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Technical report

Western Springs Pines

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1: Executive summary

One hundred and ninety-eight standing pine trees were assessed in Western Springs Forest between 21st September and 8th October 2020. Since 1988, the number of trees in the forest has been decreasing on average by 15 trees per year. Overall, the health of the forest is deteriorating. The trees are aging (97+ years old), and because of the species' known physiology and hydraulic limitation to growth, are now chronically predisposed to further decline. To estimate a remaining life span for the forest would involve a great deal of conjecture, which we prefer to avoid.

A mensuration exercise was undertaken to ascertain common tree parameters which can be used to provide an understanding of tree biomechanics, e.g. tree height to diameter ratios (H:D) and tree safety factors. The computed values for the sample distribution were then used to inform the range of inputs in a VALID tree risk assessment. The risk assessment considered the occupants of the public walking track during normal operation as the main 'target', as well as private properties and various structures (e.g. zoo and wastewater infrastructure). The VALID risk assessment produced:

- 141 'Acceptable' risks (71%)
- 6 'Tolerable' risks (3%)
- 50 'Not Tolerable' risks (25%)
- 1 'Not Acceptable' risks (1%)

Overall, the current risk to pedestrians using the walking track during normal operation is '*Not Acceptable*'. These risks are based on the current conditions and the current targets. Modelling wind patterns and future human behaviour are near impossible, which consequently produces a great deal of uncertainty about the risk of harm exposure to users of the forest in a possible future scenario where the 51 trees ('*Not Tolerable*' or '*Not Acceptable*') are removed.

If the Waitematā Local Board's long-term strategic plan involves species transition from pine forest, to broadleaf-podocarp forest, then after considering all factors, and the advice of other specialists (ecology and forestry), the most pragmatic and economic way forward would be to remove all the pine trees in a single operation. If the Local Board wish to preserve the pine forest, then the risks to the public need to be managed in a meaningful way. This will undoubtably involve removing trees which produce '*Not Tolerable*' or '*Not Acceptable*' risks, as well as ongoing specialist investigations, e.g. regular risk assessments and / or restricting access to some or all of the forest.

Prepared by

Andrew Benson (Ph.D., BSc, FdSc)

2: List of appendices

- Appendix A: Drawings 1717_001_B to 1717_007_B
- Appendix B: Description of VALID risk thresholds
- Appendix C: Comments on CWCA Quantified Tree Risk Assessment

3: Introduction

The Tree Consultancy Company (TTCC) has been engaged by Auckland Council (council) to provide detailed information relating to pine (*Pinus radiata*) trees in Western Springs. The purpose of our assessment is to provide information to the local board in order that they can make an informed decision relating to the future management of the trees. Specifically, our brief was as follows:

3.1 Project brief

- Provide an inventory of the pine trees including trunk diameter at breast height, tree height, structural condition and vitality.
- Provide a summary of the above tree characteristics in the report body.
- Carry out a VALID tree risk assessment of the pine trees in the stand, taking a proportionate approach.
- Reproduce QTRA assessments undertaken by CWCA Ltd (CWCA) in December 2019.
- Provide site plans depicting the trees and main site features (e.g. paths, sewer pipe etc).
- Provide a description of the arboricultural method/s undertaken during the visual appraisal and risk assessment along with their limitations.

3.2 Summary of previous information

A comprehensive package of information was supplied to us prior to commencing our site work, including previous expert reports as well as statements of evidence. The relevant arboricultural information can be summarised as follows:

- The trees were planted in 1923, making them 97+ years old (Wilcox, 2012; Goldwater et al., 2018).
- In 1988, there were an estimated 700 standing trees, of which 28% were in poor health and 15% were structurally compromised (Langston, 1988).
- Since 1988, the forest is losing an average of 15 trees per year, which is at least partially attributable to mortality and / or failures (e.g. snapping or uprooting) (Cammick, 2013; Collett, 2018b, a; Stejskal, 2018; Collett, 2019).
- A range of saprophytic heart-rot decay fungi have been recorded at the site as well as *Phytophothora spp, Armillaria spp* (Fraser, 2018), and burrowing termites (*Kalotermes brouni)* (Inglis, 2018).
- The most common mode of tree failure in the forest is trunk snapping (Collett, 2018b) and some trees have lost up to 1/3 of their trunk cross sections through decay / hollowing (Collett, 2018a; Fraser, 2018).
- The public footpath through the forest has been closed since 2018.
- A resource consent has been granted by way of Environment Court order to fell all the pines

4: Methods

4.1 Tree mensuration and data capture – phase 1

Between 21st and 25th September 2020, site visits were carried out to record a range of anatomical tree parameters. All data capture was undertaken by two investigators following prescribed methods to cross-check measurements and visual observations (Bechtold and Patterson, 2011). Data were assigned to individual trees using historical numbering (Cammick, 2013). The following parameters were recorded (Figure 1).

- Trunk circumference at 1.4 m – measured with a traditional measuring tape.
- Tree height – measured with a digital laser range finder (Nikon Forestry Pro, Nikon, Tokyo, Japan).
- Live crown height – measured with a digital laser range finder (Nikon Forestry Pro, Nikon, Tokyo, Japan).
- Crown radius – a visual estimate of the farthest radial branch spread.
- Live crown volume (LCV) – a visual estimate of the percentage of live foliage on the branches.
- Trunk / crown azimuth – the direction of natural lean / crown weight measured with a digital compass.
- The height of 30 snapped trunks – measured with a digital laser range finder (Nikon Forestry Pro, Nikon, Tokyo, Japan).

The laser rangefinder requires a clear, unobstructed line of sight to the top of the tree. In some cases (e.g. in dense forest or with dense tree crowns), the view may have been partially obstructed by surrounding foliage / branches. This is a limitation to the height measurements of some of the trees. Our method required at least three readings to be made from different positions for each tree with the largest reading recorded in each instance, to reflect the maximum uncertainty in the risk modelling undertaken in phase 2 of the assessment.

The following parameters were then computed (Figure 1).

- Trunk diameter at breast height (DBH).
- Height to diameter ratio (H:D) (Mattheck et al., 2002; Watt and Kirschbaum, 2011).
- Tree safety factors (Niklas, 2000; Detter et al., 2020) based on H:D distribution data for representative trees at the lower and upper ends (95% confidence limits) of the sample population as well as the mean.
- Uncompacted live crown ratio (LCR) (Bechtold and Patterson, 2011).

Tree height to diameter ratios (H:D) are used in traditional forestry to determine susceptibility to wind damage, e.g. trunk snaps (Cremer et al., 1982). It is a measure of slenderness and reflects how much taller the tree is than the width of its trunk (Equation 1). When the H:D approaches 50:1 for non-decayed solitary trees (Mattheck et al., 2002), or 60:1 for forestry blocks (Moore, 2000), trunk snapping could be expected to occur. The likelihood of trunk snapping events increases as the H:D continues to rise.

$$H{:}D = \frac{height}{DBH} \qquad \textit{Equation 1}$$

Tree safety factors are computed using a known wind speed (22.5 ms^{-1}) (Wessolly and Erb, 1998) and define an order of magnitude at which stem breakage could be expected to occur. In essence, it is a measure of the tree's reliability to resist wind loading (Niklas, 2002). Most trees have a safety factor of at least 4.5 (Mattheck and Breloer, 1994), meaning they can withstand wind loads 4.5 times greater than the normal wind load.

Live crown ratio (LCR) is computed by dividing the height of the live crown by the total tree height (Equation 2). It is a measure of the proportion of the tree which is foliated (Assmann, 1970). Live crown volume, live crown ratio and crown width are absolute indicators of forest health, and can be used to provide a broad picture of forest condition (Zarnoch et al., 2004; Interpine Forestry Ltd, 2011).

$$LCR = \frac{(height - LCH)}{height} \qquad \textit{Equation 2}$$

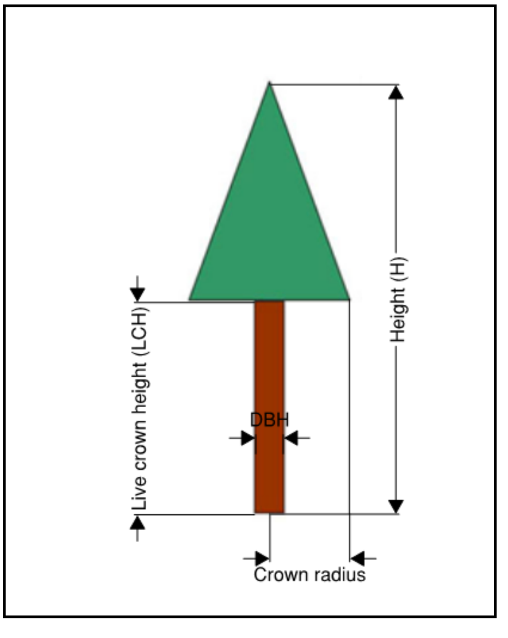


Figure 1: Tree mensuration parameters

4.2 Risk assessment – phase 2

4.2.1 Defining risk

Risk is best described as a combination of the consequences of an event together with the associated likelihood of its occurrence (Duijm, 2015) (Equation 3). It is mathematically computed as a probabilistic function of a series of events, to produce a quantitative measure of risk between 0 and 1 (e.g. Tartakovsky and Daniel, 2007; Ezell et al., 2010; Ellison, 2016). For example, the risk of a person being injured by a falling tree whilst walking along a footpath must consider the individual components of the series of events leading up to the impact. Those are:

a. The probability that a person will be in the precise location where the tree falls at the same moment that the tree falls
b. The probability that the falling tree will cause an injury
c. The probability that the tree will in fact fall at all

The maximum this can be is 1, representing a 100% chance (or a 1 in 1) that the pedestrian will be injured. The risk is calculated thus, where *P* = probability.

$$\text{Risk} = P_{(a)} \; x \; P_{(b)} \; x \; P_{(c)} \qquad \textit{Equation 3}$$

In the above, quantitative description of risk expression, a and b can be determined with sufficient precision to make a reasonable judgement, based on a). the occupancy rate of the target area (e.g. how many people walk past the tree on a typical day) and b). the size of the failing tree part, e.g. the tree's trunk diameter at the point of failure (a larger tree part is more likely to cause injury), respectively. These data are often easy to ascertain through direct observation by the risk assessor or by consulting local transport authorities for pedestrian or traffic counts. The final part of the risk equation (c) requires specialised training and experience (Smiley et al., 2017) to 'benchmark' the expected probability of failure. It is necessary for the risk assessor to have a sound working knowledge of tree biomechanics, tree biology, tree physiology and at least a rudimentary understanding of probabilistic mathematics. The final probabilistic product of the three components is used to express the risk. To provide adequate context, these fractions can be aligned with the tolerability of risk (ToR) framework (Le Guen, 2001; The Health and Safey Executive, 2001) (Figure 2), whereby qualitative descriptors are assigned to quantitative risk outputs. Ultimately, it is the responsibility of the duty holder to define their risk tolerance threshold and to take the necessary steps to manage the risks imposed on others (e.g. the general public) within the defined threshold.

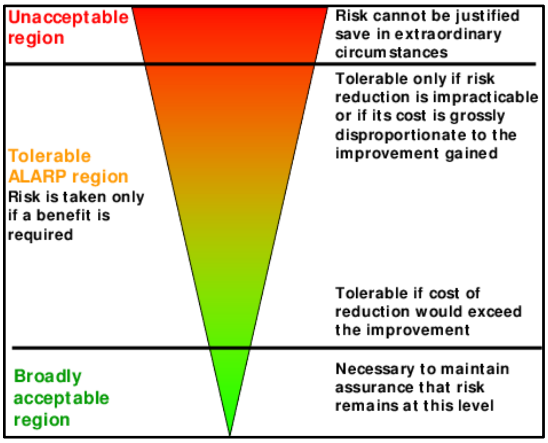


Figure 2: Tolerability of risk framework (HSE, 2001)

An important factor to appreciate about assessing risk, is that the risk assessment must consider - and subsequently express - what the most likely outcome will be in a given period of time. As the likelihood of an event occurring decreases, so too does the mathematical probability that the event will occur and ergo, so too does the risk. For the pines in the forest, the most likely event to occur across the population based on their biomechanical, anatomical, and biological attributes, as well as their known history, is that the trunk would snap. In some specific instances, alternate risks were assessed, e.g. tree 767 has a broken branch over the walking track which is more likely to detach in the next 12 months than the tree's trunk snapping.

4.2.2 VALID risk assessment

A VALID tree risk-benefit assessment was carried out on the individual pine trees in the forest (excluding dead poles) between 30th September and 8th October 2020. VALID has applied ISO 31000 - Risk Management Standards and ToR to tree risk-benefit assessment. It computes probabilistic risks and produces four possible qualitative outputs based on the computed outcomes - '*Acceptable*', '*Tolerable*', '*Not Tolerable*', and '*Not Acceptable*'. It has been developed with actual data modelling in the UK in collaboration with the Cabot professor of natural hazards & risk science at the University of Bristol.

> *"We have stress-tested VALID and didn't find any gross, critical sensitivities. In short, the mathematical basis of your approach is sufficiently robust and dependable for any practical purpose."*

Willy Aspinall
Cabot Professor in Natural Hazards & Risk Science University of Bristol

A site-specific risk assessment approach was developed in consultation with the VALID developers and has been determined to be a sound and proportionate approach to assessing the risk of pines in the forest. Briefly, the VALID assessment (and other quantitative methods) requires the user to 'benchmark' the probability of a tree (part) failing within a specified time frame (usually one year). The 'benchmark' is then adjusted based on biomechanical, biological, and environmental features such as cracks, poor health, and recent exposures to new winds, respectively. Because of what is already known about the forest (refer 3.2), a benchmark was established for all trees which recognised the most likely mode of failure (trunk snapping), the trees' anatomical features (H:D ratio), tree safety factors, overall health and anticipated wood properties (decay fungi). The benchmark was then adjusted on an individual tree basis based on the above features.

The risk assessment considered the following targets:

- Users of the walking track during normal operation
- Exposed wastewater infrastructure (e.g. pipes)
- Private property, e.g. buildings and ornamental paraphernalia
- Zoo features, e.g. fencing and buildings

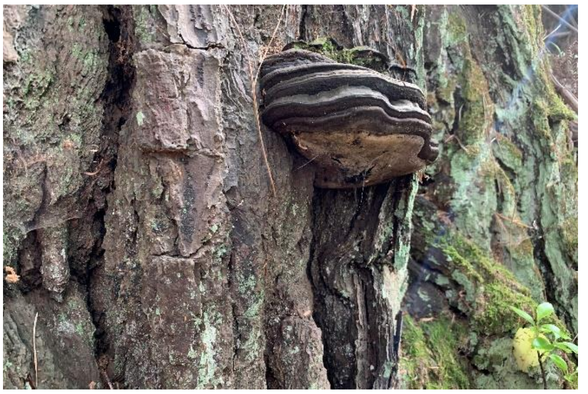
Under normal circumstances, a pedestrian count would be taken to ascertain the target occupancy, e.g. 10 pedestrians per hour. Because the walking track is closed, a pedestrian count was not possible and so the most suitable occupancy rate was ascribed based on a description of the track's typical operation, which we received from Maureen Glassey, who represents Auckland Council.

"What we do know is that the paths are used consistently by the wider community Grey Lynn and Point Chev, for walking and jogging and by other members of the public who may come to the forest as having also been to the zoo etc. We are aware that there are local school children who cut through the forest to attend schools in the area. We recognise that when there are events held at Western Springs either concerts or the speedway thoroughfare increases also."

4.2.3 Tree appraisals

Trees were examined for additional features which might a). further predispose them to failure (increase the risk) and b). lessen their predisposition to failure (lower the risk). The assessments were undertaken visually and also using a nylon mallet to tap the trunks at strategic locations, to detect local changes in acoustics which may indicate areas of altered wood quality. And, with a narrow (6 mm) probe (0.6 m long) to check for openings or cavities in accessible regions (< 2 m above ground). Limitations to using nylon mallets include thick bark, thick shell walls, wind, and traffic noise, which can all mask subtle changes in local acoustics. No decay detecting equipment was employed, since this rarely helps to inform the final risk output beyond the use of mallets and probes (Koeser et al., 2017). The overall anatomy of the trees (H:D) was also considered and as the H:D decreased from 50, so too did the likelihood that the tree would snap.

Some features observed in the forest which may increase the likelihood of failure are.



Fungal fruiting bodies which may indicate the presence of wood decay.

Weighted torque arms which can place massive sheering forces around the neutral plane (the longitudinal axis between wood under tension (upper surface) and wood under compression (lower surface)).

Signs of neutral plane sheering because of rotational torsion (left image). And obvious basal defects such as decay (right image).

Some features observed in the forest which may decrease the likelihood of failure are.

Low H:D (left image), and scaffold branching (right image) to support mass damping (Moore and Maguire, 2005)

Obvious adaptive growth at the buttress (left image), and higher volumes of live crown (right image)

4.2.4 Computing risk

To compute the final risk outputs, we have considered the targets described in 4.2.2 as well as the most likely mode of failure for individual trees (e.g. trunk snapping, or a broken branch falling) and its associated likelihood. We have modelled the risk 'footprints' by computing the anticipated length / height of the failed part (e.g. the length of the snapping trunk) projected with up to 10 degrees of lateral deflection either side of the trunk azimuth, to reflect a sufficient degree of uncertainty in the 'fall zones' for each tree or tree part. Additionally, we have allowed for 5 m of 'kickback', where the 'butt' end of the failed part may recoil backwards as the tip strikes the ground and incorporated the same 10 degrees of deflection into the model. Using accurate tree and site feature locations (Cammick, 2013) and geospatial software (QGIS.org, 2018), we have projected these 'fall zones' onto a geospatial canvas and ascertained which of the trees would strike one or more of the targets during a failure event. Trees which a). fail to strike a target or b). strike a low-value or low-use target, inherently produce '*Acceptable*' risks. For example, if a tree falls into an unused or low occupancy (< 12 persons per day) portion of the forest, then the risk to pedestrians must be '*Acceptable*'. If a tree falls onto the footpath, then the increase in target occupancy is reflected in the final computed risk. The final risk outputs are specified for a 12-month period from the date of assessment.

4.2.5 Quantified tree risk assessments (QTRA)

We have been asked to reproduce 38 individual risk scenarios identified by Mr Craig Webb of CWCA Ltd in December 2019 (Webb, 2019) using the QTRA method, and to compare Mr. Webb's results with our own. Mr. Webb's risk assessment predominantly focusses on risk scenarios which involve whole or partial tree failures onto private property, e.g. houses or zoo structures. There are some critical mathematical and methodological problems in some of the CWCA assessments which for brevity, have been described in an appendix to this report.

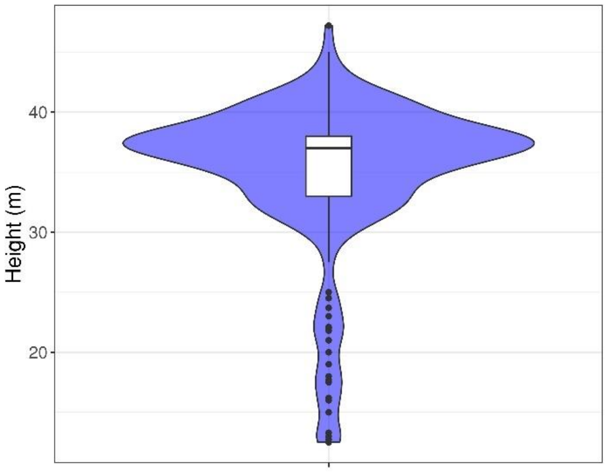
4.2.6 Data analysis and visualisation

All data were analysed using R statistical software version 3.6.3 (R Core Team, 2020). Data visualisations have been achieved using the ggplot2 package (Wickham. H, 2016) as well as QGIS (QGIS.org, 2018) for geospatial information.

5: Results and discussion

5.1 Forest health and condition

There are 198 standing pine trees (excluding poles) remaining in the forest. The mean height of the trees is 34.99 m (standard deviation (sd) = 6.41 m) and they have a mean DBH of 0.84 m (sd = 0.21 m). Figure 3 is a violin plot depicting the kernel density distribution of the height of the pine trees. What is being shown in the plot is essentially a smoothing function of the data distribution which has been spatially rendered into an irregular shape (Hintze and Nelson, 1998). In simple terms, the wider the plot, the greater number of trees are present in the stated range (the y axis). What can be seen from Figure 3, is that the majority of the trees are between 33 m and 40 m tall (the widest portion of the shape). Figure 4 is a violin plot of the DBH distribution across the population, with the majority of the trees having DBH values between 0.6 m and 0.9 m.



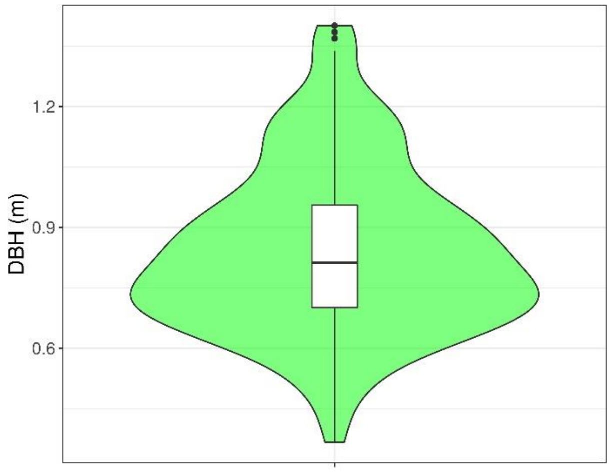


Figure 3: (left) Violin plot of Western Springs pine forest tree height (m)
Figure 4: (right) Violin plot of Western Springs pine forest tree DBH (m)

The forest has a mean live crown volume of 52% (sd = 33%) although the spread is clearly very wide across the population. Figure 5 is a pie chart of the live crown volume distribution across the forest. Thirty-one trees (16%) are standing dead and a further 57 trees (29%) have live crown volumes less than 50%, making them the most vulnerable to future decline and the effects of periods of environmental stress, e.g. drought. Overall, the forest canopy is visually very sparse and the volume of foliage on the trees is diminishing (Plate 1 and Plate 2).

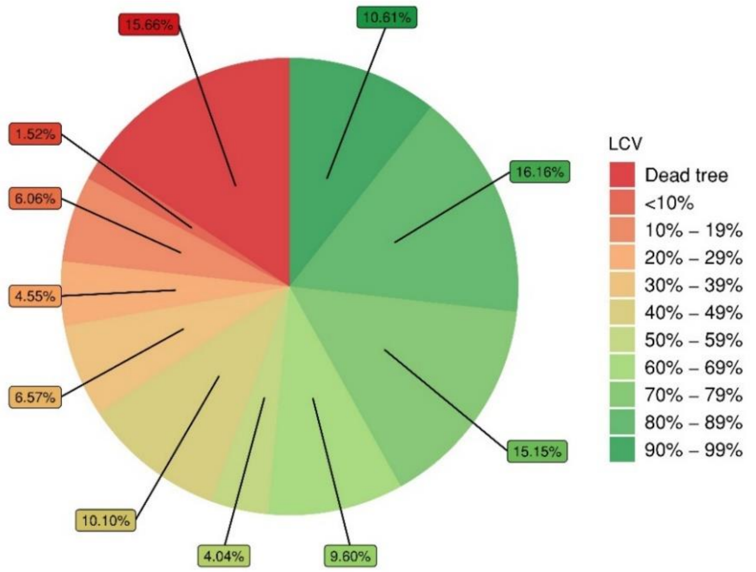


Figure 5: Pie chart of live crown volume of the Western Springs pine forest. The percentage of each LCV range is shown in the boxes.

Plate 1: (left) Depiction of tree crowns

Plate 2: (right) Depiction of tree crowns

5.1.1 The physiology of Pinus radiata

Pinus radiata have a strong isohydric tendency (Brodribb et al., 2004; Rodríguez-Gamir et al., 2019), meaning that they will shut their stomata during periods of water shortage (Tyree and Sperry, 1988; Choat et al., 2012; Manzoni et al., 2013). Stomata are the sites of gaseous exchange in all plants. Water vapour will exit the tree through the stomata thereby supplying the symplastic continuum (e.g. xylem vessels / tracheids) with the required pressure to retrieve water from the soil via the roots by way of a water potential gradient. This is analogous to sucking water from a glass through a straw. It is necessary to produce more negative pressure at the top of the straw (water leaving the stomata) than at the bottom (water entering the roots), so that the water travels upwards.

Stomata are also the site of atmospheric carbon fixation and stomatal closure is a known limitation to photosynthesis in many species (e.g. Fernandez et al., 1997; Arend et al., 2013; Fini et al., 2013; Dong et al., 2016). In isohydric species such as pines, periods of water shortage (e.g. summer drought) can induce concomitant periods where carbon fixation is curtailed. Without carbon, the trees become inherently unable to gain the necessary resources for continued growth, including mechanosensory adaptation to increasing and changing loads (e.g. producing new wood to provide strength and mechanical support). In contrast, anisohydric species are able to keep their stomata open for longer during periods of drought, allowing carbon fixation to continue (Sade et al., 2012; Martínez-Vilalta et al., 2014) and providing some resilience against xylem embolism (Brodribb and Holbrook, 2004; Alsina et al., 2007).

5.1.2 Hydraulic limitations to growth

For water to leave the tree through the stomata, there needs to be a potential gradient between the roots and the leaves. That is, the water potential must be greater at the roots than it is at the leaves, if the gradient is to be established. The water potential required to provide the necessary turgor pressure to the foliage increases as a function of tree height. In the straw analogy, it is necessary to create more negative pressure (by sucking harder) to get water through a longer straw.

Diurnal changes in meteorological conditions (e.g. increasing temperatures, wind and vapour pressure) will increase the rate of tree transpiration (water loss through the leaves), because of the atmospheric ‘pull’ on leaf water, with peak levels around midday. The water potential in leaves and stems must fall so that the flow of water up the plant can keep pace with the increased transpirational loss. However, there is a limit to the water tension that leaves and stems can endure, and eventually stomata must close, subsequently limiting water loss. When the stomata close, carbon fixation is curtailed. In the straw analogy, a person can only suck so hard on the straw to retrieve the water from the glass. When the pressure (sucking) required to draw the water through the straw exceeds the person’s ability to suck, the person must cease, and the column of water returns to normal pressure.

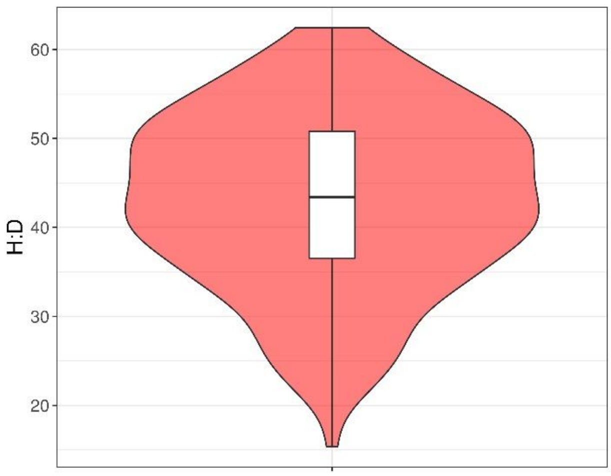
The rate of water flow through the tree is proportional to the hydraulic resistance of the water pathway from root to leaf. Hydraulic resistance increases with increasing path length (taller trees = greater hydraulic resistance) and the natural forces of gravity produce a pressure gradient of 0.01 MPa m^{-1}. In simple terms, as the tree gets taller, it is forced to close its stomata for increasingly longer portions of the day because of increasing water tension in the leaves and stems, consequently limiting carbon assimilation and hence growth. This is known as hydraulic limitation to growth (Ryan and Yoder, 1997).

To summarise the above, the underlying physiology of the pine trees (isohydricity) as well as their increasing height (hydraulic limitation to growth) are working in tandem to create a chronic condition which will continue to inhibit the natural processes associated with growth. Some have referred to this as a 'mortality spiral' (Manion, 1981). As the trees continue to age, and as water availability decreases (e.g. increasingly prolonged periods of drought), increasing numbers of trees will decline.

Where previous investigators have described the trees in the forest as "*showing signs of senescence*" (Langston, 1988), or that the trees are in "*an advanced state of decline"* (Collett, 2018b) and that "*the general decline observed in the plantation is not the result of direct pathogen activity*" (Fraser, 2018), and that "*age is the overriding factor affecting tree vitality*" (Webb, 2019); here, we describe the underlying biological mechanisms which are driving this irreversible process.

5.2 Forest structure

Figure 7 is a violin plot depicting the height to diameter ratio (H:D) distribution across the population. What can be seen from Figure 7 is that most trees have a H:D between 40 and 52 and that there is a reasonable proportion of the forest which have H:D ratios above the critical 50:1 ratio, where trunk snapping could be expected to occur for non-decayed solitary trees (Mattheck et al., 2002). Figure 7 shows individual violin plots for height to diameter ratios (H:D) in each of the live crown volume (LCV) classes. What can be seen from Figure 7, is that the trees with the highest H:D are also those which have the lowest LCV (the box in the bottom right corner). In short, this means that the trees which are anatomically most susceptible to trunk snapping are also the ones which are less able to adapt to increasing wind loads because of the previously described biological mechanisms.



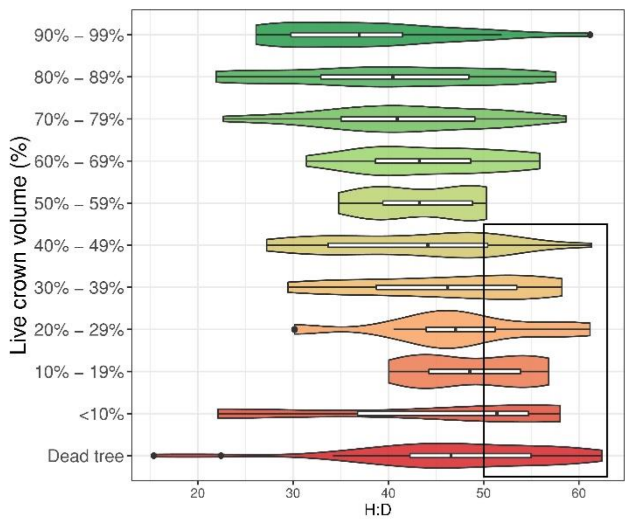


Figure 6: (left) Violin plot of Western Springs pine forest tree height to diameter ratio (H:D)
Figure 7: (right) Violin plots of tree H:D by live crown volume class

5.3 Risk assessment

5.3.1 Anatomical considerations

Figure 8 depicts the sample distribution of the 30 measured snapped pole heights in the forest. The arrows show the lower (left) and upper (right) 95% confidence limits for the data distribution as well as the mean (centre). The 95% limits define the boundaries of a sample distribution within which 95% of the sample data can be found. In essence, we are 95% confident that this is a realistic and representative measure of actual events. It is standard practice to use 95% as a measure of confidence in inferential statistics (Upshur, 2001; Gilchrist and Samuels, 2014).

Because our risk assessment relies on a). the previous observations which point to the most likely occurrence of failure in the forest being a trunk snap – as others have previously illustrated[1] (Fraser, 2018) – and b). the known anatomical features of the trees (H:D), we have estimated the heights at which the remaining trees will most likely snap based on the known data distribution of existing snapped trees. In order to reflect the maximum statistical uncertainty in our risk assessments, we have considered that trees will snap at 5.87 m (unless individual tree characteristics warrant a different assessment), which is the lower 95% confidence interval for this distribution. Projected 'fall zones' therefore consider that trees would snap at 5.87 m and allow for 2 m of additional displacement to account for horizontal momentum achieved during the failure event.

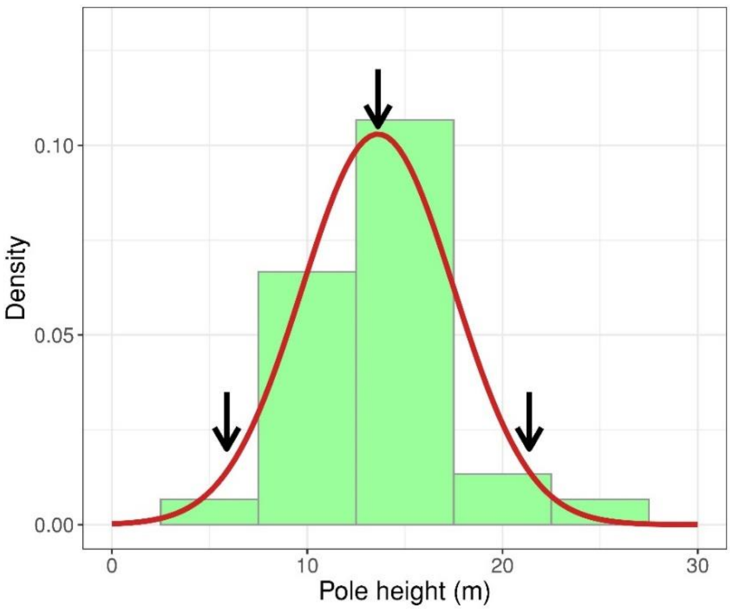


Figure 8: Sample distribution of measured snapped poles

[1] *"The stems are also very narrow, giving rise to vulnerability to breakage in winds. The heart rot at several points higher in the stems of many trees increases this failure risk."*

Figure 9 depicts the sample distribution of the H:D ratios for all remaining standing trees in the forest. The arrows show the lower (left) and upper (right) 95% confidence limits for the data distribution as well as the mean (centre). The numbers (in blue) are the computed tree safety factors at each interval. Tree safety factors ranged from 0.44 to 1.29 (mean = 0.87), meaning that when wind speeds begin to exceed 9.9 m s^{-1} (35.64 km h^{-1}), stem breakage could be expected to occur in the most vulnerable trees.

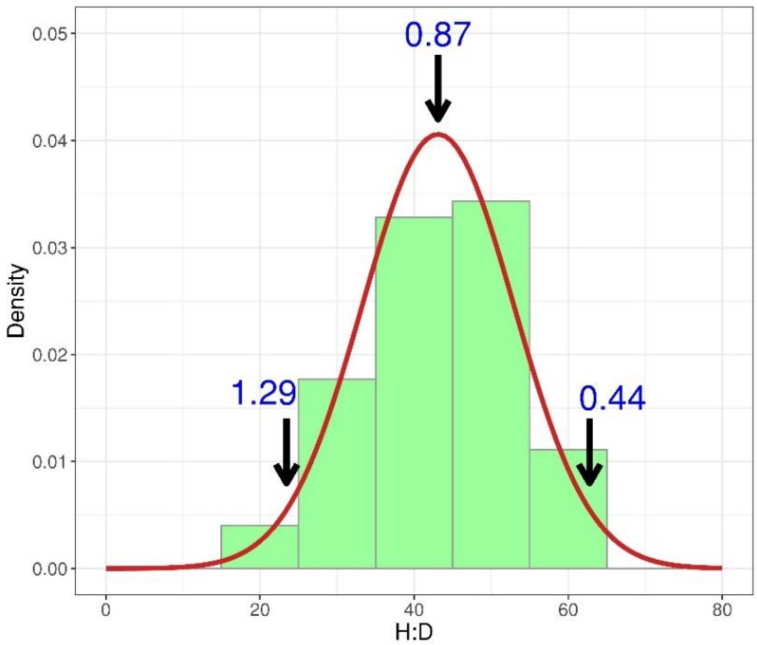


Figure 9: H:D distribution data for pine trees at Western Springs Forest

5.3.2 Computed risk outputs

Computed VALID risk outputs based on target occupancies of 120 – 1,200 individual pedestrian movements per day (e.g. at least 60 individual 'round trips') and realistic financial consequences in specific instances, have been visualised on our appended site drawings (1717_004_B to 1717_007_B). The risk outputs are defined in Appendix B. In summary, there are:

- 141 'Acceptable' risks (71%)
- 6 'Tolerable' risks (3%)
- 50 'Not tolerable' risks (25%)
- 1 'Not acceptable' risks (1%)

These risk outputs are based on current conditions and current targets (assuming normal operation of the footpath). In the event that the 51 '*Not Tolerable*' / '*Not Acceptable*' trees are removed, the forest environment will also change. That is, the trees will behave differently with new wind exposure and this is very difficult to model, requiring sophisticated software and a high level of specialist expertise.

Neither can human behaviour be reliably or accurately modelled. As the forest environment changes, e.g. portions of the forest become easier to access because of tree removals and associated secondary clearance of the understorey, so too will the target area (currently the narrow footpath) and the behaviour of its occupants. In short, there is a great deal of uncertainty surrounding the future risk exposure to pedestrians using the forest in the event that the current 51 risks are addressed. We cannot say with certainty that all the risks which are currently '*Acceptable*' would remain as such if partial forest clearance were to occur.

5.3.3 QTRA review

Table 1 on the following pages presents the computed QTRA outputs which we have reproduced from the CWCA Limited (CWCA) assessment. For the reasons explained in Appendix C, our risk outputs differ greatly, because of critical errors and the way the QTRA method has been applied by CWCA. One risk scenario is not reproducible at all. With the exception of two risk outputs, plus the irreproducible scenario (three risk scenarios in total), even though there are discrepancies between our assessments, there is no meaningful difference in the way the risks would be managed.

5.3.4 Tree management vs risk management

An often-confused perspective is the way that trees and tree populations are managed. For example, if the long-term strategic goal is to preserve a tree or group of trees for its intrinsic values, then those risks the tree(s) pose(s) must also be managed, to achieve the ultimate long-term goal of preserving the tree. For example, a veteran tree in a local park with strong cultural associations can be managed in a such a way that the risks it poses to the general public as it ages remain within acceptable limits. There will eventually come a time when the only remaining course of action which can be taken is to remove the tree (e.g. when the tree is dead), when its risks outweigh the benefits / values.

In contrast, if the long-term objective involves, for example, species transition from species A (e.g. pines) to species B (e.g. some other species), then there are many other factors which need to be considered outside of risk. The long-term strategic objective should drive the decision-making process, and as steps are taken towards achieving the ultimate strategic goal, risk can be used to prioritise the work (e.g. where budgets are constrained). But practicalities, economics and future constraints must all feed into the decision-making process. Consider owning an old car, which now has malfunctioning brakes and many other mechanical problems. The long-term strategic goal is to own a new car, and so waiting until the current car is no longer safe to drive, or has completely broken down, isn't always the best decision if the opportunity to own the new car is already available.

Table 1: Risk assessments reproduced from CWCA report using Quantified Tree Risk Assessment (QTRA) showing the annual risk of harm (AROH) for each risk scenario. Tree # = the original tree numbering (Cammick, 2013). CB = alternate tree numbering used by CWCA Ltd. Notes = TTCC comments on CWCA assessment. < 1 / 1m = < 1 / 1,000,000. 1 / 5K = 1 / 5,000. 1 / 4K = 1 / 4,000.

Tree #	CB	Scenario	AROH	Notes
753	11	Whole tree failure onto structures in back yard of 28 West View Rd	< 1 / 1 m	CWCA refers to Benchmark 5 - Quote from p7 of the V5 QTRA manual: - "*..benchmark against a structurally acclimatised tree at PoF 7,...*" CWCA benchmark 5 (ref P9 of CWCA assessment) has already considered the "*occurrence of past tree failures*" [increased exposure] and their "*age and health*". They need not be considered a second time. PoF 3 implies that there are obvious structural defects / flaws sufficient to have certainty that the tree is more likely to fail than not, in the next 12 months, yet this is not the case - ref tree 2099 (114). Possible to reflect some uncertainty in WTF by increasing PoF to 6 (i.e. 10 x more likely to fail). H:D remains well within optimal range. CWCA assumes damage caused by trunk snap is one order of magnitude (10 x) less than whole tree failure, i.e. a smaller piece of trunk will snap CWCA assumes size of part during trunk snapping is no greater than 100 mm diameter but no determination of snap height is provided. CWCA target range for human occupancy in the back yard assumes < 1 min per week
		Trunk snapping onto structures in back yard of 28 West View Rd	< 1 / 1 m	
		Whole tree failure onto human occupants in back yard of 28 West View Road	< 1 / 1 m	
		Trunk failure onto human occupants in back yard of 28 West View Road	< 1 / 1 m	
767	10	Broken branch failure onto track - pedestrian	1 / 5K	CWCA target range established using anecdotal evidence. TTCC target range established via consultation with QTRA and AC information. Target not considered to be weather affected because the limb has already 'failed' and is now only predisposed to gravitational forces, e.g. no additional wind loads are required. Conservatively, TTCC consider this as target range 2

Tree #	CB	Scenario	AROH	Notes
803	69	Whole tree failure onto zoo building	< 1 / 1 m	Tree height = 38 m. Horizontal distance to zoo building = 46 m (accounting for slope). Strike to zoo building is highly unlikely - TTCC target range reflects minor impact only, e.g. minor clean-up and superficial damage. Horizontal distance to zoo fence = 42 m. - TTCC target range reflects minor impact only. Trunk failure onto building / fence (32.2 m fall) is not physically possible - risk < 1 / 1 m CWCA benchmark 5 (ref P9 of CWCA assessment) has already considered the "*occurrence of past tree failures*" [exposure from recent failure] and their "*age and health*". They need not be considered a second time. CWCA assumes WTF more likely than trunk snapping, yet H:D ratio and knowledge of forest failures would suggest the opposite
		Whole tree failure onto zoo fence	< 1 / 1 m	
		Trunk failure - zoo building		
		Trunk failure - zoo fence		
832	67	Trunk failure - zoo building	< 1 / 1 m	Tree height = 38 m. Horizontal distance to zoo building = 37 m (accounting for slope). Horizontal distance to zoo fence = 34 m. Trunk azimuth and lower CI break height (5.9 m) indicates no strike. TTCC target range / risk reflects minimal damage to surrounding features plus clean-up costs for fallen tree in stream etc. H:D below sample mean and any predisposition to breakage
		Trunk failure - zoo fence	< 1 / 1 m	
942	81	Whole tree failure onto zoo fence, elephant enclosure	< 1 / 1 m	Tree height = 35 m. Codominant from 19 m Zoo fence = 27 m (31 m accounting for trunk azimuth) WTF would contact fence Failure of the codominant stem (upper 16 m) would not strike the fence CWCA target assessment for WTF assumes >$400K damage to fence - this seems very high CWCA assumes size of part is 25 mm to 100 mm diam. - the point of attachment at the union is > 300 mm.
		Included branch failure onto human occupants of open space SW of Meola Creek	< 1 / 1 m	
1096	94	Whole tree failure onto Meola Creek footbridge	< 1 / 1 m	Inconsistent target assignation for pedestrian occupation of the footbridge from CWCA CWCA target range established using anecdotal evidence. TTCC target range established via consultation with QTRA and AC information.
		Whole tree failure onto human occupants of walking track or Meola Creek footbridge	< 1 / 1 m	
		First order limb failure onto human occupants of walking track or Meola Creek footbridge	< 1 / 1 m	

Tree #	CB	Scenario	AROH	Notes
1874	2	Whole tree failure onto walking track - pedestrian	< 1 / 1 m	CWCA assumes property damage < $4,000. Tree clean-up cost alone would be approximately this much. Query this tree ("*relatively good condition, structurally acclimatised tree*" - BM - 6) vs tree 753 with same attributes ("*Fair to good crown condition, structurally acclimatised*" - BM - 5). These trees are only 25 m apart in the same region of the forest ("*history of recent failures nearby*"). The CWCA benchmarking exercise is inconsistent.
		Whole tree failure onto dwelling at 28 West View Road	< 1 / 1 m	
2024	19	Whole tree failure onto dwellings at 16-18 West View Road	< 1 / 1 m	CWCA assumes primary limbs are no greater than 100 mm in diameter. Most limbs fail to reach the small shed and would likely tear and land in the forest / vegetated area CWCA target range for human occupancy in the back yard assumes < 1 min per week
		Whole tree failure onto conservatory at 16 West View Rd	< 1 / 1 m	
		Whole tree failure onto human occupants in back yards	< 1 / 1 m	
		Whole tree failure onto human occupants in conservatory	< 1 / 1 m	
		Whole tree failure onto back yards of 16-18 West View Road	< 1 / 1 m	
		First-order limb failure onto human occupants in back yards	< 1 / 1 m	
		First-order limb failure onto back yards at 16-18 West View Road	< 1 / 1 m	
2025	20	Whole tree failure onto dwellings at 16-18 West View Road	< 1 / 1 m	CWCA refers to "*decay at base*" - presumably, this refers to a region on the S aspect buttress roots. The bark is absent and there is cambial necrosis but the tissue is not degraded sufficiently to warrant a ten-fold increase in the probability of failure from PoF range 5. PoF 4 reflects the maximum uncertainty in the QTRA assessment. Tree = 25 m in height. Horizontal distance from tree to 16 WVR dwelling = 38.4 m. Horizontal distance from tree to 16 WVR conservatory = 36.2 m. Although a direct strike to the conservatory is not possible, shattered glass must be considered as a result of secondary debris fallout CWCA target range for human occupancy in the back yard assumes < 1 min per week
		Whole tree failure onto conservatory in 16 West View Road -	< 1 / 1 m	
		Whole tree failure onto back yards West View Road	< 1 / 1 m	
		Whole tree failure onto human occupants of conservatory	< 1 / 1 m	
		Whole tree failure onto human occupants of back yards	< 1 / 1 m	
		First-order limb failure onto back yards of 16-18 West View Road	< 1 / 1 m	
		First-order limb failure onto human occupants of back yards	< 1 / 1 m	

Tree #	CB	Scenario	AROH	Notes
2099	114	Whole tree failure onto human occupants of walking track	1 / 4 K	CWCA assumes that the size of part is no greater than 100 mm (range 4) Quote from QTRA manual - "*the distance and orientation of fall will influence the force upon impact*". And from the QTRA user calculator - "*Select the range of size (1-4) that represents the basal diameter (excluding basal taper) of the tree or branch that is being assessed*" - therefore must consider momentum gathered by whole tree (several tons of mass). TTCC has consulted with three other New Zealand-based registered QTRA users and considered (through unanimous consensus) whole tree failure (> 450 mm - range 1). CWCA has adjusted a PoF of 1 (a 100% chance that the tree will fail) by a factor of 10 to reflect material hanging up in nearby trees. This is an unrealistic level of precision and likely an outcome not possible due largely to the momentum gathered during the failure event. Secondary debris from adjacent trees would likely hit the ground anyway. The tree's structural flaws (decay etc.) are not yet commensurate with a PoF of 1 - a 100% chance that the tree will fail.
2292	23	Whole tree failure onto studio at 14 West View Road	< 1 / 1 m	CWCA has inflated a PoF of 5 to a PoF of 4 for trunk failure because of "*Poor architecture*" - yet the H:D is currently at 38:1, making it far less prone to failure than a PoF of 4 (closer to PoF 7). CWCA has inflated a PoF of 5 to a PoF of 4 because of "*fill on root plate*" - this is not a biomechanical or structural problem and does not warrant an increase in PoF at this level. CWCA assumes that damage to the studio building / dwelling is < $40k
		Whole tree failure onto dwelling at 14 West View Road	< 1 / 1 m	
2305	22	Whole tree failure onto studio at 14 West View Road	< 1 / 1 m	CWCA discusses PoF of branch failure in description yet this risk scenario has not been explored. CWCA has inflated a PoF of 5 to a PoF of 4 because of "*fill on root plate*" - this is not a biomechanical or structural problem and does not warrant an increase in PoF at this level. CWCA assumes that damage to the dwelling is < $40k
		Whole tree failure onto dwelling at 14 West View Road	< 1 / 1 m	
2307	21	Whole tree failure onto studio at 14 West View Rd	< 1 / 1 m	CWCA inflates a PoF of 5 to a PoF of 4 for "*over extended branches*" on a "*structurally acclimatised tree*". If the tree is structurally acclimatised, the PoF inflation for over extension should begin from PoF 7 and increase to PoF 6 only
		First-order limb failure onto studio at 14 West View Rd	< 1 / 1 m	

6: Conclusions

There are 198 standing pine trees (excluding poles) remaining in the Western Springs Forest. In biological terms, the general condition of the trees is sub-optimal, and because of their underlying physiology and known limitations to growth, are now chronically predisposed to further decline, with the most vulnerable trees being those which have less than 50% of their live crowns remaining (29% of the population). The trees are also predisposed to future failure events (trunk snapping) because of biomechanical features (e.g. high H:D) which cannot be rectified at this stage in the life of the trees. Future tree failures are expected to continue.

The current risk posed by the pine trees to users of the walking track during normal operation is '*Not Acceptable*', which has been imposed by a single tree. Removing this tree would see the risk to users of the footpath as '*Not Tolerable*'. There is too much uncertainty about the future behaviour of the trees and the general public to confidently say that the residual risk to users of the footpath after all '*Not Tolerable*' risks have been removed will be '*Acceptable*'.

If the Waitematā Local Board's ultimate strategic objective is to transition the forest to a native broadleaf-podocarp environment, then the most pragmatic course of action after considering the advice of the multiple specialists involved in the delivery of this package of reporting (ecology, forestry, economics, future risk uncertainty), is to remove all the trees in a single operation, in a manner which recognises the value of the developing understorey, e.g. with a minimal disturbance footprint.

If the Local Board wish to preserve the pine forest for as long as possible, then the current and future risks will need to be managed to within a threshold that is acceptable to the duty holder. This may involve restricting access to some or all of the forest because of future risk uncertainties and will almost certainly require that the trees be managed until they reach their ultimate demise.

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Appendix A: Site drawings 1717_000 to 007 (Rev B)

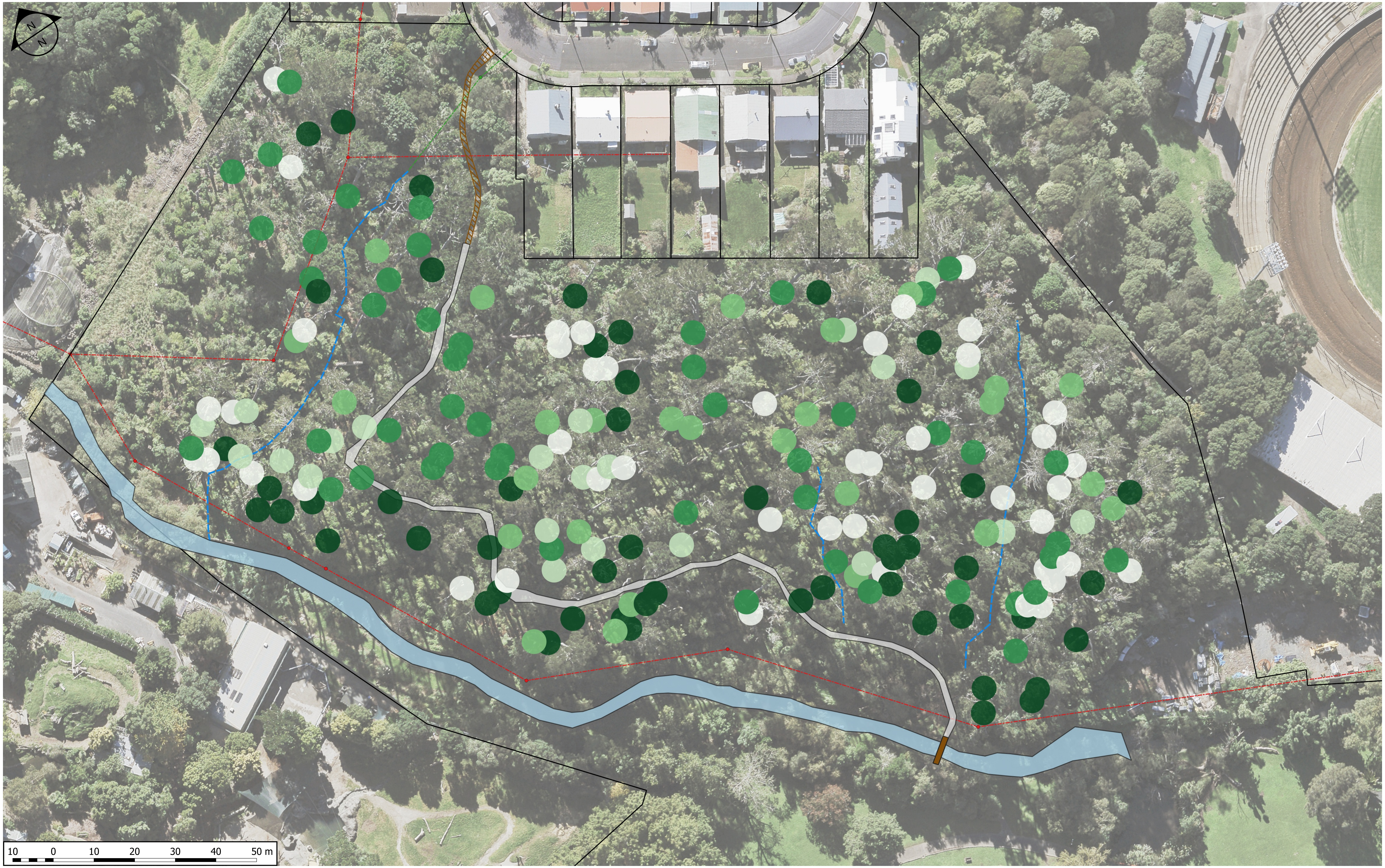
Trees (from survey)	Stream (from survey)
Trunk azimuth	Overland flow paths (from survey)
Target area	SWMH
Path (from survey)	SW pipe
Bridge (from survey)	SSMH
Staircase (from survey)	SS pipe

Auckland Council

Western Springs Pine Forest
Tree location plan

The TREE CONSULTANCY COMPANY

Job ref	1717		
Drawing	001	Rev	B
			16/10/2020



LCV

0% - 19%

19% - 38%

38% - 57%

57% - 76%

76% - 95%

Path (from survey)

Bridge (from survey)

Staircase (from survey)

Stream (from survey)

Overland flow paths (from survey)

SWMH

SW pipe

SSMH

SS pipe

Auckland Council

Western Springs Pine Forest
Tree condition plan

The TREE CONSULTANCY COMPANY

Job ref 1717

Drawing 002

Rev B

16/10/2020

H:D

	60.0 - 62.4
	50.0 - 60.0
	40.0 - 50.0
	30.0 - 40.0
	20.0 - 30.0
	15.4 - 20.0

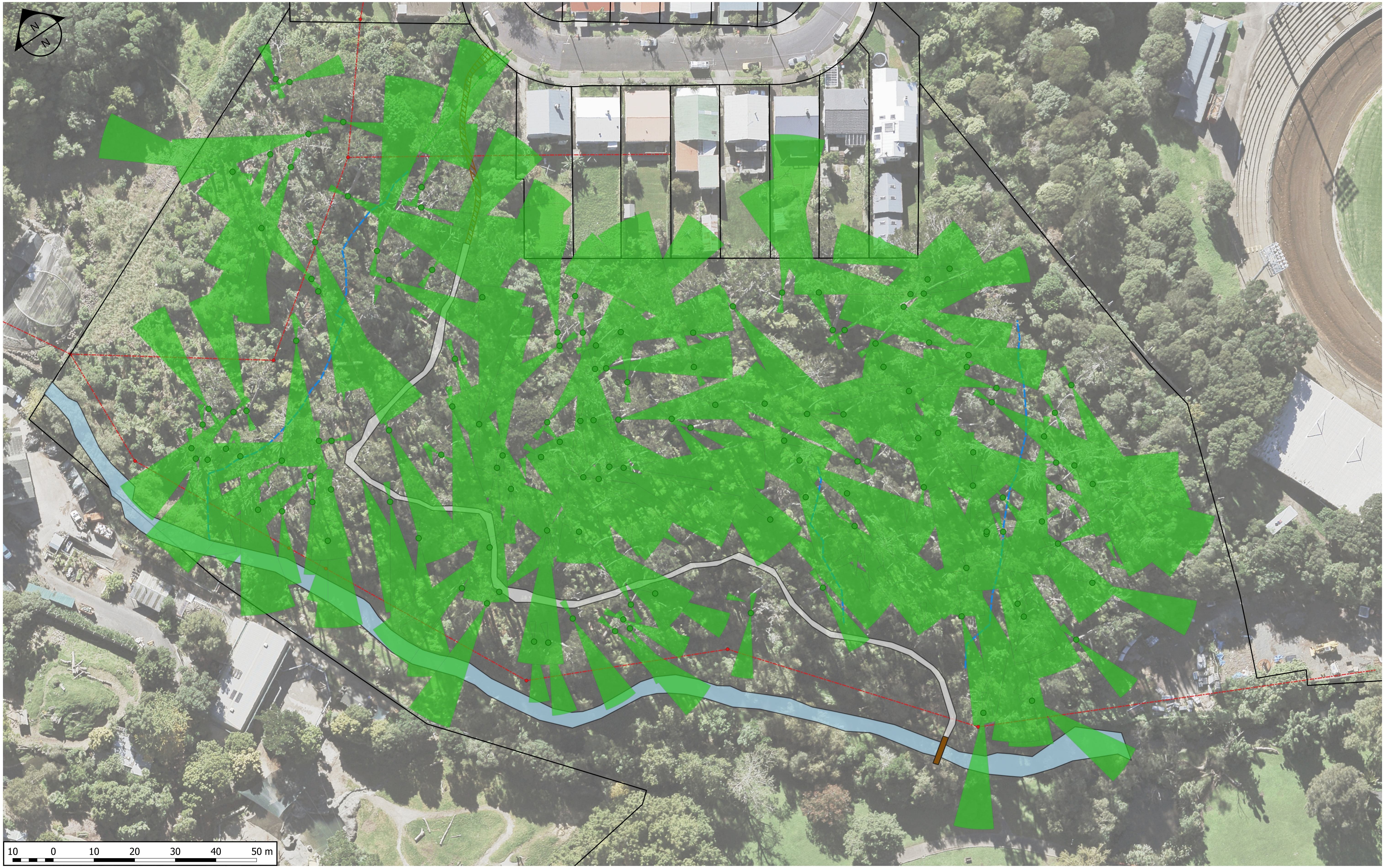
Path (from survey)
Bridge (from survey)
Staircase (from survey)
Stream (from survey)
Overland flow paths (from survey)
SWMH
SW pipe
SSMH
SS pipe

Auckland Council

Western Springs Pine Forest
Tree height to diameter ratio plan

The TREE CONSULTANCY COMPANY

Job ref	1717
Drawing 003	Rev B 16/10/2020



Trees (from survey)
- Acceptable
- Tolerable
- Not tolerable
- Not acceptable

Fall zones
- Acceptable
- Tolerable
- Not tolerable
- Not acceptable

- Path (from survey)
- Bridge (from survey)
- Staircase (from survey)
- Stream (from survey)
- Overland flow paths (from survey)

- SWMH
- SW pipe
- SSMH
- SS pipe

Auckland Council

Western Springs Pine Forest
Acceptable risks plan

The TREE CONSULTANCY ~ COMPANY ~

Job ref	1717
Drawing 004	Rev B 16/10/2020

Trees (from survey)
- Acceptable
- Tolerable
- Not tolerable
- Not acceptable

Fall zones
- Acceptable
- Tolerable
- Not tolerable
- Not acceptable

- Path (from survey)
- Bridge (from survey)
- Staircase (from survey)
- Stream (from survey)
- Overland flow paths (from survey)

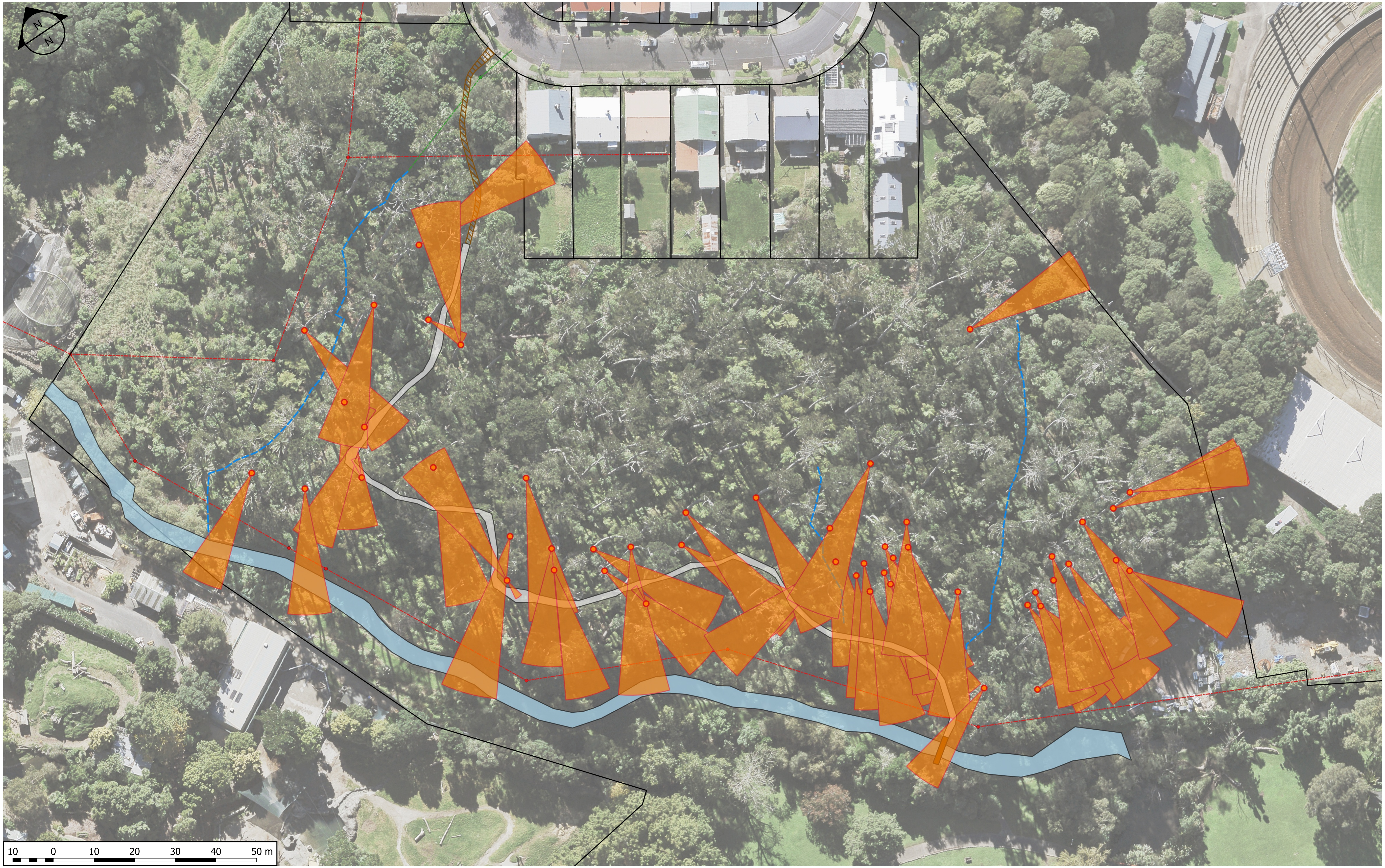
- SWMH
- SW pipe
- SSMH
- SS pipe

Auckland Council

Western Springs Pine Forest
Tolerable risks plan

The TREE CONSULTANCY – COMPANY –

Job ref	1717
Drawing 005	Rev B 16/10/2020



Trees (from survey)	Fall zones		
Acceptable	Acceptable	Path (from survey)	SWMH
Tolerable	Tolerable	Bridge (from survey)	SW pipe
Not tolerable	Not tolerable	Staircase (from survey)	SSMH
Not acceptable	Not acceptable	Stream (from survey)	SS pipe
		Overland flow paths (from survey)	

Auckland Council

Western Springs Pine Forest
Not tolerable risks plan

The TREE CONSULTANCY COMPANY

Job ref 1717

Drawing 006

Rev B

16/10/2020

Trees (from survey)	Fall zones		
Acceptable	Acceptable	Path (from survey)	SWMH
Tolerable	Tolerable	Bridge (from survey)	SW pipe
Not tolerable	Not tolerable	Staircase (from survey)	SSMH
Not acceptable	Not acceptable	Stream (from survey)	SS pipe
		Overland flow paths (from survey)	

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Western Springs Pine Forest
Unacceptable risks plan

The TREE CONSULTANCY COMPANY

Job ref 1717

Drawing 007

Rev B

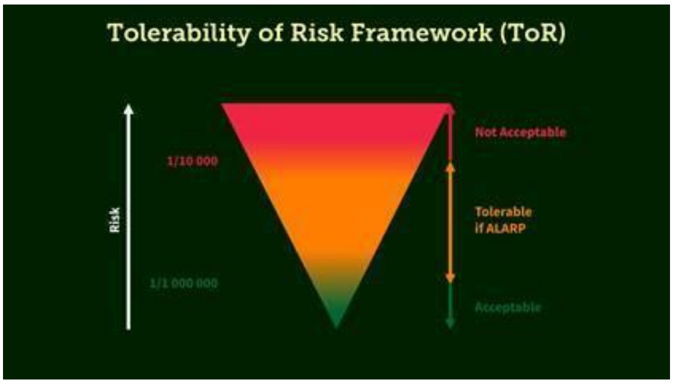
16/10/2020

Appendix B: Description of VALID risk thresholds

Hi Andrew

Thanks for passing on the enquiry about what a Tolerable risk rating means in numeric terms with VALID. Here's an explanation of VALID's 'Tolerable' & 'Not Tolerable' tree risk ratings. If the person asking wants to know more, it's covered on the 'Policy' page in the Strategies on the Risk Management page of the website.

VALID has four tree risk ratings which are based on the Tolerability of Risk Framework.



Tolerable

The risk is 'As Low As Reasonably Practicable' (ALARP). If the risk is Tolerable then the duty holder does not need to do anything to reduce the risk. However, the tree may need an increased frequency of assessment than trees with an Acceptable risk.

Not Tolerable

The risk is not ALARP. If the risk is Not Tolerable then the duty holder needs to reduce the risk to an Acceptable level. However, the risk reduction has a lower priority than a Not Acceptable risk.

VALID's risk ratings are generated using the App. The engine of the App is a risk model that's been built with a Professor of Natural Hazards & Risk Science. The Professor's an internationally distinguished expert in this field. He's test-driven the model to breaking point;

"*We have stress-tested VALID and didn't find any gross, critical sensitivities. In short, the mathematical basis of your approach is sufficiently robust and dependable for any practical purpose.*"

Willy Aspinall

Cabot Professor in Natural Hazards & Risk Science

University of Bristol

If I can be of any more help, please don't hesitate to ask.

Cheers

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VALID Tree Risk-Benefit Assessment & Management

Appendix C: Comments on CWCA QTRA methods

We have been asked to review and provide detailed comments on the QTRA assessment undertaken by CWCA. The approach taken by CWCA suffers from some critical methodological and mathematical problems that produce inaccurate risk computations which has meant that our results differ greatly. It also suffers from several numerical discrepancies which have the same outcome (different results). Additionally, our description of the target occupancy of the walking track differs. These discrepancies / differences / problems are as follows:

Target occupancy differences

1. We note that CWCA have relied upon "*anecdotal evidence*" from an unspecified source which suggests that 50 people per day use the track. It is unclear whether this allows for return visits, since the risk assessment relies upon the total daily number of pedestrians passing by the tree. That is, if 50 people use the track for a round trip (two-way journey) each day, then the actual usage of the track is 100 pedestrians per day. Doubling the exposure that a single person has to a tree is reflected in the target range. Since we have not been able to verify the anecdotal information received by CWCA, we have consulted directly with the QTRA developers using the description of pedestrian usage provided to us by Maureen Glassey, as well as a description of the area and surrounding features. We have been advised by QTRA to consider the footpath either as target range 2 or target range 3, and to consider whether it is weather affected (fewer people will use the track during periods of inclement weather when trees are most likely to fail). In consideration of the weather-affected nature of the target, we have broadly considered the track as range 3.

Numbering error

1. CWCA Ltd refers to tree 1 (previously labelled by C. Benton) as tree number 1874. The numbered tag on tree 1874 is number 2. We have applied the risk assessment using the original numbering (1874).

Methodological errors

1. There is a discrepancy in the CWCA target range when the risk of whole and partial failure is explored for tree 1096 (94). The same target area is listed as range 3 and again as range 4. This will artificially inflate the risk of harm by a factor of ten based on the CWCA methods. The occupancy of this area should not change.

2. In some instances, impossible scenarios have been considered, e.g. the height of a (falling) tree is considerably shorter than the horizontal distance between the tree and the stipulated target. For example, tree 2025 (20) is 25 m tall and the horizontal distance between the tree and the dwelling at 16 West View Road is 38 m.

3. Page 9 of the CWCA assessment has described a benchmarking exercise to ascribe a probability of failure range (PoF) based on known stand characteristics as follows:

For the purposes of the QTRA input of PoF, the failure of whole trees or substantial parts of trees (e.g. trunk snapping) must take into account the occurrence of past tree failures from various modes of failure. Many of the trees may look structurally acclimatised and show no sign of structural abnormality, however, the age and health of the trees warrants their condition to be assessed with a degree of caution.

Whole tree, or main stem failure could be reasonably expected to occur on a relatively frequent basis given the age and morphology of the trees and the history of failure in the stand. For this reason, the selected trees (with few exceptions) have been assessed from a benchmark of no greater than PoF Range 5 (i.e. two orders of magnitude more likely to fail than a structurally acclimatised tree with no sign of structural abnormality).

The method is logical and not dissimilar to our approach which we have ratified directly with the VALID developers. However, the CWCA assessment ascribes the final PoFs for several trees after considering these factors for a second time. For example:

Tree #753 – Whole tree failure onto private property

Fair to good crown condition, structurally acclimatised tree but with history of failures nearby. Benchmark 5. Increased exposure shifts PoF for trunk snapping or whole tree failure by two orders of magnitude, from 5 to 3.

The QTRA handbook provides the following guidance.

"..benchmark against a structurally acclimatised tree at PoF 7,…"

Whilst there is some logic to benchmarking at PoF 5 for the stated reasons (history of failures, age, health, and morphology), these same factors cannot be considered again ("*increased exposure*") when the final PoF is ascribed. If the tree is structurally acclimatised, the only increased exposure which need be considered is that of recent failures, which has already been considered by shifting the benchmark from PoF 7 to PoF 5. 'Double counting' these features in the PoF has the effect of inflating the final risk output. That is, several of the risks explored in the CWCA assessment are not as large as the numbers are suggesting. If this tree were assessed as a PoF 5, then the risk of harm resulting from whole tree failure onto the property at 28 West View Road is < 1/1,000,000. A PoF of 3 represents a 10,000-fold increase in the probability that this tree will fail compared to an ideal, or "*structurally acclimatised tree"*. And is only 100 times less likely to fail than a tree which is actively failing (PoF 1). A tree with a PoF of 3 would be expected to have obvious tree-risk features (*"structural abnormality"*) such as cracks, decay and signs of structural root loss, and yet these features are not observed on this tree (753) (or others in the QTRA assessment).

The consequences of this phenomenon are demonstrable by examining Tree 2099 (114) ("*significant decay in base*"). CWCA have ascribed a PoF of 2 for whole tree failure for tree 2099, which means that tree 753 (11) ("*structurally acclimatised tree*") is only a single order of magnitude less likely to fail in the next 12 months. The QTRA scale has seven orders of magnitude ranging in ten-fold increments from 1/1 (certain to fail) to < 1/1,000,000 (certain not to fail).

Tree 753

Tree 2099

Mathematical errors

The final risk scenario explored by CWCA assumes "*that the PoF of any tree failing onto the path has a 1/1 probability",* which is describing a 100% chance of any "*Random tree or tree part falling onto* [the] *walking track*" in the next 12 months. There are several mathematical issues associated with this risk scenario as follows:

1. It relies on the assumption that "*any tree*" (total = 198) is able to reach the track during a failure event, yet there are only 61 trees which would meet this criterion based on our modelling.

2. To assume that there is absolute certainty (a 1/1 probability) that one tree will fall onto the track in the next 12 months must still require an understanding of the individual probabilities of all the trees within fall distance of the track. When considering individual disjoint events where any one of those events could happen (e.g. $P_{(1)}$ OR $P_{(2)}$ OR $P_{(3)}$ OR… $P_{(n)}$), the individual probabilities must be summed, because as the number of available options increases, so too does the probability of at least one outcome eventuating (e.g. flipping a coin – a head OR a tail). For cooccurring independent events (e.g. $P_{(1)}$ AND $P_{(2)}$ AND $P_{(3)}$), the probabilities are multiplied, because the probability of a series of events occurring together decreases with an increasing number of events (e.g. winning lotto – first number AND second number AND…… Power ball).

   In this instance, it has been assumed that there is a 1/1 chance that one tree (or tree part) will fall onto the track in the next year, e.g. $P_{(1)}$ OR $P_{(2)}$ OR ..... $P_{(n)}$. On the basis that all trees are close enough to the track to meet this criteria (i.e. "*any random tree"*), without any individual descriptors of the individual probabilities, we must assume that all are equal – i.e. each tree has a 1/198 chance of failing this year (because 1/198 x 198 = 1/1) which is a PoF of 3. Any tree which has an actual probability of failure which is less than this (e.g. tree 1096 (94) which has been ascribed a PoF of 4, equating to 1/10,000 - 1/1,000), will artificially increase the probability of the other trees failing because of the way the mathematical operations are structured. Furthermore, any tree with a probability of failure which is more than 1/198 (e.g. tree 767 (10) which has been ascribed a PoF of 2, equating to 1/100 – 1/10), will artificially decrease the probability of failure of the other trees for the same reason. This arbitrarily affects the spatial distribution of risk exposure throughout the footpath with no consideration given to environmental, biological, or biomechanical features.

3. On the basis that it is not physically possible for all trees ("*any random tree*") to strike the walking track, we defer to our modelling to account for those trees within 'fall distance' of the track (those trees which are actually able to strike a pedestrian during a failure event). In the suggested scenario, assuming each tree has an equal probability of failure per point 2 above, each tree would have a PoF range of 2 (1/61). When this is applied to what we know about the target, the computed risk of harm to pedestrians (assuming trunk snapping) in this scenario is 1/4,000 (not tolerable) which represents a 100-fold discrepancy between what has been previously provided. It is important to note that the figure expressed here is a flawed contrivance produced from a misapplication of the QTRA method. It does not necessarily reflect the actual numerical risk of harm and should not be used to inform the risk decision.

4. It is unclear whether the assumption allows for multiple tree-strikes during the 12-month period. If the assumption is that only a single tree is certain to fail in the 12-month period, then when the failure event occurs (and there is mathematical certainty that it will using the specified maths), it artificially precludes any further failures in the forest for the remaining portion of the 12-month period, irrespective of environmental, biological or biomechanical characteristics, because the 100% probability event has been realised. Essentially, this approach cannot mathematically accommodate a scenario which would see two (or more) trees strike the track in a 12-month period. Similarly, a scenario where there are zero trees striking the track cannot be mathematically accommodated.

5. The QTRA target occupancy range for pedestrian traffic assumes an average human walking speed of 1.4 ms^{-1} and that a pedestrian will be exposed to the hazard for 5 seconds during their walk. Essentially, the QTRA calculation allows for an occupancy footprint with a 7-m risk of harm exposure built into it. CWCA has assumed that there is a 1/1 probability that a 12 m section of the track will be impacted by a falling tree in the next 12 months, which is 1.71 occupancy footprints, essentially doubling the pedestrians' risk of harm exposure using the suggested maths (8.5 seconds of exposure). This in effect increases the target occupancy by a single range, from 4 (according to CWCA) to 3, making the risk outputs understated by a factor of ten.

6. The assumption relies on the premise that the 12 m impact footprint results from a tree falling perpendicular to the track. There is no consideration that a tree may fall parallel to the track. A 30-m tall tree falling along the track will result in a 30-m impact footprint, further increasing the exposure of the pedestrian by a factor of 2.5 using the CWCA approach (30 m / 12 m = 2.5), or by a factor of 4.3 using QTRA maths (30 m / 7m = 4.3. 5 s x 4.3 = 21.5 seconds of exposure), which further increases the target occupancy creating a target range of 2, i.e. the risk outputs are now understated by a factor of 100.

7. We have explored this scenario directly with the QTRA developers who provide the following response:

"This is not QTRA. QTRA assesses the risk from a specific hazard, not from all hazards in a tree or a population. So the question is 'what is the likelihood that the specified hazard will fail onto the specified target within the coming year. 1/1 is certainty, and in any case, we use a range rather than a point value. If you are using QTRA you consider the frequency of pedestrian movements, and therefore each pedestrian walking the length of the track will pass each tree that is within falling distance of the track. IMO [in my opinion]*, the level of precision that is being considered here doesn't improve the risk assessment."*