Arboricultural Statement

Quantified Tree Risk Assessment
Fig trees in Laman Street, Cooks Hill - Newcastle

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Prepared for: Newcastle City Council

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1 Name and Address of Consultant

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2 Qualifications and Experience

2.1 Bachelor of Applied Science, Horticulture (Plant Production) – University of Melbourne, Burnley College.

2.2 Diploma of Applied Science, Horticulture (Arboriculture) – University of Melbourne, Burnley College (Dux of Arboriculture).

2.3 22 years experience in the arboriculture/horticulture industry (private and local government experience).

2.4 Manager of Arboriculture and tree management – Royal Botanic Gardens, Melbourne (27 Months 1997-1999).

2.5 Consultant Arborist at Tree Logic Pty Ltd since June 1999 and Director since 2003.

2.6 Knox City Council consulting arborist on planning issues from March 2000 to June 2005.

2.7 Major projects managed and completed include:

- Royal Botanic Gardens, Sydney & Domain - including Government House (2006). Full tree inventory and management report.
- Centennial Parklands, Sydney - Full tree inventory (2006)
- Adelaide Botanic Gardens and Botanic Park – Full tree inventory and management report (May 2004).

2.8 Secretary for the Victorian Tree Industry Organisation (VTIO).

3 Area of expertise

3.1 My qualifications and experience have primarily involved the management of tree issues in the urban landscape. Specifically, this has involved hazard and general assessment of tree condition on private and public land with recommendations made on preservation strategies or remedial works.

4 Expertise to make the report

4.1 Tree assessments to establish tree health, tree structure and arboricultural values are core components of Treelogic's business activities.

4.2 I have experience at Victorian Civil Administrative Tribunal and the magistrate's court as an expert witness on arboricultural matters.

4.3 I have performed training and I am licensed to perform Quantified Tree Risk Assessments (Licence No. 809) using the method developed by Quantified Tree Risk Assessment Ltd.

5 Instructions

5.1 The instructions provided to Treelogic by Philip Hewett - City Arborist, Liveable City - Infrastructure Management Services on 31 August, 2009 were to provide a report that quantifies the risk for a group of trees in Laman Street, Cooks Hill – Newcastle. The report was specifically commissioned towards a group of some 14 Fig trees located on both sides of the street, between Darby Street and Dawson Street.

5.2 Mr Hewett provided general and specific background information on the subject trees and site conditions to assist with the risk assessment.

6 Reference materials

6.1 Report by Dennis Marsden, Consulting Arborist for The Sugar Factory – Arbor Advocate titled "Assessment of Hill's Weeping Fig *Ficus microcarpa* var. *hillii* In Civic Cultural Precinct, Laman Street Cooks Hill, Newcastle", Dated 7 August, 2009.

6.2 Art Gallery attendance figures for 2008 and part of 2009 supplied by Philip Hewett - City Arborist, Liveable City - Infrastructure Management Services.

6.3 Annual Library attendance figures supplied by Philip Hewett - City Arborist, Liveable City - Infrastructure Management Services.

6.4 Motor vehicle weekly count for December 2002 supplied by Philip Hewett - City Arborist, Liveable City - Infrastructure Management Services.

6.5 Ellison, M.J. 2005. Quantified Tree Risk Assessment Used In The Management Of Amenity Trees. Journal of Arboriculture 31(2):57-64.

6.6 Ellison, M. J. 2009. Quantified Tree Risk Assessment - User Manual, Quantified Tree Risk Assessment Ltd, Australian version.

6.7 Australian Standard - AS/NZ 4360 -2004, Risk Management. Standards Australia

6.8 Statewide Mutual, '*Trees and Tree Root Management*' Best Practice Manual, Version 2, May 2003. NSW. Australia.

6.9 Helliwell, D. R. 1990. Acceptable Level of Risk Associated with Trees. Arboric. Jour. Vol. 14 No. 2:159-162.

6.10 Henderson, M. 1987. Living with Risk. The British Medical Association Guide. John Wiley and Sons, Chichester.

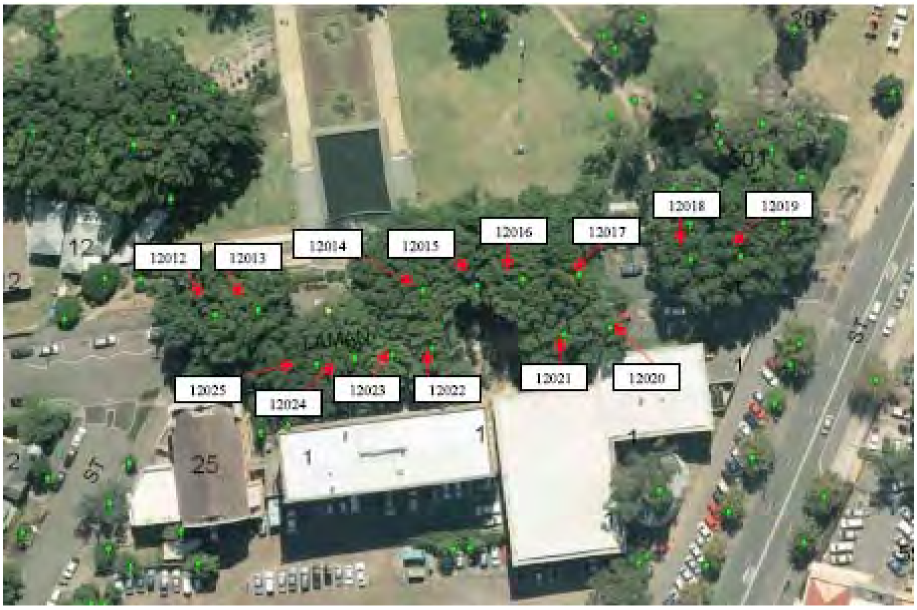
6.11 Bureau of meteorology weather information, Australian Government.

7 Background

7.1 Two mature *Ficus microcarpa* var. *hillii* (Hill's Figs) within the group failed in June 2007. The tree failures were caused by root plate failure and probably exacerbated by unusual weather conditions. Bureau of meteorology data indicates that the period of time when the failures occurred was characterised by strong winds and heavy rain. Strong winds and heavy rain provide circumstances where trees with existing stability issues are more at risk of failure. However, it is also true that storm conditions can result in tree and branch failures with trees without significant structural deficiencies.

7.2 The Fig tree group has been the focus of numerous investigations and reports over recent years and the bulk of these assessments have been conducted by Dennis Marsden, Consulting Arborist for The Sugar Factory. Mr Marsden has more recently provided a comprehensive assessment and report detailing the deficiencies of the group and concludes that there is a heightened risk of further tree failures during storm events and that the group will ostensibly require removal within the next 5-15 years. However, it is conceded in the most recent report that trees requiring removal in the shorter timeframe will largely dictate the removal of remaining trees because the nature of the planting, and tree growth characteristics, provides interdependency and cohesiveness of trees against prevailing wind patterns. In other words, there is reliance by each tree in the group on the entire canopy mass to share wind loading.

7.3 The following image illustrates the trees under review and the context of their location.



From Marsden (2009)

7.4 The foundation for much of Mr Marsden's findings on potential root instability was determined through root investigations performed in 2006. The investigation demonstrated that the root pattern for the subject trees was predominantly lineal rather than radial or symmetric. The investigation also revealed that there has been ongoing interference to roots through service installations and streetscape redesign over the life of the trees.

8 Introduction

8.1 The methods and concepts involved in tree risk management have improved significantly over the last 10 years as the discipline continues to borrow strategies from more risk aware industries and other disciplines. This has resulted in a shift away from defect driven assessments towards target focused assessments. The shift to target led assessments is supported by the fact that when no significant target is present, then there can be no significant risk of harm. For a tree-failure hazard to exist there must be potential for failure of the tree, and potential for injury or damage to result from failure. In urban situations, there will be a wide variety of situations where the value of targets in the vicinity of trees is vastly different. Risk management needs to be considerate of these variations so it may apply appropriate risk minimisation strategies.

8.2 The Laman Street Figs are located in a prominent section of the city and it is certain that interest will be high towards any management options proposed for the trees. The profile of these trees demands a risk management approach that is rigorous in its approach to define the potential risks of maintaining the trees. The adopted method should also be consistent with current best practice risk assessment methods and be presented in a language that is universal in its understanding. To this end, it is proposed that the trees be assessed using a quantitative risk assessment method. This approach is consistent with Australian Standard - AS/NZ 4360 -2004, Risk Management, Standards Australia where it discusses the types of analysis to analyse risks (Section 3.4.4, page 18). It is also referred to within the Trees and tree root management best practice manual produced by Statewide Mutual (Version 2, May 2003), where it states under Section 3.1 that the degree of probability of occurrence should be taken into consideration.

9 How Quantified Tree Risk Assessment works

9.1 An introduction to the Quantified Tree Risk Assessment System is provided as Appendix 1. This document has been produced by the developers of the system. In addition to this introductory document, the journal article that put forward the system is attached (Appendix 2) to provide a more detailed explanation of the method.

9.2 Fundamentally, the system relies on multiplying three components to arrive at a score of between 0 and 1, where 0 equals no opportunity for an event to occur and 1 equals certainty of an event occurring. It is also acceptable to provide the score as a fraction or ratio (eg. 1/100 or 1:100), which seems easier to understand because it translates well to frequently published information about the risk of certain events occurring (as indicated below).

Activity	Risk of an individual dying in any one year
Smoking 10 cigarettes a day	1 in 200
Influenza	1 in 500
Road accident	1 in 8,000
Playing football	1 in 25,000
Accident at home	1 in 26,000
Accident at work	1 in 43,000
Hit by lighting	1 in 10,000,000
Release of radiation from nearby nuclear power station	1 in 10,000,000

Table 1. (“Living with Risk“, British Medical Association, 1987)

9.3 The following excerpt has been extracted from the introductory document on the Quantified Tree Risk Assessment System (Appendix 1). It provides some guidance on establishing a level of acceptable risk for management to consider. The Quantified Tree Risk Assessment System adopts a ratio of 1:10,000 as a guide for users of the system. However, it is acceptable to adjust this level according to a persons or organisation’s willingness to accept lower or higher risk.

‘Having considered The British Medical Association Guide "Living with Risk" (Henderson 1987) and with particular reference to the conclusion "few people would commit their own resources to reduce an annual risk of death that was already as low as 1/10,000", Rodney Helliwell (Helliwell 1990) suggests that 1/10,000 might be a suitable figure to start with as a limit of acceptable risk. The UK Health and Safety Executive (HSE) suggests, "For members of the public who have a risk imposed on them 'in the wider interest' HSE would set this limit at 1/10,000 per annum" (Health and Safety

Executive 1996). In the management of trees, a property owner or manager might therefore adopt the 1/10,000 limit of acceptable risk or choose to operate to a higher or lower level'.

9.4 The primary components of a Quantified Tree Risk Assessment (QTRA) include the assessment of annual target frequency or target value; determining the impact potential of the stem or branch and determining the annual probability that a tree or branch will fail. Thus the calculation becomes:

	Target value **X** Impact potential **X** Probability of failure **=** Risk of harm
Probability	?/? ?/? ?/? ?/?

10 QTRA calculations

10.1 An assumption in this report is that all trees within the group are of a similar size, similar condition and that they are growing in similar conditions. This is clearly not the case for one of the trees in the group because it is a different species (Tree 12015). The subject tree is also suppressed and smaller in size and would probably present a different risk to the remaining group. The subject tree is not included in the remaining calculations.

10.2 With regard to the remaining trees, it is assumed that they present a similar degree of risk as each other because of their size, age, condition and growing environment similarities. Therefore, the final calculation will basically apply to each tree.

10.3 Target evaluation

There are three types of target present in relation to the subject trees: pedestrians, moving vehicles and fixed property (vehicles and buildings). The site is a heavily trafficked area because of its proximity to educational institutions, the Newcastle business district and civic services. Before any calculations or data are analysed, people/pedestrians/visitors would be assumed to be at the greatest risk from a failure event. In this respect, the focus of the calculation has been restricted to people rather than property damage.

<u>People</u>
The data provided for measuring the amount of pedestrian traffic is based on visitation to the Gallery and Library as well as vehicle counts.

The following data has been supplied by officers of Newcastle City Council
Annual average attendance to Gallery = 72,155
Annual average attendance to Library = 360,000

Beyond these figures, I believe that there would probably be pedestrian traffic that simply passes through Laman Street without visiting the Gallery or Library. This could be estimated at levels equivalent with or greater than the number of people who visit the library each year. For the purposes of the calculation, I have estimated an additional 50% of pedestrians rather than 100% of the library visitor numbers.

Annual average estimated walkthrough pedestrians = 216,077

Total number of walking pedestrians per annum (Based on gallery, library and walkthrough pedestrians) = 648,232
Divided by 365 days = 1776 per day

Each one of the pedestrians is exposed to the area beneath a single tree (20 lineal metres, average crown width) for approximately 14.4 seconds if they walk at 5km/h (average walking speed). The number of pedestrians per day multiplied by the exposure time in seconds is

25,574 seconds. This equates to approximately 0.296 of the total number of seconds in a day (86,400), which results in a probability score of 1/3.38 for target rating.

In addition to this, vehicles containing people would pass beneath the trees each day. Based on figures from the UK, vehicle occupancy is approximately 1.6 persons per vehicle. This number is consistent with Australian road management organisation statistics.

Average yearly vehicle numbers for Laman Street = 877,095
Average daily vehicle numbers for Laman Street = 2403

Multiplied by 1.6 persons per vehicle = 3844

Travelling at 40 km/h, it would take each vehicle 1.8 seconds to pass through the exposure zone of a single tree (20 lineal metres), which equates to an additional 6919 seconds of total exposure time.

Total exposure time for all pedestrians and vehicle occupants = 32,671 seconds.

A more comprehensive assessment of pedestrian and visitor attendances to the precinct would be likely to result in an even higher probability score for target rating. Special events, tours and festivals are likely to add significant numbers to the total exposure time.

The target rating probability score for pedestrians and vehicle occupants is calculated at 1/2.64

<u>Impact potential</u>
The Quantified Tree Risk Assessment System calculates impact potential on the basis of the size/diameter of the tree part most likely to fail. The range includes branches or stems between 10mm and 600mm. The upper limit of 600mm is used in the system on the basis that a branch or stem at or beyond this size will have a 1/1 probability of causing maximum possible damage to most frequently encountered targets. The main target in this equation is people and the likelihood of maximum possible damage holds true should a branch or stem of this size impact a person.

The risk of total tree failure with the subject trees appears to be the most likely event, given the history of the group. If total tree failure occurs, the subject trees are all of a size that attracts a probability score of 1/1.

The impact potential probability score is based on total tree failure and is calculated at 1/1

<u>Probability of failure</u>
The probability that a tree or parts of a tree may fail could be considered the most subjective part of the assessment but in this case there is historical information to support the calculations. If we assume that each of the subject trees has a similar probability of failure because of size, condition, age and growing environment, we can calculate the probability of failure for the 2007 calendar year (the year the two failures occurred) as 2/15 or 1/7.5. This concludes the calculation for a year where an unusual weather event occurs as:

	Target value **X** Impact potential **X** Probability of failure **=** Risk of harm			
Probability	1/2.64	1/1	1/7.5	1/19.8

The risk of harm to people from each of the subject trees is extremely high during extraordinary storm events. The question arises as to how often these events occur and what is the risk outside of these events. Bureau of meteorology data for the last 9 years reveals that maximum wind gusts over 100 km/h were recorded in 2000, 2001, (no data for 2002), 2003, 2005, 2006, 2007. 30 year recordings indicate that May and June have the recorded the highest maximum wind gust speeds (Appendix 3).

It would appear that wind gusts above 100 km/h occur reasonably frequently and that 2008 was & 2009 has been moderate in terms of maximum wind gusts. It would seem that the risk of harm is reduced in years where wind gusts and heavy rain do not occur. However, it might be argued that a greater risk of harm exists now because of the moderate weather experienced in the last two years. In other words, the likelihood of a severe weather event becomes more probable as the length of time increases since the last event.

Another approach can be applied to understand the probability of failure for the subject trees. If we acknowledge that an acceptable risk level is 1/10,000 as prescribed by the QTRA system, we can calculate what the probability of failure would need to equal to meet acceptable risk levels.

Acceptable risk level	1/10,000
divided by	
Target Rating	1/2.64
divided by	
Impact potential	1/1
equals	**1/3788**

Would it be reasonable to argue that the probability of tree failure for each of these trees is equal to 1/3788, given their history and the various detailed reports that have been prepared on them; mostly because of safety concerns? It is my opinion that the probability of tree failure is much higher than that which is required to meet the acceptable risk threshold.

Even if we were to argue that the trees are 1000 times less likely to fail under moderate weather conditions, the risk of harm for each of the trees would still be calculated at 1/2640, which still does not meet acceptable risk levels.

11 Management options

11.1 The main intention of the QTRA system is to provide a mechanism for measuring risk and managing risk. The trigger for management input is when calculations indicate that acceptable risk thresholds are not met. The methods for reducing risk may include restricting access beneath trees, pruning trees, removing trees or designing engineering solutions that attempt to stabilise trees.

11.2 The options available to the trees under review would appear to be somewhat limited because the location services high numbers of foot and vehicle traffic. It is also true that the subject trees are at the end of their useful life expectancy, given the site conditions and treatments they have been exposed to over many decades. Any attempt to prolong the life of the subject trees must be weighed against the opportunity lost to establish new trees.

11.3 I am also of the view and agree with Mr Marsden's conclusions that the future of the trees is limited by the likelihood of some of the trees requiring removal soon, if not immediately. The removal of one or more trees will result in increased and or variable wind loading on remaining trees. Variations in wind loading are problematic because the remaining trees have not developed adaptive growth patterns to tolerate those variations, thus increasing the probability of failure.

12 Accuracy, completeness and scope

12.1 The accuracy, completeness and scope of the report are appropriate in relation to the instructions given and the documents considered.

13 Declaration

13.1 I have made all the inquiries that I believe are desirable and appropriate and no matters of significance which I regard as relevant have to my knowledge been withheld.

Dean Simonsen (BAppSc. *Melb.*)
Director / Consultant Arborist

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Appendix 1

The Quantified Tree Risk Assessment System
A New Approach to Tree Safety Management

Historically, the arborist has been relied upon to make judgements about the safety of trees. The tree owner or manager's expectation is often that the arborist will provide a definitive opinion as to whether or not trees are safe. Arborists seem to accept this position and often yield to the demands of clients and lawyers by stating that this tree is safe, that tree is unsafe. Would a doctor commit him/herself to assuring you that you will not become ill during the coming year, or an engineer that your car won't be involved in an accident this year? No, of course not, there are degrees of risk associated with tree failure as there are with other health and safety issues and there are degrees of benefit to be derived from trees.

When providing advice, how then does the arborist avoid making unqualified judgements on tree safety? After all, even the most cautious and prudent arborists must provide guidance to clients. Without a method of measuring the comparative risks from tree failure, advice is likely to err heavily on the side of caution and result in tree removal or other remedial measures more often than is actually necessary. If we adopt a probabilistic risk assessment approach and provide a reasonable and justifiable limit of acceptable risk, arborists can give tree managers odds of harm occurring as a result of tree failure and managers can make well informed decisions.

For a tree-failure hazard to exist there must be potential for failure of the tree, and potential for injury or damage to result from failure. The issue that the tree manager should address is the likelihood, or risk, of a combination of these factors resulting in harm, and the likely severity of harm. Tree managers often rely on the subjective judgement of a succession of arborists when formulating management strategies and addressing budget requirements. In turn, the arborist often feels compelled to be seen to be doing something, sometimes recommending work that they consider necessary for the abatement of a hazard but often recommending work just to be seen to be doing something; being seen to fulfil their duty of care. This approach can result in unnecessary cost and the degradation of both the amenity and conservation value of a site, without having first established the risk of significant harm arising from the hazard.

Many tree owners and managers have no policies or procedures for the management of tree safety and react to only the most extreme of hazardous situations as they arise. Others do nothing more than clear fallen trees. At the other end of the scale, some landowners' set large budgets for tree safety management that may be disproportionate to the risks being managed. The Quantified Tree Risk Assessment system (QTRA) presents a new opportunity to apply tree safety management resources to a structured risk assessment program. Starting with an overview of land use and tree distribution classified by gross features such as age and species we can prioritise risk assessments and refine them to greatest effect according to the availability of resources.

Balancing Risk with Benefits

Tree managers work in a climate of increasing environmental awareness, in which trees are greatly valued and yet are potentially hazardous. There is often a need to reconcile different management objectives, especially on sites where old and perhaps structurally unstable trees are present. As trees age, they increasingly develop features that might compromise their mechanical integrity whilst at the same time providing increasingly diverse wildlife habitats and visual interest. Cavities, fissures and decaying wood together with other niches in the tree, provide habitats for many plants and animals. A large proportion of higher value habitat trees occur in rural areas, but it is important to recognise that there are also many such trees on the streets of our towns and in gardens, churchyards and city parks.

Trees confer many other benefits, being essential to our well being and generally enhancing our built and natural environments. Most trees are to some degree hazardous in that they have potential, no matter how limited, to cause harm but the removal of all tree hazards would lead to certain impoverishment in the quality of human life. Therefore, it is necessary to maintain a balance between the benefits of risk reduction and the cost of that risk reduction, not only financially but also in terms of lost amenity and other tree related benefits.

Do we have Reasonable Expectations of Tree Safety Management?

Property owners and managers, from single householders to municipalities, have a duty of care under the laws of most developed countries to ensure that people and property are not exposed to unreasonable levels of risk from the failure of their trees. In the UK, USA and Australia, for example, failure of duty of care in respect of tree safety is usually prosecuted under the tort of negligence (a tort is a law that has developed through court judgements and is referred to as 'Common Law' rather than being written in 'Statute Law').

To provide an adequate defence in the event of harm resulting from tree failure, it is usually necessary to demonstrate that you have acted reasonably in the management of your trees. In most circumstances, to do absolutely nothing is probably unreasonable. Conversely to throw money at tree safety management is usually unnecessary. Tree managers are generally expected to manage risks associated with trees to maintain them as low as is reasonably practicable.

The concept of 'Reasonable Practicability' is embodied in English and Australian statute law. In essence, 'Reasonable Practicability' is the principle of doing as much or as little as a reasonable person might be expected to do in any particular circumstances. If the defendant in a legal action has established that a risk is small, but that the measures necessary to reduce or eliminate it are great, he or she may be held to be exonerated from taking steps to reduce or eliminate the risk on the ground that it was not reasonably practicable to do so. For example, if a fairground ride were constructed to be absolutely safe, there would be little excitement in the ride, so designers of fairground rides seek a balance somewhere between the ultimate in exhilaration on one hand and absolute safety on the other. The level of risk that users of the ride might be exposed to will usually be reasonable in relation to the thrill that they seek from it

In respect of trees, the concept of 'Reasonable Practicability' can be embraced by considering together the degrees of both risks and benefits associated with trees. Lee Paine of the US Forest Service (Paine 1971) wrote, "It is high time we admit that we cannot achieve complete safety – and still provide a desirable product – any more than industry can". This statement captures the essence of 'Reasonable Practicability' and holds true to the present day. It is time to acknowledge that tree safety management should not require us to minimise the risks associated with trees or to make false or unqualified statements such as 'this tree is safe' or 'that tree is unsafe'. Instead, risk of harm from tree failure should be managed at acceptable levels whilst maintaining or maximising the multitude of benefits conferred by trees.

Acceptable Risk

We are constantly exposed to and accept or reject risks of varying degrees. For example, if we desire the convenience of electric lighting, we must accept that, having implemented control measures such as insulation, there is a low risk of electrocution; this is an everyday risk taken and accepted by millions of people.

Having considered The British Medical Association Guide "Living with Risk" (Henderson 1987) and with particular reference to the conclusion "few people would commit their own resources to reduce an annual risk of death that was already as low as 1/10,000", Rodney Helliwell (Helliwell 1990) suggests that 1/10,000 might be a suitable figure to start with as a limit of acceptable risk. The UK Health and Safety Executive (HSE) suggests, "For members of the public who have a risk imposed on them 'in the wider interest' HSE would set this limit at 1/10,000 per annum" (Health and Safety Executive 1996). In the management of trees, a property owner or manager might therefore adopt the 1/10,000 limit of acceptable risk or choose to operate to a higher or lower level.

To put the 1/10,000 probability of significant harm into perspective, table 1 is reproduced from the British Medical Association Guide and illustrates the risk of death (in 1987) from a range of hazards.

Activity	**Risk of an individual dying in any one year**
Smoking 10 cigarettes a day	1 in 200
Influenza	1 in 500
Road accident	1 in 8,000
Playing football	1 in 25,000
Accident at home	1 in 26,000
Accident at work	1 in 43,000
Hit by lighting	1 in 10,000,000
Release of radiation from nearby nuclear power station	1 in 10,000,000

Table 1. (“Living with Risk“, British Medical Association, 1987)

The Quantified Tree Risk Assessment System

The Quantified Tree Risk Assessment system is a probabilistic method of assessing the risk of significant harm from the mechanical failure of trees and expands concepts proposed by Paine (1971), Helliwell (1990, 1991) and Matheny and Clark (1994). QTRA provides a framework for the assessment of the three components of tree-failure risk – Target Value, Probability of Failure and Impact Potential. By first assessing the value or usage of targets upon which trees might fail, tree owners and site managers can establish whether or not and at what degree of rigour tree surveys are required. Where necessary, trees are then considered in terms of both impact potential (size) and probability of failure. Values derived for these three components are then multiplied together and their product is the probability of death or significant harm.

Although it might seem counterintuitive, whether or not trees have significant potential to fail should not be the first consideration. Instead tree managers should consider first the usage of the land on which a tree stands and this in turn will inform the assessment of the trees themselves. Common sense tells us that a large unstable tree located in a remote wilderness might represent a very low risk of harm to people and property but as the interface between trees and human activity becomes more intimate, the risk of harm from tree failure will increase. Harm from trees is measured in terms of loss of life or serious injury, or as monetary loss from damage to property.

The system moves the management of tree safety away from considering trees as either safe or unsafe and thereby requiring definitive judgements of either tree surveyors or tree managers. QTRA is used to quantify the risk of significant harm from tree failure in a way that enables tree managers to balance safety with tree values and operate to a predetermined limit of reasonable or acceptable risk. The system proposes adoption of 1/10,000 as a reasonable limit of acceptable risk from tree failure, although a property owner or manager might adopt the 1/10,000 limit of acceptable risk or choose to operate to a higher or lower level.

Using the Quantified Tree Risk Assessment system, it is possible, not only to identify unacceptable risks, but also to identify the components of the risk, which when adjusted will effectively reduce the overall risk of harm in the most cost efficient or appropriate manner.

Calculating the Risk of Harm

Target Evaluation. A target is anything of value, which could be harmed in the event of tree failure. Target value is the most significant and most easily quantified element of the assessment. Using QTRA we evaluate the nature of the targets within a survey area before the assessment of trees. This approach enables the tree manager to justify the prioritisation of tree surveys and establish the degree of rigour required of the risk assessment.

When working in the field, manual calculation of probabilities is impractical. To facilitate field assessment, a calculator has been developed (Fig. 1) comprising three vanes, which are rotated to select values from predetermined ranges of probability and calculate the product of the three component probabilities. Having assessed the hazard and the target, the three component probabilities are selected from the ranges 1-6 on the calculator and the three vanes are aligned to display the result in a window. The calculator displays the result as an index (one thousandth of the reciprocal) of overall probability, which is termed the 'Risk Index' For example, if the risk of harm is 1/10,000, the Risk Index is 10 (10,000 ÷ 1000 = 10). Alternatively, a digital calculator has been developed for use with tree inventory software.

Weather conditions greatly influence tree failure. A walk through woodland and other recreational areas after a moderate storm will often reveal paths and tracks littered with dead and recently living branches. The same weather conditions might at the same time result in reduced pedestrian access to recreational areas, substantially reducing the risk of harm from tree-failure. Often the nature of a defect is such that the probability of failure is greater during windy weather, whilst the probability of the site being occupied during such weather conditions is considerably reduced, e.g. woodland, park or private garden. People may venture beneath trees during high winds either in the pursuit of recreation, thus voluntarily contributing to their increased exposure harm from tree failure, or out of necessity such as en route from home to a workplace. Even in the latter example, weather conditions may be so extreme that the risk of harm from the failure of not only trees but the collapse of buildings and other storm related hazards is such that to venture out at all would be foolhardy. Conversely, the risk of branch failure in tree species susceptible to summer branch drop increases during periods of hot dry weather when pedestrians might seek shade beneath trees. QTRA includes a facility for considering these scenarios.

Impact Potential. The system categorises impact potential by the diameter of tree stems and branches. An equation derived from weight measurements of trees of different stem diameters is used to produce a data set of comparative weight estimates of trees and branches ranging from 10 to 600 mm diameter. The system uses a fraction of the dry weight of the 600 mm diameter tree in calculating probability of harm. Expressed in this way, a 10mm diameter tree is 1/23,505 of a 600mm diameter tree and a 250mm tree is 1/8.604 of a 600mm diameter tree.

Probability of Failure. Accurately assessing the probability that a tree or branch will fail is highly dependant upon the skill and experience of the assessor. Having assessed the tree, the assessor visualises 1,000, 100, or 10 similar trees in a similar state in a similar environment and estimates how many would be likely to fail during the coming year.

QTRA significantly reduces the influence of assessor subjectivity upon the outcome of the risk assessment and applies a robust structure to the assessment procedure, requiring detailed assessment of the tree only where there is a significant likelihood of unacceptable risk. By first evaluating and mapping both the general nature of the tree population within an administrative area and the range of targets upon which they could fail, the manager of a large tree population can identify the interface between trees and targets, thus enabling prioritization of risk assessments. A post-mature tree population adjacent to a busy urban thoroughfare might require biannual assessment, whereas the same tree population in a remote wilderness might never be assessed in detail. Between these extremes is a range of inspection frequency, which should be applied as appropriate to the situation.
Use of the system without training leads to misapplication of the data. To ensure, insofar as practicable, that the value of the system is maintained through consistent application training and ongoing development through a licensing programme is being developed in the United Kingdom.

Examples

Example 1

A 25.0 metre high, mature pedunculate oak (*Quercus robur*), stem diameter 900mm, in a low use area of woodland with no regularly used paths within 30.0 metres but with members of the public occasionally entering the target area. This is a mechanically unstable tree with extensive heartwood decay within the main stem and primary branches. A large opening extends to 30% of the stem girth from ground level to a height of 1.5 metres. The residual stem wall averages 100mm thick and exhibits ongoing longitudinal cracking. The crown of the tree contains extensive large diameter dead wood.
The most significant part likely to strike the target area is the stem or part of the crown with the weight of the whole tree behind it.

	Target Value		**Impact Potential**		**Probability of Failure**		**Risk of Harm**
Probability Ratio	1/120,960	x	1/1	x	1/1	=	1/120,960

The absence of structures and the very low level of public access indicate that detailed assessment of the tree is not essential. If it could be established that pedestrians are 10 times less likely to visit the woodland in very windy weather, when failure is most likely, the overall probability of harm could be reduced to 1/1,209,600 or less.

Example 2a

(before remedial action)

A mature beech (*Fagus sylvatica*) overhanging a minor road of moderate use. The crown of the tree contains long unstable dead branches up to 100mm (4") diameter. The most significant part likely to strike the target area is dead branchwood up to 100mm diameter.

	Target Value		Impact Potential		Probability of Failure		Risk of Harm
Probability Ratio	1/72	x	1/82	x	1/1	=	1/5,904

To reduce the risk to a broadly acceptable level an overall probability of 1/10,000 must be achieved. Removal of all dead wood is unnecessary. Removal of dead branches greater than 50mm (2") diameter overhanging the target should reduce the risk to an acceptable level. See example 4 for a method of considering dead or otherwise degraded trees and branches. We might also consider the reduced mass of the dead branches (see example 3).

Example 2b

(after remedial action)

	Target Value		Impact Potential		Probability of Failure		Risk of Harm
Probability Ratio	1/72	x	1/450	x	1/1	=	1/32,400

Example 3.

A mature sycamore (Acer pseudoplatanus) with a dead branch of 250mm dia. overhanging a thoroughfare with pedestrian occupancy of 9 per hour. The most significant part likely to strike the target is the 250mm dia. dead branch

	Target Value		Impact Potential		Probability of Failure		Risk of Harm
Probability Ratio	1/72	x	1/8.6	x	1/10	=	1/6,192

However, by shedding subordinate branches, the dead branch has degraded to less than half of its original mass. To reflect a mass reduced to 50% or less, the Risk Index 6.19 is multiplied by 2 to produce a revised Risk Index of 12.38 (Risk of Harm 1/12,380).

QUANTIFIED TREE RISK ASSESSMENT USED IN THE MANAGEMENT OF AMENITY TREES

By Michael J. Ellison

Abstract. A system of tree risk assessment is proposed that expands concepts developed by others and enables a probability of significant harm to be applied to tree failure risk. By evaluating the components of a tree failure hazard and assigning to them estimates of probability, the proposed system enables the skilled tree inspector to calculate the product of those probabilities to produce a numerical estimate of risk. The use of quantification in the assessment of tree hazards enables property owners and managers to operate, as far as is reasonably practicable, to a predetermined limit of reasonable or acceptable risk.

Key Words. Risk assessment; tree hazards; safety; target; quantified risk; amenity; saproxylic habitat.

Tree managers work in a climate of increasing environmental awareness, in which trees are greatly valued and yet potentially hazardous. There is, therefore, a need to reconcile different management objectives, especially on sites where old and perhaps structurally unstable trees are present. As trees age, they increasingly develop features that might compromise their mechanical integrity while providing increasingly diverse wildlife habitats and visual interest. These features include cavities and decaying wood, which together with other niches in the tree, provide habitats for many rare plants and saproxylic (deadwood) animals and fungi (Kirby and Drake 1993). In Britain, a large proportion of such trees occur in rural areas, but there are also many on the streets of towns and in gardens, churchyards, and city parks.

If old trees and their younger successors are to be managed responsibly with regard both to safety and their value, methods must be developed for the reliable assessment of hazards and valuable features alike. As far as hazards are concerned, the need is to be able to quantify them and any associated risk so that the risk can be kept within acceptable or reasonable limits without implementation of disproportionate risk control measures.

This paper introduces quantified tree risk assessment, which is an expansion of concepts proposed by Paine (1971), Helliwell (1990, 1991), and Matheny and Clark (1994). Quantified tree risk assessment provides a framework for the assessment of the three components of tree failure risk—target value, probability of failure, and impact potential. By first assessing the value or use of targets upon which trees might fail, tree owners and site managers can establish whether and at what degree of rigor tree inspections are required. By assessing the probabilities of the three components and calculating their product, it is possible for the skilled tree assessor to quantify the risk of significant harm from tree failure in a way that enables owners and managers to balance safety with tree values.

DEFINITION OF TERMS

Hazard

"A hazard is the disposition of a thing, a condition, or a situation to produce injury" (Health and Safety Executive 1995). A tree failure hazard is present when a tree has potential to cause harm to people or property.

Probability

Statistical probability is a measure of the likelihood of some event happening. There are rules of addition and multiplication in probability theory. In tree failure risk assessment, the probability that the three components will combine in a common outcome is the product of their independent probabilities.

Risk

Risk is the probability of something adverse happening. "Quantified risk assessment is a risk assessment which incorporates numerical estimates.… There are many forms of risk and therefore of risk assessment. The underlying concept is that of seeking to identify in some quantitative or at least comparative way the connection between some hazardous agency, and actual exposure to harm" (Health and Safety Executive 1995).

Acceptable Risk

We are constantly exposed to and accept or reject risks of varying degrees. For example, if we desire the convenience of electric lighting, we must accept that, having implemented control measures such as insulation and periodic inspection, there is a low risk of electrocution; this is an everyday risk taken and accepted by millions of people.

When evaluating tree failure hazards, two types of risk must be considered. We must consider the person upon whom a risk is imposed, as with the neighbor of a tree owner, and the person who accepts some degree of risk in return for a benefit, such as a tree owner or visitor to a woodland or forest.

Having considered The British Medical Association Guide's *Living with Risk* (Henderson 1987) and with particular reference to the conclusion "few people would commit their own resources to reduce an annual risk of death that was already as low as 1/10,000," Helliwell (1990) suggests that 1/10,000 might be a suitable figure to start with as the limit of acceptable risk. Furthermore, "for members of the public who have a risk imposed on them 'in the wider interest,' HSE [Health and Safety Executive] would set this limit at 1/10,000 per annum" (Health and Safety Executive 1996). In the management of trees, a property owner or manager might adopt the 1/10,000 limit of acceptable risk or choose to operate to a higher or lower level.

Cost and Benefit

Trees confer many benefits, being essential to our well being and generally enhancing our built and natural environments. Removal of all tree hazards would lead to certain impoverishment in the quality of human life. Therefore, it is necessary to maintain a balance between the benefits of risk reduction and the costs of that risk reduction, not only financially but also in terms of lost amenity and other tree-related benefits.

Value of Statistical Life

Value of statistical life is a term used in risk assessment to express the monetary value of an individual life. In the United Kingdom, this value is currently in the region of £750,000 to £1,000,000 (US$1,387,500 to US$1,850,600) (Health and Safety Executive 1995) and is proposed here to correlate the value of damage to property with the value of human life.

HAZARD ASSESSMENT

For a tree failure hazard to exist, two criteria must be fulfilled. There must be potential for failure of the tree and potential for injury or damage to result. The issue that the tree manager must address is the likelihood, or risk, of a combination of factors resulting in harm, and the likely severity of harm.

Most tree defects can be identified and assessed by the skilled inspector, but there is no evaluation methodology currently in general use that enables the inspector to quantify risk in a way that the risks associated with the retention of trees can be compared with a broadly acceptable level of risk.

A landowner or manager with responsibility for a diverse tree population, on a site comprising locations as disparate as a boundary with a busy highway, a children's play area, and a remote woodland walk, must rely on the subjective judgment of the tree inspector, employed at any point in time, when formulating management strategies and allocating budgets. Such subjectivity could result in the implementation of remedial work, perceived by the current tree inspector to be necessary for the abatement of a hazard and possibly resulting in unnecessary cost and degradation of both the amenity and conservation value of a site, without having first established the risk of significant harm arising from the hazard.

Probably the most significant recent development in the field of tree hazard evaluation is the methodology proposed by Matheny and Clark (1994). Designed primarily to assist the evaluation of tree failure hazards in urban areas, the system is relatively easy to apply and enables tree inspectors and managers to prioritize remedial action in a structured manner. The guide proposes a system of rating tree failure hazards by assessing and applying a numerical value of 1 to 4 to each of the three components that contribute to a tree failure hazard: (1) failure potential, (2) size of the tree part that could fail, and (3) target rating. The sum of the three equally weighted scores is termed the "hazard rating." A hazard rating of 12 represents the most severe hazard. The system enables the broad prioritization of tree failure hazards but does not quantify the associated risks.

THE PROPOSED SYSTEM

Quantified tree risk assessment is not a wholesale departure from current practice, but it quantifies risk within a structured framework and utilizes, but renames, the three components of the tree hazard proposed by Matheny and Clark (1994): (1) probability of failure, (2) impact potential, and (3) target value. The system enables quantification of the independent probabilities of the three components, enabling their product (risk of harm) to be compared with a generally accepted level of risk. The quantified tree risk assessment process might, in areas of very high access, involve the detailed inspection and assessment of every tree, or might, in low-access areas, require only a general overview of trees and targets. To simplify the assessment process, probabilities are presented in ranges in Tables 3, 5, and 6 (e.g., 1/1 to 1/19 and 1/20 to 1/100).

A probability of death or serious injury of 1/10,000 is suggested as the limit of acceptable risk to the public at large (Helliwell 1990; Health and Safety Executive 1996). Using the 1/10,000 limit, all risks with a probability exceeding 1/10,000 require remedial action to reduce the risk to an acceptable level, unless the risk is limited to a particular individual or group—such as a tree owner—who may choose to accept a greater or lesser risk. Additionally, the hazard could confer benefits that might be set against the risk of harm.

Target Evaluation

A target is anything of value that could be harmed in the event of tree failure. Frequent inspection of trees and assessment of associated risks may be essential in areas of high public access or where trees are within striking range of valuable or fragile structures. Conversely, in a location without structures and having very low public access, assessment of tree hazards may be unnecessary. The target value is the most significant and most easily quantified element of the assessment. In quantified tree risk assessment, evaluating the nature of the targets within a survey area before the assessment of trees enables the tree manager to prioritize inspections and establish whether and at what degree of rigor an inspection is required.

Often the nature of the defect is such that the probability of failure is greater during high winds, while the probability of the site being occupied during such weather conditions is considerably reduced (e.g., woodland, park, or private garden). People may venture beneath trees during high winds either in the pursuit of recreation, thus voluntarily contributing to their increased exposure to harm from tree failure, or out of necessity, such as en route from home to a workplace. Even in the latter example, weather conditions may be so extreme that the risk of harm from the failure of not only trees but the collapse of buildings and other storm-related hazards is such that to venture out at all would be foolhardy.

Helliwell (1991) proposed that the probability of a tree falling onto a road and actually hitting or being hit by a vehicle can be established by determining the ratio of the average length of time the section of road is occupied by vehicles to the total length of time in a day, and calculating the probability of a vehicle being in, or within the stopping distance of, the target area. Such a methodology is employed here to assess the probability of target sites being occupied by vehicles or pedestrians.

The proposed system considers three types of target. Tables 1 and 2 illustrate the calculation of vehicle and pedestrian frequencies. Vehicle and pedestrian targets and the repair value of damage to structures are combined in Table 3.

Vehicles

The occupation of vehicular targets (Table 1) is evaluated using 1996 vehicle frequency statistics for standard road classifications (Transport Statistics Great Britain 1997). Large trees standing adjacent to most classes of road have potential to impact vehicles traveling in both directions on a road. Motorways (U.S. equivalent: freeways and interstate highways) are an exception; trees in Great Britain do not have the potential to fall across all lanes of a motorway. Vehicle numbers for motorways are therefore halved (Table 1) because only half of the road is being considered as the target. In the case of vehicles, probability of impact may relate either to the tree part striking the vehicle or to the vehicle striking the fallen tree part. Both types of impact are influenced by vehicle speed. The faster a vehicle travels, the less likely it is to be struck by the falling tree but the more likely it is to strike a fallen tree. Minimum safe stopping distances (Highway Code 1989) and an average vehicle length are used in the calculation of vehicle occupation (Table 1, column 4). The probability of a vehicle striking a

Table 1. Vehicular occupation. The probability of impact (*P*) is calculated $D3600 \div S1000 = T$; $TV = H3600$; $H \div 24 = P$.

Road class	*S* Average speed (kph)	*D* Minimum stopping distance plus 6 m vehicle length (m)	*T* Time that each vehicle occupies length of road 'D' (sec)	*V* No. vehicles/day[z] (1 direction only)[y]	*H* No. hours for which a point on the road is occupied each day	*P* Probability of impact with or by a tree/branch
Motorway	113	102	3.25	30,450	27.5[x]	1/1
Trunk road (built-up area)	48	29	2.17	19,200	11.5	1/2.1
Trunk road (non-built-up area)	64	42	2.36	15,500	10.1	1/2.4
Principal road (built-up area)	48	29	2.17	15,000	9.0	1/2.7
Principal road (non-built-up area)	64	42	2.36	7,200	4.7	1/5.1
Minor road (all classes)	64	42	2.36	1,400	0.9	1/27

[z]Transport Statistics Great Britain (1997).
[y]For the purpose of assessing the probability of impact, the total number of vehicles occupying all lanes of a motorway traveling in a single direction must be considered.
[x]Due to the sheer volume of traffic using motorways and the need to consider stopping distances, the vehicular occupation period is theoretically greater than 24 h.

fallen or falling tree is the ratio of the hours a point in the road is occupied by a vehicle—including safe stopping distance—to the hours in a day.

Pedestrians
The probability of pedestrians occupying a target (Table 2) is calculated on the basis that an individual will spend, on average, 5 seconds occupying the target area, unless a longer occupation is likely, as with a habitable structure or park bench. For example, ten pedestrians per day each occupying the target area for 5 seconds is a daily occupation of 50 seconds, by which the total seconds in a day are divided to give a probability of target occupation. When evaluating pedestrian and vehicular frequency (events) during daylight hours, we must consider whether frequency will be significantly reduced during hours of darkness. The calculation of frequency must in all cases be the total hours in a year divided by the number of events in a year. Although a tree failing during the day might be more likely to strike a mobile target than the same tree at night, it is the frequency of the targets and not the failure of the tree that is most significantly influenced by the time of day. The sum of the higher daytime occupation and the lower nighttime occupation is the daily occupation. Similarly, a single annual event attracting large numbers of visitors could significantly increase the target value and should be included in the assessment.

Structures
When evaluating a target structure, it is necessary to consider the approximate value of repairs or replacement that might be required if the tree should fail. The values in Table 3 represent cost of repair or replacement.

The ranges of repair value for structures used in Table 3 are derived from a value of "hypothetical life" of £1,000,000 (US$1,850,000). For example, target range 2 represents a probability of pedestrian occupation up to 1/20; £1,000,000 ÷ 20 = £50,000. Thus, structures likely to incur a repair cost of £50,000, which is one-twentieth the value of a hypothetical life, are apportioned a ratio of 1/20.

Individual trees should be selected on the basis that they are within striking distance of a significant target or that their failure could result in neighboring trees striking a target. Example 1 (see section titled Calculating Risk of Harm) illustrates that an individual tree cannot represent an unacceptable risk of significant harm if within striking distance of only a target within range 6 (assuming that the tree manager is operating to an acceptable level of risk of 1/10,000).

Having established that a tree requires assessment, the inspector should assess it according to current practice. Tree inspection procedure is well documented elsewhere (Matheny and Clark 1994; Mattheck and Breloer 1994; Lonsdale 1999) and is not discussed here.

Impact Potential
A small, dead branch of less than 10 mm (0.4 in.) diameter is unlikely to cause significant harm even in the case of direct contact with a target, while, on average, a falling branch with a diameter greater than 150 mm (6 in.) is likely to cause harm in the event of contact with all but the most robust target. The increased potential for injury in relation to the size of tree or branch is proportional to a degree, yet the tree or branch will reach a size where the increased severity of injury is no longer significant. Similarly, most property likely to be affected by tree failure can incur only a limited level of damage before further damage is likely to be inconsequential (i.e., when it is beyond economic repair).

The mass of a falling tree or branch contributes to the force that will occur upon impact with a target but does not alone determine the potential severity of harm. The distance and orientation when falling will influence the force upon impact. Other trees or branches might impede the path of a falling tree or branch, and it might be predicted that the failure of a branch will result in it being hung up without presenting an immediate danger or that it might fall unimpeded. Additionally, a tree or branch may be decayed to such an extent that it will disintegrate or exert only a minor force upon impact. For these reasons, it is probably unrealistic to calculate the effect of the height from which a branch could fall, but it is necessary to be aware that factors other than mass will contribute to the force upon impact, although these factors might be recorded only where they are particularly significant in a given situation.

The system categorizes impact potential by the diameter of tree stems and branches. An allometric biomass equation derived from dry weight measurements of trees of different stem diameters (Tritton and Hornbeck 1982)

Table 2. Pedestrian frequency. Occupation of the target area calculated from an average occupation of 5 seconds, other than constant and 50% occupied.

Pedestrian frequency	Total occupation per day (seconds)	Probability of occupation
Constant	86,400	1/1
50% occupied	43,200	1/2
100 per hour	12,000	1/7.2
50 per hour	6,000	1/14.4
10 per hour	1,200	1/72
5 per hour	600	1/144
1 per hour	120	1/720
1 per day	5	1/17,280
1 per week	0.71	1/120,960

Table 3. Target ranges for structures, pedestrians, and vehicles. Vehicular, pedestrian, and structural targets are categorized by their frequency or monetary value. For example, the probability of a vehicle or pedestrian occupying a target area in target range 4 is between the lower and upper limits of 1/10,000 and 1/500. Using the value of a "hypothetical life" of £1,000,000 the structure value within the target range 4 is £101–2,000.

Target range	Structure (repair value)*	Pedestrian frequency	Vehicular frequency	Probability ratio[z]
1	(a) Very high value (b)Habitable	> 36 per hour–constant	(a) Motorway (b) Trunk road, built-up and non-built-up areas (c) Principal road, built-up area	1/1
2	High value	10–36 per hour	Principal roads, non-built up-area	1/20
3	Moderate–high value	1–9 per hour	Minor roads, moderate use or poor visibility	1/100
4	Moderate value	< 1 per hour	Minor roads, low use and good visibility	1/500
5	Low value	≤ 1 per day	Minor private roads and tracks (no data available)	1/10,000
6	Very low value	≤ 1 per week	None	1/120,000

*Structure values represent the likely cost of repair or replacement. Very high = £50,001–1,000,000; high = £10,001–50,000; moderate–high = £2,001–10,000; moderate = £101–2000; low = £11–100: very low = ≤£10.

is used to produce a data set (Table 4) of comparative dry weight estimates of trees and branches ranging from 10 to 600 mm (0.4 to 24 in.) diameter. An upper limit of 600 mm has been selected to represent a 1/1 impact potential on the premise that impact from a tree with a stem diameter of 600 mm (24 in.) has a 1/1 probability of causing maximum possible damage to most frequently encountered targets. From this point, the impact potential reduces to 1/23,500 for a 10 mm (0.4 in.) branch or tree. For initial assessments, the probabilities are grouped into ranges 1 through 5 in Table 5. Impact potential range 1 represents a range of diameter greater than 450 mm (18 in.) and is calculated from the estimated dry weight of the 600 mm (24 in.) diameter tree. Range 1 has a 1/1 probability of causing significant harm upon impact with a target. Range 5 represents 10 to 25 mm (0.4 to 1 in.) diameter and has a probability 1/2,500 of causing significant harm upon impact with a target. If, in exceptional circumstances, the failure of a branch of less than 10 mm (0.4 in.) diameter is considered significant, it has a probability of 1/23,500.

Table 4. Biomass dry weight estimates (Tritton and Hornbeck [1982]).

Dbh* (mm)	Dry weight (kg) $y = ax^b$**	Fraction of dry weight (600 mm) as a ratio
10	0.11263	1/23,505.722
25	1.0713	1/2,471.6699
50	5.8876	1/449.74
100	32.357	1/81.834
150	87.67	1/30.203
200	177.82	1/14.891
250	307.77	1/8.604
300	481.81	1/5.496
350	703.8	1/3.762
400	977.26	1/2.71
450	1305.5	1/2.03
500	1691.4	1/1.566
550	2138	1/1.24
600	2647	1/1

*Diameter at breast height, 1.37 m (4.5 ft).
**x = dbh (mm); y = dry weight estimate; a = allometric coefficient 0.1126294414; b = allometric coefficient 2.458309949.

Probability of Failure

Accurately assessing the probability that a tree or branch will fail is highly dependent on the skill and experience of the assessor. This component of the system provides five ranges, each range representing a range of probability of failure within a year, expressed as both a percentage and a ratio calculated from the upper value of that range. Having assessed the tree, the assessor should visualize 100 similar trees in a similar condition in the same environment and estimate how many would be likely to fail during the coming year. If the answer to this question is none, then consider 1,000 or 10,000 trees. A probability of failure range 1 to 5 (Table 6) is then selected. Employing this method of assessing probability, inspectors become increasingly aware both of features and conditions that lead to tree failure and of the probability of tree failure. Observing the patterns and frequency of tree failure within this structured framework and applying scientific knowledge to these observations can significantly increase the consistency with which tree inspectors assess the probability of tree failure.

Table 5. Impact potential.

Impact potential range	Size of part (mm diameter) likely to impact target	Impact potential
1*	> 450	1/1
2	251–450	1/2
3	101–250	1/8.6
4	26–100	1/82
5	> 10–25	1/2,500

*Range 1 is based on a diameter of 600 mm (24 in.).

CALCULATING RISK OF HARM

When working in the field, manual calculation of probabilities is impractical. To facilitate field assessment, a calculator has been developed (Figure 1) comprising three vanes, which are rotated to select values from predetermined ranges of probability and calculate the product of the three component probabilities. The probability ranges are labeled 1 through 6 (Tables 3, 5, and 6 and Figure 1). Alternatively, the probabilities in a spreadsheet format can be loaded onto handheld data collection devices for use with tree inventory software.

Having assessed the hazard and the target, the three component probabilities are selected from the ranges 1 through 6 on the calculator, and the three vanes are aligned to display the result in a window. The calculator displays the result as an index (one thousandth of the reciprocal) of overall probability, which is termed the risk index. For example, if the risk of harm is 1/10,000, the risk index is 10 (10,000 ÷ 1000 = 10).

Table 6. Probability of failure. The probability that the tree or selected tree part will fail within a year.

Probability of failure range	Probability of failure percentage	Probability ratio
1 Very high	51–100	1/1
2 High	11–50	1/2
3 Moderate	1–10	1/10
4 Low	0.1–0.9	1/100
5 Very low	< 0.1	1/1,000

Example 1

The tree is a 25 m (82.5 ft) high, mature pedunculate oak (*Quercus robur*), stem diameter 900 mm (36 in.), in a low use area of woodland with no frequently used paths within 30 m (100 ft) but with members of the public occasionally entering the target area. There is extensive heartwood decay within the main stem and primary branches. A large opening extends to 30% of the stem girth from ground level to a height of 1.5 m (5 ft). The sound stem wall thickness averages 100 mm (4 in.) and exhibits signs of longitudinal cracking. The crown of the tree contains extensive large-diameter dead wood. The most significant part likely to strike the target area is the stem or part of the crown with the weight of the whole tree behind it.

	Target value	Impact potential	Probability of failure	Risk of harm
Probability ratio	1/120,000	× 1/1	× 1/1	= 1/120,000

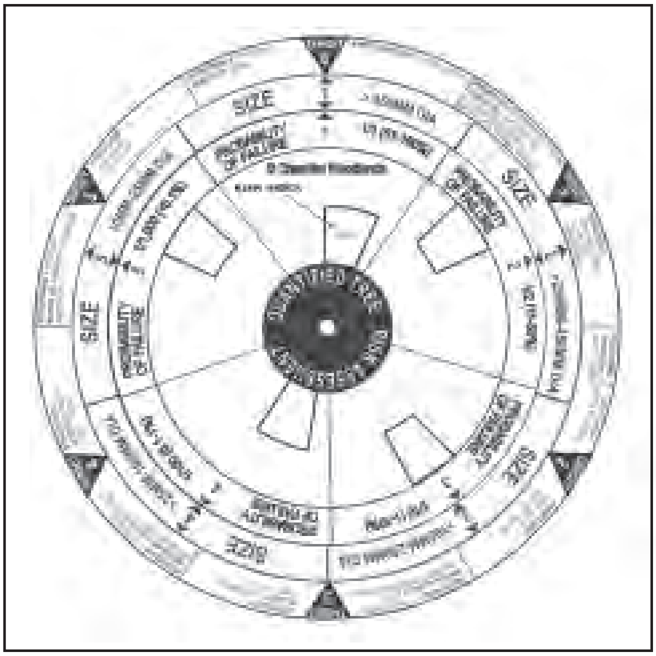

Figure 1. Quantified tree risk assessment calculator illustrating Example 1.

The absence of structures and the very low level of public access indicate that detailed assessment of the tree is not essential. If it could be established that pedestrians are 10 times less likely to visit the woodland in very windy weather, when failure is most likely, the overall probability of harm could be reduced to 1/1,200,000 or less.

If the initial assessment places the risk above or close to the acceptable limit, the risk assessment can be refined using probability 1/1 for any of the components and multiplying the result by the more accurate probability. For example, if the highway in example 2 (below) had been accurately surveyed using an electronic traffic counter, and it had been established that the usage was on average seven vehicles per day, it could be stated with confidence that the probability of target occupation was 1/5,000. The risk would then be calculated: impact potential 4 × probability of failure 1 × target value 1 = risk of harm 1/82. ∴ risk of harm × measured target value 1/5,000 = revised risk of harm 1/410,000.

Example 2
(Before Remedial Action)

The tree is a mature beech (*Fagus sylvatica*) overhanging a minor road with good visibility. The crown of the tree contains long, unstable, dead branches up to 100 mm (4 in.) diameter. The most significant part likely to strike the target area is deadwood up to 100 mm diameter.

	Target value	Impact potential	Probability of failure	Risk of of harm
Probability ratio	1/100	× 1/82	× 1/1	= 1/8,200

To reduce the risk to a broadly acceptable level, an overall probability of 1/10,000 must be achieved. Removal of all deadwood is unnecessary. Removal of dead branches greater than 50 mm (2 in.) diameter overhanging the target should reduce the risk to an acceptable level.

(After Remedial Action)

	Target value	Impact potential	Probability of failure	Risk of harm
Probability ratio	1/100	× 1/450	× 1/1	= 1/45,000

The predefined ranges used on the calculator are designed to simplify field operation of the system. If a high-value tree is identified as requiring remedial action that will significantly reduce its value, a more detailed evaluation of the target value and probability of failure, establishing probabilities rather than a probability ranges, will provide a more accurate quantification of risk.

DISCUSSION

Property owners and managers have a duty (under English law) to ensure, insofar as reasonably practicable, that people and property are not exposed to unreasonable levels of risk from the mechanical failure of trees in their control. To achieve this, prudent owners and managers employ arborists to advise on the health, mechanical integrity, and management of trees.

While our knowledge of tree structure, tree defects, and host–pathogen interactions is ever increasing, the dynamic interactions among a diverse range of tree taxa, wood-digesting organisms, and environment are of such complexity that precise quantification of potential for tree failure is unlikely to be achievable. However, with training and the application of a systematic approach, reasonable estimates of probability of tree failure can be achieved.

Evaluation of the targets on which trees might fail might require input from property managers, arborists, and others. Reasonable estimates of target value can be achieved by assessing monetary value and the frequency of target occupation.

Stem or branch weight is probably the most realistic measure of impact potential to apply in the quantification of tree failure risk, and the relationship between diameter and the mass of the stem or branch provides a readily measurable estimate of this component of the risk.

Weather conditions greatly influence tree failure. A walk through woodland and other recreational areas after a moderate storm will often reveal paths and tracks littered with dead and recently living branches. The same weather conditions might result in reduced pedestrian access to recreational areas, substantially reducing the risk of harm from tree failure. Conversely, the risk of branch failure in trees susceptible to summer branch drop (Lonsdale 1999) increases during periods of hot, dry weather when pedestrians might seek shade beneath trees. The influence of weather on tree failure and patterns of pedestrian, equestrian, and cyclist access requires further consideration and research.

The concept of reasonable practicability is a central tenet of English law, which is evident throughout the English Health and Safety legislation and guidance (e.g., Health and Safety at Work Act 1974) and in judgments of the higher courts in relation to tree failure. In regard to trees, this concept should be embraced through the implementation of reasonably practicable tree safety management. If absolute safety from tree failure were achievable, society would almost certainly find the cost in terms of tree losses unacceptable. In this regard, Paine (1971) suggests that "it is high time we admit that we cannot achieve complete safety—and still provide a desirable product—any more than industry can."

The use of quantification in the assessment of tree hazards enables property owners and managers to operate, as far as is reasonably practicable, to a predetermined level of acceptable risk. Application in both urban and rural situations over a period of 8 years indicates that when using the proposed system, risk reduction measures required in high-value target areas are broadly comparable with or below the level of remedial action that might be considered appropriate without the system. In low-value target areas, the risks associated with tree failure hazards are frequently considerably lower than assumed or perceived prior to applying the system.

Using the proposed system, the assessment of the same tree by different inspectors not trained to a unifying standard has produced variable results, comparison of which indicates that a common standard of training in tree inspection is required. Matheny and Clark (1994) asserted that "training of personnel in field assessment is absolutely essential" and "perhaps the most important aspect of training is to develop consistent evaluation procedures, among individuals and over time." Experience of the proposed system reinforces the view that training of personnel involved in inspection and assessment of trees is in need of standardization. Also lacking standardization is the vocabulary used by tree inspectors. In the United Kingdom, the terms stem, trunk, bole and butt are all used to describe the same part of the tree; this example is by no means isolated. Inconsistent use of terminology can lead to misinterpretation of data by subsequent inspectors, property owners and managers, and by contractors employed to implement remedial measures.

CONCLUSIONS

Tree safety management should not seek to minimize the risk of harm resulting from tree failure but should balance the benefits of risk reduction with the associated costs in terms of both lost tree value and financial expenditure.

By allocating quantifiable values to the probability of failure and impact potential of trees, and to targets on which trees might fail, the arborist can, with training, assess tree failure hazards with sufficient accuracy that property owners and managers are able to consider the risk of significant harm from tree failure against a level of reasonable or acceptable risk. Using the proposed system, it is possible, not only to identify unacceptable risks, but also to identify the elements of the risk, which, when adjusted, will effectively reduce the overall risk of harm in the most cost efficient or appropriate manner.

The proposed system not only significantly reduces the influence of assessor subjectivity on the outcome of the risk assessment, but it also applies structure to the assessment procedure, requiring detailed assessment of the tree only where there is a significant likelihood of unacceptable risk. By first evaluating and mapping both the general nature of the tree population within an administrative area and the range of targets upon which they could fail, the manager of a large tree population can identify the interface between trees and targets, thus enabling prioritization of risk assessments. A post-mature tree population adjacent to a busy urban thoroughfare might require biannual assessment, whereas the same tree population in a remote wilderness might never be assessed in detail. Between these extremes is a range of inspection frequency, which should be applied as appropriate to the situation.

Use of the system without training leads to misapplication of the data. To ensure, insofar as practicable, that value of the system is maintained through consistent application, the author intends to provide training and ongoing development through a licensing program in the United Kingdom and elsewhere.

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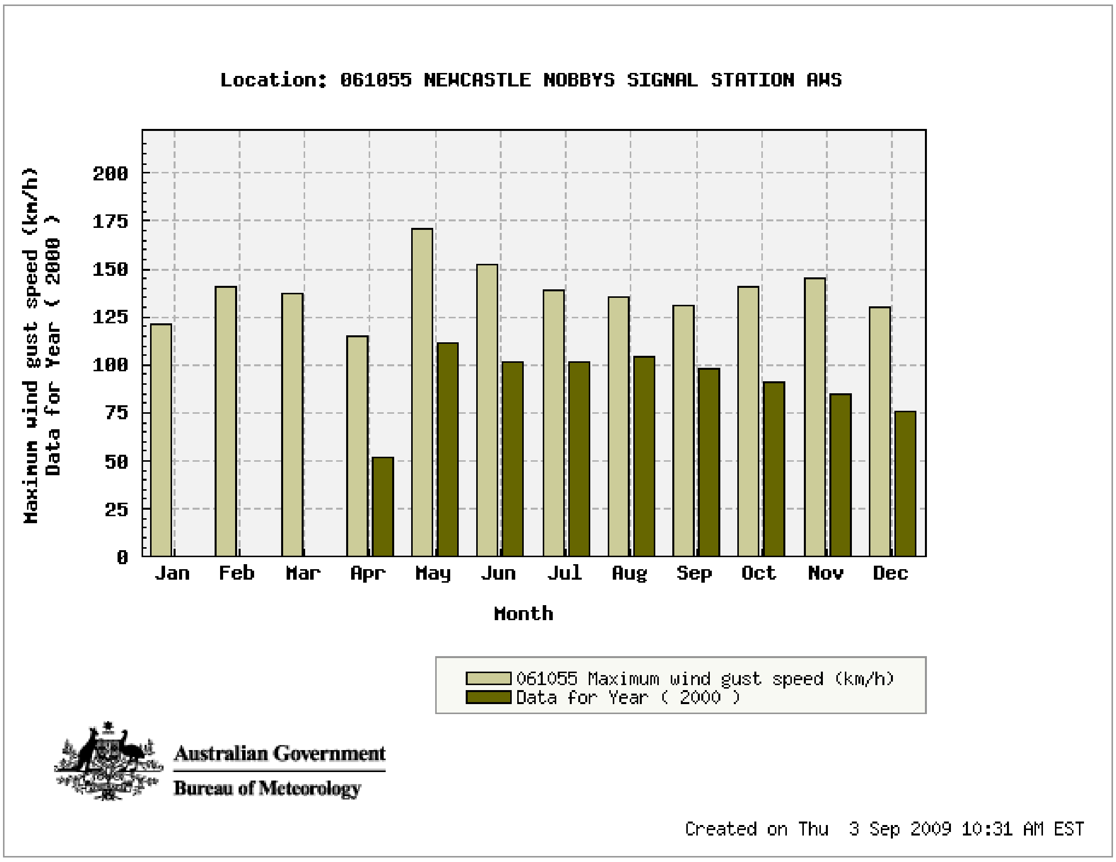
Résumé. Un système d'évaluation des risques associés aux arbres est proposé, ce qui améliore les concepts développés par d'autres et permet de déterminer une probabilité de dommage significatif qui peut être appliquée à l'évaluation du risque de bris d'un arbre. En évaluant les composantes d'un arbre dangereux et en leur attribuant une estimation de leur probabilité de bris, le système proposé permet à un inspecteur arboricole expérimenté de calculer le produit de ces probabilités afin de d'établir une estimation numérique (quantifiée) du risque. L'emploi d'une quantification dans l'évaluation des arbres dangereux permet au propriétaires d'arbres et aux gestionnaires de fonctionner selon des limites prédéterminés de risques raisonnable ou acceptable, et ce aussi loin où cela demeure encore raisonnablement faisable.

Zusammenfassung. Hier wird ein System von Baumrisikobewertung vorgeschlagen, welches weit über die Konzepte von anderen hinausgeht und eine Wahrscheinlichkeit von signifikantem Schaden in Anwendung auf das Baumversagensrisiko ermöglicht. Bei der Bewertung der Komponenten eines Baumversagens und das Vergleichen mit Schätzungen der Wahrscheinlichkeit könnte das vorgeschlagene System den geschulten Bauminspektor zur Kalkulation des Produktes dieser Wahrscheinlichkeiten befähigen, um eine numerische Schätzung der Risiken zu produzieren. Die Nutzung der Quantifikation bei der Bewertung von Baumschäden befähigt den Baumbesitzer und Manager zu handeln, soweit es zu einem vorherbestimmten Limit eines akzeptablen Risiko praktikabel ist.

Resumen. Un sistema de evaluación de riesgo de árboles está propuesto para que expanda los conceptos desarrollados por otros y habilite una probabilidad de daño significativo a ser aplicado en árboles de riesgo. Mediante la evaluación de los componentes de falla de un árbol de riesgo y asignándoles estimadores de probabilidad, el sistema propuesto capacita a inspectores experimentados de árboles para calcular el producto de estas probabilidades para producir una estimación numérica de riesgo. El uso de la cuantificación en la evaluación de árboles de riesgo capacita a los propietarios y manejadores para operar, tanto como sea práctico y razonable, con un predeterminado límite de riesgo aceptable.

Appendix 3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Data for Year (2000)
Australian Government
Bureau of Meteorology
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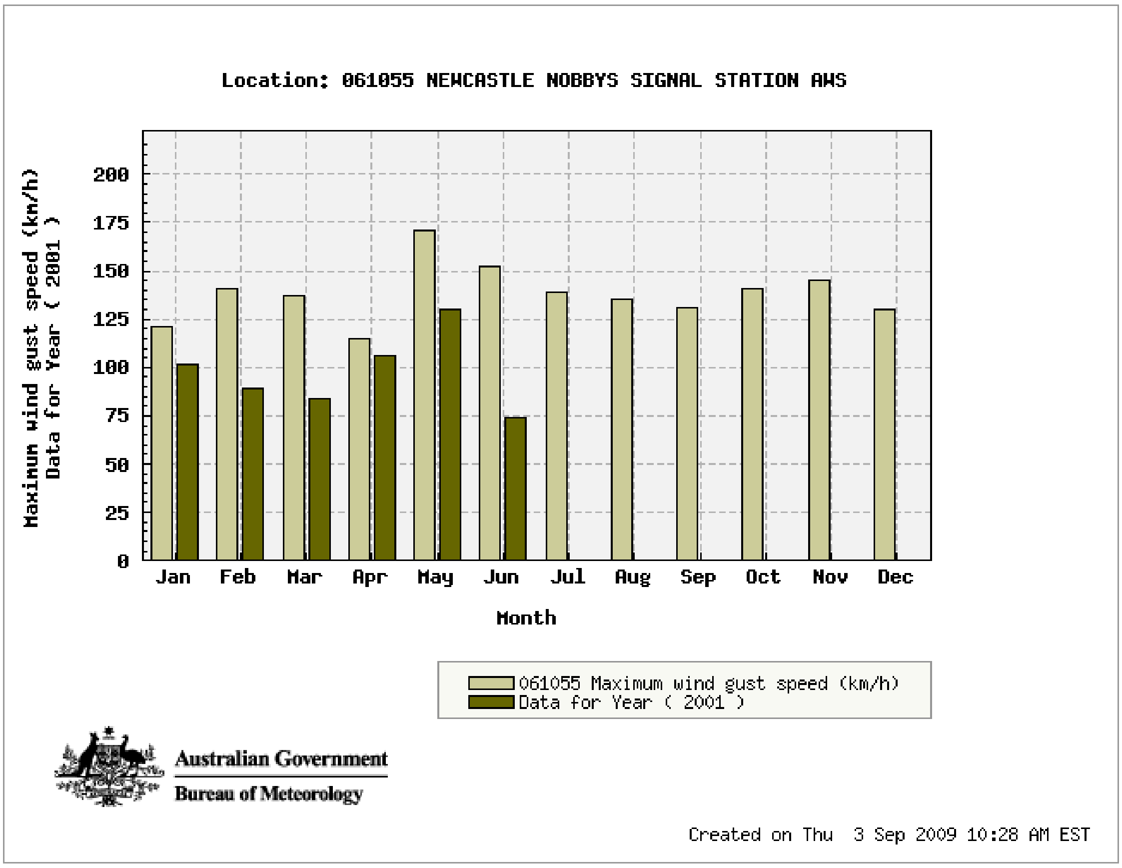
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Australian Government
Bureau of Meteorology
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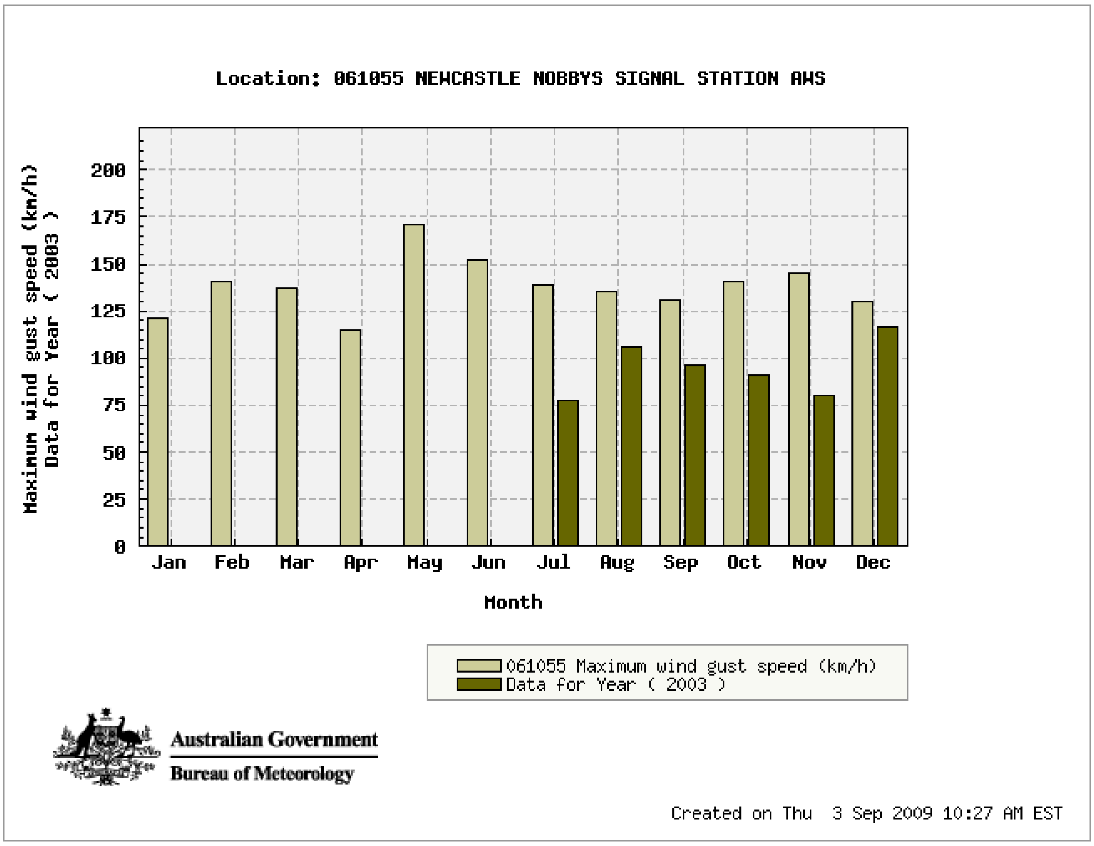
Appendix 3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Bureau of Meteorology
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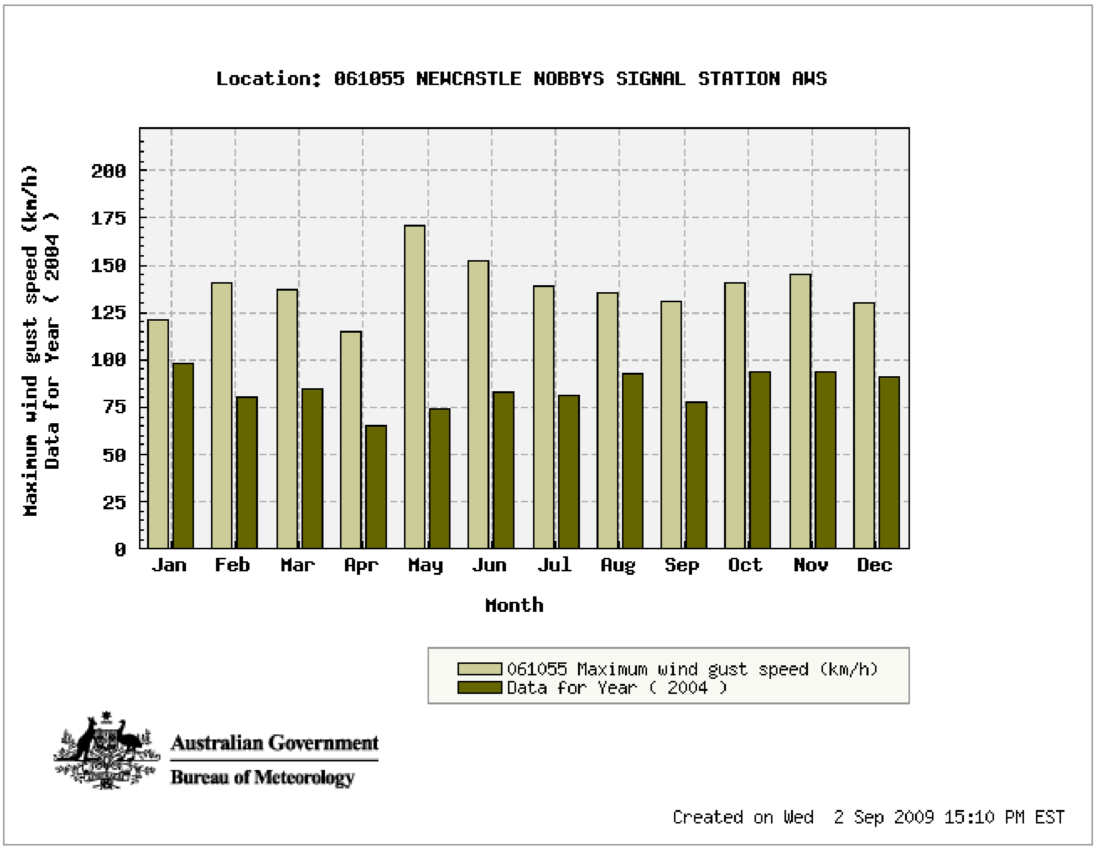
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Australian Government
Bureau of Meteorology
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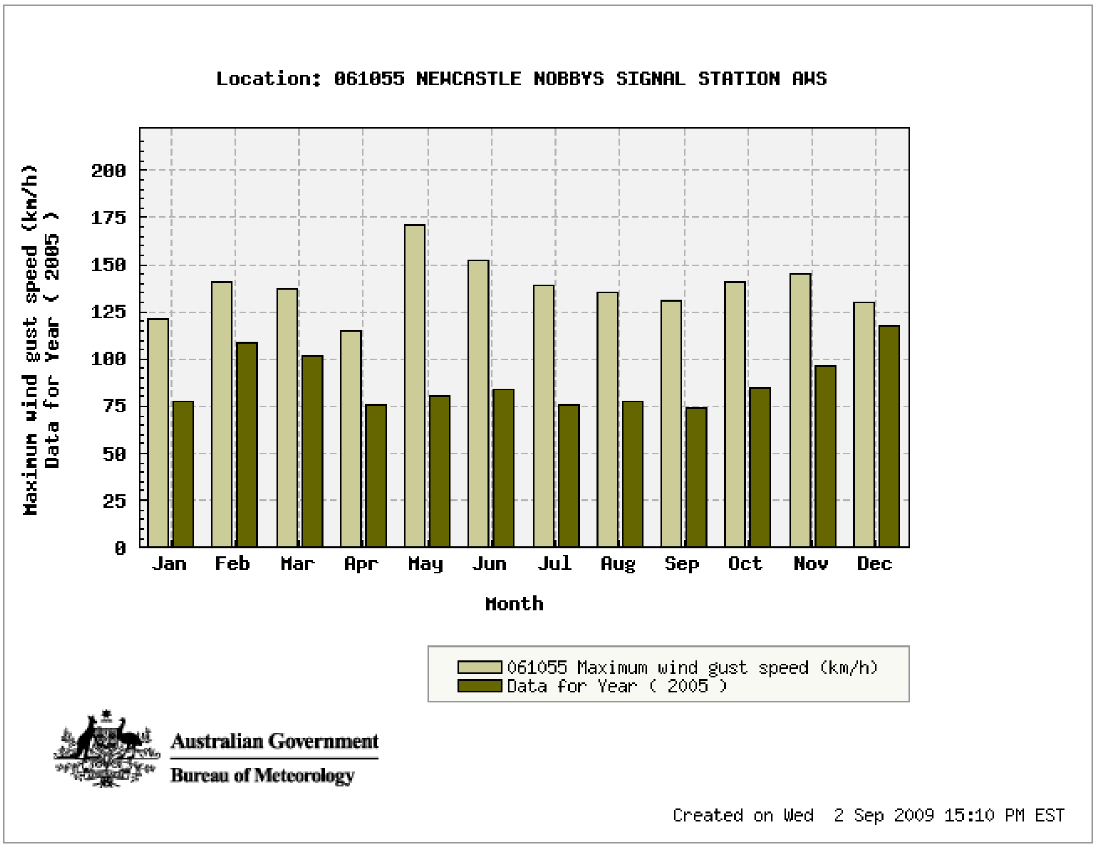
Appendix 3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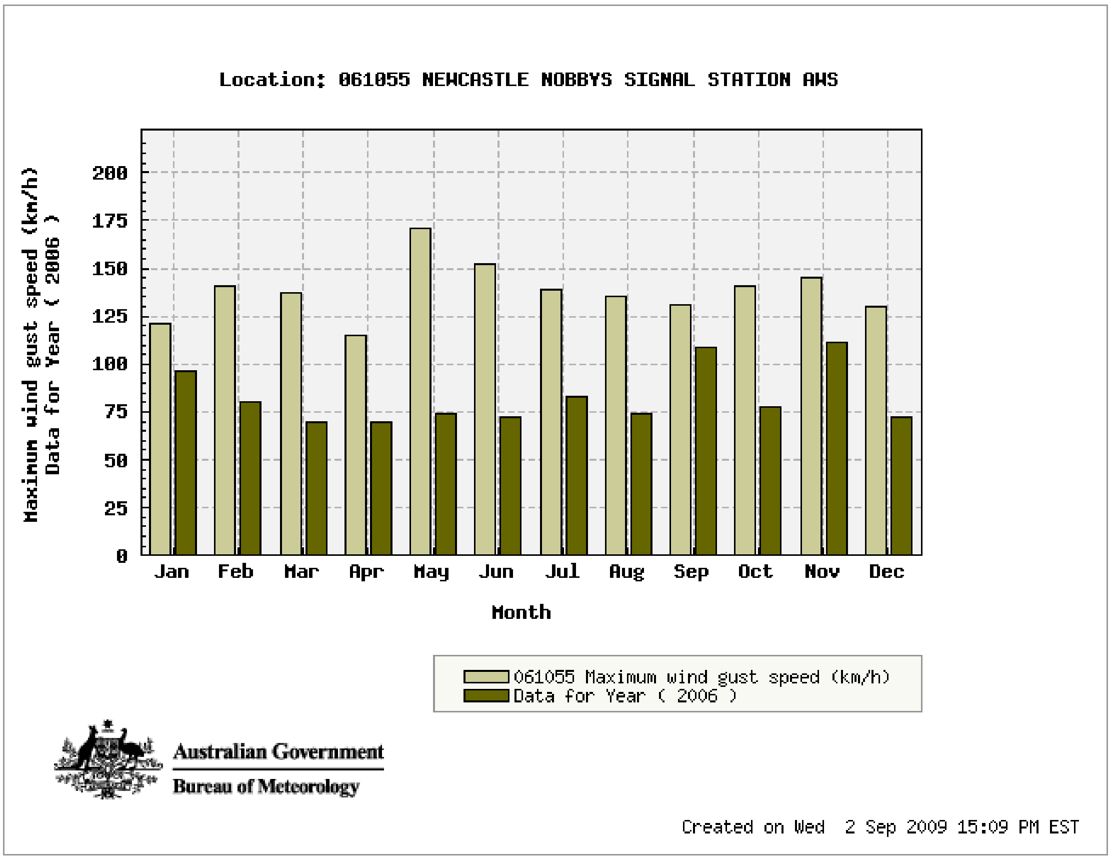
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Bureau of Meteorology
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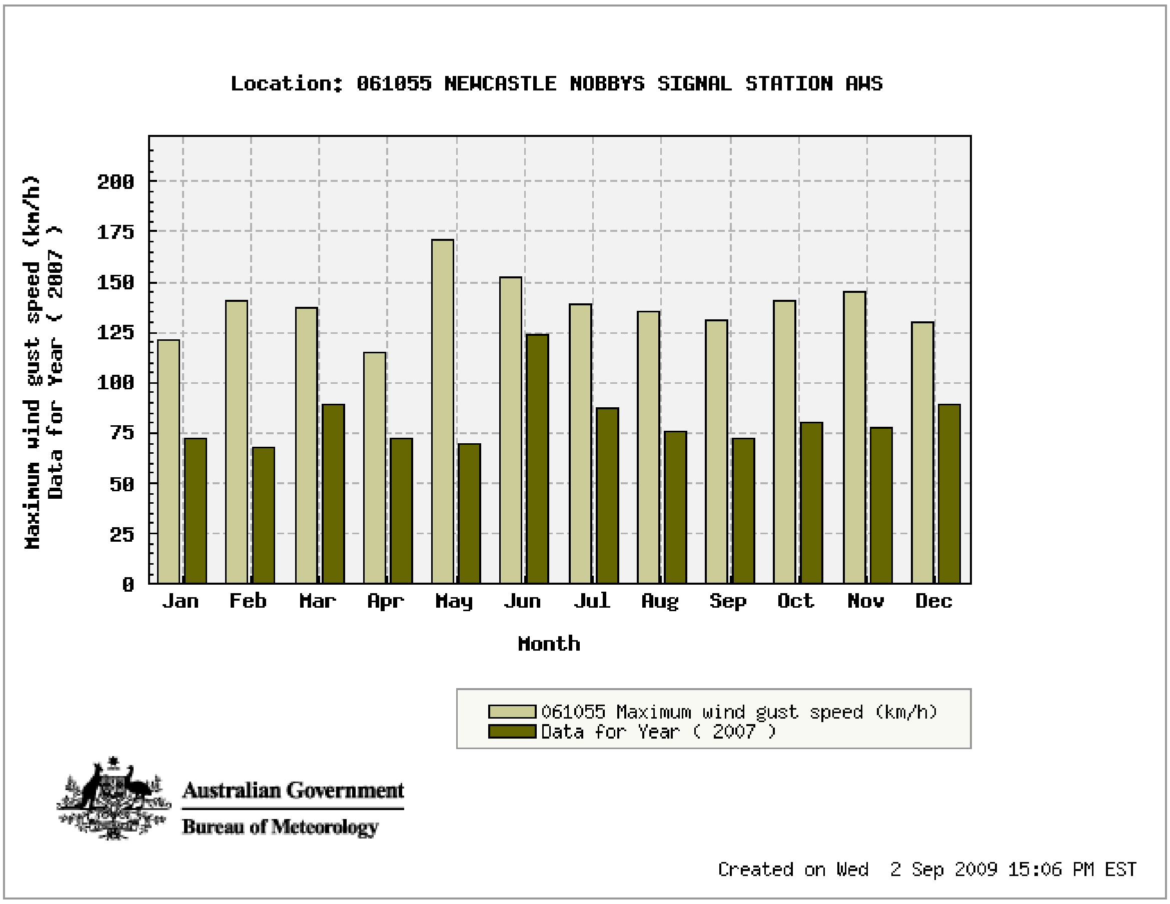

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Data for Year (2007)
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Data for Year (2007)
Australian Government
Bureau of Meteorology
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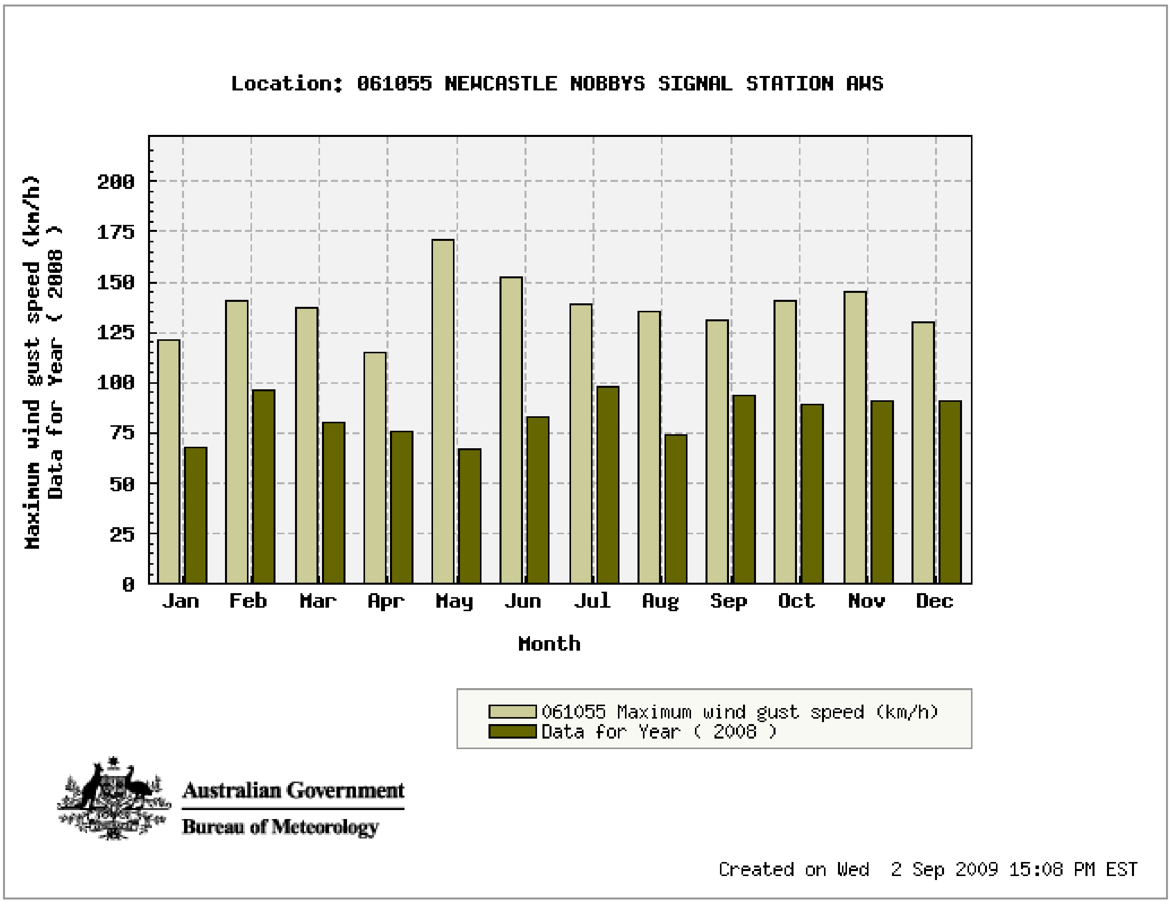

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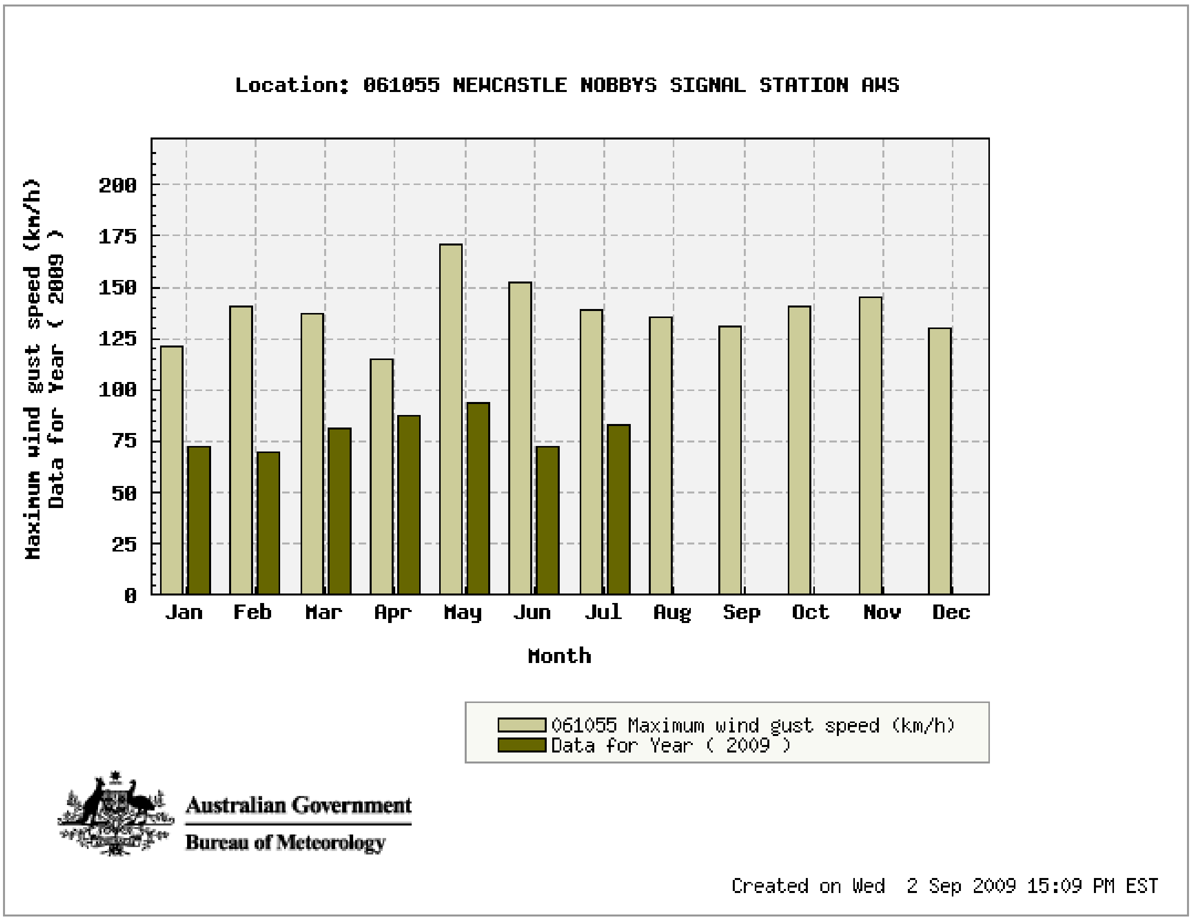
061055 Maximum wind gust speed (km/h)
Data for Year (2008)
Australian Government
Bureau of Meteorology
Created on Wed 2 Sep 2009 15:08 PM EST

Appendix 3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Maximum wind gust speed (km/h)
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061055 Maximum wind gust speed (km/h)
Data for Year (2009)
Australian Government
Bureau of Meteorology
Created on Wed 2 Sep 2009 15:09 PM EST

Arboricultural Consultancy

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