Liveable City.John Johnston.PH
Phone: 02 4974 2271

The City of Newcastle

PO Box 489, Newcastle
NSW 2300 Australia
Phone 02 4974 2000
Facsimile 02 4974 2222
Email mail@ncc.nsw.gov.au
www.newcastle.nsw.gov.au

30 July 2013

Dr Gary Watson
Arboriculture & Urban Forestry Editor-in-Chief
University of Illinois at Urbana-Champaign (Adjunct)
Urbana, IL
USA

By email to atheobald@isa-arbor.com Amy Theobald, Editorial & Production Manager

Dear Dr Watson

ARTICLE PUBLISHED IN THE JULY 2013 ARBORICULTURE & URBAN FORESTRY JOURNAL

We write concerning an article published in the July 2013 edition of Arboriculture & Urban Forestry. The article, *'Review of QTRA and Risk-based Cost-benefit Assessment of Tree Management'* was authored by Mark Stewart, Dealga O'Callaghan and Mark Hartley.

It is Council's position that the article includes inaccurate reporting and as a result it appears to be an unbalanced portrayal of the City of Newcastle, Council officers and consultants in the purported 'Case Study' of the Laman Street trees issue.

The specific concerns are as follows:

1. The article purports to describe the situation in Laman Street, Newcastle immediately following a storm in 2007. We submit that the description is the opinion of the authors and does not accord with the facts. Detailed reporting of the facts has been readily accessible on Councils web site for more than 3 years. Council's technical investigations into root architecture contradict the assertions of the published article Documents 1-4.

2. Mark Hartley had a professional relationship with Save Our Figs Inc (SOF) the community activist group who campaigned unsuccessfully to overturn the elected Council resolution to replace the Laman Street trees. Amongst a wide range of activities, the community campaign included two court proceedings against Council. The Court found in Councils favor in the first and SOF withdrew from the second. Mr Hartley's professional relationship with SOF is not disclosed in the article and this raises questions given the implied and actual criticisms embedded in the published article. Court judgments - here and here

3. The article states *"Without any further testing, three of these trees were removed"*. As none of the authors has any firsthand knowledge of the circumstances of the removal of trees in Laman Street in 2007 we reject the imputation of indiscriminate tree removal embedded in that opinion. We refer to the case study history of tree failures in Newcastle here

4. The article states *"It is important to be aware that, even if the trees had moved, this movement would not have harmed people or property as this was a serviceability failure rather than a structural failure"*. This opinion was proffered by engineer Mark Stewart and heritage engineer Bill Jordan in a presentation to Council on the Laman Street trees. The presentation attempted to show fault with Councils risk assessment. Council officers attending the presentation were not permitted to question the presenters. Council published a response to the presentation the following day here. 'Serviceability failure' is an engineering concept of no relevance or application in tree management. We ask why the statement was published when any competent researcher could have discovered the facts and thus avoided the embedded imputation of error and incompetence on the part of Council and of ourselves. There is no evidence to support their claim.

5. A statement in paragraph three of the Case Study refers to a report by consultant arborist Dennis Marsden. The statement is factually incorrect and would have been seen to be incorrect had there been a more rigorous review of the manuscript prior to publication. Sugar Factory Report

6. A statement in paragraph four refers to a QTRA report prepared for Council. There is no reference to the author or the report despite this information being readily accessible through a simple web search. That report did not conclude that the risk of harm was 1 in 19.8 per tree, per year. Why was this error not evident during manuscript review? QTRA report 1

7. A second QTRA report is also mentioned, again there is no author or reference despite this information being readily accessible. QTRA report 2

8. A statement in paragraph five of the article says *"In the absence of evidence to the contrary, these trees can be treated as statistically independent"* We believe that if the QTRA and associated reporting had been properly reviewed it would have been clear that there was extensive and thoroughly investigated evidence to the contrary. QTRA report 1

9. The final paragraph of the case study refers to a QTRA for the Laman Street trees conducted by UK arborist Mike Ellison. There is no citation in the article to that assessment. The article does not reveal Mr Ellison's contractual relationship with Save Our Figs Inc in producing his risk estimates.

10. The article implies that the initial QTRA report to Council was the basis for Councils resolution to remove and replace the Laman Street trees. This is demonstrably incorrect. Council decisions and Newcastle City Council - Key documents

11. We say that the actual and implied criticisms of the Council, its officers and consultants are founded on misreporting of the facts and on unsubstantiated assumptions about the Laman Street tree issues. We assume the criticisms to be the views of the three authors since there is no clarification in the article as to contribution. We assume that engineer Mark Stewart is the academic and lead author and that arborist Dealga O'Callaghan contributed context on the UK tree risk, and arborist Mr Hartley contributed on the Laman Street trees. It is our opinion that Mr Hartley's and Mr Stewart's involvement with the political campaign opposing Councils resolution ought to be disclosed in the article.

12. Mark Stewart and engineer Bill Jordan briefed the full Council on the first QTRA report for Laman Street. Their comments focused on aspects of that single risk assessment report. They did not review the extensive technical reporting that underpinned Councils determinations.

13. Mark Hartley and Bill Jordan represented community activists in a mediation meeting with Council. They presented their views during a breakout session with Council internal staff. The mediation did not alter Councils view on the trees.

14. In deciding to withdraw insurance cover relating to the Laman Street trees, Council's insurer was privy to all documents pertaining to the case including reports and statements on behalf of SOF by Mark Hartley, Mark Stewart and others critical of Councils risk and technical reporting.

15. We draw your attention to the background material that shows the complexity of the Laman Street issues and the facts of the matter. Media release Peer review and Peer review and engineers report on pull testing and Treenet Symposium Paper We are of the opinion that any reasonable review of the literature on the Laman Street issues would reveal a substantially different situation than that presented in the article.

16. Council has recently completed hydraulically assisted excavation of stumps in Laman Street in order to learn about root systems confined by dense infrastructure. The excavations graphically illustrate the validity of Councils assumptions about root plate asymmetry and the consequential risks in Laman Street.

With regard to the matters above we submit that:

- the ISA has, in the opinion of Council, left itself open to the allegation that it has published inaccurate and misleading statements concerning the investigations and assessment of the Laman Street trees by the City of Newcastle, its officers and consultants.
- the published article arguably does not accord with the aims of the ISA to publish high quality research.
- the published article on its face appears to not have been subject to the application of academic rigor by way of a review process, and as a result is in Council's opinion neither balanced nor fair.
- there may be a conflict with the ISA copyright provisions in that the article published in the July 2013 ISA Journal has been previously published in The Bark which is the journal of Arboriculture Australia (article submitted Feb 2013) Both articles are substantially the same except for their titles.

We invite your reply to justify what appears to be a flawed article.

Yours faithfully

Frank Cordingley
DIRECTOR LIVEABLE CITY

Liveable City.John Johnston.PH
Phone: 02 4974 2271

18 September 2013

The City of Newcastle

PO Box 489, Newcastle
NSW 2300 Australia
Phone 02 4974 2000
Facsimile 02 4974 2222
Email mail@ncc.nsw.gov.au
www.newcastle.nsw.gov.au

Dr Gary Watson
Editor-in-Chief
Journal of Arboriculture & Urban Forestry

By email to gwatson@mortonarb.org

Dear Dr Watson

ARTICLE PUBLISHED IN THE JULY 2013 ARBORICULTURE & URBAN FORESTRY JOURNAL

Thank you for your response to Council's concerns about the Review of QTRA article in the July 2013 edition of the journal. This letter explains why Council has reason to be extremely concerned at the extent of errors and misrepresentation of the facts relating to Laman Street, Newcastle, as published in the journal. The case study of the Laman Street issues casts doubt and denigrates Council. In our search for reasons as to how the authors could so misconstrue the facts, we believe it is relevant to note that one of the authors had a pecuniary involvement with the community group Save Our Figs who campaigned to prevent the removal of the Laman Street trees. Another of the authors also assisted in that campaign. We are therefore very encouraged by your willingness to consider publishing a letter detailing our concerns on the content of that paper.

First we point to where we are in agreement with the article. We agree that a QTRA should be subject to rigorous and independent review and the documents posted to Council's website show that is what occurred with the risk assessments for the Laman Street trees. Council's risk assessors and peer-review arborists are independent, licensed QTRA practitioners and acknowledged experts in their field. We agree on the need for tree risk management processes to consider the benefits provided by trees. This has been Council policy since 2002 with the adoption the Statewide Mutual Insurance best practice approach to tree management and with the 2007 adoption of the Urban Forest Policy.

We agree that the process of estimating a probability of failure is subject to uncertainty. Council's arboriculture officers are trained in QTRA and other methods of risk assessment and are familiar with the inherent subjectivities involved.

We accept that QTRA, or in fact any tree risk assessment, should be viewed only as an aid to support decision-making. We maintain that the use of QTRA or any other risk-based approach should not be done in isolation. It should be used as a tool to assist in managing the urban forest. In the case of Laman Street there were, in addition to risk assessments, many other investigations and reports, all of which are available to the public and researchers. It was this body of evidence that informed the decision making of Council. The argument that was prominent in the debate around the removal of the figs, and that is implied in the subject article that Council based its entire strategy on one risk assessment, is untenable. For example Council used the following key elements in its arguments for the removal of the trees:

- Constrained, linear and inadequately development root plates.
- Damaged roots due to cumulative public utility and other infrastructure works.
- Extensive crown asymmetry imposing an eccentric load onto the root plates.
- Growth of the crowns above the shelter of the adjacent buildings.
- Support and protection of the trees in a grove with the trees acting as a group in large wind events.
- Evidence that the trees were resisting overturning in part by using adjacent infrastructure that was not designed for this purpose.
- An extensive case history of large tree failures in the City with particular emphasis on large figs in roads.
- University of Newcastle wind tunnel modelling.
- A series of risk assessments including but not limited to QTRA.

You advised that the manuscript was subjected to the journal's scholarly peer-review process, and when we referred to "inaccurate reporting" you said that by the nature of your journal, you do not do reporting of any kind, and so we take that to mean that the case study was not subject to review. This is to our detriment because the article contains so many errors and distortions that it cannot be considered as either balanced or accurate.

The following points relating to specific paragraphs detail our concerns. In isolation, some might be thought less than significant, but because they are numerous and have been published in a reputable journal, then the potential to damage Council and mislead the industry about Laman Street is both significant and unwarranted.

1. In paragraph one of the case study (p166) the statement that the trees were growing in confined openings between the street and the sidewalk is incorrect. Mr Marsden's 2009 report (a report referenced in the article) shows that eight trees were growing in the footway and six were in the parking lane.

2. In paragraph one, the statement that some of the trees had started to grow over adjacent hard surfaces is incorrect. The authors have confused reports concerning fig trees in Laman Street west. Figure 2 in the article is a picture lifted from one such report and does not illustrate the situation at the base of any of the fourteen Laman Street (east) which is the focus of the case study.

3. Paragraph one refers to past topping of the trees, but apart from mention of 'gaps at the base of four trees', this is the only reference in the entire article as to any risk issues with the trees. The evidence reported by Mr Marsden and other reports on Council's website, shows the trees had defective root plates and were growing to failure as their crowns had risen well above the protection afforded by the Art Gallery. Why omit any reference to the substantive and documented issues of crown exposure, crown asymmetry and defective root plates? Mr Marsden's 2009 report (pp 14-18) details these issues. While the authors ignore, or are inexplicably unaware of these well-known substantive issues, it does not mean that the issues did not exist at the time or that Council did not address them in its decision making.

4. Paragraph two (p166) refers to gaps at the base of four of the trees. Mr Marsden's above-mentioned report found evidence of root plate movement in two and not four trees.

5. In paragraph two (p166) the statement *"Without any further testing, three of these trees were removed"* is not only incorrect, but it insinuates that testing could have been undertaken and the removals were in error. There was no method for testing the stability of street trees with roots interlocked with pavement, high voltage power and communications cabling. Council officers confirmed the visible evidence of structural root failure after a 2007 storm caused extensive damage in Newcastle. In developing a risk management response, it was prudent for Council to consider the recent history of fig tree failures in adjacent streets, and the 2006 Laman Street investigations showing the absence of mechanically effective root plates. The available technologies such as static and dynamic testing were at the time, and appear still to be very experimental and essentially untested and unproven on figs (or any substantial tree) growing in pavement in an urban environment. Essentially, any results, even if the tests were found by Council to be feasible or affordable (they were not) would have been interpreted based on no available relevant published information. In other words the whole process would have been a large experiment using scarce public funds with no guaranteed outcome. It is relevant here to point out that Save Our Figs (SOF) the community group opposing tree removal engaged one of the authors, Mark Hartley. He wrote to Councillors in September 2010 arguing that a pull test 'would put an end to any uncertainty'. Mr Hartley's letter included a quotation to undertake the testing himself. In an open letter distributed widely in November 2010, Mr Hartley again proposed a static pull test for each of the Laman Street trees.

6. In paragraph two (p166) the statement *"... even if the trees had moved...."* is incorrect because it denies the facts. The evidence was unequivocal - the two southern trees did move. The movement was observed, measured and photographed, then reported to Council with details published to Council's website. An opposite tree on the northern side of Laman Street was assessed for increased exposure after removal of two trees on its windward side. Increased wind load exacerbated by extreme crown asymmetry and the accumulated evidence of a linear root plate led to a decision to remove the tree. The evidence published on Council's website supports Council's decision. Evidence from hydraulic excavation of the root plate of one of the wind-rocked trees and published to Council's website shows severed wounded buttress roots; weak, linear root regeneration, and absence of compression support. The safety implications from very large trees with mechanically compromised root plates in the most heavily used public place in the city, made tree removal unavoidable. In view of the published evidence there is no justification for denying the condition of the trees or for insinuating that Council erred as with the statement *"... even if the trees had moved....".* The best possible connotation that can be placed on this statement is that the authors failed to investigate or read any of the readily available information when preparing their paper.

7. The claim in paragraph three (p166) that a consultant was engaged to assess the safety of the trees is simply not correct. The detailed brief at page 5 of Mr Marsden's 2009 report makes no requirement to assess tree safety.

8. In paragraph three (p166) the authors claim that Mr Marsden concluded that trees be removed within five years based only on a stage one visual tree assessment. This is not only incorrect; it is also a repeat of the SOF attack on Mr Marsden's credibility made during their Public Voice presentation to Council in 2010. At that presentation they wrongly accused Mr Marsden of recommending tree removals to another local government council, without undertaking stage two VTA investigations. They claimed that based on VTA alone he had recommended removal of 100 trees, with 35 trees for immediate removal. They contrasted their view of Mr Marsden's approach with that of Enspec claiming that Enspec adopted a preservation approach characterised by scientific testing such as the use of sonic tomography. Mr Marsden was forced to publicly defend himself despite having made no recommendations whatsoever for tree removal - in fact his recommendation was for stage two investigations. There is no justification for the authors to misconstrue Mr Marsden's conclusions or to make a statement attacking Mr Marsden's credibility as they have done in the case study. Mr Marsden's 2009 report conclusions include ten paragraphs addressing the full range of matters required by the brief. There is no truth to the claim that Mr Marsden had recommended tree removal based on a stage one VTA.

9. Paragraph four (p166) refers to a September 2009 QTRA report prepared for Council but the report is not referenced despite being readily accessible at the time the manuscript was being prepared, and still is accessible today on Councils website.
http://www.newcastle.nsw.gov.au/__data/assets/pdf_file/0012/100065/09R3340_LamanStFigs_1.pdf

10. Paragraph four (p166) states incorrectly that the September 2009 QTRA concluded a risk of harm of 1 in 19.8 per tree per year. That QTRA report details the reasons for assessing the trees as a group as opposed to isolated individuals. On page six a probability of failure is calculated for the 2007 calendar year, and a risk of harm is estimated at 1 in 19.8 for a year when an unusual weather event occurs. The assessor says that the risk of harm to people from each of the trees is extremely high during extraordinary storm events. The September 2009 QTRA was not a standard QTRA conforming strictly to the product user manual. There is no 'rule book' or mandatory procedure for conducting a QTRA or for any other risk assessment method. The adequacy or otherwise of any particular risk assessment is ultimately determined through the courts.

11. In paragraph four (p166) the statement "*... the reports declared the level of risk as "unacceptable."* " is incorrect - the reports did not declare the risks unacceptable. The September 2009 QTRA (p7) says the probability of tree failure is much higher than that which is required to meet the acceptable risk threshold. A second QTRA by an independent consultant (also unreferenced), concludes that the risk of harm was not within the acceptable limit. To say that a risk is not within the acceptable limit, or that it is higher than that required to meet the acceptable risk threshold, is to state a fact, but saying that a risk is 'unacceptable' is stating an opinion. There is no justification for such misreporting

12. The last paragraph of the case study (p167) refers to a January 2012 QTRA by Mike Ellison who is said to have estimated a ROH of 1 in 170,000 for the 'worst' tree and 1 in 2,000,000 for the 'best' tree. The source of these estimations is not referenced so the figures and the means by which they were determined cannot be validated. As a consequence of this, the authors' argument that Laman Street QTRA reveals large discrepancies in the estimation of probability of failure between two licensed QTRA practitioners and the developer of QTRA does not stand. Table 1 (p167) of the article compares the results for a single tree in Laman Street but as we have said, Mr Ellison's figures are not validated and therefore the data in table 1 cannot be used to support the proposition. The Council's September 2009 ROH has been misconstrued as we have shown and so the figures are not comparable with figures estimated in accordance with the prescribed QTRA method, if that is how they were estimated.

13. The final paragraph of the case study (p167) states that Council's licensed QTRA practitioners calculated a ROH more than 8000 times higher than that derived by the developer of QTRA. In view of the inherent subjectivity of estimating a probability of failure, there is no justification for insinuating that the developer of QTRA is any more adept at estimating a ROH than any of the licensed users engaged by Council. In order to judge the efficacy of QTRA for the Laman Street trees, it would be necessary to review the brief for each assessment and the assumptions and actions underpinning the assessor's estimations. As we have shown, this cannot be done with respect to the estimations ascribed to Mr Ellison. It is relevant here to point to the public record that shows that Mr Ellison was flown from the UK to Newcastle under contract to SOF as part of their campaign to prevent the removal of the Laman Street trees. During his visit to Newcastle Mr Ellison went on record as acknowledging that he had limited experience with the tree species, and that he made no detailed inspection of any of the trees because access was denied by perimeter security fencing.

14. The last sentence in paragraph four (p166) is wrong in stating that Council made a decision to remove the trees based on the level of risk. As explained at the beginning of this letter, there is no evidence whatsoever to show that risk estimations for the Laman Street trees were ever considered as anything more than aids to Council's decision-making. The documentation published on Councils website shows the extent and importance of considerations other than risk that contributed to the decision to remove and replace the Laman Street trees. These included environmental, financial, liability, social and heritage studies, facilitated design workshops as well as practical and political considerations. Over the course of three years Council developed and implemented a responsible and defensible risk management approach whilst planning the renewal of Newcastle's most important cultural space. Estimations of risk contributed to the process but there is no basis for framing the Laman Street issue as a debate hinging on mathematical probabilities as attempted in the journal article.

To conclude, it appears the authors have spent their time criticising a single QTRA report rather than engaging with Council and discussing the real reasons for the removals based on the body of evidence collected over many years.

The decision to remove the Laman Street trees was a well reasoned decision that went before Council in the form of 22 reports over three years and the decision was supported by a majority of Councillors.

The lead author had the opportunity to outline his arguments in a briefing to Council. At that meeting Professor Stewart agreed that he had not looked at any of the other reports into the trees other than the September 2009 QTRA, and it appears from the article that he still has not done so. It is telling that Councillors chose to agree with the officers' reports, despite a significant community pressure, rather than with Professor Stewart.

It should be noted that since the trees were removed root mapping of three of the trees has been completed. The information from that exercise validates Council's case for tree removal as it confirms and complements our previous investigations as to the inadequate root plate architecture for large figs growing in constrained urban conditions.

We believe the journal's scholarly peer-review process failed for whatever reason, to identify and correct errors and distortions in respect of the Laman Street case study. In addition, the peer-review process failed to identify that unverified data and reports were used to support the authors' arguments and conclusions. As a consequence the article does not bring credit to the ISA and its journal and the reputation of Council, its officers and consultants is damaged.

The City of Newcastle is justifiably proud of its groundbreaking achievements in urban forest policy development, and its systematic asset based approach to managing more than 112,000 public trees.

We therefore seek your support in reaffirming our reputation by way of publication of this letter at the earliest possible opportunity.

Yours faithfully

John Johnston
MANAGER INFRASTRUCTURE MANAGEMENT SERVICES

NB: As requested we have attached a copy of the Arboriculture Australia article that preceded publication in your journal.

Quantified Tree Risk Assessment: A Critical Review

Professor Mark G. Stewart[1], Australian Professorial Fellow Director, Centre of Infrastructure Performance and Reliability, The University of Newcastle, New South Wales 2308, Australia

Dr Dealga O'Callaghan, Chartered Arboricultural Consultant, Dealga's Tree Consultancy Limited, Liverpool, England

Mark Hartley, Senior Consulting Arborist, Arborist Network, Sydney, Australia

Submitted: February 2013

An abridged version of this article is to appear in the Journal of Arboriculture & Urban Forestry in 2013.

1 Corresponding Author: ph +61 2 49216027, email: mark.stewart@newcastle.edu.au

1. INTRODUCTION

An important aspect of tree management is to assess the likelihood of a tree causing harm (injury, death and/or property damage, disruption of activities). In recent years, the potential for trees to cause harm has been highlighted by elevated media coverage of tree caused injuries or fatalities. The reality, however, is that the risk of being killed or injured by a tree is extremely low. For example, about three people per year in the United Kingdom (U.K.) are killed by trees in public places, and the fatality risk per tree is 1 in 150 million for all trees in the U.K. or 1 in 10 million for trees in or adjacent to areas of high public use (HSE 2007, NTSG 2011). In the United States (U.S.), there were 407 deaths from wind-related tree failures in the 13 year period 1995-2007 (Schmidlin 2009), or 31 fatalities per year (note that the U.S. population is 5 times that of the U.K.)

There has been much debate about the risk trees pose to human populations. In the U.K., the debate was heightened following a high profile case, *Poll v Bartholomew* (2006) which involved a motorcyclist being hurt by a tree that failed. It was never clarified as to whether the tree fell on to Mr Poll or he came around the corner on his bike and collided with the fallen tree, in any event he sustained personal injuries. In this case, the Court decided that a large private estate did not have an adequate system for the inspection and management of trees, which was an annual drive/walk by assessment. The Court concluded that inspections should be undertaken by qualified and competent inspectors. Speculation that this judgment placed an excessive burden of tree inspections on landowners created an air of anxiety. This resulted in much uncertainty and many trees being unnecessarily felled for fear of litigation (e.g., NTSG 2011). This understandably made decision-makers more risk averse than they otherwise might have been.

Systems have been developed to try and assess the likelihood of trees failing, and the harm that might be caused in the event of failure. Matheny and Clark (1994) developed a hazard evaluation system that assigns a numerical value between 1 and 4 for (i) failure potential, (ii) size of part, and (iii) target rating. These are then totalled to produce a hazard rating between 3 and 12. Other tree risk assessment systems include: THREATS & THREATS-NR (www.flac.uk.com), The Bartlett Tree Expert Company's 'Tree Risk Management' 2nd Edition (Smiley et al. 2007), and the ISA's Best Management Practice for Tree Risk Assessment (Smiley et al. 2011).

Ellison (2005) took a probabilistic approach to risk, and developed the Quantified Tree Risk Assessment (QTRA) system. This system attempts to provide a quantitative framework for the assessment of the three components of tree risk: (i) target value, (ii) probability of failure, and (iii) impact potential. The system assesses the probabilities of the three components of risk and calculates their product, which allows skilled tree inspectors to quantify the risk of harm from tree failure, which in turn facilitates the balance between tree safety and tree value.

Quantified Risk Assessment (QRA) has been in wide use in risk management since the 1960. The QRA assesses hazard likelihood and system vulnerability using sound physical modelling of failure processes, and recognition of uncertainty and variability of influencing variables. This is absent from the QTRA system which seems to rely more on subjective assessments, particularly for probability of tree failure. Moreover, the QTRA system does not consider 'benefits' in the risk assessment component where costs and benefits are compared, but rather relegates this to information contained in the practice notes.

In principle, QTRA is a welcome development because a quantified risk-based approach to tree management is based on sound decision support principles. This paper explains the principles of QRA, and identifies some weaknesses in the QTRA process that could be rectified by the incorporation of additional QRA principles in any revision of QTRA. The paper will also show how a cost-benefit analysis that considers risk of harm, costs of tree removal, benefits of tree amenity, and other costs and benefits can be used to compare costs and benefits in a rigorous manner. This type of risk and economic assessment can better inform decision-makers.

2. QUANTIFIED TREE RISK ASSESSMENT (QTRA)

The QTRA process is developed and documented by Ellison (2005) and the Quantified Tree Risk Assessment User Manual V3.06 (2012). Risk of harm (ROH) is calculated as (Ellison 2005):

Risk of Harm = Probability of failure × Target value × Impact potential (1)

where 'harm' is defined as serious injury or death. Probability of failure is the annual probability that a tree or selected tree-part will fall. The target value is the probability that a person, vehicle or property will be impacted. The impact potential is the probability of harm a falling tree, or part of a tree, can cause to a pedestrian or vehicle. The risk is deemed "unacceptable" if the ROH exceeds 1 in 10,000.

3. CASE STUDY - LAMAN STREET FIG TREES IN NEWCASTLE

The city of Newcastle in New South Wales (Australia) had 17 mature fig trees (*Ficus microcarpa* var. *hillii* (Hill's weeping fig) on both sides of Laman Street in the heart of the city, see Figure 1. These trees were estimated to be in excess of 70 years of age. They have been lopped (topped) on multiple occasions. Over the last few decades, however, lopping treatment has ceased and trees were left unpruned. Although growing in confined openings between the street and footpath (sidewalk), the trees were considered to have good health and vitality. Some of the trees had started to grow partially over the adjacent hard surfaces.

In June 2007, a severe east-coast low caused wind speeds of 124 km/hr and intense rainfall. As a result, gaps appeared between the base of four trees and the adjacent hard surfaces, see Figure 2. Without any further testing, three of these trees were removed. The fourth tree that was thought to have moved was monitored over the following month to check for further movement. This tree was then determined by Newcastle City Council (NCC) to be stable, and subsequently retained. It is important to be aware that, even if the trees had moved, this movement would not have harmed people or property as this was a serviceability failure rather than a structural failure.

In August 2009 NCC engaged a consultant to assess the stability and safety of the remaining 14 trees. The Stage 1 Visual Tree Assessment concluded that "*the trees with the shortest SULE (Safe Useful Life Expectancy) will dictate the outcome for the entire group. The shortest SULE is category 4: remove within 5 years*" (Marsden 2009). In response to this determination NCC sought to have the risk posed by the trees assessed in order to determine an appropriate management strategy.

In September 2009, a Quantified Tree Risk Assessment (QTRA) was prepared for Newcastle City Council. It concluded that the risk of harm (ROH) was 1 in 19.8 per tree per year, and that the probability of tree failure was 1 in 7.5 per tree per year (see Table 1). A subsequent report by another arboricultural consultant reviewed this first QTRA report and concluded in 2010 that *"On review I believe that this report provides a reasonable assessment of the quantified risk of harm."*[1] Both consultants were 'licensed' QTRA practitioners. Since the ROH exceeded the QTRA suggested ROH threshold of 1 in 10,000, the reports declared the level of risk as "unacceptable". Based on the level of risk, NCC made a decision to remove the trees in late 2011, and the trees were finally removed in February 2012.

The 14 remaining trees survived for over 4.5 years (June 2007 to February 2012) before they were eventually removed. While there may be some correlation between tree performance along a street, there is no evidence of this occurring in Laman Street as failures were isolated events (i.e. one or two trees may fail, but not all trees at the same time) due to the high variable nature of localised tree root conditions and wind environment. In the absence of evidence to the contrary, these trees can be treated as statistically independent. Using the QTRA results the expected (average) number of deaths or serious injuries in four and a half years between the storm and tree removal is

$$E(\text{fatalities}) = N \times ROH \times \text{time} = 14 \times 1/19.8 \times 4.5 = 3.2 \text{ fatalities or serious injuries} \quad (2)$$

where N is the number of trees (N=14), and T is the time period in years (T=4.5)

Similarly, the expected (average) number of failures in four and a half years is

$$E(\text{tree failures}) = N \times Pr(\text{tree failure}) \times \text{time} = 14 \times 1/7.5 \times 4.5 = 8.4 \text{ tree failures} \quad (3)$$

The probability that no tree should fail in four and a half years is

$$Pr(\text{no tree failures}) = [1 - Pr(\text{tree failure})]^{N \times time} = [1 - 1/7.5]^{14 \times 4.5} = 0.012\% \text{ or } 1/8,000 \quad (4)$$

and so the probability of at least one tree will fail in four and a half years is

$$Pr(\text{at least one tree failure}) = 1 - [1 - Pr(\text{tree failure})]^{N \times time} = 1 - [1 - 1/7.5]^{14 \times 4.5} = 99.99\% \quad (5)$$

These relatively straightforward probabilistic analyses were not included in the consultant reports prepared for NCC. Likewise, these probabilities appear not to have been considered and/or appropriately weighed by NCC in making the decision to remove the trees. This type of analysis enables a 'reality check' when extrapolating rates of failure and harm for a single tree to a group of trees. These analyses indicate that the ROH provided to NCC by the QTRA assessors were excessively high. Moreover, all 14 trees remained upright, despite a predicted 99.99% probability that at least one tree would fail in a 4.5 year period.

A risk of death (or harm) per tree per year of 1 in 19.8 is the highest estimate observed by the lead author for any activity. A single fig tree in Laman Street is ten times more dangerous than smoking 10 cigarettes a day (BMA 1990), ten times more dangerous than World War Two (Mueller and Stewart 2011), 75 times more dangerous than mountain climbing (BMA 1990), and 500,000 times more dangerous than trees in public places in the U.K. (see Introduction where fatality risk per tree is 1 in 10 million for trees in areas of high public use).

A QTRA of the 14 trees was undertaken by Mike Ellison in January 2012. He estimated the ROH to be 1 in 170,000 for the worst tree, and ROH of 1 in 2,000,000 for the best tree (see Table 1). The largest discrepancy occurred in the estimation of probability of failure. The fact that two 'licensed'

1 *key documents are available on the NCC web site: www.newcastle.nsw.gov.au/environment/tree_management/laman_street_figs/key_documents*

QTRA practitioners can calculate a ROH that is more than 8,000 times higher than that derived by the developer of QTRA is a cause for concern.

4. QUANTIFIED RISK ASSESSMENT (QRA) AND DECISION-MAKING

There is a long history dating from the 1960's on QRA and its application to decision-making. Applications of QRA range from assessing the safety of nuclear power plants, off-shore platforms, aircraft, missiles, toxic materials to assessing the cost-effectiveness of medicines to road safety to aviation security to flood protection for communities. These applications arise because there is uncertainty and variability of the hazard and risks, the costs of failure are high or catastrophic, costs of protection are also high, and public safety needs to be safeguarded. The decisions also affect many interested parties, so there is a need for a decision process that has scientific rigour, is transparent, and acceptable to society. An understanding of the principles and practices that underpin QRA provide context for future developments to QTRA. We would recommend that the QTRA system should develop longer and more intensive training that includes the principles of QRA as a starting point.

4.1 Risk Assessment Process

In performing a QRA, a number of steps are basic to the analysis, and independent of the system being considered. As applied in the engineering, insurance, pharmaceutical, and many other industries for many decades, the basic definition of risk has been standardized by international agreement (ISO 31000-2009). The process is shown in Figure 3 and can be summarised as (Stewart and Melchers 1997):

1. **Define context.** The system being examined, and the internal and external influences, must be known and defined.
2. **Analyse hazard scenarios.** Identification of what might go wrong, when and where, is crucial to the analysis. Once the potential threats and scenarios have been identified, it is necessary to identify how and why these threats or scenarios can be realised.

   It requires the threat or hazard scenarios to be examined (and understood) in considerable detail. Information from databases and other past experiences will play an important part in hazard scenario analysis.
3. **Analyse risk**

   RISK = (probability of failure) × (consequences) (6)

   Risk (or expected loss) may be given in terms of dollars, the number of human fatalities, etc. for a specific time period (often annually). Typically, the probabilities are estimated from a combination of relevant data and statistics, predictive models of system reliability, and subjective judgments as a last resort.
4. **Evaluate risks.** Analysed risk must be compared with criteria of risk acceptability, usually applying past experience as a guide. If the risk of death is less than one in a million per year, risks are conventionally considered acceptable if the benefit exceeds the cost.
5. **Treat the risk.** If the estimated risk exceeds the risk acceptance criteria, risk treatment is required. This may involve risk avoidance, risk reduction, or risk transfer. In all cases, the proposed course of action requires careful evaluation. Consideration must be given to possible options and to the likely effect of their implementation, such as opportunity costs. This might involve one or more new risk analyses to gauge the effect of changes.
6. **Monitor and review.** Usually a risk analysis presents only a snapshot of the risk at a particular point in time. Therefore, there is a need to monitor the system and to repeat the risk analysis at regular intervals.

The key objective of a risk assessment is to make an informed risk-based decision. Thus, evaluating the risk by deciding on risk acceptance criteria is a crucial step. In the steps above, the two substantive and challenging steps are (i) analysing the risk, and (ii) evaluating the risk. These two steps are now discussed.

4.2 Analyse Risk

Assessing the consequences of system failure is often relatively straightforward. The consequences of a failure event are generally measured in terms that directly affect people and their environment such as loss of life or injury and economic losses. The estimation of consequences can often be fairly accurate. For example, the consequences of a bridge collapse are cost of replacing the bridge, vehicle occupant fatalities, and indirect losses due to traffic diversions, loss of business/productivity and other social costs. The most contentious issue is how to place a monetary value on a human life. Paté-Cornell (1994) suggests that a cost per life saved of $2 million or less is appropriate for current practice, and the United States Department of Transport adopts a figure of $3 million (Viscusi 2000). For homeland security cost-benefit assessments, Robinson et al. (2010) recommend a Value of Statistical Life (VSL) of $6.5 million in 2010 U.S. dollars. For most activities a VSL ranging between $2-$10 million is typical (Viscusi 2000), as this provides a reasonably accurate reflection of societal considerations of risk acceptability and willingness to pay to save a life.

Estimating the probability of failure is, in general, more challenging to predict than consequences. This is particularly so for low probability events, where failures are rare and the system under consideration is unique or one-off in terms of its design, manufacture, operation or environment (such as offshore platforms, long-span bridges). For engineering systems, failure probabilities are often calculated from computational models that consider the variability and uncertainty of system response, loads, environment, and workmanship. Such analyses can take many person-years to develop. If performance data are available in terms of failures and successes then statistical methods can be used to calculate failure probability and databases assemble such statistics. Either way, a thorough understanding of statistics and probabilistic methods is required.

As a last resort, expert opinions may be elicited (Ayyub 2001, Paté-Cornell 2002). Expert opinions are subject to a number of issues and problems and so should be used with some caution. However, Paté-Cornell (1986) concludes that '*experts' opinions are indispensable given the scarcity of unquestionable data sets*'.

What underpins any method for estimating failure probabilities is an understanding of the failure modes and their cause. In other words, sound physical modelling of failure processes, and recognition of uncertainty and variability of influencing variables, will lead to more robust estimates of failure probabilities.

4.3 Evaluate Risks or Risk Acceptance Criteria

While risks are seldom acceptable, they are often tolerable (or accepted reluctantly) if the benefits are seen to outweigh the costs. The Health and Safety Executive in the United Kingdom puts it this way:

> *"Tolerability does not mean acceptance. It refers to the willingness to live with a risk to secure certain benefits and in the confidence that it (risk) is being properly controlled. To tolerate a risk means that we do not regard it as negligible or something we might ignore, but rather as something we need to keep under review and reduce still further if and as we can."* (HSE 1992).

There is a large amount of literature devoted to the problem of how to define what risks are acceptable to society, and those which are not, since all activities bear some risk (for a review see Stewart and Melchers 1997). The regulators of potentially hazardous industries and activities such as the U.S. Nuclear Regulatory Commission, Federal Aviation Administration, and the Environmental Protection Agency set risk acceptance criteria based on (i) annual fatality risk, and (ii) cost-benefit analysis.

4.3.1 Annual Fatality Risks

Stewart and Melchers (1997) and Mueller and Stewart (2011) reviewed the quantitative safety goals used by the U.S. Nuclear Regulatory Commission, U.K. Health and Safety Executive, Australian and Dutch hazardous industrial development regulators, and others. The consensus risk acceptance criteria obtained for involuntary fatality risk to an individual are shown in Figure 4, and are designed to provide a viable, if somewhat rough, guideline for public policy:

- Annual fatality risks higher than the range 1×10^{-4} to 1×10^{-3} (one in a thousand to one in ten thousand) are deemed unacceptably high or a *de manifestis* risk.
- Annual fatality risks in the range of 1x10-3 to 1x10-6 (one in ten thousand to one in a million) are generally acceptable if the benefits outweigh the risks to provide an economic or social justification of the risk.
- Annual fatality risks smaller than 1×10^{-6} to 1×10^{-7} (one in a million to one in ten million) are deemed as negligible and further regulation is not warranted.

4.3.2 Net Benefit or Cost-Benefit Analysis

Many risks can be reduced, but at increasing cost until they become excessive compared with the benefit. If annual fatality risks are not unacceptably high or are negligible, then risks may be acceptable if the benefits outweigh the risks. The 'benefit' is the reduction in risk (damages or fatalities averted) associated with a decision, and the 'cost' is the cost of the decision. The net benefit or net present value (NPV) is equal to benefit minus the cost. The net present value or net benefit is (e.g., Stewart 2010):

$$NPV = E(B) + \Delta R\left[\Pr(failure)\times Consequences\right] - C_{\Delta R} \quad (7)$$

where E(B) is the expected benefit from the decision not directly related to mitigating the risk; Pr(failure) is the probability of failure assuming no risk mitigating measures; and Consequences is the loss or consequence if failure occurs. The reduction in risk (ΔR) is the degree to which the decision or risk mitigating measures reduces the likelihood of failure and/or the losses sustained in a failure. The cost of reducing the risk including opportunity costs is $C_{\Delta R}$. This equation can be generalised for any time period, discounting of future costs, and more detailed time-dependent cost and damage consequences. If NPV>0 then there is a net benefit and so the measure is cost-effective.

4.3.3 Risk Aversion

For low probability-high consequence events decision-makers tend to be risk-averse because of the catastrophic or dire nature of the hazard or event. However, while many individuals may be risk-averse, government and society are risk-neutral when assessing risks because governments have a high degree of cost and benefit diversification not available to individuals (Sunstein 2002, Faber and Stewart 2003, Ellingwood 2006). A 'risk neutral' risk assessment entails using mean or average estimates for risk and cost-benefit calculations, and not worst-case or pessimistic estimates, as mandated, for example, by the U.S. Office of Management and Budget (OMB 1992).

Probability neglect is a form of risk aversion as decision-makers are clearly averse to events of large magnitude irrespective of the probability of it actually occurring. Utility theory can be used if the decision maker wishes to explicitly factor risk aversion into the decision process (Jordaan 2005, Stewart et al. 2011).

The issue of risk aversion is not a new one, but has been well researched and documented for politically sensitive and controversial decisions such as nuclear power safety and aviation safety. In these cases, risk acceptance criteria have been developed based on annual fatality risks and net benefit analysis using expected (mean) values.

4.3.4 Peer Review

Finally, a peer review will add to the quality of the risk analysis and assessment, and the decision-making process and so enhance the credibility of decisions. This is particularly so for decisions which have the potential for political and public repercussions or where the assets have heritage, ecological or cultural significance.

5. QUANTIFIED TREE RISK ASSESSMENT (QTRA)

5.1 Calculation of Risk of Harm

The probability of failure is the most subjective parameter to quantify when estimating Risk of Harm. According to the QTRA User Manual V3.06 (2012) there is an order or more of magnitude between each probability of failure range used on the QTRA calculator starting from 1/1 and ranging to 1/1,000,000. The QTRA User Manual (2007) points out that trees that have a low probability of failure *"are at significant risk of failure only during very extreme weather events"*, a statement supported by the observations of Guggenmoos (2010) in relation to damage to overhead power lines following catastrophic storm events in North America.

There seems to be little guidance to QTRA practitioners on how to assess the probability of failure. There are no instructions on how to undertake a statistical analysis of tree failures, how likelihoods may be estimated from wind speed and rainfall records (if these are the hazards contributing to failure), how mode of failure affects failure probabilities, how to estimate 90th or 95th percentile confidence intervals on predictions, or how to extrapolate probability of failure per tree to a group of trees, see Equations (2) to (5). At this moment, the QTRA process of estimating probability of failure is subject to a degree of uncertainty because of the complex variables involved in tree biomechanics and tree failure, variable weather conditions, and varying levels of expertise of the assessors.

There is also a need to compile datasets on tree failures and failure rates in a format suitable for benchmarking. The International Tree Failure Database (ITFD), for example, may be very useful for determining the number of failed trees, but a calculation of probability of failure (failure rate) requires also the number of trees that have not failed (ie. unfailed trees), and the time period over which failures were observed, see Eqn. (10).

Benchmarking allows the predicted probability of failure to be compared to known statistics of failure obtained from relevant datasets. For example, is the assessed tree likely to be 10 times more likely to fail than an average tree, about the same, or 10 times less? Probability of failure may also increase with time if deterioration is observed, or perhaps those that have failed were weaker and so remaining trees are less vulnerable. Calculated risks will be most sensitive to probability of failure, and more scientific approaches and detailed guidelines are needed to better estimate this parameter.

The QTRA guidelines provide significantly more detailed instructions on quantifying target value. This is to be expected since it is not particularly difficult to assess the likelihood that people or vehicles will be under a tree at any point in time. In a busy street it will be approximately 50-100%, and for a park, maybe 10-20%. Either way, any estimate will be accurate to ±10-20%.

One issue that needs further elaboration is that trees are most vulnerable during periods of high wind and/or rain. These are circumstances where many people avoid the outdoors thus reducing the target value quite considerably. Although the influence of weather is not discussed by Ellison (2005), it is discussed and some guidance is provided in the QTRA User Manual (2012).

The guidelines for impact potential are quite prescriptive, and are based on size of tree part likely to impact the target. Impact potentials vary from 1/1 (100%) for a 450 mm diameter tree part to 1/2,500 for a 10-25 mm tree part. If a tree or tree-part were to fall, and a person was under the tree at the time, there will not be 100% surety of harm to the person no matter how large the tree-part. A tree has a large canopy, and a tree could fall away from an individual, or a tree-part fall on the opposite side to where a person is standing. Therefore, the upper limit of 100% seems too high, and a more reasonable upper limit may be say 25% or 50% depending on the size of the tree. Impact potentials would seem to be over-estimated in the QTRA guidelines.

Finally, there is some evidence that results from a QTRA are highly subjective. Norris (2007) asked twelve experienced arborists to assess eight trees using eight different risk assessment methods (see Figure 5). For QTRA, the risk of harm ranged from 1/19 to 1/128 million. The lowest and highest values were obtained from QTRA licensed practitioners. The range in probability of failure was 1/2 to 1/50,000. Such a large discrepancy should be a concern, as should the discrepancies between two licensed QTRA practitioners and Mike Ellison who developed QTRA, in the case of the Laman Street fig trees.

5.2 Risk Acceptance Criteria

If the ROH exceeds 1 in 10,000 then the QTRA process deems that the risk is "unacceptable" and remedial action is needed to reduce the risk to an acceptable level (Ellison 2005). In principle, this risk acceptance criterion has much merit, but may be viewed as prescriptive. There is much evidence that annual fatality risks that exceed 1 in 1,000 are unacceptable, and that risks between 1 in 1,000 and 1 in 1 million may be acceptable if the benefits outweigh the risks (see Section 4.3.1). There is no clear consensus about at precisely what level risks become unacceptable, so any prescribed safety goal needs to be interpreted with some flexibility. Ellison (2005) notes that "*the hazard could confer benefits that might be set against the risk of harm*". This infers a cost-benefit assessment, but the QTRA process does not offer guidance on how a cost-benefit analysis should be undertaken. The two cost-benefit examples to follow are provided to illustrate some key cost-benefit assessment concepts.

5.2.1 Example 1 - Net Benefit of Tree Removal

Let us assume that tree removal is the recommended decision, and this will cost $10,000 per tree. If this cost is spread over T years, then the annual cost discounted to present values is

$$C_A = \frac{C_T}{\sum_{t=1}^{T} \frac{1}{(1+r)^t}} \quad (8)$$

where C_T is the total cost and r is the discount rate. If costs are annualised over T=10 years at r=3% then this gives a present value of approximately $1,200 per year. This might be viewed as a direct cost. However, an opportunity cost might also be associated with loss of amenity (shade, viewpoints, property value) which might be say $1,000 or $5,000 per year.

The benefit of tree removal is that it will remove all risk, and so ΔR=100%. Another benefit of tree removal is that it may eliminate root damage to pavement and services producing maintenance savings of $250 per year. The losses if a tree were to fail would be damage to adjacent property and loss of life totalling $5 million.

All costs are converted to annual costs to ensure consistency of units. All values are illustrative only to help explain parameters and trade-offs between costs and benefits. The NPV or net benefit for tree removal is (Eqn. 7):

$$NPV = E(B) + \Delta R\left[ROH \times C_{loss}\right] - C_{\Delta R} \quad (9)$$

where

- ROH = annual risk of harm (ROH) per tree
- E(B) = $250 per year (no root damage to infrastructure)
- ΔR = 100% (tree removal eliminates all risk)
- C_{loss} = $5 million (consequences of tree failure)
- $C_{\Delta R}$ = $1,200 per year (cost of tree removal and no loss of amenity)
- $C_{\Delta R}$ = $2,200 per year (cost of tree removal and $1,000 loss of amenity)
- $C_{\Delta R}$ = $6,200 per year (cost of tree removal and $5,000 loss of amenity)

Table 2 shows that net benefit varies as a function of ROH for losses of amenity of $0, $1,000 and $5,000 per year. If ROH is 1/100 then net benefit of tree removal is $44,000-$49,000 with net benefit highest when there is no loss of amenity. When ROH=1/1,000 then the net benefit of tree removal reduces to $4,050 and $3,050 for loss of amenity of $0 and $1,000, respectively. However, when ROH=1/1,000 and loss of amenity is $5,000 per year then there is not a net benefit of tree removal, but a net loss of $950 per year. A lower ROH of 1/10,000 produces net losses irrespective of level of loss of amenity. To be sure, more detailed analyses are possible, but this example shows that even if ROH exceeds the prescribed QTRA safety goal of 1/10,000, there can still be a net benefit to retaining a tree once all costs and benefits of tree removal are considered.

5.2.2 Example 2 - Net Benefit of Risk Mitigating Measure

Rather than removing the tree it is possible to employ a risk mitigation strategy to reduce the exposure of people to a potential hazard. This might include, for example, restricting vehicle access to an adjacent road, redirecting pedestrian traffic, or closing the street on high wind days. Such risk mitigation measures might be expected to reduce the target value considerably. We assume a 75% reduction in target probability, equivalent to a risk reduction of ΔR=75%. The cost of risk mitigation measures may be $15,000 per year. Maintenance costs associated with root damage to pavement and services costs $250 per year. Hence, $C_{\Delta R}$ =$15,250 per year, and C_{loss}=$5 million as assumed above. A benefit of retaining the trees may be public amenity, which may vary from E(B)=$1,000 to E(B)=$5,000 per year.

Net Benefit is calculated from Eqn. (9) using the parameters described above (see Table 3). If the ROH is 1/100 or greater then risk mitigating measures are cost effective. However, the benefits of such measures reduces as ROH decreases, even when the public amenity and benefit of retaining the tree is valued at E(B)=$5,000 per year. If the ROH is 1/100, the net benefit for tree removal is $49,050 (assuming no loss of amenity), and $22,500 if risk mitigating measures are put in place that reduce risk by 75% (compare Tables 2 and 3). It follows that a decision aimed at only maximising net benefit would be to remove the tree - this assumes that economic assessment is the sole criterion for decision making. However, if a decision was to retain the trees for non-quantifiable reasons (heritage value, tourism, etc.) then risk mitigating measures are also cost-effective and justifiable with a net benefit of at least $22,250. Clearly, different cost inputs will lead to different results and decisions.

5.3 Improvements to QTRA

The priority for improvement lies in more accurate and robust assessment of failure probabilities, as this is the parameter in the risk equation subject to the highest uncertainty (and error). The element of subjectivity needs to be ameliorated. This means more scientific approaches are needed, and that results are benchmarked with known risks to ensure that results pass a 'reality check'. The figures used by the assessor must have at least some semblance to reality.

Hazard identification is an important first step to understand the cause of tree failure, and then the frequency and severity of these events. This might involve assessing the annual probability that a wind speed exceeds a certain value, or rainfall exceeds a specific value. Statistical and probabilistic models for natural hazards are well researched and documented; for example, Wang and Wang (2009) provide stochastic wind field models for most locations in Australia for cyclones and storms.

If the tree under consideration is similar in age, condition and exposure to other trees, then the failure probability may be derived as

$$\text{Probability of Failure} = \frac{n(\text{failed trees over time period T})}{N \times T} \text{ per year} \quad (10)$$

where n() is the number of failed trees over time period T, N is the total number of failed and unfailed trees, and T is measured in years. It is preferable to consider times periods in excess of one year as this will average out the failure probability over time and be more likely to consider the effect of extreme events.

The larger the sample size (NxT) the more confidence there is in the calculation. It follows from binomial theory that the 90% confidence limits of such as a result is

$$\text{Probability of Failure} \pm 1.645\sqrt{\frac{\text{Probability of Failure} \times (1 - \text{Probability of Failure})}{N \times T}}$$

(11)

Taking the Laman Street figs as an example, if n(failed trees) is 2 over T=10 years, and total number of trees is N=16, then the probability of failure given by Equation. (10) is 0.0125 or 1/80. The 90% confidence interval for this estimate is 0.0125±0.0144 which means that there is 90% probability that the probability of failure lies between 0.0 and 0.0269 (1/37). Calculations such as these help provide an indication of upper and lower bounds.

If statistically robust estimates of probability of failure are not available, then the probability of failure of the tree under consideration may be compared with an average tree where the probability of failure is known. For example, the probability of failure of trees in public places in the U.K. is at least 1 in 10 million (assuming target value and impact potential are unity) (HSE 2007, NTSG 2011). An assessment may then conclude that the tree has a risk that is 10 or 100 times higher than a typical tree, or perhaps less. This requires some subjectivity, but helps provide comparative risks.

The setting of risk acceptance in the QTRA process should be broadened to include cost-benefit or other decision theory considerations. Such considerations are particularly useful where the decision has repercussions well beyond ensuring public safety. Risk mitigating measures such as site access restrictions, and tree removal can be assessed in a rigorous and methodical manner that aims to incorporate the costs and benefits of all interested parties.

A QTRA should use mean estimates for risk calculations as governments mandate risk-neutral risk assessments. While it may seem prudent to select conservative estimates, if the QTRA's three parameters are doubled, then ROH increases eight fold. If excessively conservative values are used at each opportunity then the calculated ROH becomes illogical.

A clear example of the consequence of not using the mean (or using the extreme conservative) occurred when an assessor of the figs in Laman Street determined that the probability of tree failure was 1 in 7.5 per tree per year. This figure was derived on the assumption that since two trees failed in 2007, then the likelihood of tree failure would be the same in the following year disregarding the fact that the weather in 2007 was an extreme event with annual probability of exceedance of approximately 5% (Stewart 2012). It also ignored the fact that for the previous several decades no trees failed.

Decisions partially or fully based on QTRA can significantly affect the wellbeing of the public. Thus, the decision-making process should include within it quality assurance measures and a peer review to add confidence to any decision made. Quality assurance procedures tend to focus on internal reviews. Peer review is an independent and critical review of risk analysis and risk assessment procedures and should obviously be conducted by recognised experts. If a peer review produces risks or recommendations that are in conflict with previous reports, then there should be an opportunity for all parties to see if a consensus can be reached. If not, then the decision-makers can decide if more studies are needed, or can make a decision recognising lack of consensus and the use of alternate decision criterion to reach a decision.

Finally, while quantitative decision support tools, such as QRA and QTRA, hold some appeal to decision-makers, they cannot capture the full and diverse range of societal considerations of risk acceptability. Therefore, a QTRA should be viewed only as an aid to decision support, where decisions about public safety will often require social, economic, cultural, environmental, political and other considerations.

6. CONCLUSIONS

A QTRA should be subject to rigorous and independent review to judge the veracity of the calculated risks. The QTRA system should develop longer and more intensive training that includes the principles of QRA as a starting point. This could reduce the risk of wide discrepancies between individual QTRA users. There is also a need for any risk management process involving trees, not only to assess the risk but to consider the benefits provided by trees - i.e., to conduct a risk-based cost-benefit analysis. Whilst crude data sets relating to tree failures do exist, the International Tree Failure Database (ITFD) for example, considerable work is still required in this area. In the meantime, tree risk assessors should, as far as reasonably possible, rely on benchmarks to ensure that their assessments are not outside of the realms of reality and include at least some form of scientific rigour.

REFERENCES

Ayyub, B.M. (2001), *Elicitation of Expert Opinions for Uncertainties and Risks*, CRC Press, Boca Raton.

BMA (1990), *The BMA Guide to Living With Risk*, The British Medical Association, Penguin Books, London.

Ellingwood, B.R. (2006), Mitigating Risk from Abnormal Loads and Progressive Collapse, *Journal of Performance of Constructed Facilities*, 20(4):315-323.

Ellison, M. J. (2005), Quantified Tree Risk Assessment Used in the Management of Amenity Trees. *J. Arboric. International Society of Arboriculture*, 31(2): 57-65.

Faber, M.H. and Stewart, M.G. (2003), Risk Assessment for Civil Engineering Facilities: Critical Overview and Discussion, *Reliability Engineering and System Safety*, 80(2):173-184.

Guggenmoos, S. (2009), Managing tree caused electric service interruptions. UAA Quarterly (Special Edition) 4-9.

HSE (1992), The Tolerability of Risk from Nuclear Power Stations, Health and Safety Executive, HMSO, London. 1992.

HSE (2007), Agriculture Safety, LAC 23/22, Health & Safety Executive/ Local Authorities Enforcement Liaison Committee (HELA), Health and Safety Executive, 10 September 2007.

ISO 31000-2009, *Risk Management—Principles and Guidelines*, International Organization for Standardization, Geneva, Switzerland, 2009.

Jordaan, I. (2005), *Decisions Under Uncertainty: Probabilistic Analysis for Engineering Decisions*, Cambridge University Press.

Mueller, J. and Stewart, M.G. (2011), *Terror, Security and Money: Balancing the Risks, Benefits and Costs of Homeland Security*, Oxford University Press, Oxford and New York.

Marsden, D. (2009), *Assessment of Hill's Weeping Fig Ficus microcarpa var. hillii In Civic Cultural Precinct, Laman Street Cooks Hill, Newcastle*, 7 August 20009.

:heny, N. P. and Clark, J. R. (1994), *A photographic guide to the evaluation hazard trees in urban areas* (2nd ed). ISA Publication, Champaign, Ill.

ris, M. (2007), Tree Risk Assessments - What Works - What Does Not - We Tell?, *ISAAC Conference*, Perth, 2007.

SG (2011) *Common sense risk management of trees – Guidance on trees public safety in the UK for owners, managers and advisers*, National Tree ety Group, Forestry Commission Publications, ISBN 978-0-85538-840-9

B (1992), *Guidelines and Discount Rates for Benefit-Cost Analysis of leral Programs (Revised)*, Circular No. A-94, October 29, 1992, Office of nagement and Budget, Washington, DC.

é-Cornell, E. (1986), Probability and Uncertainty in Nuclear Safety :isions, *Nuclear Engineering and Design*, 93: 319-327.

é-Cornell, M.E. (1994), Quantitative Safety Goals for Risk Management of ustrial Facilities, *Structural Safety*, 13:145-157.

é-Cornell, E. (2002), Risk and Uncertainty Analysis in Government Safety :isions, *Risk Analysis*, 22(3): 633-646.

l v Bartholomew (2006) England & Wales High Court [EWHC] Queen's ich Division [QB] (Bristol: 4BS50384)

RA (2012), User Manual V3.06, QTRA Ltd Licensed Product.

binson, L.A., Hammitt, J.K., Aldy, J.E., Krupnick, A. and Baxter, J. (2010), uing the Risk of Death from Terrorist Attacks, *Journal of Homeland Security l Emergency Management*, 7(1).

Schmidlin, T.W. (2009), Human Fatalities from Wind-Related Tree Failures in the United States 1995-2007, *Natural Hazards*, 50(1):13-25.

Smiley, E.T., Fraedrich, B.R., Hendrickson, N., and Percival, G. (2007), *Tree Risk Management* 2nd Edition (F A Bartlett Tree Expert Company Inc).

Smiley, E.T., Matheny, N. and Lilly, S. (2011), *Tree Risk Assessment*, International Society of Arboriculture, Champaign,, Illinois.

Stewart, M.G. and Melchers, R.E. (1997), *Probabilistic Risk Assessment of Engineering Systems*, Chapman & Hall, London.

Stewart, M.G. (2010), Acceptable Risk Criteria for Infrastructure Protection, *International Journal of Protective Structures*, 1(1):23-39.

Stewart, M.G., Ellingwood, B.R. and Mueller, J. (2011), Homeland Security: A Case Study in Risk Aversion for Public Decision-Making, *International Journal of Risk Assessment and Management*, 15(5/6): 367-386.

Stewart, M.G. (2012), Quantified Tree Risk Assessment: A Critical Review, Presented at *2012 Arboriculture Australia*, UAAA & SMA National Conference Hobart, 27 April – 2 May 2012.

Sunstein, C.R. (2002), *The Cost-Benefit State: The Future of Regulatory Protection*, ABA Publishing, American Bar Association, Chicago.

Viscusi, W.K. (2000), The Value of Life in Legal Contexts: Survey and Critique, *American Law and Economic Review*, 2(1):195-222.

Wang, C-H. and Wang, X. (2009), *Hazard of Extreme Wind Gusts in Australia and Its Sensitivity to Climate Change*, CSIRO National Research Flagship Climate Adaptation, May 2009.

	Probability of failure	Target value	Impact potential	Risk of Harm (ROH) per tree per year
ewcastle City Council Assessment (2009)	1/7.5	1/2.64	1/1	1/19.8
lke Ellison Assessment (2012)				
Best Tree	1/100,000	1/20	1/1	1/2,000,000
Worst Tree	1/1,000	1/20	1/8.6	1/170,000

ble 1. Results of QTRA for a Single Tree in Laman Street (Newcastle).

	Cost of Tree Removal Including Opportunity Costs ($C_{\Delta R}$)		
isk of Harm per Tree per Year (ROH)	$1,200	$2,200	$6,200
'20	$249,050	$248,050	$244,050
'100	$49,050	$48,050	$44,050
'1,000	$4,050	$3,050	-$950
'10,000	-$450	-$1,450	-$5450
'100,000	-$900	-$1,900	-$5,900
'1,000,000	-$945	-$1,945	-$5,945
'10,000,000	-$950	-$1,950	-$5,950

ite: each entry represents benefit minus cost result for each ROH and cost of tree removal.
itries that are positive would be considered cost-effective to remove a tree.

ible 2. Net Benefit of Tree Removal as Function of Risk of Harm (ROH) and Cost of Tree Removal Including Opportunity Costs ($C_{\Delta R}$).

	Value of Tree Amenity E(B) per year		
isk of Harm per Tree per Year (ROH) Without isk Mitigating Measures	$0	$1,000	$5,000
/20	$172,250	$173,250	$177,250
/100	$22,250	$23,250	$27,250
/1,000	-$11,500	-$10,500	-$6,500
/10,000	-$14,875	-$13,875	-$9,875
/100,000	-$15,213	-$14,213	-$10,213
/1,000,000	-$15,246	-$14,246	-$10,246
/10,000,000	-$15,250	-$14,250	-$10,250

ote: each entry represents benefit minus cost result for each ROH and value of tree amenity.
itries that are positive would be considered cost-effective to implement risk mitigating measures.

able 3. Net Benefit of Risk Mitigation that Reduces Risk by ΔR=75%.

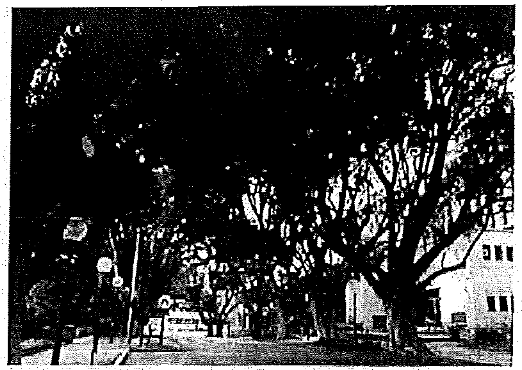

Figure 1. Laman Street Looking East – April 2010.

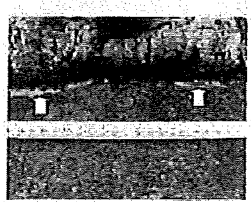

Figure 2. The Gap Observed Between One of the Trees and the Adjacent Hard Surface (Marsden 2007).

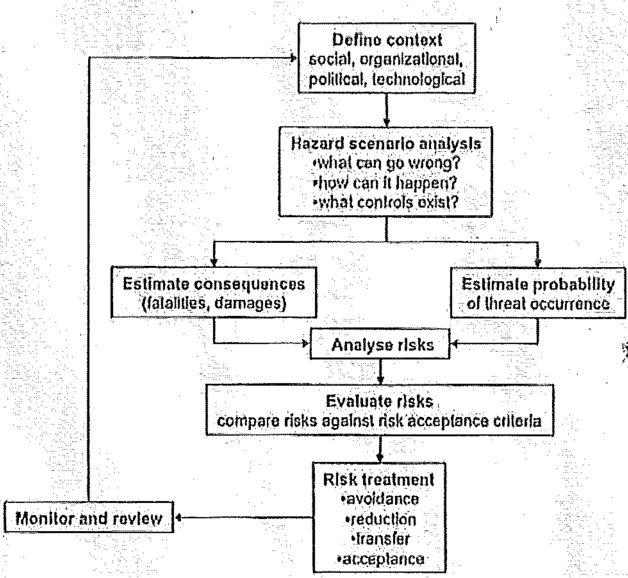

Figure 3. Risk Assessment Process

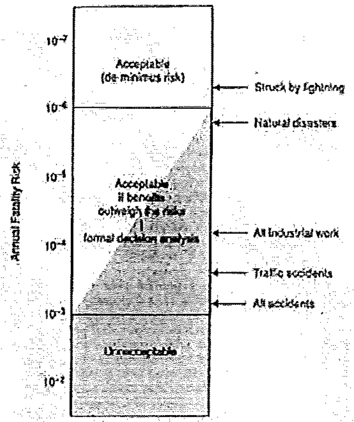

Figure 4. Generally Agreed Risk Acceptance Criteria for Annual Fatality Risks (Stewart and Melchers 1997).

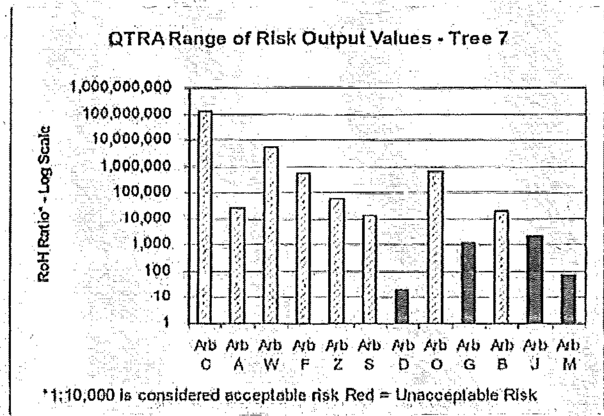

Figure 5. Range of Outcomes Using QTRA (Norris 2007).