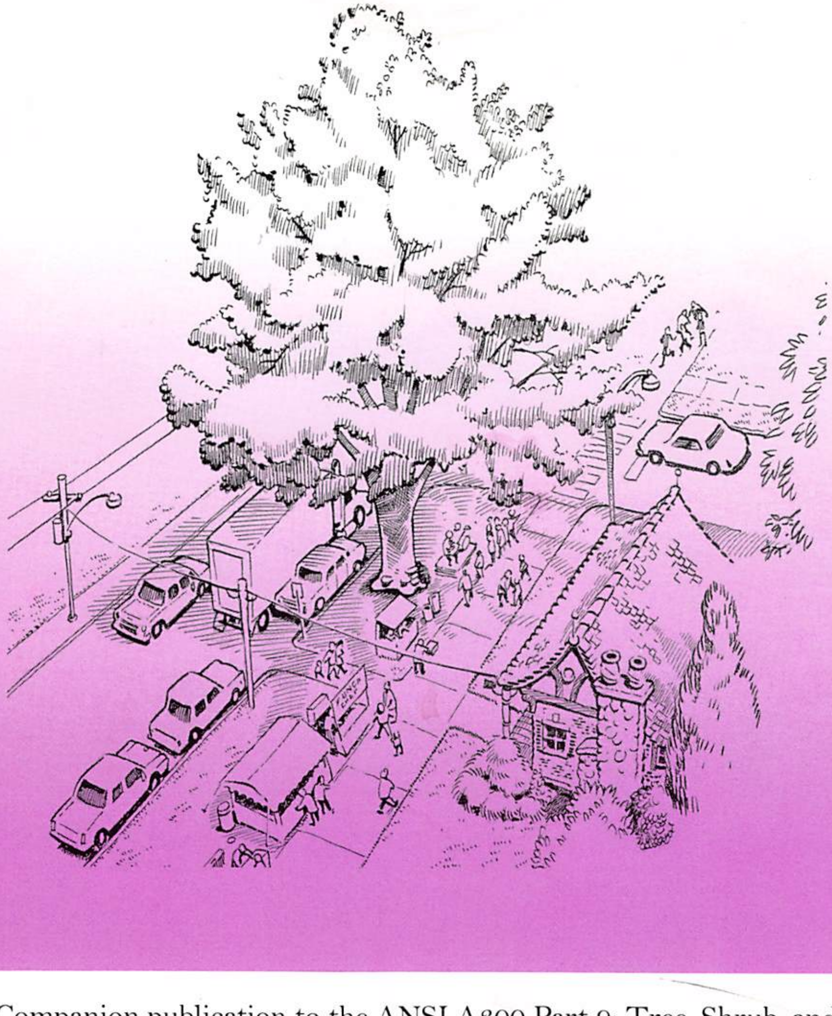
Best Management Practices

Tree Risk Assessment

Second Edition



Companion publication to the ANSI A300 Part 9: Tree, Shrub, and Other Woody Plant Management—Standard Practices (Tree Risk Assessment a. Tree Failure)

Best Management Practices

TREE RISK ASSESSMENT
Second Edition 2017

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Preface

The International Society of Arboriculture (ISA) has developed a series of publications known as Best Management Practices (BMPs) to aid in the interpretation of professional standards and to guide work practices based on current science and technology. These publications are intended as guides for practicing arborists, urban foresters, tree workers, and their supervisors.

This BMP was developed to be consistent with the International Standards Organization standards ISO 31000:2009 *Risk Management—Principles and Guidelines*, IEC/ISO 31010:2009 *Risk Management—Risk Assessment Techniques*, and ISO Guide 73:2009 *Risk Management—Vocabulary*; *American National Standard for Tree Care Operations—Tree, Shrub, and Other Woody Plant Management—Standard Practices (Tree Risk Assessment a. Tree Structure Assessment)* (ANSI A300, Part 9); and other national standards.

One way in which the ANSI Standard differs from some of the other standards is that it addresses only tree risk assessment and not the overarching goals and issues of tree risk management. In addition, the ANSI Standard is aimed at guiding the practices of arborists, not tree owners or managers. This BMP is similarly aimed at arborists who perform tree risk assessment and does not incorporate comprehensive guidance for tree risk management or for owner/manager practices or responsibilities.

Tree risk management is the application of policies, procedures, and practices used to identify, evaluate, mitigate, monitor, and communicate tree risk (Figure P1). Various people share responsibilities for tree risk management—including the tree owner or manager, the tree risk assessor, and the arborist providing service work (Table P1).

This document is intended to serve as a guide for arborists to assess tree risk as accurately and consistently as possible, to evaluate that risk, and to recommend measures to achieve an acceptable level of risk. In doing so, tree risk assessors should recognize the value of preserving trees and the importance of avoiding unnecessary treatments. It is not the intent of this document to provide direction for developing risk management policy or for providing legal guidance.

It is impossible to maintain trees free of risk; some level of risk must be accepted to experience the benefits that trees provide. The National Tree Safety Group (NTSG), which is a partnership of organizations in the United Kingdom, has drafted a guidance document that identifies five key principles for tree risk management. This document provides a foundation for balancing tree risk and the benefits that trees provide:

- Trees provide a wide variety of benefits to society
- Trees are living organisms that naturally lose branches or fall
- The risk to human safety is extremely low
- Tree owners have a legal duty of care
- Tree owners should take a balanced and proportionate approach to tree safety management

Because trees are unique living organisms, not all practices can be applied in the same way to all trees. Procedures and methodologies should be selected and applied as appropriate, with consideration for what is reasonable and proportionate to the specific conditions and situations. Departures from this BMP should be made with careful consideration of the objectives and with supporting rationale. For litigation defense, the entire assessment and departures from this BMP should be documented.

The information in this guide is not sufficient for the arborist to perform tree risk assessment; training and experience are also necessary. In some jurisdictions, certification, qualifications, or licenses are required to conduct tree risk assessments.

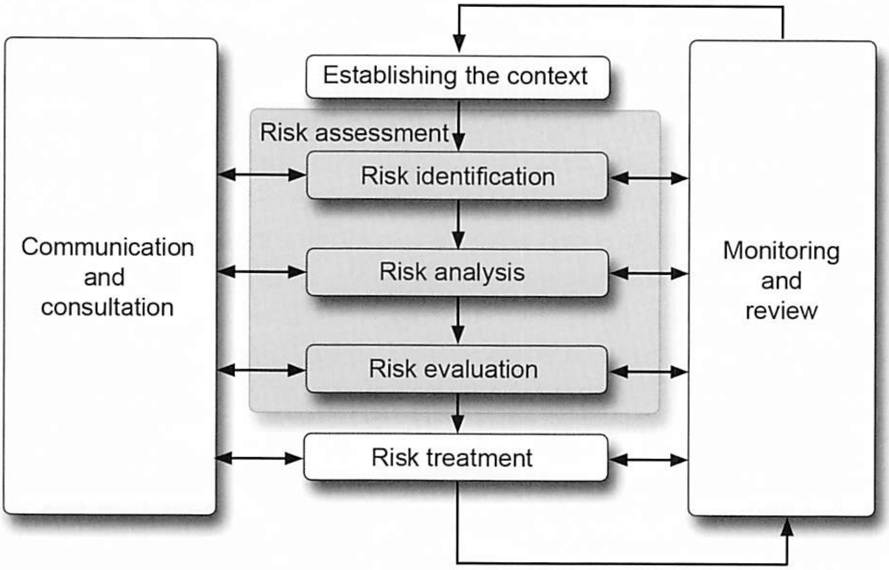

Figure P1. Contribution of risk assessment to the risk management process. *©IEC. This material is reproduced from IEC 31010:2009 with permission of the American National Standards Institute (ANSI) on behalf of the International Electrotechnical Commission. All rights reserved.*

Table P1. Guidance on the intended roles of the tree risk manager, tree risk assessor, and the arborist. In addition, legal counsel can provide advice on duty of care, professional responsibilities, negligence, title and boundary matters, and other issues. All recommendations should be made in accordance with industry standards and regulations.

Tree Risk Manager (tree owner, property manager, controlling authority)	**Tree Risk Assessor** (unless regulated by controlling authorities)	**Arborist/Tree Worker**
Duty of care responsibility	Develop or accept scope of work, including time frame (shared with risk manager)	Provide requested services:
Define and communicate tree risk management policies	Identify tree and site conditions to inspect	Tree work safety review
Determine the need to inspect the trees in question	Identify significant targets, estimate occupancy rates and target zone	Pruning
Establish the budget	Assess and classify the likelihood of a tree failure impacting a target	Removal
Identify the geographical limits of the tree inspection	Assess the potential consequences of a tree failure impacting a target	Support systems
Specify the desired level of assessment	Analyze tree risk	Lightning protection
Determine or accept the scope of work (shared with risk assessor)	Consider if advanced assessments are needed	Tree health treatments
Decide the level of acceptable risk	Develop options for treatments to mitigate risk	Transplanting
Establish the inspection frequency	Estimate residual risks after treatment	Tree replacement
Verify target zone uses and occupancy rates	Recommend an inspection frequency	Identify the need for follow-up treatments
Prioritize work	Develop report	
Choose among risk mitigation options	Send report to client and explain findings to the client, if needed	

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1. Introduction

Trees provide numerous benefits to those living and working in the urban environment. These benefits increase as the age and size of the trees increase. However, as a tree gets older and larger, it is also more likely to shed branches or develop decay or other conditions that can predispose it to failure. In assessing and managing trees, we should strive to strike a balance between the risk that a tree poses and the benefits that individuals and communities derive from trees.

Many trees are located where the consequences of failure are minor or negligible. In urban and developed areas where people, property, and activities could be injured, damaged, or disrupted, the consequences of tree conflict or failure may be significant or severe. Decisions on whether a tree inspection is required or what level of assessment is appropriate should be made with consideration for what is reasonable and proportionate to the specific conditions and situations. These are tree risk management issues.

It is impossible to maintain trees free of risk. Some level of risk must be accepted to experience the benefits that trees provide. Fortunately, tree failure that results in serious damage, injury, or death is rare. Tree failures during "normal" weather conditions are often predictable and preventable. However, any tree, whether it has visible weaknesses or not, will fail if the forces applied exceed the strength of the tree or its parts. For example, hurricane-force winds, heavy snow, or freezing rain can break solid, defect-free trees.

Tree risk assessors often must perform risk assessments with limited information about the structural condition of the tree and the environment that affects it. Tree risk assessors form opinions about what is likely to occur in the future based upon their experience and what is observed. These assessments are then provided to a tree owner or manager to make decisions about tree management.

Arborists serving as tree risk assessors should have specialized education, training, skills, and experience, and they should be properly insured to provide this service. Familiarity with basic tools and equipment is needed for many assessments. Specialized tools or equipment may be required for some assessments. In some jurisdictions certification, qualifications, or licenses are required to conduct tree risk assessments.

The purpose of this document is to guide arborists to assess tree risk as accurately and consistently as possible, to evaluate that risk, and to understand which treatments can achieve an acceptable level of risk. In determining treatments, the tree risk assessor should recognize the importance of preserving trees and avoiding unnecessary treatments.

It is not the intent of this document to provide guidance for developing risk management policy or for addressing legal issues.

2. Risk Assessment Basics

Basic Definitions

There are a number of key definitions required for the understanding of tree risk assessment concepts. Below is a partial list of these definitions. A more comprehensive list can be found in the Glossary.

- **Risk** is the combination of the likelihood of an event and the severity of the potential consequences.

  In the context of trees, risk is the likelihood of a conflict or tree failure occurring and affecting a target, and the severity of the associated consequences—personal injury, property damage, or disruption of activities.
- **Tree risk assessment** is a systematic process used to identify, analyze, and evaluate tree risk. Risk is assessed by categorizing or quantifying both the *likelihood* (probability) of occurrence and the *severity* of consequences.
- **Tree risk evaluation** is the process of comparing the assessed risk against given risk criteria to determine the significance of the risk.

  The magnitude of risk can be categorized or calculated and compared to the client's tolerance to determine if the risk is acceptable.
- **Targets (risk targets)** are people, property, or activities that could be injured, damaged, or disrupted by a tree failure.
- **Failure (tree failure)** is the breakage of stem, branches, or roots, or the loss of mechanical support in the root system.
- **Harm** is personal injury or death, property damage, and/or disruption of activities.
- **Tree risk management** is the application of policies, procedures, and practices used to identify, evaluate, mitigate, monitor, and communicate tree risk.
- **Event** is the occurrence of a particular set of circumstances. In tree risk assessment, an event is a tree affecting a target.
- **Likelihood** is the chance of an event occurring. In the context of tree failures, likelihood refers to: 1) the chance of a tree failure occurring, 2) the chance of impacting a specific target, and 3) the combination of the likelihood of a tree failing and the likelihood of impacting a specific target.

- **Consequences** are the effects or outcome of an event. In tree risk assessment, consequences include personal injury, property damage, or disruption of activities due to the event.

> **Risk vs. Hazard**
>
> Arborists and foresters have used the term *hazard assessment* to describe the process of inspecting and evaluating the structural condition of trees and the harm that could occur in the event of failure. The more accurate and appropriate term *risk assessment* is now standard.
>
> Risk is the combination of the likelihood of an event and the severity of the potential consequences.
>
> A *hazard* is a likely source of harm. In relation to trees, a *hazard* is the tree part(s) identified as a likely source of harm.
>
> A tree is considered *hazardous* when it has been assessed and found to be likely to fail and cause an unacceptable degree of injury, damage, or disruption—that is, it poses a high or extreme risk.

Types of Risk Associated with Trees

Trees can pose a variety of risks, which are categorized into two basic groups: conflicts and structural failures. The majority of this publication focuses on structural failures of trees.

Conflicts

Risk can arise when there are conflicts between trees and societal functions. As trees grow, they may produce potentially problematic flowers, fruit, roots, branches, and leaves, and these may conflict with pavement, the structures around them, and people. In some situations these conflicts can cause harm. Conflict can also occur between power lines and trees. This contact can interrupt power supplies, can propagate fires, and can injure or kill people. Although not the focus of this BMP, more information on tree conflicts is provided in Appendix 1.

Structural Failures

Tree failure is the breakage of stems, branches, or roots, or the loss of mechanical support from the root system. Structural failures occur when the forces acting on a tree exceed the strength of the tree structure or soil supporting the tree. Even a structurally strong tree will fail when a load or force is applied that exceeds the strength of one or more of its parts.

Most tree structural failures involve a combination of structural defects and/or conditions, such as the presence of decay or poor structure, and a loading event, such as a strong wind.

Major Defects and Conditions That Increase Potential for Tree Failure

- Dead parts
- Broken and/or hanging branches
- Cracks
- Weakly attached branches and codominant stems
- Decayed or missing wood (mechanical damage or cankers)
- Unusual tree architecture (lean, balance, branch distribution, and lack of taper)
- Loss of root support

The severity of each defect depends on the loads to which it is exposed and the degree of response growth present.

Approaches to Risk Assessment

Before a tree risk assessment takes place, it is important to establish the context of the assignment. *Context* defines the parameters of the risk assessment including objectives, how risk will be evaluated, communication flow, applicable policies or legal requirements, and limitations of the risk assessment. Tree risk assessment is the systematic process to identify, analyze, and evaluate tree risk. The manner in which this process is applied depends on the context and the methods used to carry out the risk assessment.

The two primary approaches to risk assessment are *quantitative* and *qualitative*. Each has advantages and limitations, and each may be appropriate with different objectives, requirements, resources, and uncertainties. Both quantitative and qualitative approaches are valid when applied properly with reliable data and valid assumptions. With training and experience, reliability can be improved for each approach.

Quantitative Risk Assessment

Quantitative risk assessment estimates numeric values for the probability and consequences of events, and then produces a numeric value for the level of risk, typically using the formula:

$$\textbf{Risk} = \textbf{Probability} \times \textbf{Consequences}$$

An advantage of quantitative assessment is that tree risk can be compared not only to other trees but also to other types of risk, as might be necessary for municipal decisions in which resources must be allocated among departments, for example. The calculations can vary from simple to complex as risks are analyzed independently or in combination. Even if complex statistical analyses are carried out, users must remember that the calculations are estimates and must ensure that the accuracy and precision reported are consistent with the data and methods employed. In most cases, the numeric inputs required for quantitative assessments are derived from subjective interpretations and may vary significantly among assessors. Our ability to quantify probability is often limited when applied to trees because they are natural structures and we have little systematically-collected data on which to base probabilities. Since numeric data are not always available and both systematic and statistical uncertainties can be high, full quantitative analysis is often not warranted or practical for tree risk assessment.

Qualitative Risk Assessment

Qualitative risk assessment is the process of using categorized ratings of the likelihood and consequences of an event to determine a risk level and evaluate the level of risk against qualitative criteria. Often, ratings are combined in a matrix to categorize risk. Inherent subjectivity and ambiguity are also limitations of the qualitative approach. In order to increase reliability and consistency of application, it is important to provide clear explanations of the terminology and significance of the ratings defined for likelihood, consequences, and risk. Qualitative risk assessment approaches are recognized and respected methods of risk assessment that are used internationally by many governments and businesses.

Qualitative Numeric Assessments

There are several qualitative numeric tree risk assessment systems that have been used to assign numbers to certain factors to derive an estimate or ranking of relative risk. The rankings are sometimes used to prioritize work. The assigned numbers, which are actually categorizations and do not represent a quantitative mathematical relationship, are either added or multiplied to develop an overall relative level of risk. Risk professionals caution that addition or multiplication of these ordinal numbers is mathematically incorrect. Some of these systems were designed to estimate level of risk for individual trees and others were designed to prioritize work within a population of trees. If a qualitative numeric system is employed, it should be used only for the intended purpose and with an understanding of its limitations.

BMP Assessment Approach

The methodology of the risk assessment selected should be appropriate to the situation and should consider the goals and the resources available. With the context defined, the specific techniques should be selected based upon:

- Needs of the decision makers and the level of detail required
- Resources available and what is reasonable for the potential consequences
- Availability of information and data
- Expertise required

A matrix-based, qualitative approach to tree risk assessment has been selected for expanded explanation in this guide, but quantitative assessments are not precluded from best management practices. Whichever technique is chosen, users should recognize the limitations as well as the nature and degree of uncertainty in the data and information available.

There is typically a considerable level of uncertainty associated with tree risk assessment due to our limited ability to predict natural processes (rate of progression of decay, response growth, etc.), weather events, traffic and occupancy rates, and potential consequences of tree failure. Sources of uncertainty should be understood and communicated to the risk manager/ tree owner.

A primary goal of tree risk assessment is to provide information about the level of risk posed by a tree over a specific time frame. This is accomplished in qualitative tree risk assessment by first determining the categories for likelihood and consequences of tree failure. These two factors are determined by:

1. Evaluating the structural conditions that may lead to failure; the potential loads on the tree; and the tree's adaptations to weaknesses—to determine the likelihood of failure. Guidance for evaluating tree

condition and assessing likelihood of failure are presented in Appendices 2 and 3, and in other publications (see Additional References).

2. Evaluating the likelihood that a failed tree or tree part could strike people or property or disrupt activities within the specified time frame.

3. Assessing and categorizing the value of potential damage or harm to the targets in order to estimate the consequences of failure.

With ratings for the likelihood and consequences, the level of risk then can be estimated or categorized.

It is important to define what risk is being rated. For example, "The risk of the large, dead branch in the oak tree in Mrs. Smith's back yard failing and hitting the garage" may be very different from "The risk of the oak tree in Mrs. Smith's back yard failing at the base and hitting people using the patio below." Multiple risks may be rated for any given tree, but the assessment report should state clearly what risk(s) are rated to minimize ambiguity or confusion.

3. Levels and Scope of Tree Risk Assessment

Tree risk assessments can be conducted at different levels of detail and may employ various methods and tools. The level selected should be specified in the scope of work established between the risk assessor and the client prior to conducting an assessment. The level(s) should be appropriate for the assignment. Three levels of tree risk assessment are defined and described within this text:

- Level 1: Limited visual assessment
- Level 2: Basic assessment
- Level 3: Advanced assessment

If conditions cannot be adequately assessed at the specified level, the assessor may recommend a higher level or different assessment. However, the assessor is not obligated to provide the higher level if it is not within the scope of the original assignment, without additional compensation, or without modifications to the agreement or contract.

In addition to specifying the level of inspection, tree risk assessors also should describe pertinent details regarding the method. For example, a Level 1 assessment can be done by walking by, driving past, or flying above the trees. The method used will greatly influence the cost and reliability of the results.

At any level of assessment, if a situation is encountered where tree failure is imminent and a high-value target is present and likely to be struck by the failure, the situation should be reported to the client as soon as possible. In addition, immediate action may be required to restrict access to the target zone.

Level 1: Limited Visual Assessment

Level 1 risk assessment is a visual assessment from a specified perspective of an individual tree or a population of trees near specified targets. It is conducted to identify obvious defects or specified conditions. Typically, one or two of the three factors assessed during a Level 1 tree risk assessment (likelihood of failure, likelihood of impact, consequences) is/are held constant. For example, if assessing street trees, the likelihood of impact and the consequences of failure might be assumed to be the same for each tree on a block, and therefore the assessor would only need to determine each tree's likelihood of failure.

Level 1: Limited Visual Assessment Process

The process of limited visual assessment should:

- Identify the location and/or selection criteria of trees to be assessed.
- Determine the most efficient route and document the route taken.
- Assess the tree(s) of concern from the defined perspective (for example, walk-by or drive-by).
- Record locations of trees that meet the defined criteria (for example, significant defects or other conditions of concern, trees that require mitigation, or trees that require a higher level of assessment).
- Evaluate the risk based on observations and assumptions (a risk rating is optional).
- Identify trees needing a higher level of assessment or prompt action.
- Submit recommendations or report.

A Level 1 assessment usually focuses on identifying trees with *imminent* and/or *probable* likelihood of failure that are adjacent to specific pre-defined targets and could impact the target(s). Using another example, in a Level 1 risk assessment along a utility line, the assessor would pre-define the target as the electrical conductor, and would identify trees likely to fail and impact the target. In this example, the consequence of failure—disruption of electrical services—is held constant.

Limited visual assessments are the fastest, but least thorough, means of assessment and are intended primarily for quick assessment of large populations of trees. When conducted by trained professionals, limited visual assessments can provide tree managers with an adequate level of information that can accomplish their risk management goals. These assessments are often done on a specified schedule, or may be done immediately after storms to rapidly assess a tree population.

A limited visual assessment, performed from one side or by an aerial flyover, typically looks for *obvious* defects such as dead trees, large cavity openings, large dead or broken branches, fungal fruiting structures, large cracks, and severe or uncorrected leans. In addition, the client may specify certain conditions of concern, such as lethal pests or symptoms associated with root decay.

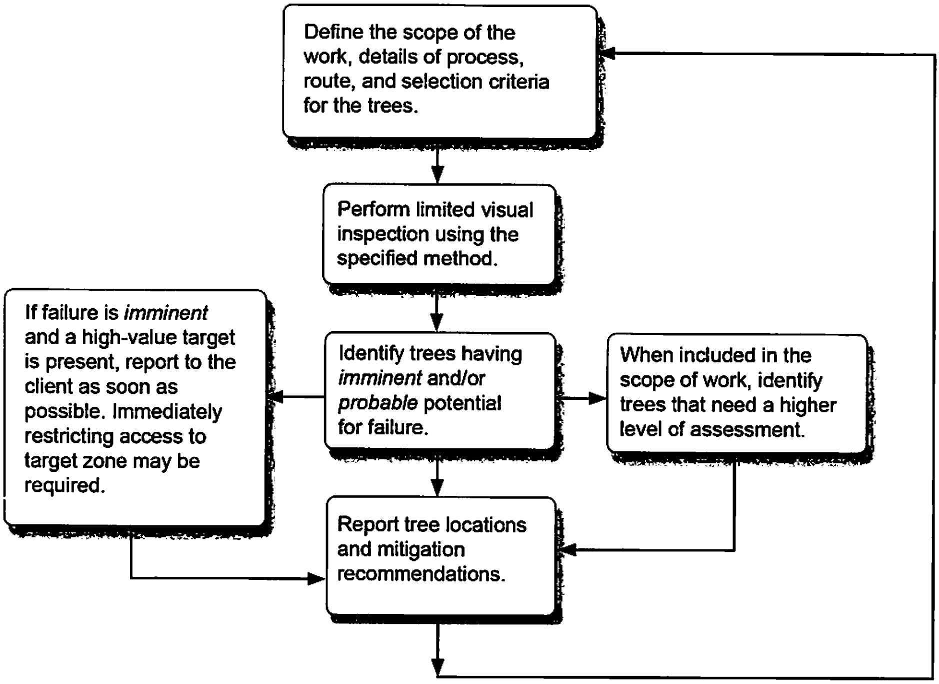
The scope of work should specify the perspective or type of inspection. The type of inspection may include one of the following:

- **Walk-by** is a limited visual inspection of one or more sides of the tree, performed as the inspector walks past a tree. The inspector may need to stay on the sidewalk or footpath, on public property, or within a right-of-way. The scope of work may, in some cases, specify that the assessor must walk around certain trees to gain a more complete perspective.
- **Drive-by** (windshield) is a limited visual inspection of one side of the tree, performed from a slow-moving vehicle. The scope of work also may specify that the inspector must walk around certain trees or record images to verify or document observations. This type of inspection is often performed by municipalities, utilities, or other agencies or landowners who have large populations of trees to inspect with limited budgets.
- **Aerial patrol** is observation made from an aircraft overflying utility rights-of-way, other areas, or individual trees. This type of inspection is conducted by some electric utility companies or their contractors to identify threats to the electric transmission system. Unmanned aerial vehicles (UAV) may be used for either Level 1 or Level 3 inspections. Sometimes a more detailed, ground-based inspection may be specified to confirm observations. Images may be recorded to document observations.
- **LiDAR** (Light Detection and Ranging), is a remote sensing method that uses laser technology to measure tree size and location in relation to the target of concern. In this case, the assessor may focus on the likelihood of impact if a failure were to occur.

When a tree of concern is identified, certain specified information about that tree should be recorded. At a minimum, this information should include the tree location and any recommended remedial action. In addition, it may include the species name, tree size, defect or condition identified, and a work priority. A higher level of inspection may also be recommended, if that option is included in the scope of work.

A constraint of limited visual inspections is that some conditions may not be visible from a one-sided inspection of a tree, nor are all conditions visible on a year-round basis. Also, a Level 1 risk assessment may not be adequate to make a risk mitigation recommendation. The assessor may use the Level 1 inspection to determine which trees require further inspection at the basic or advanced levels after which an appropriate mitigation can be recommended.

Flow Chart of Level 1: Limited Visual Assessment Procedures



Level 2: Basic Assessment

A Level 2 or basic assessment is a detailed visual inspection of a tree and its surrounding site, and a synthesis of the information collected. It requires that a tree risk assessor inspect completely around the tree—looking at the site, and at visible buttress roots, trunk, and branches. This is the level of assessment that is commonly performed by arborists in response to clients' requests for individual tree risk assessments.

A basic assessment may include the use of simple tools to gain additional information about the tree or defects. Simple tools may be used for measuring the tree and acquiring more information about it or any potential defects. However, the use of these tools is not mandatory unless specified in the scope of work. Measuring tools may include a diameter tape, clinometer, or tape measure. Other inspection tools include:

- **Binoculars.** Binoculars may be used to inspect the upper portions of a tree's crown to look for cavities, nesting holes, cracks, weak unions, and other conditions and tree responses.

- **Mallet.** The trunk may be sounded with a non-damaging instrument such as a broad-headed mallet made of wood, rubber, leather, or resin. The tree risk assessor strikes the tree trunk in multiple places and listens for tone variations that may indicate hollows, sapwood decay, or dead bark (Figure 1).

Figure 1. Sounding. The tree risk assessor can strike the tree with a mallet and listen for tonal variations that indicate dead bark or internal hollows.

- **Probe.** A probe is a stiff, small-diameter rod, stick, or wire that is inserted into a cavity to estimate its size and extent (Figure 2). Because there may be sections of nonfunctional wood adjacent to a cavity, this type of measurement should be considered only an approximation of the extent of decay.
- **Digging tools.** A trowel, shovel, or other hand tool can be used to conduct minor excavations to expose surface roots or the root collar. Care should be taken not to damage roots during the excavation process. More extensive root collar excavations are considered an advanced assessment.

The primary limitation of a basic assessment is that it includes only conditions that are detected from a ground-based inspection on the day of the assessment. Internal, belowground, or upper-crown conditions, as well as certain types of decay, may be impossible to see or difficult to assess and may remain undetected.

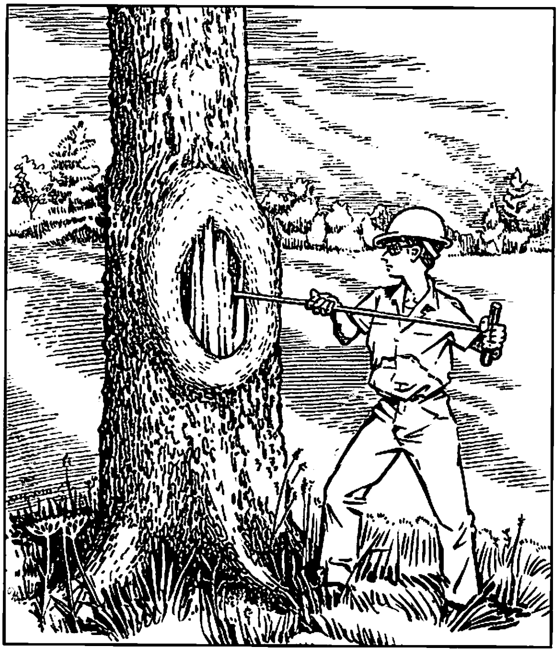
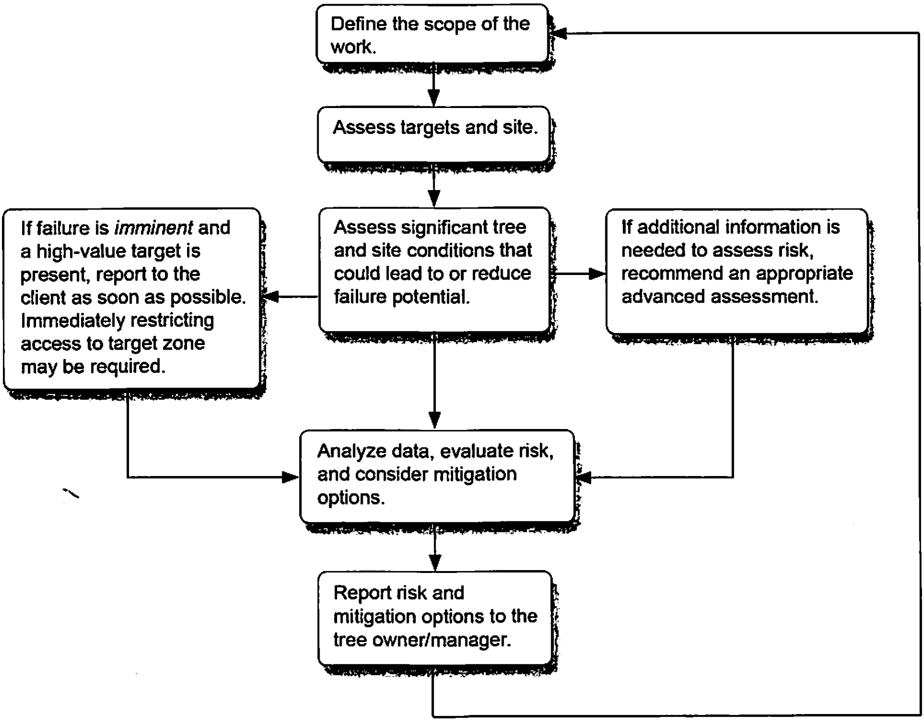


Figure 2. Probing. The tree risk assessor can use a stiff, small-diameter rod or stick to probe into cavity openings to estimate their size and extent.

Level 2: Basic Assessment Process

- Locate and identify the tree or trees to be assessed.
- Determine the targets and target zone for the tree or tree parts of concern.
- Review conditions and available site history. Assess general tree health.
- Assess unusual or expected loads, or changes in load, on the tree and its parts.
- Inspect the tree visually—using binoculars, mallet, probe, or trowel, as desired by the arborist or as specified in the scope of work.
- Record observations of site conditions, defects, and outward signs of possible internal defects and response growth.
- If considered necessary, recommend an advanced assessment.
- Analyze available data to determine the likelihood and consequences of failure in order to evaluate the degree of risk.
- Develop mitigation options and estimate residual risk for each option.
- Develop and submit a report, including, when appropriate, advice on re-inspection intervals.

Flow Chart of Level 2: Basic Assessment Procedures



Level 3: Advanced Assessment

Advanced assessments are performed to provide detailed information about specific tree parts, defects, targets, or site conditions. They usually are conducted in conjunction with or after a basic assessment if the tree risk assessor needs additional information and the client approves the additional service. Specialized equipment, data collection and analysis, and/or expertise are usually required for advanced assessments. These assessments are therefore generally more time intensive and more expensive.

Procedures and methodologies should be selected and applied as appropriate, with consideration for what is reasonable and proportionate to the specific conditions and situations. The risk manager/property owner should consider the value of the tree to the owner and community, the possible consequences of failure, and the time and expense needed to provide the advanced assessment. Advanced assessments can provide additional information that may make the difference between recommending tree or branch retention or removal. The tree risk assessor should identify what additional information is needed and recommend the appropriate technique(s).

While there are many types of advanced assessments that can be conducted (see page 22), a few are described in Appendix 5. Tree risk assessors are cautioned, however, that all technologies involve some uncertainty. Each technology has limitations; any evaluation of an individual tree or target will not be an accurate measure, but a qualified estimation.

Standard safe work practices and procedures should be applied for all levels of assessment.

Defining the Scope of Work

Prior to beginning a tree risk assessment, the scope of work should be defined. The tree risk assessor and client must agree on the goals, limitations, and budget of the tree risk assessment. Some clients may be very experienced and will have already developed a sophisticated scope of work. Often, however, the risk assessor plays a significant role in documenting the scope.

Any property boundaries that restrict access to the tree(s) should be identified. Local government or authority's requirements for inspection, reporting, and permitting should be considered. If a written report is to be presented to someone other than the person who contracts with the tree risk assessor, that person or agency should be identified.

The scope of work should include specifications for the following:

Identifying the tree(s) or area to be assessed. This may be the location of a tree (for example, "the large oak tree in the front yard") or it may include selection criteria (for example, "all trees on Main Street greater than 12 inches [30 cm] in diameter"). When assessing trees for a municipality or large property, it is important to have maps with defined boundaries and clear directions for assessing boundary trees.

The level and details of the assessment. One or more of the three levels of assessment should be specified, as well as details that are to be included within each level. If a limited visual inspection is selected, how the inspection is to be conducted and what information is to be recorded should be described. For example, "The inspection procedure is a 'walk-by' from the sidewalk, looking for any obvious, aboveground defects."

Details of conditions to be assessed may also be included in the scope of work. For example, trees often have many small, dead branches present, but the tree risk assessor is concerned only about larger branches that can result in serious consequences if they fail. Specifications for assessment may state that only branches greater than 2 inches (5 cm) in diameter should be noted. Similarly, details can be specified for the minimum degree of lean, live crown ratio, degree of taper, or other conditions of concern (see Appendix 3).

For all levels of assessment, if the tree risk assessor determines that a higher level of assessment or a different type of assessment is needed, that recommendation should be made to the client.

The method of reporting. The manner of reporting and any additional documentation should be defined. The preferred method is a written report. In some instances, however, the report may be verbal (oral) with a recommendation for mitigation, or a work order for the mitigation. In general, verbal reports are not recommended because of the potential for misinterpretation in the chain of communication.

Timetable for inspection and reporting. The time of the inspection and due date for the report should be specified.

Risk rating and mitigation. Risk assessments typically include a rating of the current tree risk, options and/or recommendations for mitigating risk, evaluation of the residual risk after mitigation, and the recommended inspection interval, if applicable.

If a situation is encountered in which tree failure is *imminent* and a high-value target is present and likely to be impacted, the situation should be reported to the client as soon as possible. In addition, immediate action may be required to restrict access to the target zone.

Level 3: Advanced Techniques

Many techniques can be considered for advanced risk assessment.† Some situations may be assessed with several techniques. Advanced assessment techniques include:

- Aerial inspection and evaluation of structural defects in high stems and branches
  - * visual inspection from within the tree crown or from a lift
  - * unmanned aerial vehicle (UAV) photographic inspection
  - * decay testing of branches
- Detailed target analysis
  - * property value
  - * use and occupancy statistics
  - * potential disruption of activities
- Detailed site evaluation
  - * history evaluation
  - * soil profile inspection to estimate root depth
  - * soil mineral and structural testing
- Decay testing
  - * increment boring
  - * drilling with small-diameter bit
  - * resistance-recording drilling
  - * single-path sonic (stress) wave
  - * sonic tomography
  - * electrical impedance tomography
  - * radiation (radar, X-ray)
  - * microscopic analysis for fungal type
- Health evaluation
  - * tree ring analysis (in temperate zone trees)
  - * shoot length measurement
  - * detailed health/vigor analysis
  - * starch assessment
- Root inspection and evaluation
  - * root and root collar excavation
  - * root decay evaluation
  - * ground-penetrating radar
- Storm/wind load analysis
  - * detailed assessment of tree exposure and protection
  - * computer-based estimations according to engineering models
  - * wind reaction monitoring over a defined interval
- Measuring and assessing the change in trunk lean
- Load testing
  - * hand pull
  - * measured static pull
  - * measured tree dynamics

†Inclusion of specific techniques in this list should not be considered an endorsement of that technique.

4. Assessing Targets, Sites, and Trees

The likelihood of a tree failure impacting a target is the combination of the likelihood of tree failure and the likelihood of that failed tree or tree part impacting a target. These factors must be assessed individually, then combined to determine the likelihood of failure and impact. Likelihood of failure and impact is then combined with the consequences of the failure to categorize risk. These assessments are performed while inspecting the targets that could be affected if the tree failed, site characteristics that influence tree structural stability, and tree structural condition.

Targets

In tree risk assessment, targets are people, property, or activities that could be injured, damaged, or disrupted by a tree failure. Targets include people, buildings, animals, power lines, infrastructure, vehicles, landscape structures, and other property that may be damaged or harmed by a tree failure (Figure 3).

Areas near a tree that are often evaluated for the presence of targets include streets, parking areas, footpaths, and play areas. Although damage to structures is possible, the bigger concern is the people who use them, even if people are not present at the time of the evaluation. Normally an assessor should not identify the sidewalk or road as a target, but should consider the people who use the sidewalk or road. Another example is that when assessing the risk of a tree failing in a parking area, the assessor should consider possible damage to cars that may be parked nearby, the frequency and intensity of use of the area, and injury to people who drive the cars.

The most important situations to assess are locations where people are frequently present, such as places with heavy pedestrian traffic. The greatest potential for injury from tree failures occurs in places where many people are unprotected. Examples are bus stops and well-treed city centers. This is especially important in areas where people will congregate under trees during storms.

Roadways are a commonly assessed target area. Possible consequences of a tree falling across a road include: the tree striking a vehicle and possibly injuring people inside, a moving vehicle running into the tree that has just failed, crashes associated with rapid stopping or swerving to avoid the fallen tree, and disruption of access to points further along the road. There are also costs and inconvenience factors associated with closing the road during the clean-up and remediation process.

Electric lines and facilities are targets of great importance to electrical utility risk managers and users of electric power. Electric lines brought down by a falling tree can be a threat to people who make contact with them; they can cause large fires; and the costs, inconvenience, and possible losses associated with disruption of service can be significant.

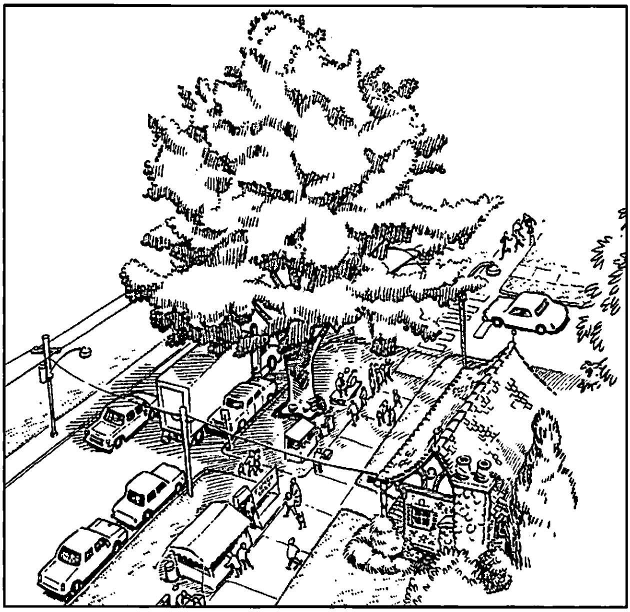


Figure 3. Targets. Risk targets are people, property, or activities that could be injured, damaged, or disrupted by a tree. If this large tree were to fail at the root system, targets would include the pedestrians, food vendors, traffic, parked cars, power lines, and the house.

Targets can be categorized by their ability to move or be moved. A static target is one that is fixed or not readily moved. Examples include buildings, utility facilities, or other structures. Movable targets are those that can be relocated, such as sculptures, picnic tables, parked cars, or swing sets. A mobile target is one that is in motion or intermittently moving. Examples include pedestrians, bikes, and vehicles on a sidewalk, footpath, or road.

Known targets are those visible to the arborist, and those that the arborist has been told about by the client. It is preferable to consider targets in consultation with the client, so that targets that are not present at the time of the assessment may be included. The scope of work should define targets of concern and often may consider only high-value targets (e.g., people, houses, or power lines).

Target Zone

The target zone is the area that the tree or tree part is likely to hit if it fails. When determining the target zone, the assessor considers the direction of fall, the height of the tree, crown spread, slope of land, wind, potential for dead branch shattering, or other factors that might affect spread of debris. The target zone guideline for a whole-tree failure is often a circle around the tree with a radius equal to about 1 to 1.5 times the height of the tree. Trees with asymmetric crowns or leans may have irregularly shaped target zones. For a branch failure, the target zone is the area in which the branch could strike.

The target zone for dead trees or trees with dead or brittle branches is generally larger than those with live, flexible branches, because dead and brittle branches are more likely to shatter upon hitting the ground and may spread debris some distance beyond the tree (Figure 4). In some situations, the target zone also may be larger when one tree could cause the failure of others that it could fall into. Conversely, the target zone may be reduced in size by adjacent larger trees, strong lower branches, or other factors that will not allow the tree or branch to fall in a given direction.

Trees and branches sometimes fall in unusual ways, striking outside of what would normally be considered the target zone. The direction of tree failure is often more closely related to wind direction than to the location of the defect on the tree. The direction that wind will come from during a storm is unpredictable and should not be confused with the direction of the prevailing wind.

Occupancy Rate

Targets can be categorized by the amount of time that they are within the target zone—their occupancy rate. Occupancy rates can be classified as constant, frequent, occasional, or rare. Constant occupancy means that the target

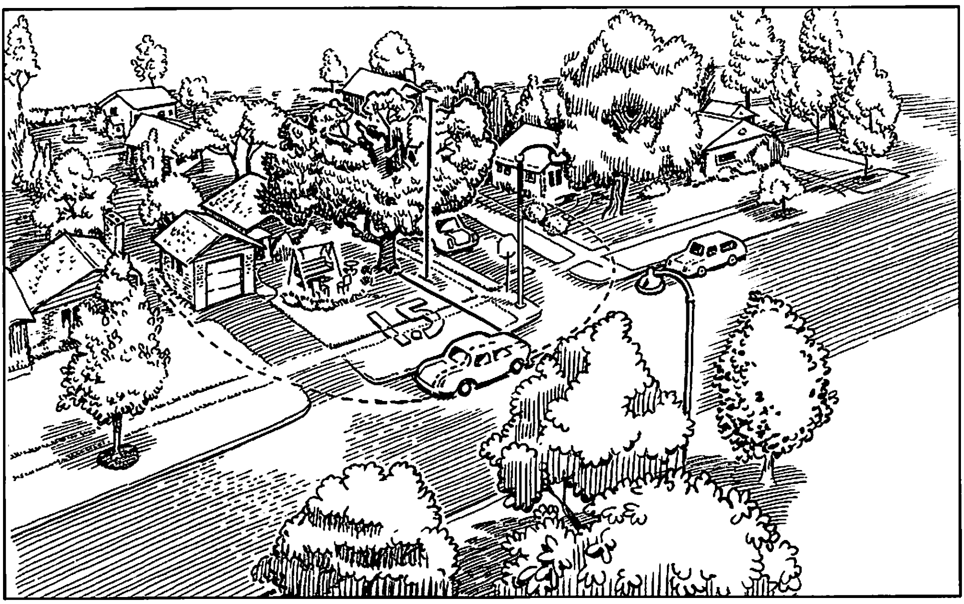


Figure 4. The target zone is the area where a tree or tree part is likely to land if it were to fail. Due to the brittle dead branches at the top of this tree, the target zone radius is equal to 1.5 times the tree height.

is always present or may be present nearly all day, most days of the week. Frequent occupancy is when the target is within the target zone a large portion of the day. Occasional occupancy refers to infrequent or irregular occupancy. Rare occupancy means that the area is not commonly used by people or other mobile targets.

Not all targets are present in the target zone at all times. Static targets are constant. Movable and mobile targets can be in any of the four classifications.

Occupancy rate is a primary component in an assessment of the likelihood of impacting a target. The tree risk assessor can consult with the client to determine targets and their occupancy rates. For example, a field with large trees may be used as a parking lot (car park) during football games, but it might be unoccupied most of the time. The client or tree manager may also define whether the risk assessment is to consider low- or high-use times, or both. Continuing the example, if the risk assessor is not told about the high-use times, then the target rating would be much lower than if the high-use times are considered exclusively.

Site Factors

Site factors have significant influence on both the likelihood and consequences of tree failure. Site factors that can be used to evaluate the likelihood of tree failure impacting the target include the history of previous failures, including branch, trunk, root, and soil failure; vegetative cover type; land use; and wind exposure (Figure 5). It is important to consider the significance of site changes such as forest clearing, trenching, earth excavation or filling, groundwater lowering or raising, infrastructure repair, or other construction. For example, a fully exposed lone tree, retained after removing adjacent trees, may be more likely to fail than the same tree within a stand protected from the wind. Site use can be assessed from features such as sidewalks, pavements, paths, play areas, picnic tables, and other objects.

Site examinations can provide information on root damage and/or disease and susceptibility to root failure. Soil factors such as frequency of saturation; compaction; erosion; textural gradients; restrictions to root growth from shallow, impermeable layers; and restrictions by roads, rock, or building foundations may also be considered. Trees are more susceptible to windthrow during storms when the soil is saturated. Site topography, including slope and aspect, should also be considered.

Because trees grow and develop, constantly responding to the forces and conditions that they are exposed to, they adapt over time. Assessors should take note of site changes that any trees present may not have had sufficient time or resources to respond to. For example, recently exposed forest-edge trees may be more susceptible to failure due to increased wind exposure, inadequate root systems, and/or changes in soil hydrology.

Wind and Weather

Most tree failures occur during storms when strong wind, rain, snow, or ice loads exceed the tree's capacity to withstand the load. Wind speeds are strongly affected by topography. In urban areas, wind speeds vary depending on placement in the landscape; trees that are located on the leeward side of taller buildings are exposed to slower wind speed than those along streets through which wind is funneled by surrounding structures. Knowledge of regional and local climate, wind and precipitation patterns, and observation of specific site conditions are important in assessing the likelihood of failure.

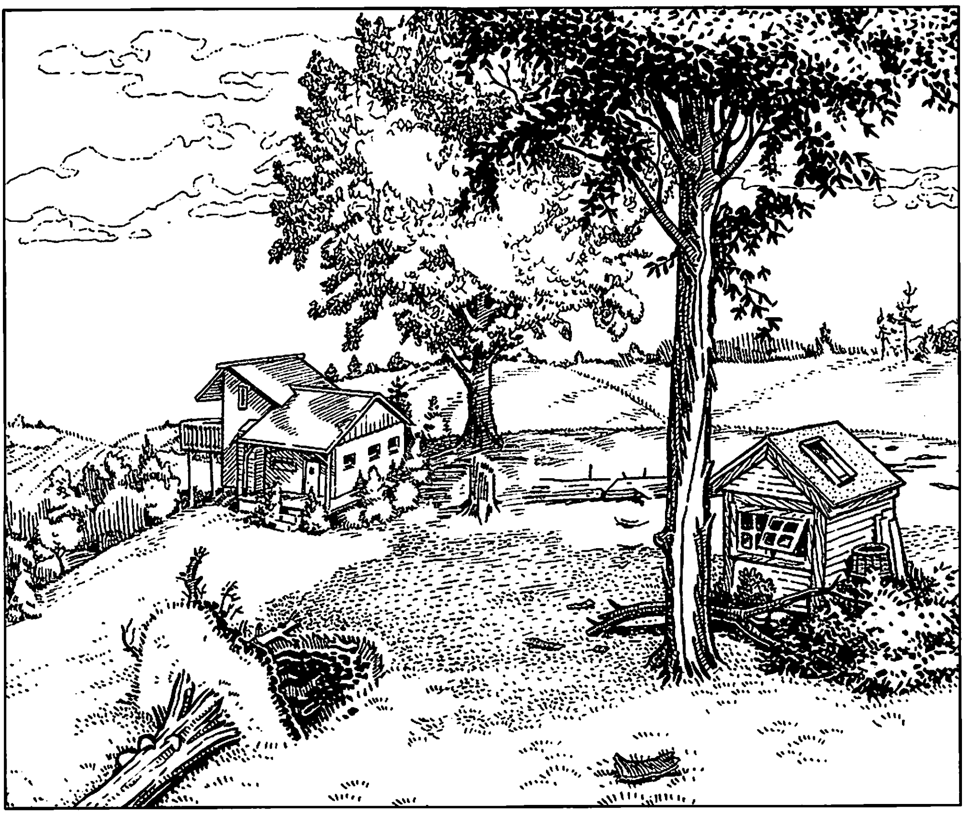


Figure 5. Site factors that affect a tree risk assessment at this location include a history of previous branch, trunk, and root failures; wind exposure as affected by the slope of the land; location at the top of a hill; and saturated soil conditions that increase the likelihood of whole-tree failure.

Tree failures in normal wind speeds are usually associated with serious, uncorrected, or unmitigated structural defects or other conditions, alone or in combination.

When wind speeds are extreme (strong gale force in many areas), even defect-free trees can fail. When wind speeds reach hurricane force, failure of defect-free trees can be widespread. Wind speed is variable: winds can be sustained, but commonly occur in gusts that may exceed the reported wind speed. Microbursts that produce strong lateral winds can fell even non-defective mature trees.

Normal and Extreme Wind

Storms can be classified into three broad categories based on frequency of occurrence, wind speed, and precipitation—normal, extreme, and abnormally extreme. "Normal weather" is a meteorological term used to describe the weather based on a location's average temperature, wind, and precipitation for the previous 30 years. Extreme and abnormally extreme storms are less clearly defined. Normal storms occur multiple times during the defined time frame. Normal storms may include thunderstorms, snow, and light accumulations of freezing rain in areas that are subject to those conditions.

Extreme storms occur less frequently within the defined time frame. These events may include severe thunderstorms, accumulations of freezing rain, and straight-line winds.

Abnormally extreme storms are unpredictable and occur infrequently. These events include tornados, hurricanes, heavy freezing rain, or other events.

The Beaufort scale is a commonly used means of categorizing wind speed on a scale of 1 to 12. Force 9 is a strong gale with a wind velocity of 47–54 mph (76–87 kph or 21–24 m/s); this is normal in many areas. Tree failures at or below this level are often associated with defects or conditions that affect a tree's strength or stability.

Force 10 is a storm wind with a velocity of 55–63 mph (88–101 kph, 25–28 m/s); in many areas these wind speeds are considered extreme.

Force 11 wind (64–72 mph, 102–116 kph, 29–32 m/s), Force 12 hurricane-force wind (>73 mph, >117 kph, >33 m/s), or higher winds are considered abnormally extreme in most geographic areas. At these wind velocities, failure of defect-free trees can be widespread.

It is important for tree risk assessors to be familiar with the weather conditions for the region in which they are assessing trees. Tree failures are often associated with forces and additional loading that are associated with weather. To help assessors calibrate, weather condition guidance is built into the definitions for the ratings of likelihood of failure.

In some locations where strong winds are rare or infrequent, the wind speed at which failures of structurally sound trees occur may be lower. For example, in some tropical areas where gale force winds are rare, trees may fail at wind speeds that would not damage most adapted temperate-zone trees. Trees adapt to their locations and to the wind speeds that commonly occur in an area. Most trees have significant additional strength to resist occasionally higher wind speeds.

When evaluating wind loads during tree risk assessment, the assessor should consider the normal range of wind and weather conditions for the region. For example, strong winds may be within the range of normal conditions, but a tornado, hurricane/typhoon, or microburst would be outside the realm of consideration. If a region is prone to strong storms or heavy snowfall and such events are likely to occur in the established time frame, the assessor should consider the likelihood for failure during such events.

Tree Failures

Trees fail when the load on them exceeds their strength. Some tree failures can be predicted because certain structural defects or conditions often lead to structural weaknesses. Arborists should recognize and assess the common conditions that can predispose trees to failure in order to categorize the likelihood of failure (see Appendix 3). Yet, through response growth (see Appendix 4), trees can strengthen weak areas and support loads, thereby reducing the likelihood of failure. A visual assessment includes looking for and considering the significance of structural conditions, individually and in combination, that may increase or decrease the likelihood for failure (Figure 6). Not all conditions and defects have a significant impact on tree structure.

When more than one defect or condition is present in a tree, the possible combined effects on likelihood for failure should be considered. For example, a trunk lean of 10 degrees may not be of great concern on many trees, but if there is a large, decayed root on the side opposite the lean, then the likelihood of failure increases if significant loads are likely to occur and the tree has not compensated for the defect with response growth.

Tree failures usually occur when there is a critical combination of tree defect(s), conditions, and contributing environmental factors such as wind, rain, freezing rain, or snow. With the exception of sudden branch drop, calm-day tree failures are very rare and usually result from extreme defects.

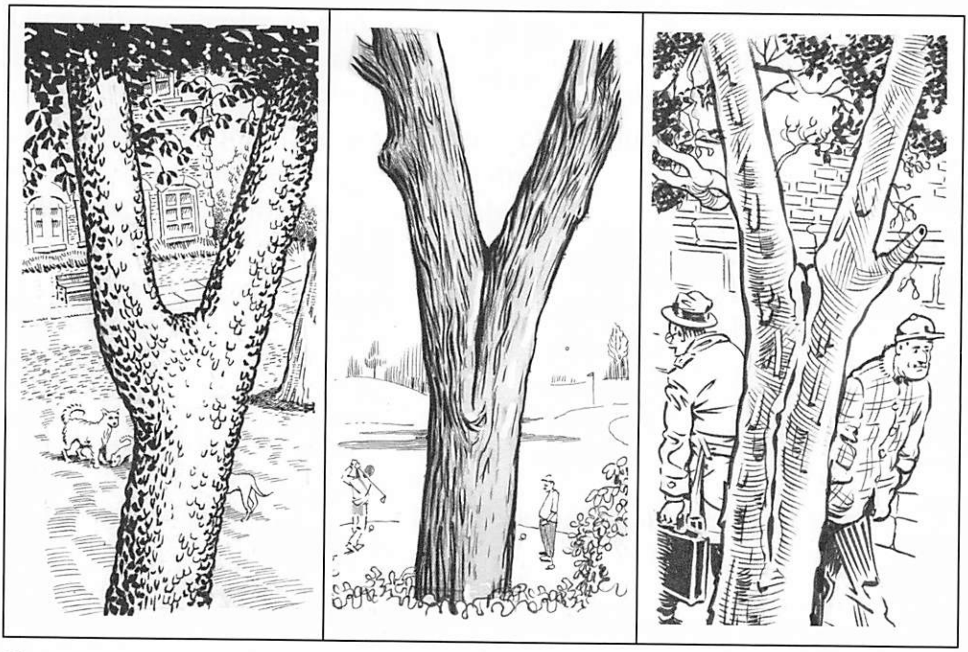


Figure 6. Likelihood of branch union failure is affected by the comparative size of the two stems, the shape of the union, and the presence of included bark and cracks. For these unions, the likelihood of failure increases from left to right.

Tree Species Failure Profiles

For many tree species and sites, there are recurring patterns of tree failure. Species failure profiles provide information on the most likely failure points in a tree species. Tree risk assessors can consider local species' failure patterns when performing tree risk assessments. Knowing the most common ways in which a species fails can aid in determining when a higher level of assessment may be needed. For example, with species that have failure patterns associated with root decay, a visual assessment may not reveal the defect; therefore, it may be appropriate, in some instances, to recommend a higher level of assessment.

Failure profiles also may aid in the identification of species that fail at a low wind speed and those that can withstand high wind speeds or other loads. For example, some species can have codominant branch failures at wind speeds as low as 35 mph (56 km/h), so failure of species with that condition is more likely than it is for most other species.

Failure profiles can be developed locally, identified using the International Tree Failure Database, or they may be derived from other sources. The tree risk assessor must keep in mind that tree failure profiles are an aid during analysis, but they do not substitute for working through the steps of the assessment process. All portions of the tree should be considered, not just those that are associated with the most common failure patterns of the species.

Protection and Multiplicative Factors

Protection factors are structures that will reduce the likelihood of impact or the consequences of tree failure. For people, common protection factors include houses or other structures, and vehicles. Trees or branches that stand between the tree being assessed and a target also may serve as protection factors. If they are strong enough they may stop the fall of another tree or branch from above.

Protection factors are considered when assessing the likelihood of impact and consequences. The assessor should determine if the protection is strong enough to stop the impact. If it is, then the likelihood of impact is reduced. If the protection is not strong enough to stop the impact, will it reduce the damage to the target? If it will, the protection factor should be taken into account when assessing consequences.

The opposite of protection factors are conditions that may increase (multiply) the target zone and likelihood of impact. If a large tree falls against another tree, the force of the impact may cause one or more sequential failures (the domino effect). This is more likely with wet or saturated soil and species prone to root or soil failures. Sequential, whole tree failure may also occur if newly exposed trees are not well adapted to the lack of shelter they have following the failure of an adjacent tree.

Tree Health vs. Structural Stability—Separate but Related

Tree risk assessors should not confuse tree health and tree stability.

High-risk trees can appear healthy in that they can have a dense, green canopy. This may occur when there is sufficient vascular transport in sapwood or adventitious rooting to maintain tree health, but inadequate strength for structural support.

On the other hand, trees in poor health may or may not be structurally stable. For example, tree decline due to certain types of root disease is likely to cause the tree to be structurally unstable, while decline due to drought or insect attack may not.

One way that tree health and structure are linked is that healthy trees are more capable of compensating for structural defects. A healthy tree can develop adaptive growth that adds strength to parts weakened by decay, cracks, and wounds.

The structural condition of a tree should be assessed even if the tree appears to be healthy.

5. Tree Risk Categorization

Tree risk assessment reports should include a rating of risk. In a qualitative tree risk assessment, assessors can use a matrix to help categorize risk. The risk category is then compared to the level of risk that is acceptable to the client, the controlling authority, or societal standards. If the risk category defined for the tree risk exceeds the level of acceptable risk, mitigation options should be presented.

When categorizing tree risk, the factors to be considered are the likelihood of a tree failure impacting a target and the consequences of the failure. The likelihood of a tree failure impacting a target is determined by considering two factors:

1. The likelihood of a tree failure occurring within a specified time frame. The likelihood of tree failure is determined by examining structural conditions, defects, response growth, and anticipated loads.
2. The likelihood of the failed tree or tree part impacting the specified target. Impact may be the tree directly striking the target, or it may be a disruption of activities due to the failure.

These two factors are evaluated and categorized using a matrix to estimate the likelihood of the combined event: a tree failure occurring and the tree impacting the specified target. The likelihood of that combined event is then compared with the expected consequences of a failure impacting the target to determine a level of risk.

Likelihood of Failure

Judgment about the significance of defects, conditions, and response growth can be guided by the information related to likelihood of failure described in Appendices 3 and 4, species failure profiles, site conditions, and tree risk assessor experience. While likelihood of failure guidelines are presented in this BMP for individual defects and conditions, the assessor should consider known compounding factors as well as any response growth in the tree, which may have compensated for the condition. Guidelines should be considered a starting point and should be modified as needed so that they are appropriate for the tree and site. Significant deviation from these guidelines or other standards that are used should be noted and in a report.

Before assessing the likelihood of failure, a time frame must be specified to put the likelihood rating in context. The time frame is the length of time, for instance the number of years, for which the assessor is deciding whether or not a specific failure is likely to occur. Without a stated time frame, the rating for likelihood of failure is meaningless. The longer the time frame, the less reliable the rating, because conditions that affect failure are prone to change over time. Time frames of one to three years are common. Time frames greater than five years are often not appropriate because the uncertainty over that period can be excessive. Long time frames can unnecessarily increase the rating for likelihood of failure, which could lead to unnecessary mitigation.

Assessments may also be conducted using several time frames. For example, an assessment can be done for the next 12 months and for the next five years. In some cases, the results will be different. Sometimes, having assessments consider more than one time frame can be helpful for the tree owner/manager in making mitigation choices. Whatever time frame is established, the time frame cannot be considered a "guarantee period" for the risk assessment.

The likelihood of failure can be categorized using the following guidelines:

Imminent–Failure has started or is most likely to occur in the near future, even if there is no significant wind or increased load. This is a rare occurrence for a risk assessor to encounter, and may require immediate action to protect people from harm. The *imminent* category overrides the stated time frame.

Probable–Failure may be expected under normal weather conditions within the specified time frame.

Possible–Failure may be expected in extreme weather conditions, but it is unlikely during normal weather conditions within the specified time frame.

Improbable–The tree or tree part is not likely to fail during normal weather conditions and may not fail in extreme weather conditions within the specified time frame.

Tree defects and conditions are typically considered individually when assessing single trees, but they can be considered in aggregate as long as the risk being assessed is clearly defined that way. For example, the likelihood of failure of a specific dead branch might be rated as *possible,* while the likelihood of failure of any one of several dead branches in a tree might be rated as *probable*. Similarly, two or more modes of failure (codominant stems, dead branch, etc.) might be rated in aggregate, although this is more complex to consider. Once again, it is essential to define the risk that is being assessed.

Likelihood of Impacting a Target

To estimate the likelihood of the failed tree impacting the target, the arborist should consider the occupancy rate of any targets within the target zone, the direction of fall, and protection factors that could affect the impact of the failed tree or tree part as it falls toward the target (Figure 7).

The likelihood of impacting a target can be categorized using the following guidelines:

High–The failed tree or tree part is likely to impact the target. This is the case when there is a constant target, with no protection factors, and the direction of fall is toward the target.

Medium–The failed tree or tree part could impact the target, but is not expected to do so. This is the case for people in a frequently used area when the direction of fall may or may not be toward the target. An example of a *medium* likelihood of impacting people could be passengers in a car traveling on an arterial street (frequent occupancy) next to the assessed tree with a large, dead branch over the street.

Low–There is a slight chance that the failed tree or tree part will impact the target. This is the case for people in an occasionally used area with no protection factors and no predictable direction of fall; a frequently used area that is partially protected; or a constant target that is well protected from the assessed tree. Examples are vehicles on an occasionally used service road next to the assessed tree, or a frequently used street that has a large tree providing protection between vehicles on the street and the assessed tree.

Very low–The chance of the failed tree or tree part impacting the specified target is remote. Likelihood of impact could be *very low* if the target is outside the anticipated target zone or if occupancy rates are rare. Another example of *very low* likelihood of impact is people in an occasionally used area with protection from being struck by the tree failure due to the presence of other trees or structures between the tree being assessed and the targets.

Targets are usually assessed on an individual basis, but they can also be combined to provide the client with a better perspective of what would happen in case of a tree failure. For example, consider a situation with a straight tree, with considerable root decay, in a courtyard surrounded on three sides by a house, a garage, and a workshop, at various distances from the tree. The house, which is only partially within the target zone, can be considered as an individual target with a *medium* likelihood of impact. Another approach is to consider all three targets in aggregate as "structures." In that case, the likelihood of impact would be *high,* since the structures surround the tree on three sides and, if the tree were to fail, it would probably impact one of the structures. This situation is a good example of the need to clearly define what risk is being rated, in this case, is risk being considered to "the house" or "structures"?

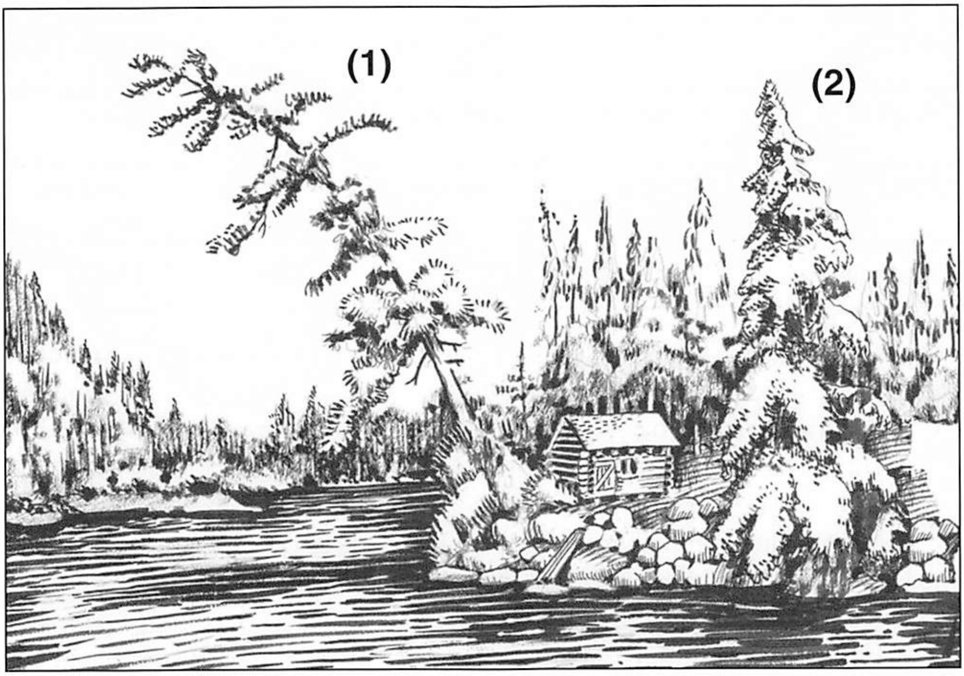


Figure 7. Likelihood of impacting a target is dependent on tree features, target zone occupancy rates, and any protection factors. Here, the likelihood of the leaning tree (1) falling on the cabin is *very low*, and the likelihood of the tree on the right (2) falling on the cabin is *medium*.

Categorizing the Likelihood of a Tree Failure Impacting a Target

After determining the likelihood of failure and the likelihood of impacting a target, the combined likelihood of a failure impacting a target can be categorized. Matrix 1 is used to relate these likelihood factors within a given time period. The resulting terms *(unlikely, somewhat likely, likely,* and *very likely)* are defined by their use within the matrix and are used to represent this combination of occurrences in Matrix 2, the risk rating matrix, which will be introduced later.

An example of determining the likelihood of a failure impacting a target is as follows: A tree with a large, dead branch is growing next to a one-story house. The dead branch is on the side of the tree away from the house. The likelihood of a dead branch failure within the next year was classified by a tree risk asses-

Matrix 1. The likelihood matrix used to estimate the likelihood of a tree failure impacting a specified target.

Likelihood of Failure	Likelihood of Impact			
	Very Low	Low	Medium	High
Imminent	Unlikely	Somewhat likely	Likely	Very likely
Probable	Unlikely	Unlikely	Somewhat likely	Likely
Possible	Unlikely	Unlikely	Unlikely	Somewhat likely
Improbable	Unlikely	Unlikely	Unlikely	Unlikely

sor as *probable.* The house is a static target with a constant occupancy rate. However, the likelihood of the branch falling from the opposite side of the tree through the rest of the tree to the house is *very low.* This results in a likelihood of impacting the house rating of *unlikely.*

On the other hand, there is a car parking area located directly under the branch and there are no lower branches that would mitigate the fall of the branch. A car is parked under the tree for 14 to 16 hours per day, and the driver is present for a few minutes each day as she walks between the house and the car. Thus, the human occupancy rate in the target zone is rare and the occupancy rate for a car in the parking area is frequent. There are no factors that would affect the fall of the branch on this side of the tree, so the rare human occupancy rate translates to a *very low* likelihood of impacting the driver. When that is combined with a *probable* failure likelihood, the combination results in the likelihood of a failure impacting the driver as *unlikely.*

The occupancy rate for a car in the parking area is frequent, making the likelihood of striking it *high*. Combining the *high* likelihood of impact with the *probable* likelihood failure of the branch, the likelihood of failure and impact for the car becomes *likely.* As illustrated in this example, it is not unusual to have multiple targets with different values and occupancy rates. The most important risk targets should be considered when conducting a risk assessment, and the risk(s) being rated should be defined.

Categorizing Consequences of Failure

The consequences of a tree failing and impacting a target are a function of the value of the target and the amount of injury, damage, or disruption (harm) that could be caused by the impact of the failure. The amount of damage depends on the part size, fall characteristics, fall distance, and any factors that may protect the target from harm.

It is often said that without a target, a tree poses no risk, but that may not mean that the failure has no consequences because trees have value. If a tree fails, the value and benefits associated with that tree are lost or diminished. Therefore, there are always some consequences associated with failure.

When evaluating consequences, consider the size of the tree or tree part that could fail, and how it could impact a target. Generally, a small branch has less potential to cause damage than a large branch. Small branch failures occur more frequently, and even a small branch could cause personal injury, a power outage, or a traffic accident (Figure 8). Branches less than 1 inch (2.5 cm) in diameter usually are not considered in most tree risk assessments. The minimum size branch that should be considered by the tree risk assessor may be specified in the scope of work. In some situations, the minimum branch diameter of concern may be as large as 4 inches (10 cm) in diameter. For example, if a 4-inch (10 cm) diameter branch falls on a house from a height of 10 feet (3 m) above the roof, the degree of damage would be low, and no injury to people inside would be expected. If the same size branch were to fall from near the top of a large tree with no branches in between to slow it down, more extensive damage could occur.

In estimating how much damage could occur from a tree failure, consider the relative amount of force with which it is likely to strike the target. A falling tree or branch will gain speed as it accelerates toward the ground. So, in general, the higher the distance from which a branch falls, or the greater the distance from the tree to the target, the greater the force that the tree or branch will have at the point of impact. If the distance from a tree trunk to a well-built, multi-story house is short, a tree that fails may simply lean against the house, causing minor damage. On the other hand, if the distance is such that the tree can accelerate significantly before the trunk strikes the house, damage may be much greater. If there are lower branches in the tree that are likely to slow or stop the fall of the trunk, damage may be lessened. In this example, the lower branches serve to protect the target. Large-diameter, wide-growing branches that are low on the trunk also may affect the fall pattern of a tree. If the branches contact the ground well before the trunk, the fall may be slowed or stopped, or the tree may roll.

Protection may be provided by structures that surround the people in the target zone. If the protection factor is not strong enough to stop the impact, then the assessor should judge whether it will reduce the consequences.

Buildings that are substantial provide protection to people inside them so this factor is considered in the likelihood of impact.

Vehicles provide some protection against small-diameter falling branches. People in vehicles struck by a medium-sized branch may be injured but are usually not killed, so the level of consequences is reduced by the structure of the vehicles.

Trees can also cause accidents if they fall across a motorway in front of moving traffic. Because of this, when evaluating targets near roads and parking lots, consideration should be given to traffic flow, speed, street configuration, and occupancy rates.

Consequences of failures can be categorized using the following guidelines:

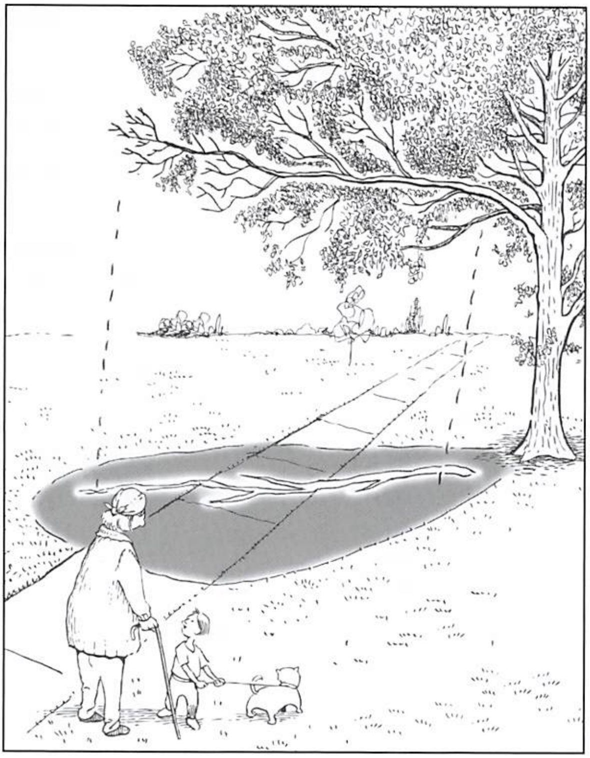


Figure 8. A medium-sized branch can cause *significant* or *severe* consequences to the people it strikes.

Severe consequences are those that could involve serious personal injury or death, high-value property damage, or major disruption of important activities. Examples of severe consequences include:

- Injury to one or more people that may result in hospitalization or death
- Destruction of a vehicle of extremely high value > 30,000
- Major damage to or destruction of a house
- Serious disruption of high-voltage distribution circuits or transmission power lines

Significant consequences are those that involve substantial personal injury, property damage of moderate to high value, or considerable disruption of activities. Examples of significant consequences include:

- Injury to a person requiring medical care
- Serious damage to a vehicle

- High monetary damage to a structure >$ 10000 < 30,000
- Disruption of distribution primary voltage power lines
- Disruption of arterial traffic that causes an extended blockage and/or rerouting of traffic

Minor consequences are those that involve minor personal injury, low- to moderate-value property damage, or small disruption of activities. Examples of minor consequences include:

- Minor injury to a person, typically not requiring professional medical care
- Damage to a landscape deck
- Moderate monetary damage to a structure or vehicle $ 1000-10000
- Short-term disruption of power on secondary lines, street lights, and individual services
- Temporary disruption of traffic on a secondary road

Negligible consequences are those that do not result in personal injury, involve low-value property damage, or disruptions that can be replaced or repaired. Examples of negligible consequences include:

- Striking a person, causing no more than a bruise or scratch
- Damage to a lawn or landscape bed
- Minor damage to a structure, requiring inexpensive repair
- Disruption of power to landscape lighting
- Disruption of traffic on a neighborhood street

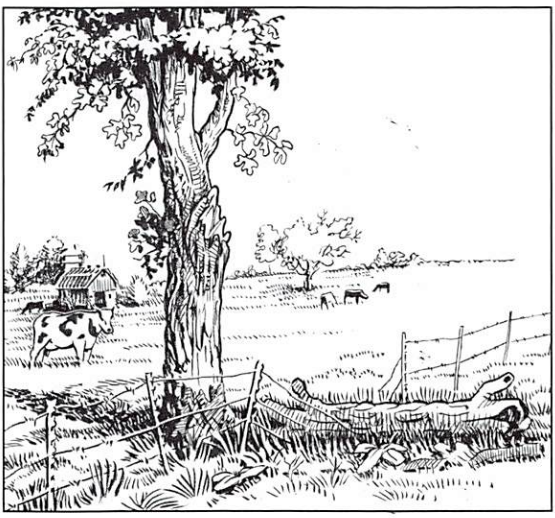


Figure 9. Categorization of the consequences of tree failure is based on the value of the target and the amount of harm that may be done to it. Here, the primary consequences of the failure are considered *negligible*.

Continuing the example from the prior section, the consequences of a medium-sized dead branch striking a house would be *minor*, the consequences of that branch striking an unoccupied car could be *significant,* and the consequences of impacting a person would be *severe* (Figure 10). These consequences are combined with the likelihood of failure and impact to determine the risk rating.

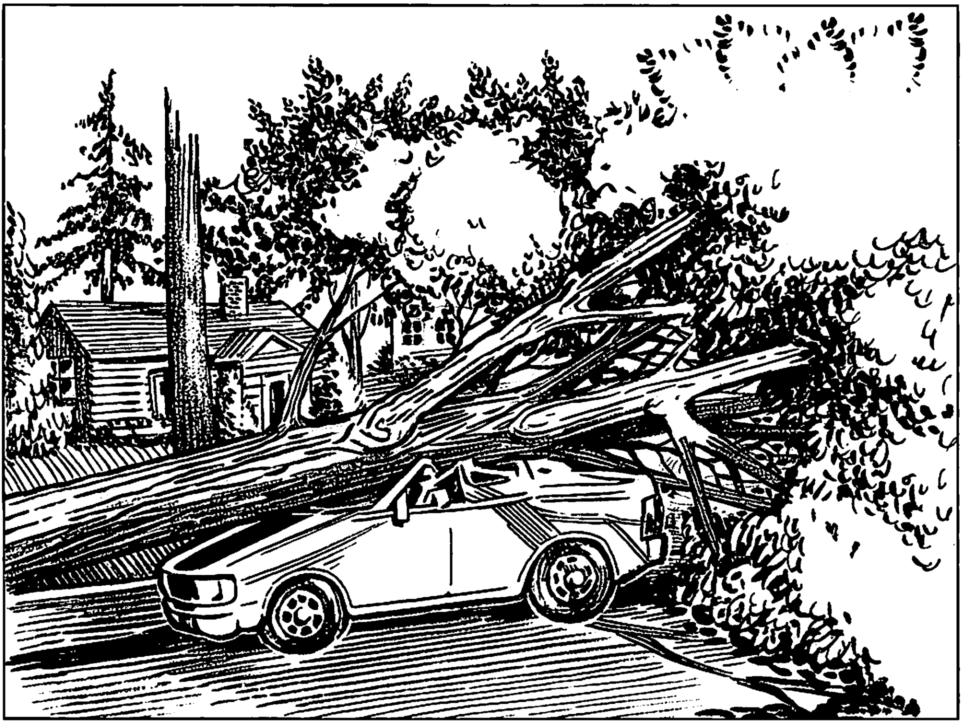


Figure 10. The consequences of a tree falling on an unoccupied parked car are considered *significant.* If the car were occupied, the consequences would be considered *severe.*

Tree Risk Rating

A risk rating matrix (Matrix 2) is a means of combining ratings of likelihood and consequence factors to determine a level or rating of risk. The matrix approach was selected for use in this guide because of its broad acceptance, ease of use, and effective application for rating tree risk. This matrix was designed specifically for the evaluation of risk posed by tree failures. The limitations associated with using a matrix include the inherent subjectivity and uncertainty associated with the selection of both the likelihood and consequence factors, and the lack of comparability to other types of risk assessed using other means.

In the tree risk assessment matrix, four terms are used to define levels of risk: *extreme, high, moderate,* and *low.* These risk ratings are used to communicate the level of risk and to assist in making recommendations to the owner or risk manager for mitigation and inspection frequency. The priority for action depends upon the risk rating and the risk tolerance of the owner or manager.

Extreme–The extreme-risk category applies in situations in which failure is *imminent*, there is a *high* likelihood of impacting the target, and the consequences of the failure are *severe*. The tree risk assessor should recommend that mitigation measures be taken as soon as possible. In some cases, this may mean restricting access to the target zone area to avoid injury to people.

High–High-risk situations are those for which consequences are *significant* and likelihood is *very likely* or *likely,* or consequences are *severe* and likelihood is *likely*. This combination of likelihood and consequences indicates that the tree risk assessor should recommend that mitigation measures be undertaken. The decision for mitigation and timing of treatment depends upon the risk tolerance of the tree owner or risk manager. In populations of trees, the priority of high-risk trees is second only to extreme-risk trees.

Moderate–Moderate-risk situations are those for which consequences are *minor* and likelihood is *very likely* or *likely;* or likelihood is *somewhat likely* and consequences are *significant* or *severe*. The tree risk assessor should recommend mitigation. The decision for mitigation and timing of treatment depends upon the risk tolerance of the tree owner or manager. In populations of trees, moderate-risk trees represent a lower priority than high- or extreme-risk trees.

Low–The low-risk category applies when consequences are *negligible* and likelihood is *unlikely;* or consequences are *minor* and likelihood is *somewhat likely*. Some trees with this level of risk may benefit from mitigation or maintenance measures, but immediate action is not usually required. Tree risk assessors may recommend retaining and monitoring these trees or mitigating the risk. Although the risk is already in the lowest category, the actual risk may still be reduced, if desired.

Most trees have more than one failure mode (location or manner in which failure is likely to occur) and may have multiple potential targets. For example, a tree with excessive root decay may also have several dead branches; the whole tree could fail from root decay, and dead branches may fail. Similarly, the whole tree may fall on a house, while the dead branches would fall only on the driveway. When evaluating individual trees, it is appropriate to evaluate each failure mode/target combination as an independent event and to report its risk, recommended mitigation options, and residual risks. The assessment report should state what specific risk each rating applies to.

Steps in Developing a Tree Risk Rating

1. Identify possible targets, including those identified by the client.
2. Identify tree part(s) and/or failure mode(s)—that is, the location or manner in which failure could occur.
3. Assess and categorize likelihood of failure for each part of concern within a specified time frame.
   (Imminent / Probable / Possible / Improbable)
4. Assess and categorize likelihood of tree/part impacting target.
   (High / Medium / Low / Very low)
5. For each failure mode/target combination, categorize the likelihood of failure and impact (Matrix 1).
   (Very likely / Likely / Somewhat likely / Unlikely)
6. For each failure mode/target, assess consequences.
   (Severe / Significant / Minor / Negligible)
7. For each failure mode/target, categorize the risk (Matrix 2).
   (Extreme / High / Moderate / Low)

Risk aggregation is the consideration of multiple risks in combination; it is difficult to do even with complex mathematical analyses. Therefore, the tree risk assessor *cannot* simply add or multiply the risk ratings for the individual failure modes to reach a whole-tree risk rating.

What the tree risk assessor *can* do is identify—among all the failure mode/target combinations assessed—the failure mode/target combination having the greatest risk, and report that as the tree risk rating. Assigning a tree risk rating for a tree may be useful, especially when prioritizing mitigation of risk for a population of trees. For example, in a given situation, whole-tree failure may be *unlikely,* but it could have *significant* consequences if it occurs; using Matrix 2, the risk rating is *low.* At the same time, failure of a dead branch may be *very likely,* but with *minor* consequences; the risk rating is *moderate.* The risk rating would be reported as *moderate,* the higher of the two ratings. This rating often is presented as the single risk level for the tree, especially when dealing with populations of trees and limited visual assessments. It is important to note, however, that if measures are taken to mitigate the highest risk, there still is residual risk associated with that tree, including the remaining risk factors. The risk rating for that tree may or may not change based upon the remaining risk factors.

Matrix 2. Risk rating matrix showing the level of risk as the combination of likelihood of a tree or tree part failing and impacting a specified target, and severity of the associated consequences.

Likelihood of Failure & Impact	Consequences of Failure			
	Negligible	Minor	Significant	Severe
Very likely	Low	Moderate	High	Extreme
Likely	Low	Moderate	High	High
Somewhat likely	Low	Low	Moderate	Moderate
Unlikely	Low	Low	Low	Low

Risk Perception and Acceptable Risk

How people perceive risk and their need for personal safety is inherently subjective; therefore, risk tolerance and action thresholds vary among tree owners/managers. What is within the tolerance of one person may be unacceptable to another. It is impossible to maintain trees completely free of risk—some level of risk must be accepted to experience the benefits that trees provide.

Acceptable risk is the degree of risk that is within the owner/manager's or controlling authority's tolerance, or that which is below a defined threshold. Some countries have a framework directive, which defines thresholds of risk tolerance and acceptability. Municipalities, utilities, and property managers may have a risk management plan that defines the level of acceptable risk. Safety may not be the only criterion used by the risk manager to establish acceptable levels of risk; budget, a tree's historical or environmental significance, aesthetics, and other factors also may come into the decision-making process. Tree risk assessors may also assess risk within a population of trees and use that information to prioritize remedial action.

For extreme-risk trees, the tree risk assessor should notify the owner/manager as soon as possible and, in some cases, recommend or implement immediate restriction of access to the target zone to avoid injury. For lower levels of risk, however, some discussion is usually required to understand the client's risk tolerance and to determine appropriate mitigation treatments. In considering risk and mitigation measures, tree risk assessors should communicate the benefits of trees as well as the consequences of losing them.

People often use the terms "hazard" or "hazardous" when discussing risk assessments. A hazard tree (hazardous tree) is a tree identified as a likely source of harm. Hazardous trees are those that have been assessed and have been determined to pose an unacceptable risk. A *hazard* is the tree part(s) identified as a likely source of harm. Arborists should take care in their choice of words to avoid unintended meanings, which could, in some cases, have serious implications if a case ends up in court. Arborists are cautioned against declaring a tree to be "safe" or suggesting that trees can be made "safe." Trees are living organisms that sometimes fail unexpectedly despite reasonable efforts to responsibly maintain them. Tree risk assessors can only recommend measures to reduce, not eliminate, the risk of unanticipated structural failure.

6. Risk Mitigation: Preventive and Remedial Actions

Mitigation is the process of reducing risk. Measures to mitigate risk can be arboricultural, to reduce the likelihood of failure or the likelihood of impact; or they can be target-based, to reduce the likelihood of impact or consequences of failure.

Tree risk assessors should resist the ultimate security of risk elimination based on tree removal and consider possibilities for retaining trees when practical. Trees offer many benefits, so removal should be considered as a last option to reduce or eliminate risk. In many cases, there are other options available to reduce risk to an acceptable level. These options include the following:

Target management. Movable targets within the target zone may be temporarily or permanently relocated (Figure 11). Mobile targets, such as pedestrian or vehicular traffic, can be rerouted or restricted from using the space within the target zone. These often are the solutions that will have the lowest impact on the tree and are therefore preferred if tree preservation is a primary management goal.

Figure 11. Target management. With movable targets, one option for risk mitigation is to relocate the target to outside of the target zone. Note, however, that the public might move targets into the target zone, unaware of the risk.

Pruning. Dead, dying, and weakly attached branches can be pruned in accordance with the applicable national pruning standards or ISA's *Best Management Practices: Tree Pruning*. Wind resistance can be reduced with reduction pruning and, to some extent, thinning. Topping is not recommended due to the long-term problems with weak sprouts and the entry of wood decay fungi. Crown raising can eliminate lower branches that could be interfering with structures, pedestrian or vehicle traffic, signs, or safe views. Excessive raising, however, can reduce taper development, change sway patterns, and limit the tree's ability to damp the effect of dynamic wind loading.

Installing structural support systems. Structural support systems can be installed to limit movement of certain tree parts. Various types of hardware are used, depending upon the goals. Examples include:

- Cables (flexible braces) installed in the upper crown to limit the movement of weak unions or codominant stems.
- Brace rods (rigid braces) installed close to or through weak unions, or through split sections.
- Guys installed to improve anchorage and stabilize lean.
- Props installed to support some leaning trees and low branches from below.

Adding lightning protection for susceptible trees in significant- and severe-consequence locations.

Modifying the site to improve conditions for the tree (for example, to provide drainage to reduce failure associated with wet soil). Increasing tree vitality can allow time for the tree's response growth to mitigate risk of failure.

Using a tree growth regulator (TGR) in conjunction with pruning may extend the reduction in wind resistance or clearance from utilities and structures for several years.

Use of tree growth regulators and modification of the site to improve conditions should be considered long-term mitigation measures. While they can be effective in reducing long-term risk, they should not be implemented to achieve immediate risk reduction.

In some low-use locations, dead and decaying trees may be retained for wildlife habitat or other uses. Selection of suitable wildlife habitat trees must consider the tree's risk, as well as its value for wildlife. One management strategy is to ensure that wildlife habitat trees are maintained at a height shorter than the distance to the nearest target.

Over-mature trees in natural settings may reconfigure as they age and deteriorate, a process sometimes called “natural retrenchment.” They may continue to grow trunk diameter while branches die and fail—reducing overall height of the tree and increasing stability. Where tree risk is a concern, tree risk assessors can imitate this process by recommending crown reduction. Eventually, however, even tall stumps without branches will fail when the roots decay. For this reason, trees near targets that are retained for wildlife habitats should be monitored and considered for removal or mitigation if the risk exceeds allowable thresholds.

Mitigation may involve more than one action. The tree risk rating based on the highest risk factor assigns an overall tree risk, but typically there are other factors that also should be considered, which may require additional actions if the tree is to be retained. Once the highest risk factor has been mitigated, the tree risk rating goes to the next highest risk factor.

With some extreme-risk trees, mitigation may involve the immediate restriction of use within the target zone before removing the tree. Tree removal may require using a crane or an aerial lift because additional loads on the tree—from the weight of a climber or from lowering branches—may cause the tree to fail. However, on some occasions, tree removal is not necessary, even for high-risk trees. Removing the target, pruning, or installing a support system may significantly reduce the risk posed by the tree to a level that is acceptable to the client.

Mitigation

Guidelines for tree risk mitigation:

- Extreme-risk trees should be mitigated as soon as possible. Immediate action may be required to restrict access to the target zone.
- High-risk trees should be mitigated as soon as it is practical.
- Moderate-risk situations may not require mitigation but, if deemed necessary, could be mitigated when budget, work schedule, or pruning cycle allows. If the risk is acceptable to the client, the tree(s) could be retained and monitored.
- Low-risk trees should be retained and monitored (if appropriate) or mitigated, if desired, when the budget, work schedule, or pruning cycle allows.

Work Prioritization

With a single, privately owned tree, there is little need for the prioritization of work. The owner will decide what action to take and schedule the work. The exception is with extreme-risk trees, where the tree risk inspector should recommend that the work take place as soon as possible and the target zone may need to be restricted immediately.

With populations of trees, such as in municipal or utility applications, work may need to be scheduled well in advance. The risk assessment can be used to establish the work priority to mitigate the highest risk situations first. If a tree with an extreme risk is discovered, the owner/manager should be notified promptly, and action should be taken as needed. In the rare event that failure is in progress, immediate action may be needed to restrict access to the target zone and notify the client. Trees with lower levels of risk can be scheduled on an appropriate maintenance cycle.

Clearly it makes sense to mitigate high-risk trees before moderate-risk trees. Judgment should be exercised in prioritizing mitigation within groups of trees rated at the same level of risk. Factors to be considered include: location, targets, tree or part size, and the logistics of mitigation.

Residual Risk

Residual risk is the risk remaining after mitigation. Following any mitigation action, there is a residual risk posed by that tree. With tree removal, that residual risk is brought to near zero; however, even stumps can pose a tripping risk. The level of residual risk needs to be acceptable to the risk manager/owner. Some countries follow the principle of "as low as reasonably practicable" (ALARP). To meet this principle, one must demonstrate that the cost involved in further reduction of risk would be grossly disproportionate to the benefit gained. ALARP is sometimes applied in situations where large populations of trees are being managed.

In general, if the residual risk following mitigation would exceed the tolerance of the client, the specified treatment might not be the best course of action. As previously noted, however, tree removal should not be recommended without due consideration of the benefits that would be lost.

While the highest risk factor is often the focus of remedial action, the tree risk assessor may recommend mitigating options for each condition evaluated, and estimate the residual risk following those actions. The level of residual risk should be part of a complete report so that an informed decision can be made regarding the mitigation options.

Inspection Frequency and Timing

Timing of the initial risk assessment and frequency of future assessments is often not at the discretion of the tree risk assessor. However, after a tree has undergone the initial assessment, an inspection frequency should be recommended based upon the level of risk/residual risk and the goals of the client. The time between assessments is known as the inspection interval. It is best to reassess trees on a regular, recurring basis because site and tree conditions change over time.

The inspection interval typically ranges between one and five years, but inspections may be more or less often, depending upon the age of the tree, level of risk, specific conditions, client goals and resources, or regulations. For example, a low-risk tree may be assigned an inspection interval of three to five years, or perhaps more. For a high-risk tree, an inspection period of several months to one year may be recommended. Generally, it is a good idea to inspect trees with known structural weaknesses and high-value targets after major storms or other exceptional events on the site (such as forest clearing, trenching, or other construction work) to identify damage or changes in condition that may have occurred.

The time between tree risk assessments conducted by or on behalf of municipalities, utilities, and other entities that manage large populations of trees is often defined by risk managers acting on behalf of those agencies or their controlling authority. Public agencies, utilities, and large property managers may identify zones of similar tree population, site usage, and facility type. The inspection interval for each zone is then specified. Zones of higher priority should be inspected more frequently than zones with lower priority.

Scheduling assessments in a specific season can aid the assessment. For instance, the crowns of deciduous trees are more easily assessed for failure likelihood in the winter than when in full leaf in the summer, because the branch structure and unions are more easily seen. If a particular decay fungus produces annual fruiting bodies (conks, brackets, or mushrooms) at specific times of year but the structures subsequently degrade or disappear, identification of that decay will be easier if the inspection is scheduled to correspond with emergence of the fruiting bodies. Staggered inspection intervals, such as every 8 or 16 months, will allow the tree risk assessor to see the trees in different seasons. For the utility arborist, assessments can be combined with periodic line clearance pruning operations or conducted as separate activities. Commercial arborists may include assessments as a part of a plant health care program. Municipal arborists may include inspections as a component of cyclic pruning programs, or as part of routine citizen response inspections.

7. Risk Reporting

After conducting a tree risk assessment, the information, conclusions, and recommendations must be communicated to the owner/manager, client, designated person, or agency. The preferred method is to prepare a detailed written report, since this protects both tree risk assessor and client from misunderstandings.

In some instances, however, the report also may be verbal (oral) or videographic. The tree risk assessor may want to supplement oral reports with a brief e-mailed or written confirmation to the client. The risk assessor and the client can keep copies for future reference.

A work proposal or work order with a recommendation for risk mitigation also may be considered a form of a risk assessment report. The tree risk assessor should maintain copies of all risk assessment reports.

The following items should be included in a detailed written report or other accompanying documentation:

1. Name of the tree risk assessor and the date of assessment.
2. Description of the scope of work.
3. Location and/or identification of the tree(s) assessed.
4. Level of inspection (limited visual, basic, or advanced) and details of the method (for example, "Basic assessment, using a mallet and a probe").
5. Targets, occupancy rates, likelihood of impacting the target, and potential consequences of failure.
6. Site factors that were considered (history of failure or storm patterns).
7. Documentation of the likelihood of failure, such as a list of tree conditions, structural defects, and response growth that were observed; measurements of defects (size and shape) may be included.
8. Risk rating, including information on specific failure mode/target combinations, and conclusion.
9. Options and/or recommendations for mitigation (for example, "Move target, prune, or remove the tree").
10. Residual risk information.

11. Recommendations for reassessment (interval, level, and type).
12. Limitations of the assessment.

For populations of trees, the report also may suggest priorities for mitigation. That information, plus any additional information, can be included in a multi-year, large-area management plan, if that is required by the scope of work.

Limitations of Tree Risk Assessment

Limitations of tree risk assessment arise from uncertainties related to trees and the loads to which they are subjected. The scientific study of tree failure is relatively young; there is still much to learn. As an example, there are advanced techniques for determining wood condition, but specific wind speeds and/or wind direction that will cause a specific tree to fail are unknown.

Tree risk assessors perform assessments with limited information about the structural condition of the tree itself and the environment that affects it. For instance, root decay may be present but not visible at the time of the assessment. Similarly, abnormally extreme winds that create loads greater than the tree can bear are not always predictable. Experience, training, and education influence how the tree risk assessor sees the situation and analyzes it to form an opinion about what is likely to occur in the future.

Tree risk assessors should include the limitations of their assessments in their risk assessment report, including the limitations of the methodology used, and any limitations related to the ability to access or assess the tree, site, or potential targets.

Some of the limitations that are common to risk assessment reports include:

- Tree risk assessment is limited in scope to the specific risk(s) of interest, not any and all risks.
- Tree risk assessment considers significant known and/or assigned targets and visible or detectable tree conditions.
- Tree risk assessments represent the condition of the tree at the time of inspection.
- Not all defects are detectable and not all failures are predictable.
- The time period for risk categorization should not be considered a "guarantee period" for the risk assessment.
- Only those trees specified in the scope of work were assessed, and assessments were performed within the limitations specified.

Appendix I

Tree-Related Conflicts That Can Be a Source of Risk

Conflicts result when trees interfere with people, property, or activities. Conflicts can result in personal injury, death, property damage, or disruption of activities. Common tree-related conflicts are described.

- **Allergies.** Some trees produce materials that can cause allergic reactions in people. These materials include flowers, pollen, sap, fruit, nuts, scents, or trichomes (hairs) from leaves.
- **Electric utilities.** Trees growing next to or under high-voltage electric facilities have been known to cause power outages when contact is made. Touching a tree that is energized represents an indirect contact with the power lines, and in some cases, may result in injury. Similarly, large trees may grow close enough to power lines that anyone climbing the tree could come into direct contact with them.
- **Fire.** Tree leaves, bark, and wood are flammable under certain conditions. In dry climates, consideration must be given to the size, species, and location of trees that are growing close to structures and electrical utilities. Tree failures impacting electric lines can create an elevated risk of wildfire. In nearly all climates, certain mulches, such as pine needles, are flammable.

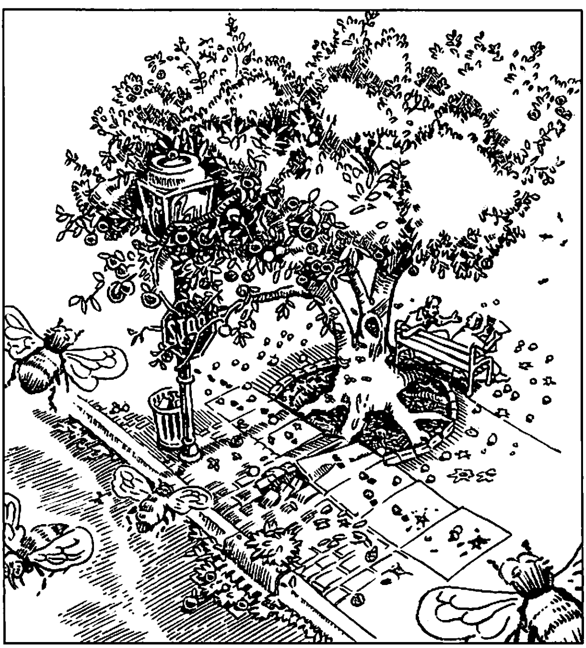


Figure A1-1. Conflicts result when trees interfere with people, property, or activities and may result in harm. In this case, conflicts include attraction of stinging insects, falling and fallen fruit, pavement lifting, interfering with street lighting, and blocking visibility of the stop sign.

- **Fruit.** Trees with female flowers produce seeds, but only a few species produce nuisance fruit and cones. Fruit can produce a slippery or unstable walking surface that may result in pedestrian falls. Large cones from some pines, and fruit from some palms, fruit trees, and some tropical species are known to cause damage when fruit falls onto pedestrians or vehicles.

- **Insects and other animals.** Trees often serve as nesting habitat for a variety of animals. When disturbed, some may bite or sting, causing minor to severe injuries.
- **Lightning.** Lightning strikes trees because of their height and conductivity. Strikes can result in serious damage to the tree. Large splinters of wood may be thrown when the tree is struck. Even strikes that do not cause extensive tree damage can side flash to people, animals, structures, and underground utilities, and may result in injury, death, damage, or fire.
- **Low branches as obstructions.** Low branches can cause damage to vehicles or harm to pedestrians, especially at night. Many municipalities have regulations that define the minimum vertical clearance allowed over streets and sidewalks.
- **Obstruction of traffic control signs, signals, and views.** When tree branches obstruct traffic control signs and stoplights, vehicles may fail to stop or yield to opposing traffic. The same is true with obstructed views. If branches obstruct the view of traffic at intersections, driveways, or railroad crossings, drivers may not see oncoming traffic or pedestrians.
- **Pavement lifting.** As tree roots grow in diameter, they can lift concrete and heave asphalt pavement and pavers, which can result in an uneven surface. The maximum allowable amount of pavement displacement is regulated in some communities and in some countries.
- **Road-edge trees.** Out-of-control vehicles might crash into trees that are near the edge of a road, resulting in personal injury or property damage. Trees close to the road edge may limit drivers' ability to see large animals, such as deer or moose that cross regularly. The distance from the edge of the road to a tree is regulated in some areas. In general, the higher the speed limit, the greater the required "clear zone" (the distance between the road edge and trees).
- **Root damage to infrastructure.** Roots can penetrate cracked or leaking pipes, causing the disruption of flow. Roots can also grow around and break pipes, causing leakage and the potential for explosion if gas lines are broken.

- **Thorns.** While trees with thorns can be placed appropriately to exclude people, there are places where they are inappropriate. These locations may include playgrounds, elementary schools, sidewalks, and other places where unwitting individuals may contact them.

Conflict	Common Management Strategy
Allergies	Species selection, flower treatments
Electrical utilities	Pruning, growth regulation, engineering solutions, removal
Fire	Species selection, vegetation management, mulch selection, pruning, removal
Fruit	Species selection, flower treatments, growth regulators
Insects and nesting animals	Pest management, restriction of cavity openings, nest relocation
Lightning	Lightning protection system
Low branches over streets or walkways	Crown raise to height that provides clearance or is specified by government authority; reroute traffic to avoid contact with tree
Obstructed signs and views	Pruning, raising, growth regulation, vegetation management, sign relocation
Pavement lifting	Species selection, planting location, root barriers, pavement modifications, root pruning, soil modification
Road-edge trees	Species selection, vegetation management, guard rails, speed limits
Root damage to pipes or other underground utilities	Design underground utilities to avoid root damage; inspect pipes as needed and replace when intrusion is excessive
Thorns	Species selection, thorn removal, pruning, removal

Appendix 2

Loads on Trees

When evaluating tree risk, the tree risk assessor needs to assess the effects of expected loads on the likelihood of failure. "Load" is a generic term describing the result of various forces acting on a structure. The two natural forces that exert loads on trees are gravity and wind. Gravity acts as a constant pull on the mass of the tree, generating static load from self-weight and the weight of water (condensation, rain, snow, or ice) on leaves and branches.

Energy from wind exerts a dynamic (changing) force on leaves and branches from friction and pressure. Wind forces within the canopy vary because wind energy is transferred to the leaves and branches as the wind moves through the crown, causing branches to bend and twist. In addition, there may be loads from climbers, rigging operations, epiphytes, or other sources. These forces all result in stresses and strains in the tree structure.

Bending moments are generated by lateral forces acting on a lever arm. Their magnitude depends on the amount of force and the length of the lever arm. The center of wind load can only be estimated because of the varying nature of wind and the tree crown. The lever arm length is often approximated as the height of the center of the crown.

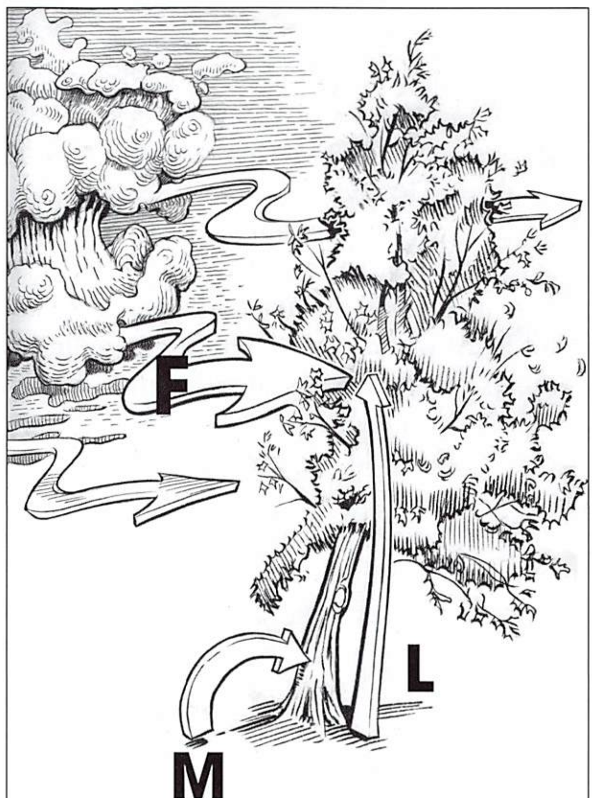


Figure A2-1. Wind affects the entire tree crown but is often calculated as the force (F) at a single point acting at the center of pressure. The bending moment (M) of the tree is calculated by multiplying the resultant force by the distance from the ground (L) to the center of pressure.

Bending Moment (M) = Force (F) × Lever Arm Length (L)

The most common wind-related lateral force on a tree is called "drag." Because wind force varies with the square of the velocity of the wind, a small increase in wind speed can result in a large increase in drag force. Wind speed changes with height above ground, so taller trees and trees at higher altitudes are subject to higher winds.

Drag is also dependent on the wind-intercepting surfaces (frontal area and volume of crown facing the wind); wind resistance (drag coefficient) of the tree; and the density of the air. Wind-intercepting surfaces and drag coefficient of the tree change with wind velocity due to the streamlining and reconfiguration of leaves, twigs, and branches. The degree of streamlining differs among tree species and with individual trees. Within a range of wind speeds, the higher the wind speed, the more streamlining.

Wind energy needs to be either dissipated within the tree or transferred into the roots and soil. At low wind velocities, leaf and twig movement dissipates most of the wind energy. As wind speed increases, progressively larger branches move. When wind forces are large enough to bend the trunk, a greater amount of energy is transferred to the soil via the root system.

Dynamic movement also affects the loads. Gusts and turbulences generate loads on the tree at different frequencies and intensities, causing a complex dynamic reaction. Wind moves branches in different directions in a seemingly uncoordinated fashion. This movement acts to dissipate wind energy and slow the movement of larger branches in a process called "mass damping," which results in reductions in trunk loading and oscillation. Branches and twigs with different diameters and lengths add to damping by moving at different speeds with different loads. If a tree lacks interior or lower branches, there is less damping within the crown, so more force is transferred to the trunk. This can lead to a higher stress in the branches, branch attachments, trunk, or roots.

When trees are close to other trees or structures, or have a normal branch development within the crown, energy can be transferred or dissipated when branches collide. Trees also may lose leaves, twigs, and branches in high winds, which further dissipates energy and reduces wind resistance by providing a smaller frontal area. Branch loss also may adversely reduce the amount of damping and branch collisions that occur.

Loads on a tree lead to internal stresses. Stress is a force exerted over an area, mathematically defined using the formula:

Stress = Force/Area

There are four basic stresses within a tree:

Compression is squeezing a material.

Tension is stretching or pulling a material, the opposite of compression.

Shear stress occurs when components of a material attempt to slide relative to one another.

Torsion is a type of shear stress caused by a twisting force.

Stresses can occur alone or in combination. When gravity acting on a branch pulls or bends it downward, the bending moment creates tension in the top of the branch (fibers are stretched) while the bottom of the branch is under compression (fibers are pushed together). In the middle of the branch, the "neutral plane" experiences shear stress, where the fibers in tension and those in compression meet and try to slide in opposite directions. Bending, therefore, involves at least three stresses: compression, tension, and shear, and may also have a torsional component.

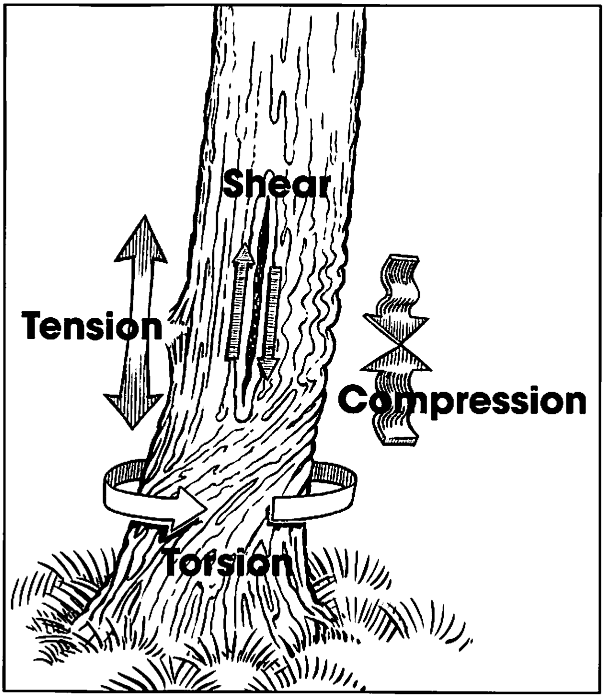


Figure A2-2. The four basic stresses within a tree are compression, tension, shear, and torsion.

Torsional stress occurs when a branch, trunk, or root twists, leading to maximum stress near the perimeter. Trees with asymmetrical crowns may experience an uneven wind load, resulting in higher levels of torsion.

The stress formula shows that stress increases either when there is an increase in load or when there is a decrease in cross-sectional area. Cross-sectional area can be decreased by cuts or injuries to the trunk or by internal loss of wood or wood strength, such as from fungal decay. Stress also may be increased locally at a sharp angle bend, a notch cut or canker, or other conditions collectively referred to as "stress raisers." Under load, stress raisers may act as failure initiation points—the point where breakage starts.

Stress is also a function of tree height or branch length. A taller tree that has the same trunk diameter as a shorter tree has higher stress in the lower trunk, if all other conditions are equal. The actual stress is also dependent upon the trunk cross-sectional size and shape, crown configuration, and wind exposure.

Strength is defined as the ability to withstand stress without failure. Strength is a species-specific property of wood as a material, and of the tree as a structure. Breaking stress is the magnitude of stress sufficient to cause failure. In general, the wood of temperate tree species is about twice as strong in tension as in compression. In all species, for a failure to occur, the stress on the trunk, branch, root system, or associated soil must exceed the strength of that part.

Conifers are stronger under compression

Appendix 3

Structural Defects and Conditions That Affect the Likelihood of Failure

Certain structural defects or conditions are more likely to lead to failure than others. Individual defects or conditions may or may not, in and of themselves, indicate a serious structural problem; but in combination, and under additional loads, they may contribute to failure. On the other hand, through response growth (see Appendix 4), trees can strengthen weak areas and support loads, thereby reducing the likelihood of failure. A visual assessment includes looking for and determining the significance of each of the structural conditions, individually and in combination, that increase and decrease the likelihood of failure.

Some guidelines for classifying the likelihood of failure based on certain defects and conditions are presented in this appendix. For the sake of comparison, the time frame has been standardized at three years. The assessor should be mindful that these are general guidelines and are highly dependent

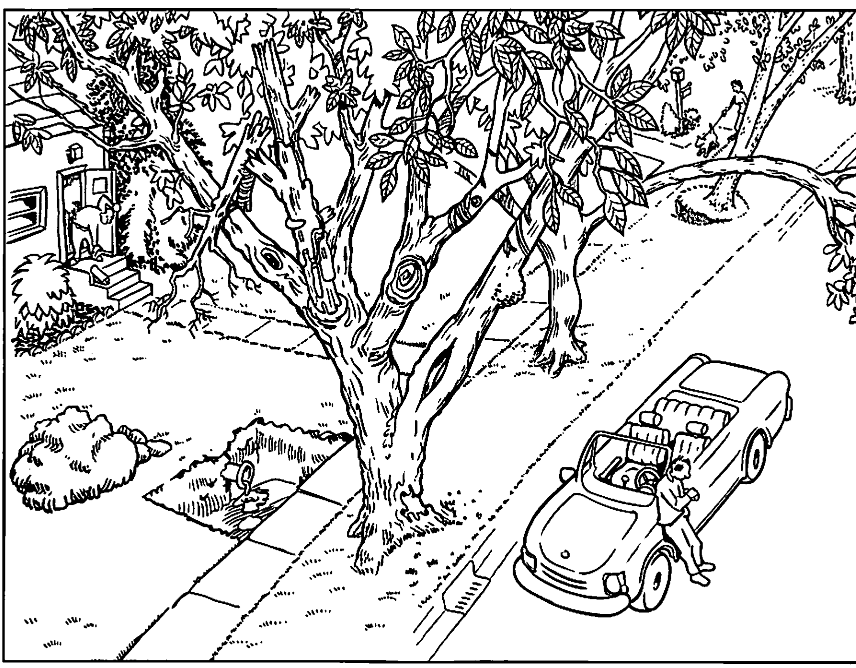


Figure A3-1. Tree risk assessors need to look for defects or conditions that indicate a potential problem. Numerous conditions can be seen here, including: a broken, hanging branch; a dead branch; a cracked branch; cavity openings; root plate lifting; an over-extended branch; a weak branch union; and severed roots.

on tree species, loads, response growth, the time frame being considered, and other factors. The main structural defects and conditions that should be assessed are discussed here.

Dead or Dying Parts

When a target is present, dead trees are an obvious concern, as are dead or dying branches and roots. However, some species hold dead branches for many years, so familiarity with tree species and local climate is important. Signs and symptoms of dead trunks or branches are a lack of leaf growth; dead, loose, or missing bark; missing buds; and broken or blunt branch tips. The larger the size of the dead part and the higher it is above the target, the greater the concern. Dead or loose bark often can be detected by sounding the trunk. Dead branches vary in their likelihood of failure from *possible* to *imminent,* depending upon the species, branch weight, the type and extent of decay, infestation by wood-consuming insects, and the length of time the branch has been dead.

Dead roots can be much more difficult to identify, but they can cause significant loss of stability. The decay rate of dead roots is dependent upon tree and fungal species, climate, soil type, and tree health. Some species' roots deteriorate very quickly (within one year), while in other species, dead roots may provide structural support for a decade. If the root decay profile of a species is known, it should be considered when retaining trees for wildlife habitat.

Broken or Hanging Branches

Broken branches are branches that have experienced a structural failure. They may remain partially attached at the point of breakage, or they may have completely detached and started to fall. Branches that are broken and lodged in the crown of the tree are called "hangers" or "lodged branches." The likelihood that the branch will continue its fall depends upon how it is being held and if the branch is decaying. The failure likelihood of most hangers is considered *probable* or *imminent.*

Cracks

Cracks are separations in the wood in either a longitudinal (radial, in the plane of ray cells) or transverse (across the stem) direction. Longitudinal branch cracks (also called shear plane cracks or neutral plane failures) most commonly occur when branches are overloaded by freezing rain or snow.

Potential for failure can be classified based on tree species, loads, response growth, site conditions, the time frame being considered, and other factors. Terminology used for categorization of the likelihood of failure is as follows:

Imminent–Failure has started or is most likely to occur in the near future, even if there is no significant wind or increased load. This is a rare occurence for a risk assessor to encounter, and may require immediate action to protect people from harm.

Probable–Failure may be expected under normal weather conditions within the specified time frame.

Possible–Failure may be expected in extreme weather conditions, but it is unlikely during normal weather conditions within the specified time frame.

Improbable–The tree or tree part is not likely to fail during normal weather conditions and may not fail in extreme weather conditions within the specified time frame.

Keep in mind that likelihood of failure must have a time frame specified to have meaning. The imminent category overrides the stated time frame.

Cracks also occur when stems are torsionally stressed or are below codominant unions that are splitting apart. Because internal decay may weaken a stem, longitudinal cracks may be associated with the presence of decay. Trunks or branches with cracks that extend completely through the stem or branch have partially failed and are at risk of complete failure. Transverse cracks indicate that the fibers in the wood have pulled apart or buckled. They occur when wood is under excessive tension or compressive forces. Cracks are a sign of localized failure and may indicate that tree or branch failure ranges from *possible* to *imminent,* depending upon loading forces and tree response.

Response growth may compensate for cracks. Internal cracks may be indicated by seams and ribs where wood has been added at the edges. Where a shear plane crack extends through a branch, response growth might occur in the form of compression, tension, or woundwood. Likelihood of failure should be adjusted to account for response growth.

Growth cracks that form in the outer bark during periods of rapid trunk growth, such as in early or midsummer, or during the rainy season in tropical regions, are not considered structural defects.

- **Seams** are lines formed where two edges of bark meet at a crack or wound. The likelihood of failure at a seam is generally considered *improbable* to *possible* if there is solid wood behind the seam. Sometimes, however, the seam covers decay or old cracks. Depending upon the extent of decay, exposure to loads, and weight distribution, failure at seams may be considered *possible* to *probable*.

- **Ribs** are longitudinal bulges of response growth that can indicate an internal crack or decay. Ribs that contain active cracks should be evaluated similarly to other cracks. Ribs that cover closed cracks should be evaluated similarly to seams.

Weakly Attached Branches and Codominant Stems

Certain branch arrangement and attachment configurations are associated with higher rates of failure, including: codominant branches, included bark, shape of branch union, adventitious branches, multiple branches originating at one point, a tree's history of branch failure, and sudden branch drop.

- **Nearly equal size stems or branches (codominant).** Typically, strong branch attachments develop when the size of the branch is less than one-half the diameter of the parent stem. When the diameter of the branch and parent stem is similar, the attachment may be weaker. Stem orientation, weight distribution, and branch configuration will affect stress at the union, making failure more or less likely.
- **Included bark.** Bark that is embedded between a branch and its parent stem, or between codominant stems, decreases the strength of the attachment. The likelihood of failure of branches with included bark is largely dependent on the stress experienced by the branch from wind, ice, snow, or other loads. For many species, failure of codominant stems with included bark may be considered *possible* to *probable*. If there is significant decay in or near the union, the likelihood of failure can be *probable* or *imminent,* depending upon loads and weight distribution. Presence of response wood at the union may reduce the likelihood of failure. The presence of associated cracks may indicate an increased likelihood of failure.
- **Shape of branch union.** The shape of the union provides additional information about union strength. Stems that divide in a gentle U-shape tend to be stronger than those with a sharper V-shape. Likelihood of failure of a codominant stem with a V-shape is often considered *possible* to *probable*. Failure of U-shaped unions is *improbable* to *possible*. In some tropical species [e.g., *Pterocarpus indicus* (Angsana)], the presence of adventitious roots at the union may indicate a crack and should be investigated further.

- **Adventitious branches.** Strong branch attachments form when branch and trunk wood develop together over time. Adventitious branches—such as epicormic shoots or watersprouts, which often are produced after storm-related branch breakage, lion-tail pruning, or topping—are weaker because less holding wood has formed. If these branches are attached near a cut or broken branch end, decay developing from the opening may reduce the strength of the attachment over time. If decay is not present, likelihood of failure in these branches should be considered *possible.* If decay is present, the likelihood of failure may be considered *probable,* depending upon load and weight distribution. If significant new holding wood has developed, the likelihood of failure may be reduced to *possible* or *improbable.*
- **Multiple branches originating at one point.** When several branches originate from the same place on the stem, the branches tend to be more weakly attached than single branches of the same size. There is not enough space for holding wood to develop around each branch when multiple branches arise at one level. For some species that tend to fail at this point, the likelihood of branch failure should be considered *possible* to *probable,* depending upon load, weight distribution, and shape of branch union. If decay is also present near the point of multiple branch attachments, likelihood of failure is increased.
- **History of branch failure.** Trees that have experienced branch failure in the past may be more likely to experience branch failure in the future. The tree risk assessor should look for patterns of weak branch attachments, decay, decline, poor weight distribution, or other defects associated with previous failures. Failure of additional, similarly constructed branches is *possible* to *probable.*
- **Sudden branch drop (SBD).** Sudden branch drop is not well understood. In some climates, tree genera such as *Acer, Ailanthus, Albizia (Paraserianthes), Andira, Delonix, Eucalyptus, Fraxinus, Khaya, Liquidambar, Pinus, Populus, Pterocarpus, Quercus,* and *Ulmus* are known to drop branches unexpectedly in calm conditions and in high temperatures. Because failure occurs without additional load, the material properties must change or cracks must propagate for the wood to fail. These property changes are most likely related to changes in wood hydration. Formation of cracks may be related to temperature changes and drying of wood. Failures typically occur

ability to compensate for strength loss by increasing diameter growth is severely limited. The likelihood of failure depends on the amount and location of sapwood that is missing, the amount and type of internal decay, tree size, lean, weight distribution, and exposure to loads.

Tree Architecture

Tree growth and branching characteristics can affect how a tree moves in the wind, how the load of the crown is distributed, and the tree's stability. Problems with other structural defects become more significant when tree architectural abnormalities are present. Tree architectural characteristics to consider include the following:

- **Lean** is the angle of the trunk measured from vertical. For most trees, lean develops as the tree grows away from neighboring trees or structures, toward light. Trees that lean may be stable for long periods of time. However, leaning trees can be less stable than vertical trees because weight is unequally distributed over the trunk and root system. Trees with uncorrected leans and leaning trees on slopes with saturated or unstable soils are often less stable than straight trees or those with corrected leans.

  Trees may also lean because of a partial failure of the lower stem or roots, or soil conditions that allow excessive root movement. Trees that increase in lean over a short time period are of concern and should be examined promptly. Lifting of the soil on the side of the tree opposite the direction of lean, or a depression on the side of the lean, may indicate that the roots or soil are failing. Lean angle can be determined using several means, including interpretation of photographs or use of a digital level. The residual stability of a leaning tree may be determined by load tests. The likelihood of failure of a recently leaning tree is often *probable* to *imminent.*

- **Corrected leans (sweeps)** are characterized by a leaning lower trunk and a top that is more upright. Trees may develop this form when growing at the edge of a group. Such trees are stable under normal conditions, but may be less stable than straight trees under additional loads. A sweep also may develop when a tree leans due to partial failure and reaction wood growth has turned the crown upright. The likelihood of failure increases as the lower trunk angle and crown weight increase. Trees with corrected leans are often considered to have a likelihood of failure from *improbable* to *possible.*

- **Bows** are leans characterized by the top of the tree bending over more than the lower trunk, creating a curve. Trees may develop this form when growing at the edge of a group or next to structures. Such trees are stable under normal conditions, but are less stable than straight trees under additional loads.

  Bows also may occur under snow or ice loading or during high winds. Some trees never recover from or respond to this type of damage. Bowed trees also should be examined for longitudinal cracks. The likelihood of bowed tree failure may be *possible* to *probable* if it has not increased the stem diameter by compensation growth. If cracks are present, the likelihood of failure may be *probable* to *imminent* if the tree is subjected to loads from wind, snow, or freezing rain.

Figure A3-2. The pattern of tree lean can affect the likelihood of failure. Illustrated here from left to right are a straight lean, a bow, and a corrected lean or sweep.

- **One-sided or unbalanced crowns.** Ideally, branches are evenly distributed vertically and horizontally around the trunk. Trees with even branch distribution tend to distribute the loads evenly along the trunk, reducing the likelihood of trunk and root failure as compared to trees with uneven branch distribution. A tree may have most of its branches on one side if it is growing close to another tree or structure, has uneven crown dieback, is damaged by a storm, or has been pruned in that manner. In most cases, trees develop response wood to support the asymmetric crown. Asymmetric crowns can, however, contribute to failure when other problems are present, such as compromised root anchorage.

- **Live crown ratio.** The ratio of the vertical extent (height) of the live crown to the height of the entire tree is the live crown ratio (LCR). LCR is affected by growing conditions, pruning history, previous branch failures, or natural branch shedding. Low LCR most commonly develops naturally where trees are growing in dense stands, but it can also be created by crown raising. Low LCR can be a condition of concern, especially if the tree originally developed in forest conditions and was recently exposed to higher wind conditions. Ideally, the LCR should be greater than 65%—that is, the upper 65% of the tree has live branches. When ratios are less than 50%, there may be reason for concern when other structural defects are present. In some species, an LCR less than 33% may indicate a higher likelihood of failure. For some tropical tree genera with extremely hard wood (e.g., *Casuarina* spp.), a low LCR may not necessarily be a cause for concern.
- **Taper (slenderness).** Taper is the change in diameter over the length of trunks, branches, and roots. Taper is important for even distribution of mechanical stress. The degree of taper can be calculated by dividing tree height or branch length by the trunk or branch diameter (H/D). The same units are used for both height and diameter (feet or meters). Accurate measurements are essential when determining both height or length and diameter because minor errors can have a major impact on the ratio. When H/D is large (that is, the tree is very slender for its height), the tree may be more prone to failure than when the tree has moderate or high taper with a small H/D ratio. Reported critical H/D values vary from 50:1 to 90:1. Because of the size of this range, H/D ratio is rarely used by itself to classify likelihood of failure.

  The amount of stem taper is often related to LCR. Lower LCRs are associated with less taper. As with LCR, trees that were originally grown in forest conditions, and recently exposed to more wind because of the removal of adjacent trees, are of greatest concern. Taper concerns do not apply to palms or to trees in an undisturbed forested area where individual trees are surrounded by other trees and are therefore protected from falling and the effects of wind.

- **Overextended branches** are those that extend outside the normal crown area. Branches outside of the normal crown may experience higher loads during high winds, freezing rain, or snow storms, and are more likely to fail in these conditions. Horizontal branches tend to be stronger than those growing at an upward angle, when all other conditions are equal.

Root Problems

When roots are severed, decayed, broken, undermined, or restricted, they may provide less anchorage. Other root-related problems, including buried buttress roots and stem-girdling roots, can affect root decay or response growth, which, in turn, affects tree stability. In addition to structural problems with roots, some soils allow excessive movement of structurally strong roots, especially when saturated, which also can affect stability.

Root problems are often difficult to detect. Soil and site conditions around the tree can sometimes provide information on changes that have damaged the root system or affected soil strength. Symptoms to look for include the following:

- **Dead, decayed, or missing roots** can be identified by a cavity in the root collar, a canker that extends to the soil line, or a visibly pruned or broken root stub. Likelihood of failure increases with the number of roots that have been cut and with the number of decayed roots, and can be decreased by the presence of response growth.
- **Fungal fruiting structures** attached to roots or the root collar area are definite indicators of root decay. Root decay assessment is an advanced assessment technique that may be recommended or conducted when definite indicators of decay are present.
- **Dead or detached bark** indicates that the cambium is dead, and it is likely that the wood beneath is damaged, decayed, or dysfunctional. If bark is easily removed, the sapwood should be examined for the presence of fungal mycelium, fans, and rhizomorphs, all of which are definite indicators of decay.
- **Abnormal root flares or fused buttress roots.** Larger than normal flare at the base of the tree and fusing together of buttress roots may indicate that root decay is present. Both of these conditions are response growth that may indicate the presence of defects, but they also add strength to resist bending and aid stability.

- **Buried root collar.** For most tree species, if the buttress roots are not visible, then there is soil against the trunk of the tree. Soil against the trunk may accelerate sapwood or heartwood decay.
- **Basal decay.** Decay in the base of the tree may indicate root decay, because most fungi that decay the butt or base of the tree start as root decay fungi.
- **Stem girdling.** When there is a root, strap, chain, rope, rock, concrete, or other material tightly against the lower trunk or buttress roots, growth and response growth can be severely limited. This can lead to both health and stability problems.

Visual indicators of root/soil defects that may indicate reduced stability

- Dead or missing roots
- Fungal fruiting structures
- Lack of root flare
- Stem-girdling roots
- Dead or loose bark
- Wounded roots
- Root cuts
- Soil mounding or cracking
- Crown dieback or decline
- Restricted root space
- Soil erosion
- Excessive soil moisture
- Adventitious roots
- Termite nests/mounds at tree base

Visual indicators of compensation

- Wide root flare
- Fused buttress roots

- **Wounded roots.** The upper surface of roots tends to compartmentalize well when damaged by lawn mowers or trimmers. However, decay may develop in these wounds if the damage is recurring or severe, or if the tree declines in vitality.
- **Oozing** from the lower trunk and buttress roots may be associated with a root disease. Root disease may impact tree health, such as from *Phytophthora* infection, or may affect stability, as with an extensive *Armillaria* infection.
- **Adventitious roots** develop when the trunk is buried or there is a loss in root function. They can serve as an indicator of and as compensation for root problems.

Tree and site conditions that can indicate the potential for root-related structural problems:

- **Crown dieback, thinning, or decline.** Root decay can restrict the movement of water and nutrients into the crown, which can lead to crown dieback, thinning, or decline. This may take years to become apparent after root damage.
- **Evidence of trenching, grade changes, compaction, or other root or soil disturbance** may be seen as depressed lines on the soil surface, sharp drop-offs, or other changes in levels; areas that lack vegetation; or mounds of soil. New pavement or foundation near a tree can also indicate that roots have been damaged.
- **Soil mounding or cracking** is associated with a leaning trunk and may indicate that the roots are lifting the soil. Dry soil may also have cracks that are unrelated to tree movement.
- **Restricted soil space.** If rooting area is restricted by structures, soil compaction, impermeable soil layers, excessive soil water, or a high water table, the root system may not develop well enough to adequately anchor the tree.
- **Excessive soil moisture.** If the soil is frequently saturated due to flooding, high water table, or other conditions, soil cohesion and shear strength may be reduced, resulting in a loss of the anchoring ability of the roots. A change in soil hydrology from site preparation work can also affect soil moisture levels.
- **Soil erosion.** Loss of soil due to wind or water flow can reduce root contact with the soil and compromise the effect of reaction wood development.

Appendix 4

Response (Adaptive) Growth

Response growth is new wood produced in response to damage or loads, which compensates for higher strain (deformation) in marginal fibers; it includes reaction wood (compression and tension), flexure wood, and woundwood. The amount of new wood that a tree produces depends upon species, health, energy reserves, and available resources (such as water, light, and nutrients). Distribution of new wood is determined in large part by mechanical stress, but it is also governed by physiological and morphological conditions. The newest layer of wood experiences the greatest torsional, compressive, and tension stress. As a consequence, new wood cells' compression or extension under bending loads is greater than the deformation experienced by other cells. The repeated deformation of cambium cells influences the number and orientation of new wood cells and their material properties.

Reaction wood is wood produced in response to gravity in leaning trunks and branches. Compression and tension wood are the two types of reaction wood that are anatomically unique and act mechanically to compensate for stem lean or subsidence of branches. Compression wood, which is common in conifers, exerts compressive forces on the lower side of a stem or branch. Tension wood, which is common in hardwoods, exerts tension forces on the upper side of a stem or branch; however, some hardwoods also may produce compression wood.

Figure A4-1. One type of reaction wood that forms in response to a crack or mechanical stress can be seen as a rib; in this case the rib is formed in response to a crack.

Some response growth occurs in areas of the tree that are affected by movement caused by changing loads. Sometimes termed "flexure wood," it is formed in stems and branches in response to wind loading. It is anatomically similar in some respects to tension wood.

The development of trunk taper and buttress roots are examples of load-responsive (flexure) growth. On stems or branches, bulges or enlarged areas may develop to compensate for higher load or loss of structural strength from internal decay or other weakness. Near a crack, obvious response growth may appear as spiraling or straight ribs.

Woundwood is produced in response to cambial damage. Woundwood is typically denser than and chemically different from other wood, and it resists decay better than normal wood. Its development also reinforces the strength of wounded areas. If a wound or cavity is not readily closed due to the size of the opening or other factors, woundwood may enlarge or curl inward at the edge of the cavity (a feature commonly called a "ram's horn"), adding strength to the opening. The rate of woundwood development is partially dependent upon tree health and species characteristics.

Trees develop more wood or stronger wood in some areas than is needed to support the tree under normal load conditions—an internal safety factor. The magnitude of the safety factor can vary significantly in different parts of the tree and as a tree ages. This overdevelopment helps to support the tree under extraordinary loads of strong winds, snow, or ice.

Tree risk assessors should look for and assess the significance of response growth when evaluating the likelihood of failure. Areas of increased growth should be interpreted as indications of the tree's response to a structural weakness, stimulus, or repeated movement. Health and vigor of the tree are important factors in predicting the tree's capability to compensate for strength loss due to defects.

When response growth is recognized, the tree risk assessor should try to determine its

Properties that show the potential for or presence of response growth

- Crown healthy, vigorous, good color, good growth, and few pests
- Bark healthy and intact
- Woundwood well developed around cuts, cracks, and openings
- Local increases in wood growth, such as ribs and bulges, near a structural defect
- Enlargement in diameter in areas weakened by internal decay
- Distinct demarcations between healthy and damaged tissue
- Well-developed, wide root flare
- Corrected trunk lean

cause and evaluate its effect on the likelihood of failure. Trees can adapt to weaknesses and stand for many decades if sufficient structural compensation occurs.

Strong response growth indicators imply that the tree has substantial stored energy reserves and is working well to maintain biological health and mechanical stability. Poor response growth may suggest that the tree is biologically weak and is unable to fend off decay or resist increased load. It could also indicate that the decay is recent or is insignificant. Health and vigor of the tree are important factors in predicting the tree's ability to compensate for increased mechanical stress due to decay or increased wind load. Currently, however, there are few guidelines for evaluating the effectiveness of response growth in compensation for structural weaknesses.

Figure A4-2. The swelling around this cavity opening started as woundwood. It provides additional strength to compensate for wood lost to decay.

Appendix 5

Description of Selected Types of Advanced Tree Risk Assessments

Advanced assessments are performed to provide detailed information about specific tree parts, defects, targets, or site conditions. Many techniques can be considered for advanced risk assessment. A few commonly used assessment methods are described here.

Aerial Inspection

Aerial inspection (crown inspection) is the inspection of the aboveground parts of a tree not visible from a ground-based inspection, including the upper trunk and the upper surfaces of stems and branches. Aerial inspections usually include a visual assessment for defects, conditions, and response growth. Conditions of particular importance include inspection of significant branch unions, cracks in branches, sunscald on the tops of branches, and bark damage from bird or animal feeding. In addition, aerial inspections may include evaluation of internal decay.

Aerial inspection can be done from an aerial lift, adjacent building, ladder, unmanned aerial vehicle, or by climbing the tree; however, the tree risk assessor should determine that the tree is safe to climb before entering the tree. Visual inspection from the ground using binoculars is not considered an advanced assessment, but it may be part of a basic assessment.

Assessment of Internal Decay

It is difficult to estimate or quantify the location and extent of internal wood decay during most basic assessments. When necessary to more accurately determine the location and extent of decay, it can be estimated with one of several decay-detecting techniques, including drilling and the use of sonic devices.

After estimates are made of the location and amount of solid wood present around a column of internal decay, several methods are available to evaluate the significance of the decay. Some methods are based upon engineering models of pipe strength and recommended thresholds for minimum solid wall thickness. Modifications for species, location and amount of decay, dimensions of the tree, additional defects, and site conditions should be made by adapting the thresholds, but there is little guidance for such adaptations. Other methods adapt mechanical principles or engineering models in order to compare expected wind loads with the estimated load-bearing capacity of the tree.

These models have limitations because they are based upon certain assumptions that may not coincide with actual tree conditions. For example, trees may differ from common models for strength loss due to decay when tree trunks are not circular in cross section, or when they have included bark, nonlinear fibers, or off-center decay. Wood in trees also does not have uniform strength throughout; some areas may be stronger and some weaker.

While high precision can be achieved during measurements, assumptions required to complete any evaluation carry an inherent possibility of error, which could be cumulative in the calculations. Nevertheless, mathematical models and calculations can be useful in some advanced tree risk assessments.

Several decay-detection devices are on the market, but not all have been demonstrated (through independent research) to be effective tools, and there may be differences in precision, resolution, and reliability. Two well-established technologies are described.

Drilling. Two types of drilling tools can be used to evaluate the extent of decay: a handheld electric drill and a resistance-recording drill. Both distinguish between solid and decayed wood by the resistance to penetration as the drill moves through the wood.

It is important to carefully select testing locations so that the size and configuration of the decay column can be estimated. Before testing, sounding or visual assessment should be used to determine the best locations to test. The tree risk assessor should conduct sufficient testing to visualize the approximate extent of the decayed area. However, the tree risk assessor should take care to avoid unnecessary or excessive wounding. Tree risk assessors should also consider that drilling into decay can breach CODIT walls (especially wall 4), which may allow decay to spread. The number of drillings should be as few as possible but as many as needed.

One type of drilling device is a handheld electric drill fitted with a long (8 to 18 inches, 20 to 45 cm), small-diameter (1/8 inch, 3 mm), full-fluted drill bit. Evaluation is primarily limited to the advanced stages of decay. Accuracy relies in large part on the experience and expertise of the operator.

A resistance-recording drill drives a small-diameter (1/8 inch, 3 mm) flat-tipped spade bit into the tree. As the bit penetrates the wood, the resistance to penetration is recorded. With training and experience, an inspector can distinguish solid wood from voids and decay. Incipient decay, effectiveness of compartmentalization, and response growth rates may be estimated from profiles created by some high-resolution resistance drills.

Sonic Assessment. Sonic wood assessment instruments send a sound (stress) wave through the wood and measure the time for the wave to travel from the sending point to the receiving point. If a crack, cavity, or decay is present, the sound travels around the defect, increasing the transmission time (time of travel) from the sending point to the receiving point, as compared to the transmission time through wood with no defect. The device, however, cannot distinguish the *type* of defect (decay, cracks, embedded bark, or cavities) that increased the transmission time.

Measuring the transmission time between two points can be a quick test to reveal the presence of cracks or decay between the two points. However, conducting only one test may miss even major defects; tests at additional points are needed to provide a comprehensive inspection. Thus, two sets of points, forming perpendicular lines, are considered the minimum by many operators in order to detect large, centrally located defects. In addition, reference values are needed for any measurement.

Sonic tomography instruments use measurements between many points to create a two- or three-dimensional picture (tomogram). By comparing the results of all time-of-travel measurements, it is possible to detect and map defects within the trunk. The tomogram illustrates the remaining load-carrying parts of the inspected cross section. The resolution of tomography is directly related to the number of sensors used on a tree. In contrast to drilling, sonic devices have substantially less risk of breaching CODIT wall 4.

Root Assessment

Root Inspection and Evaluation. The extent of damage or decay in tree butts, buttresses, and roots is difficult to evaluate in a basic inspection because most roots are beneath the soil surface and root architecture is not visible. Several types of evaluations can be conducted on roots to inspect for decay. The simplest is the visual assessment of buttress roots at the basal flares, or when the top surfaces of the roots are exposed. When not exposed, the tree risk assessor would first need to excavate soil or other materials covering the root collar to conduct the assessment. This process is called root collar excavation (RCX). At a minimum, the RCX should reveal the top of the buttress roots to the point where the root is nearly horizontal, or follow roots a distance equal to or greater than the trunk diameter. Depending upon the goal of the assessment, the excavation may need to continue further out along the root. The least injurious method of excavation available should be used. This may involve the use of high-pressure air or water. If necessary, hand tools can be used. Care must be taken not to damage the roots or trunk during the excavation process. After excavation, roots can be inspected for evidence of cutting, injury, decay, response growth, or other conditions.

Root Decay Evaluation. When evaluating root decay, the tree risk assessor should consider that decay in roots typically progresses from the bottom of the root upward. Drilling and sonic techniques can help determine the number of roots with decay and the extent of root decay within each root, but they are not designed to quantify the amount of strength loss in the root system. Tree risk assessors should also consider that drilling into decay in roots can also breach CODIT wall 4, which may allow compartmentalized decay to spread. The number of drillings should be as few as possible but as many as needed.

Measuring Change of Lean

A changing angle of lean indicates a higher likelihood of failure. Sometimes it is difficult to determine if a tree's lean is changing. A digital level or other device can be used to monitor small changes in lean angle. When trunk angle measurements are made over time, it is important that they be taken at the same location each time. However, digital level readings taken during the dormant season cannot be directly compared with readings taken when the tree has foliage. The same is true during times of drought, rain, snow, or ice glazing.

Load Tests

Load tests are used by specially trained tree risk assessors to assist in evaluating the potential for failure. There are several types of load tests: hand pull test, measured static pull test, and measured dynamic test. Load tests do not attempt to detect internal decay, but use deformation or deflection to detect weakness in the structure and assess the load required to initiate the failure process.

A hand pull test involves installing a line in the tree, and then pulling and releasing the line several times to move the tree or branch. When testing root and trunk stability, the line is placed high in the crown. When the line is pulled, trunk and root plate movement is observed. Excessive trunk, root, or soil movement may indicate instability. Branches also may be tested in this fashion: the line is run over the branch and pulled, and the tree risk assessor looks for movement and crack openings. This technique is most commonly used in a pre-climbing inspection. Because the tree or branch reaction is monitored only visually, tree risk assessors are cautioned against overloading the tree or tree part and initiating failure. The tree risk assessor should be outside the target zone when conducting this type of test.

In a **static pull test**, sensors are attached to the tree to measure marginal fiber strain (stretching and compressing) in the stem or branches, and/or inclination (change in angle) of the root flare in response to a controlled pull. The amount of deformation and inclination, measured by sensors, is compared to reference values to evaluate strength or stability. Working within specific thresholds for tolerable deformations is required to avoid overloading of the tree during the load test. The sensor readings after unloading should confirm that the tree has returned to its original position.

Dynamic load tests take place under natural wind conditions or with static pulls, and are used to measure the movement of an individual tree. Sensors are placed on the trunk and/or near the base to measure fiber strain and/or inclination of the root plate.

Glossary

acceptable risk–the degree of risk that is within the tolerance or threshold of the owner, manager, or controlling authority.

advanced assessment (Level 3)–an assessment performed to provide detailed information about specific tree parts, defects, targets, or site conditions. Specialized equipment, data collection and analysis, and expertise are usually required.

aerial inspection–inspection of parts of a tree not visible from the ground, including the trunk, stems, and branches; aerial inspections may include evaluation of internal decay.

aerial patrol–overflights of a utility right-of-way, large areas, or individual trees to record the location of trees that are likely to fail and cause harm.

basic assessment (Level 2)–detailed visual inspection of a tree and surrounding site that may include the use of simple tools. It requires that a tree risk assessor inspect completely around the tree trunk looking at the visible aboveground roots, trunk, branches, and site.

bending moment–a turning, bending, or twisting force exerted by a lever, defined as the force (acting perpendicular to the lever) multiplied by the length of the lever.

client–the person or organization for whom professional services are rendered. Usually, the owner or manager responsible for the trees.

CODIT–acronym for Compartmentalization of Decay in Trees (see *compartmentalization*).

compartmentalization–natural defense process in trees by which chemical and physical boundaries are created that act to limit the spread of disease and decay organisms (see *CODIT*).

consequences–effects or outcome of an event. In tree risk assessment, consequences include personal injury, property damage, or disruption of activities due to the event.

cracks–separation in wood fibers.

decay–process of degradation by microorganisms.

defect–an imperfection, weakness, or lack of something necessary. In trees, defects are injuries, growth patterns, decay, or other conditions that reduce the tree's structural strength.

drive-by assessment–limited visual inspection from only one side of the tree, performed from a slow-moving vehicle; also may be called a windshield assessment.

event–occurrence of a particular set of circumstances. In tree risk assessment, a tree or tree part falling and impacting a target.

failure (tree failure)–breakage of stems, branches, roots, or loss of mechanical support in the root system.

failure mode–location or manner in which failure could occur or has occurred; for example, stem failure, root failure, or soil failure.

harm–personal injury or death, property damage, or disruption of activities.

hazard–situation or condition that is likely to lead to a loss, personal injury, property damage, or disruption of activities; a likely source of harm. In relation to trees, a hazard is the tree part(s) identified as a likely source of harm.

hazard tree (hazardous tree)–a tree identified as a likely source of harm.

impact (*verb*)–striking a target or causing a disruption that affects activities.

inspection frequency–the number of inspections per given unit of time (for example, once every three years).

inspection interval–time between inspections.

lean–predominant angle of the trunk.

lever arm–the distance between the applied force (or center of force) and the point where the object will bend or rotate.

likelihood–the chance of an event occurring. In the context of tree failure, the term may be used to specify: 1) the chance of a tree failure occurring; 2) the chance of impacting a specified target; and 3) the combination of the likelihood of a tree failing and the likelihood of impacting a specified target.

likelihood of failure–the chance of a tree failure occurring within the specified time frame.

likelihood of failure and impact–the chance of a tree failure occurring and impacting a target within the specified time frame.

likelihood of impact–the chance of a tree failure impacting a target during the specified time frame.

limited visual assessment (Level 1)–a visual assessment from a specified perspective such as a foot, vehicle, or aerial patrol of an individual tree or a population of trees near specified targets, to identify specified conditions or obvious defects.

mallet–a broad-headed hammer made of wood, plastic, or resin used for sounding a tree.

mitigation–the process for reducing risk.

owner/manager–the person or entity responsible for tree management, or the controlling authority that regulates tree management.

probability–the measure of the chance of occurrence expressed as a number between 0 and 1 (0–100%), where 0 is impossibility and 1 is absolute certainty.

probe–a stiff, small-diameter rod, stick, or wire that is inserted into a cavity or crack to estimate its size or depth.

qualitative risk assessment–a process using ratings of consequences and likelihood to determine risk significance levels and to evaluate the level of risk against qualitative criteria.

quantitative risk assessment–a process used to estimate numerical probability values for consequences, and to calculate numeric values for risk.

residual risk–risk remaining after mitigation.

response growth (adaptive growth)–new wood produced in response to loads to compensate for higher strain in marginal fibers; includes reaction wood (compression and tension), flexure wood, and woundwood.

ribs–longitudinal bulges of response wood growth.

risk–the combination of the likelihood of an event and the severity of the potential consequences. In the context of trees, risk is the likelihood of a conflict or tree failure occurring and affecting a target, and the severity of the associated consequences—personal injury, property damage, or disruption of activities.

risk aggregation–the consideration of risks in combination.

risk analysis–the systematic use of information to identify sources and to estimate the risk.

risk assessment–the process of risk identification, analysis, and evaluation.

risk evaluation–the process of comparing the assessed risk against given risk criteria to determine the significance of the risk.

risk management–the application of policies, procedures, and practices used to identify, evaluate, mitigate, monitor, and communicate risk.

risk matrix–a tool for ranking and displaying risks by assigning ratings for consequences and likelihood.

sounding–the process of striking a tree with a mallet or other appropriate tool and listening for tones that indicate dead bark, a thin layer of wood outside a cavity, or cracks in wood.

structural defect–feature, condition, or deformity of a tree that indicates a weak structure or instability that could contribute to tree failure.

sudden branch drop–sudden, unanticipated failure of a tree branch with little or no discernible defect; often associated with long, horizontal branches and warm temperatures.

taper–change in diameter over the length of trunks, branches, and roots.

target (risk target)–people, property, or activities that could be injured, damaged, or disrupted by a tree failure.

target zone–the area where a tree or tree part is likely to land if it were to fail.

time frame–time period for which an assessment is defined.

tree risk assessment–a systematic process used to identify, analyze, and evaluate tree risk.

tree risk management–the application of policies, procedures, and practices used to identify, evaluate, mitigate, monitor, and communicate tree risk.

unacceptable risk–a degree of risk that exceeds the tolerance of the owner, manager, or controlling authority.

walk-by assessment–a limited visual assessment, usually from one side of the tree, performed as the tree risk assessor walks by the tree(s).

windthrow–uprooting and overthrowing of a tree caused by wind.

wood decay–the process of wood degradation by microorganisms.

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Matrix 1. Likelihood matrix.

Likelihood of Failure	Likelihood of Impact			
	Very Low	**Low**	**Medium**	**High**
Imminent	Unlikely	Somewhat likely	Likely	Very likely
Probable	Unlikely	Unlikely	Somewhat likely	Likely
Possible	Unlikely	Unlikely	Unlikely	Somewhat likely
Improbable	Unlikely	Unlikely	Unlikely	Unlikely

Matrix 2. Risk rating matrix.

Likelihood of Failure & Impact	Consequences of Failure			
	Negligible	**Minor**	**Significant**	**Severe**
Very likely	Low	Moderate	High	Extreme
Likely	Low	Moderate	High	High
Somewhat likely	Low	Low	Moderate	Moderate
Unlikely	Low	Low	Low	Low

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