
<th>Crown Depth</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height-to-diameter ratio &lt;60</td>
<td>0</td>
<td>Crown depth ratio &gt; 35%</td>
<td>0</td>
</tr>
<tr>
<td>Height-to-diameter ratio 60 - 90</td>
<td>3 PLUS</td>
<td>Crown depth ratio 20 – 35 %</td>
<td>3</td>
</tr>
<tr>
<td>Height-to-diameter ratio &gt;90</td>
<td>5</td>
<td>Crown depth ratio &lt; 20%</td>
<td>5</td>
</tr>
</tbody>
</table>

4. Shape and size of a stand of trees

<table>
<thead>
<tr>
<th>Size</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 50m wide</td>
<td>10</td>
</tr>
<tr>
<td>50 – 100m wide</td>
<td>5</td>
</tr>
<tr>
<td>Greater than 100m wide</td>
<td>0</td>
</tr>
</tbody>
</table>

5. Derivation of FSHC

<table>
<thead>
<tr>
<th>Total Score</th>
<th>Forest Stand Hazard Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to 8.0</td>
<td>1</td>
</tr>
<tr>
<td>8.0 – 13.5</td>
<td>2</td>
</tr>
<tr>
<td>14.0 – 19.0</td>
<td>3</td>
</tr>
<tr>
<td>19.5 – 24.5</td>
<td>4</td>
</tr>
<tr>
<td>25.0 – 30.0</td>
<td>5</td>
</tr>
<tr>
<td>Over 30</td>
<td>6</td>
</tr>
</tbody>
</table>

FTHC (Forest Treatment Hazard)

1. Intensity of proposed operation

<table>
<thead>
<tr>
<th>Intensity</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low (eg. respacing, chemical thinning)</td>
<td>0</td>
</tr>
<tr>
<td>Moderate (eg. fertilising, light thinning)</td>
<td>5</td>
</tr>
<tr>
<td>High (eg. heavy thinning, clearfall )</td>
<td>10</td>
</tr>
</tbody>
</table>

2. Scale of operation

<table>
<thead>
<tr>
<th>Scale</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low &lt;1Ha</td>
<td>0</td>
</tr>
<tr>
<td>Moderate 1 – 5ha</td>
<td>5</td>
</tr>
<tr>
<td>High &gt;5ha</td>
<td>10</td>
</tr>
</tbody>
</table>

3. Orientation to prevailing wind

<table>
<thead>
<tr>
<th>Orientation</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low - parallel to prevailing wind</td>
<td>0</td>
</tr>
<tr>
<td>Moderate - 45° to prevailing wind</td>
<td>5</td>
</tr>
<tr>
<td>High - 90° to prevailing wind</td>
<td>10</td>
</tr>
</tbody>
</table>
4. Soil saturation and strong winds

<table>
<thead>
<tr>
<th>Soil Saturation</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low - soil not prone to saturation</td>
<td>0</td>
</tr>
<tr>
<td>Moderate - soil prone to saturation (dry season only)</td>
<td>5</td>
</tr>
<tr>
<td>High - soil prone to saturation &amp; poorly scheduled</td>
<td>10</td>
</tr>
</tbody>
</table>

5. Derivation of FTHC

<table>
<thead>
<tr>
<th>Total Score</th>
<th>Forest Treatment Hazard Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to 8.0</td>
<td>1</td>
</tr>
<tr>
<td>8.5 – 13.5</td>
<td>2</td>
</tr>
<tr>
<td>14.0 – 19.0</td>
<td>3</td>
</tr>
<tr>
<td>19.5 – 24.5</td>
<td>4</td>
</tr>
<tr>
<td>25.0 – 30.0</td>
<td>5</td>
</tr>
<tr>
<td>Over 30.5</td>
<td>6</td>
</tr>
</tbody>
</table>

FWRC (Forest Wind Risk)

1. Derivation of forest wind risk class

The scores for windthrow hazard (WHC X2), forest stand hazard (FSHC) and the forest treatment hazard (FTHC) are added to give a total score for forest wind risk class (FWRC).

<table>
<thead>
<tr>
<th>Total Score</th>
<th>Forest Wind Risk Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to 9 points</td>
<td>Low</td>
</tr>
<tr>
<td>10 – 13 points</td>
<td>Moderate</td>
</tr>
<tr>
<td>Greater than 13 points</td>
<td>High</td>
</tr>
</tbody>
</table>
Appendix 3

Windthrow monitoring procedures and data forms (from Strathers et al, 1994)

Windthrow monitoring procedures

Clearcut edges
Divide the perimeter of an opening into 15-30 segments of equal size. Randomly locate a 0.05 hectare (12.6 meter radius) circular plot in each segment. The outside edge of the plot should touch the original opening boundary. Record plot location, soil, topographic and standing tree characteristics. Record the attributes of any windthrow or windsnap whose point of germination is in the plot (see sample data sheet page 58).

Partial cuts
Two alternative monitoring systems are offered. For units with detailed timber cruise and soils maps and data, it may be necessary only to record the attributes and location of windthrow. Systematically locate strip plots 10 meters wide across the full width of the unit. Orient the strips so that they are non-parallel to slope and prevailing storm wind direction. Existing cruise strips may make good centerlines. Record strip length. Tally, map and record the attributes of any windthrow or windsnap whose point of germination is in the strip.

Alternatively, systematically locate 0.05 hectare circular plots ensuring good coverage of the unit. Record soil, topographic and standing tree characteristics. Record the attributes of any windthrow or windsnap whose point of germination is in the plot.
## Windthrow Monitoring – Example Plot Sheet

<table>
<thead>
<tr>
<th>District:</th>
<th>License:</th>
<th>C.P:</th>
<th>Block:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boundary Section:</td>
<td>Plot Size</td>
<td>Surveyor</td>
<td>Date:</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Plot 1</th>
<th>Plot 2</th>
<th>Plot 3</th>
<th>Plot 4</th>
<th>Plot 5</th>
<th>Plot 6</th>
<th>Plot 7</th>
<th>Plot 8</th>
</tr>
</thead>
</table>

- **Boundary shape:**
- **Boundary aspect:**
- **Valley orientation:**
- **Plot aspect:**
- **Plot slope:**
- **Plot elevation:**
- **Slope position:**
- **Eco. Association:**
- **Soil profile:** (Forest soils of Tasmania)
- **Rooting depth:**
- **Depth impeding layer:**
- **Type impeding layer:**

**№ of standing trees:**
- Snag
- Veteran
- Dominant
- Co-dominant
- Intermediate
- Suppressed

**% species composition**

**№ of windthrown trees:**
- Snag
- Veteran
- Dominant
- Co-dominant
- Intermediate
- Suppressed

**% species composition**

**№ of windsnapped trees:**
- Snag
<table>
<thead>
<tr>
<th>Veteran</th>
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<td>Dominant</td>
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<tr>
<td>Suppressed</td>
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<tr>
<td>% species composition</td>
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<tr>
<td>Root rot</td>
<td></td>
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<tr>
<td>Tree health</td>
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<tr>
<td>Wind Hazard class</td>
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Comments:
### Appendix 3 – continued

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<th>C.P:</th>
<th>Block:</th>
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<tbody>
<tr>
<td>Boundary Section:</td>
<td>Plot size:</td>
<td>Surveyor:</td>
<td>Date:</td>
</tr>
</tbody>
</table>

#### Wind force indicators

**Topographic exposure:**
- □ Crest
- □ Bowl
- □ Valley bottom perpendicular to prevailing wind
- □ Saddle
- □ Upper slope
- □ Shoulder

**Boundary orientation:**
- □ Windward
- □ Sub-parallel
- □ Lee

**Stand attributes:**
- □ Uniform – high density
- □ Uniform – moderate density
- □ Uniform – low density
- □ Uneven – high density
- □ Uneven – moderate density
- □ Uneven – low density
- □ Taller than average
- □ Intermediate
- □ Shorter than average

**Tree attributes:**
- □ Taller than average
- □ Intermediate
- □ Shorter than average
- □ Large dense crowns
- □ Moderately dense crowns
- □ Small open crowns

#### Overturning resistance indicators

**Tree attributes:**
- □ Low taper
- □ Moderate taper
- □ High taper
- □ No butt flare
- □ Moderate butt flare
- □ Large butt flare
- □ Root or stem rot
- □ No root or stem rot

**Rooting depth:**
- □ Shallow (<.4m)
- □ Moderate (.4-.8m)
- □ Deep (> .8m)

**Soil drainage:**
- □ Poor
- □ Imperfect
- □ Imperfect
- □ Good

#### Other indicators

**Windthrow in stand:**
- □ Extensive
- □ Moderate
- □ Minor
- □ None

**Windthrow along adjacent edges:**
- □ Extensive
- □ Moderate
- □ Minor
- □ None

**Pit and mound microtopography:**
- □ Extensive
- □ Moderate
- □ Minor
- □ None
<table>
<thead>
<tr>
<th></th>
<th>Low</th>
<th>Moderate</th>
<th>High</th>
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</thead>
</table>

Forms from Strathers et al (1994)
Bibliography


Smith, R.S. (2002). Tolerance and tree development. Greening Australia Queensland, Brisbane

