CONSERVING TREES DURING SITE DEVELOPMENT

-- A TRAINING MANUAL --

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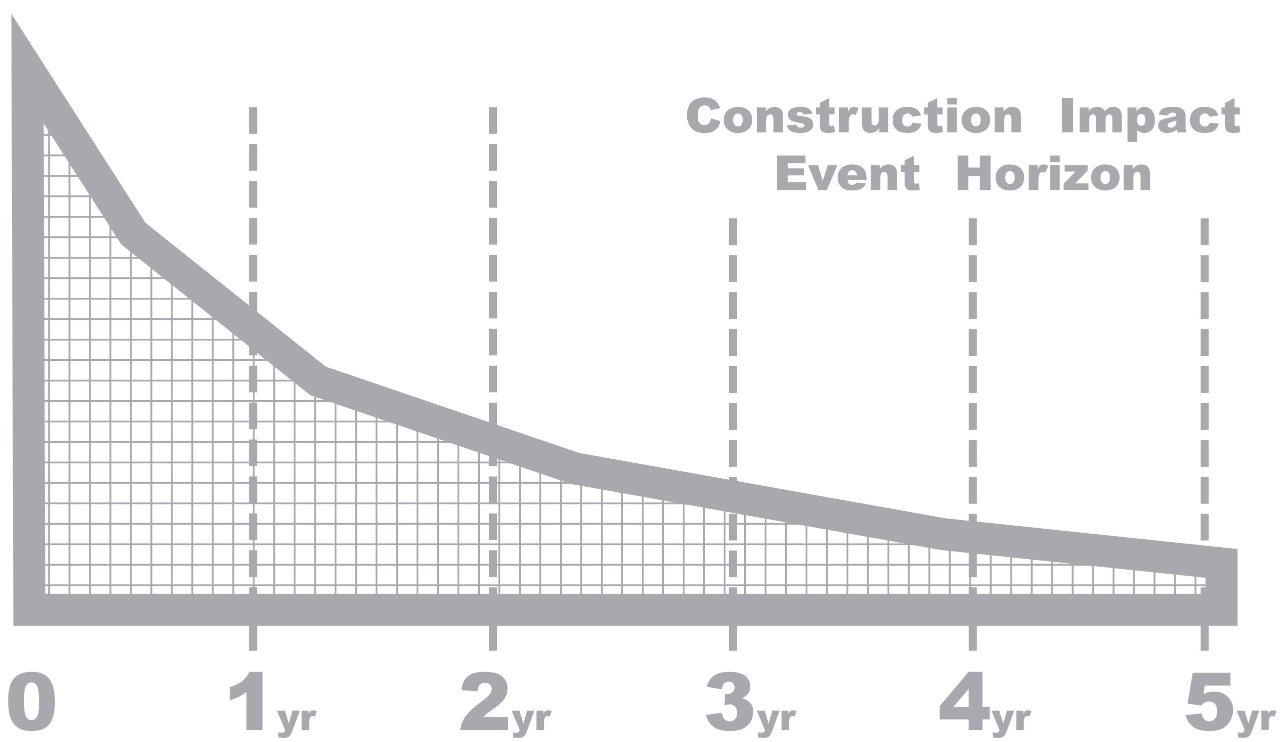

This manual is an educational product designed for helping tree professionals appreciate and understand a number of unique basic aspects of conserving trees during site development and hardscape construction. This product is a synthesis and integration of peer-reviewed research and educational concepts regarding how trees respond to site disruption and mechanical / chemical injury, and how to assess and prevent tree stress and damage. This manual is for awareness building and educational development through assessments and construction activity observations. This educational product does not represent national standards or best management practices.

At the time it was finished, this manual contained models of tree conservation thought by the author to provide the best means for considering fundamental tree health care issues surrounding site development and construction activities. The University of Georgia, the Warnell School of Forestry & Natural Resources, and the author are not responsible for any errors, omissions, misinterpretations, or misapplications from this educational product. The author assumed users would have some basic tree and soil background. This educational product was not designed, nor is suited, for homeowner use. Always seek the advice and assistance of professional tree health providers before, during, and after site development.

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Trees are valuable to sites where people live, work, shop, and play. Tree-generated values impact psychological, social, ecological, and biological aspects of daily life. Planting, cultivation, and conservation of trees on sites where land-use or structural changes occur are important to people.

Modifying the human environment through building, renovating, or removal of physical structures or landscape features is a part of development. Significant changes in a tree's soil, water, energy and biological resources can occur during and after this process. Understanding site and tree constraints, and various forms of problems on sites, can help preserve tree values.

Tree quality concerns can be grouped into three distinct time periods:

A) pre-development planning and site evaluation -- Pre-development concerns revolve around site selection, project planning, and tree and forest attributes;
B) construction activities -- Construction concerns concentrate on site-layout, tree protection zones and site-damage control; and,
C) post-development mitigation and monitoring – Post-development concerns concentrate on restoration of sustainable tree functions and values.

Within each of these time periods, are five site conservation components which affect tree and soil quality. Each issue has a number of assessment processes which can be used to better control development activities around trees and their soils. Specific development site assessments are provided later in this publication.

COMPONENT #1: Tree-Literate Design

Tree quality management around development sites must begin early in the project planning stage as part of a site-team effort. Tree and site attributes, and their relationship with the design process and construction methods, determine post-development survival, continued tree success, and any requirement for therapeutic treatments.

The first step in tree management is getting tree-literate professionals involved in the planning process. There are times when biological components of a design process may be ignored or given low priority. This action leads to poor tree quality and diminished value production. A tree health care provider must be involved with all the sites within site development and planning in order to accentuate, or at least maintain, tree values.

Protection of tree and site quality are key aspects in developing a site. To assure whole tree quality, all tree parts must be protected from acute and chronic damage while short and long-term resource degradation is minimized. Tree quality must be interwoven early into the design process, and continually with construction methodologies. Tree quality must be a part of client perceptions and expectations, and translate clearly into planning and design activities. Tree health care professionals must be part of site planning!

COMPONENT #2:
Pre-Development Site Evaluation

Systematic site and tree evaluation are essential for maintaining tree values and managing risks on construction sites. There are many great assessment tools for use in both the office with computer generated plans, and in the field covering both pre- and post-construction. These assessments are key to minimizing tree and soil damage, and for maintaining project-to-project and site-to-site management success memory.

Begin a pre-development evaluation process at least one growing season in advance of site development activities, if possible. There are many tree and site features to examine -- some of the more important are discussed below.

Numbers. How many trees are present on-site affects many aspects of development. As a rule, the more trees on a site, the more a forest-like atmosphere is generated (up to a point). Over-abundance can be a problem. Sites with too many trees can be as limiting and unresponsive to development as sites with too few trees. Building in dense, overstocked stands can result in decline and death of many trees. Remaining trees are prone to windthrow, pest, storm and ice damage.

The biological occupancy level of trees on a site can be easily determined. Any site, depending upon its inherent productivity, can only hold a given amount of leaf surface area. This leaf surface area can be concentrated onto a few large trees or onto many small trees. Figure 1. For example, 600 five-inch trees, 150 ten-inch trees, 65 fifteen-inch trees, or 40 twenty-inch trees all carry similar total crown volumes per acre. There is a trade-off between the numbers of trees and their sizes for similar site occupancy.

Basal Area. One way to estimate site occupancy or tree density is by measuring basal area (BA). Basal area is a forestry measure that determines the cross-sectional area (in square feet) of all the trees on an acre at 4 ½ feet above the ground (called DBH). This measure can be easily estimated using an angle gauge or prism (or a US 5 cent coin) at a number of random points in an area. Basal area is a direct estimation of crown area or site occupancy.

Using basal area can help quickly establish site occupancy, and expectations of how a site will respond to development. A wooded site would be considered overstocked and unresponsive if basal areas are greater than 75 square feet per acre. A wooded site is under-stocked if basal areas are less than 35 square feet per acre. Tree parks or savannah sites would carry 21-40 square feet of basal area.

Species. Another site feature to examine is the tree species mix. Each tree species, and each unique individual, will respond to stress and strain of site development activities in different ways. Some species vary widely in their response to mechanical injury, pest attack, soil modifications, and micro-climatic changes associated with construction. As more tree tissues, physical space and essential resources are disrupted, the more a tree must effectively react to these changes to insure survival.

The variability of general tree reactions to construction damage represents a range of tolerances. Some trees tolerate damage well -- others tolerate damage poorly. The relative tolerance differences between native species in this region are given in Figure 2, along with primary limiting factors for each. This list represents only broad expectations of tree reactions and cannot anticipate reactions to specific sites changes and circumstances. It is assumed each species is being evaluated within their home range.

Species Tolerance. A species' tolerance to development activities can be divided into three categories; good, medium and poor. These categories are broad recognitions of species reactions to activities around construction sites within one-and-one-half times the drip line radial distance from a tree. For example, a poor tolerance rating signifies a tree which will have difficulty reacting well to site development activities.

Limitations symbolize critical constraints governing species tolerances on development sites. There are five categories of poor tree reactions: physical injury (compartmentalization and decay problems); pest complications (chronic and acute attacks); soil constraints (aeration, compaction, and water availability attributes); limited climatic tolerances (native range, hardiness, and micro-climatic change problems); and, all of these reactions combined.

Diversity. The greater variety of trees on a site, the better chances for long-term health of all trees. A mix of several different species can insure a healthy diversity of tree cover. There should be a diversity of sizes, species, and crown positions across a site. Strive for maintaining or establishing at least 2 tree canopy layers -- medium height and tall / emergent height. Ideally, the species mix should have no more than 15% from any one tree family, no more than 10% from any one tree genera, and no more than 5% of any tree species. This type of diversity mix helps provide sustainability.

For each corner of the site, work for at least three species per crown class. Do not mix different species uniformly across the site. If a site has only one existing species, such as only pine, only hickory, or only cottonwood, the site is at risk for tree problems. Invest in, and manage toward, great genetic and spatial (horizontal and vertical) diversity.

Size. A diversity of tree sizes is also important. There should be a mix of small, medium, and large trees. As a general perception rule for a wooded look and feel to a site, for every existing large tree (11 inches diameter or greater), there should be five medium sized trees. For every medium sized tree (5-10 inches diameter), there should be five small trees. For every small tree (1-4 inches diameter) there should be ten seedlings / saplings. Figure 3.

Crowns. Another valuable evaluation technique is examining tree crowns as an estimate of a tree's potential response to change. Mature trees with a large volume of living crown can react most favorably to development. The proportion of living branches or living crown should ideally comprise 66% of mature tree height. Most trees should at least carry a minimum 35% live crown. If the live crown is less than 20% of total height, problems may develop after construction. Small crowned trees (<10% live crown) would be candidates for removal before construction begins. Figure 4.

Old Damage. Past damage on a site must be recognized, mitigated, or worked around. Site and tree damage may have resulted from past construction, logging, storm, erosion, or land clearing. It is difficult to use machinery between and around trees without damaging tree parts or site resources. Such injuries lead to decline, decay, pests, susceptibility to additional damage, and structural problems. Severe mechanical damage will make it more difficult for trees to adjust to any site changes.

Carefully examine the bottom 20 feet on tree trunks and the basal 10 feet of root area for any scrapings, tears, or wounds. If mechanical injury disrupts more than 1/3 of the trunk's circumference, removal is warranted. The basal portion of the tree withstands the most concentrated structural loads and are most prone to debilitating damage. Survival for trees with severe damage in this basal portion is usually poor over the long-run. Risk assessments should completed and hazardous trees removed before construction begins.

Soil Problems. The soil surface mirrors past site abuse and current health. The soil surface can show soil disruption, heavy equipment use, and compaction. Soil movement across the surface from natural processes or from equipment can lead to tree damage and site productivity losses. Removing soil can severely damage roots. Excessive fill (defined primarily by soil texture and bulk density) around existing trees can suffocate roots and cause tree decline or death.

Erosion from past and present activities can destroy site productivity and tree quality. The presence of many exposed surface roots and lack of natural litter suggest excessive erosion, compaction, and/or drainage problems. Establishing tree protection areas well before construction begins is critical. Physically protect roots and rooting areas with mulch, fences, plywood sheets, pads, and other physical barriers.

COMPONENT #3: Pre-Development Treatments

After pre-development site and tree evaluations have been completed, treatments can be recommended to minimize potential damage and maximize positive tree reactions to change. Preferably one full growing season in advance of any development activity on a site, and if warranted by tree and site characteristics, treatments could include:

- -mark utility and equipment access corridors and assure needed vehicle clearances;
- -mark construction danger zones and tree protection zones;
- -prune, clean, deadwood, and clear trees;
- -mulch tree protection areas;
- -set-up tree protection barriers;
- -establish irrigation needs and methods;
- -fertilize with any essential element showing deficiency in tissue samples, except for nitrogen; and,
- -make low concentration / slow release / low yield nitrogen applications.

In the past, seldom were tree health care professionals allowed the luxury of timely advanced access to sites for evaluations or treatments. Usually tree health care providers are called to fix tree quality concerns after site development activities have commenced and some construction damage has already occurred. Without early tree health care intervention on development sites, trees will show biological and structural problems decreasing tree longevity and benefits generated.

COMPONENT #4:
Managing Construction Impacts

The first and most critical rule in working with tree quality on development sites is to "get there first!" The first impact to a tree and its soils can be the most damaging and facilitate further damage. Tree quality managers need to be the first to approach all trees on a site and make removal, treatment, and preservation decisions.

Locate Trees! Tree quality managers need to insure that every person on a site knows where trees are actually located -- not some general circle on a site plan. Plans should include accurate and precise locations for the trunk, crown, and major soil areas colonized by roots. Remember construction equipment and development plans do not damage tree quality and site resources -- individuals accomplish these actions. Use on-site education, daily monitoring, and/or a strong series of fines, penalties, and rewards to help people remember trees are important.

Once a site plan is available, determine where tree quality and site resource damage are most likely to be concentrated. When trees are not accurately recorded on site plans, go onto the site and outline on the ground with string where various planned structures and areas will occur.

Define Zones. If a tree is within thirty feet of the string delineating the structure footprint, it is in the "construction danger zone" and should normally be removed to facilitate good construction. Trees within this zone are easily and consistently damaged during construction. These trees decline and die due to damage, or eventually become a hazard to structures and people in the area. Figure 5.

High quality trees between zero and sixty feet from any structure can be individually protected with barriers and stem, branch and root paddings or wraps, if the tree value is warranted. The area between zero and sixty feet from structures is the "tree protection zone." Trees already in poor condition should be removed. Tree protection barriers should be installed before construction begins anywhere on the site. Barriers will not prevent all damage but will remind people working on a site that trees are important and barriers should be respected.

Provide Space. Protect as much open soil surface as possible below a tree's crown. Trees require physical space and soil volume to colonize and control. Valuable soil features include:

-- physical space for support and pore volume;
-- open surface area for oxygen, carbon-dioxide, and water movement; and,
-- an adequate and sustainable supply of essential soil resources.

To summarize this point, trees with large areas in which to grow have the best chance of being healthy, long-lived, and developing few problems. A tree quality manager assists a tree to colonize and effectively utilize a site.

There are a number of ways to determine how much space is minimally needed for tree survival and growth. One effective means of determining a protection distance is using a site-occupancy measure. The expected diameter (DBH) of a tree 10-15 years in the future is estimated. The expected tree diameter in inches is then multiplied by 2.5 to yield the number of feet in diameter of a tree protection area (critical rooting area). Many times with mature trees, only the current critical rooting area is determined, not providing for any future growth.

Eliminate Potential Problems. Always limit construction machine access, material storage, chemical or cement rinsing, vehicle parking and site-office locations to non-tree areas. Do not let construction equipment near trunks or main rooting areas. Construction activities should not occur beyond 60 feet from site development hardscape, building footprint, or site construction access routes.

Soil level changes over the site can disrupt and destroy roots and negatively modify the soil environment. Fills and cuts, leveling, and surface cultivation or tilling all can damage or kill trees. An often overlooked but critical soil component is water availability and water movement. Soil changes or movement on a site can completely change water flow patterns, ponding, and soil aeration patterns. Soil cuts can drop water tables and take available water away from established tree root systems.

Soil Compaction. Construction activities can destroy soil resources, functions and values. Soil bulk density or compaction changes can be the most constraining and damaging, while remaining hidden to most site users and planners. Compacted sites do not support vigorous tree growth. Construction sites can easily have 50% greater bulk density than native soils. Increasing bulk density by one-third can be expected to cost a tree one-half of its root and shoot growth.

Soil compaction constrains root growth by acting as a physical barrier to root growth and by blocking oxygen movement to the root surface. Tree roots have difficulty physically penetrating soils with bulk densities greater than 1.7 g/cc, and as the proportion of air pore space (macro-pores) in a soil drops below 15%. Soil compaction is measured as a combination of bulk density of the soil and soil texture. Both components must be known to determine the full extent of tree damaging compaction.

Solutions to compaction problems on development sites include:

A) deep tillage or sub-soiling (if no tree roots are present);
B) mulching and composting to reinvigorate soil health (if moisture and aeration are assured);
C) amending with large, porus, non-compactible solids to create an aerated soil framework;
D) selective use of porus or open structure surfaces as long as compaction is not used to stabilize the units;
E) deep core aerators (12-18" depth);
F) vertical mulching using an auger to drill holes in the soil and backfilling with washed, graded, and non-compactable materials (including some native soil) which leave hole tops open to the atmosphere;
G) radial trenching away from the tree stem base to 16-24 inches of depth and backfilling with washed, graded, and non-compactible materials (including some native soil) with the trench top left open to the atmosphere; and,
H) air gun (knife/spade) which stirs soil and does minimal damage to roots.
I) suspended soil systems where a framework carries the compacting weight and tree soil is minimally impacted.

Items to maintain tree quality through soil management include: prevent and restore high bulk density soils; avoid, treat, and prevent soil contamination by construction materials; and, improve nutrient cycling, moisture balance, and soil structure by top-dressing with organic matter.

Assign Space. Design and control access corridors for utility installation, both underground and overhead. Depending upon local codes for underground utility corridors, two or three trenches are the most needed for all the various utilities. Unfortunately, seldom do various utility providers cooperate in the installation processes to minimize tree quality loss. Utilities lines should be designated to non-tree areas for access, such as along driveways and sidewalks. Working with utility service providers to generate serpentine corridors and tunneling (soil piercing) under tree rooting areas are essential.

Provide room for trucks and construction equipment to get back and forth to the building site. Two access points are needed because large equipment or delivery trucks can not turnaround without extensive site quality losses. An incoming and outgoing access route should be designated for deliveries. This does require a designated, non-tree area for storage of construction materials and parking spaces for construction related vehicles, including laborers and subcontractors.

BMP Checklist. There are a number of important tree quality conservation items to note and manage as site development activities occur. These include: (Figure 6)

1) Know site development and building regulations concerning trees in your area.

2) Establish fenced tree protection areas. For trees in harm's way, use tree protection barriers, wraps, and pads, keeping them in good repair.

3) Include contractual penalties in real dollars for tree protection area violations and tree barrier damage. Allow dollars to educate reluctant or tree-illiterate people and companies.

4) Plan a cement wash-out pit and designate a chemical holding area, both away from tree protection areas.

5) Limit site parking and material storage to already damaged areas.

6) Allow no site-offices, equipment, or material storage in tree protection areas.

7) Keep refueling and equipment maintenance areas away from trees and native soils.

8) Control toilet, lunch, break and burn areas, and associated refuse.

9) Control and limit on-site soil storage.

10) Control and minimize grade changes, and prevent significant water and soil flow / accumulation changes on-site across tree protection areas.

11) Allow only two construction access drives into the site -- one in, one out.

12) Control utility over-head and under-ground corridors.

13) Be careful of fire dangers to site and surrounding woods during and after construction.

A key component in assessing development impacts on trees is the systematic evaluation of potential damage which may occur, and damage which is already present on a site and its trees. Many forms of damage tends to occur repeatedly over a site, and from site to site. This constant and repetitive damage comes from fundamental anti-tree and tree-illiterate activities. Under scrutiny of a systematic assessment, these patterned damage forms can be prevented or minimized.

Recognizing Good Trees

Some types of damage (one-time, one-spot, chance occurrences) can be assessed but are difficult to prevent. Accidents occur and past history on a site may provide a heritage of tree problems. By attempting to categorize and catalog potential damage, patterns can be recognized and steps taken to minimize tree injury and site degradation. Please note many development activities, and the continued presence of biologically efficient and structurally sound trees, are mutually exclusive (spatially and temporally). Decisions must be made early in the planning process to maintain tree quality of life and minimize tree injuries and site damage.

Development Monitors

As development activities occur on a site, continually monitoring damage for tree quality and site resources is essential. Timely communications of potential damaging activities, as well as damage which has occurred, is key to tree health and structure. Development of a damage class assessment system will help tune and quantify managerial responses. An assessment process which helps define site problems will help project expected tree life-span changes and losses.

Expected tree reactions to site resource constraints and physical tree damage during site development, and for a number of years after, will vary from: immediate and out-right death; single-year decline and death; multiple-year decline and death; and, decline with major living mass loss. The latter two expectations are the most common among residual trees, and the most ignored and difficult to prove a cause-and-effect relationship correlated with construction activities.

Head of the Class

One method of assessing site development issues impacting trees is to use a systematic assessment process. This type of assessment generates a set of multiple values suggesting short-term and long-term tree and site quality changes, concentrating on losses. This development site assessment requires a tree health care provider monitor tree and site changes before, during, and after human activities. Potential damage, and actual damage, can be placed into one or several classes of tree and site problems. This assessment is to help people recognize, categorize, and manage effective tree responses to site changes.

In order to assess development site issues with trees and soils, and to help place damage into specific classes each of which can be targeted for management intervention, a number of tools are here provided. These tools help an assessor more clearly, accurately, and precisely identify and quantify the extent of site and tree damage.

Arriving To Conserve

Damage recognition classes are divided into tree and site compartments where managerial intervention can be targeted. Assessment tools are provided in each class to allow for a more precise and objective means in gauging tree and soil damage. Note no assessment tool can replace an experienced, tree-literate, professionally trained observer. Seek out credentialed tree health care providers for site development planning and for this type of assessment.

Damage classes and associated assessment tools provided here are not a comprehensive collection of perfect infallible items, but a beginning set of minimal standards or best management practice guides. This assessment process is a beginning designed to help forge awareness and recognition of issues and problems which can over time decrease tree and soil quality, and increase liabilities.
Figure 7.

Actions Not Regrets

The purpose of tree and site assessment for site development related problems is to stimulate and encourage actions to, at least, help tree health and structure. It is hoped this assessment would help modify how site development activities are planned in the office and executed in the field. Only by changing how people visualize site development as a tree-affirming and ecologically sustainable process can tree and soil assets losses be minimized.

As each tree and site area are assessed for damage, potential actions should be developed that strive to solve short-term and long-term site problems. These actions should rest in one or more of the following five management catagories:

1. Immediate safety of people and protection of property (safety management);
2. Minimize liability risks developing over time (risk management);
3. Protection of tree and soil assets (tree health and structure management);
4. Manage value appreciation of tree assets (sustainable ecological management);
5. Modification of current goals, objectives, and management plans (reevaluation of management process).

Putting Trees First

Deciding to act on assessment suggestions could include changing project design, modifying construction activities and site management plans, tree removal, tree planting, soil or tree therapeutic treatments, and/or reexamination of site resources and management objectives possible.

Damage assessment forms developed should include individual tree and site reviews, as well as an overall negative impacts to trees and soils which stratifies the work area by intensity of activity and potential damage extent. Assessments can be converted into workorder guides for prescribing immediate treatments. These written assessments also serve as an archive record which can assist in diagnosis and amelioration processes in the future.

Assessment Horizon

Included here are a number of tools for helping determine extent and severity of tree and soil damage. Each must be modified by species, site, circumstances, and management objectives as determined by an experienced assessor. These tools are designed to protect tree quality and minimize damage. As such, they are biologically conservative over a five year time span. Continued tree growth and reactions to change, constant or declining site resources, and disruption of tree reactions and site resources by management activities can compound long-term (>6 years) problems not assessed here. Structural damage and chronic stress problems will remain with a tree for its life.

Other assessment tools are not associated with a damage class, but allow the extent of tree and soil damage to be appreciated. The seasonal timing of tree damage does change tree reactions and potential impacts. One of the most important aspects of assessing construction damage to trees is the amount of time development activities occur on a site. Both the absolute time span and the timing of damage in comparison to tree growth patterns are critical to assessing damage and estimating recovery times. Use of a construction damage timing table is both a method of training new assessors and a means of quantifying the potential extent of damage to trees. A sample worksheet for keeping tract of major impacts, as determined by damage class is provided. All these assessment tools help formulate what actions are needed or what actions should be delayed.

Roots & Space Assessment Tools

Understanding how calculations of critical rooting area diameter, radius, and soil surface areas around a tree are made are given in Figure 8.

Figure 9 shows a site view from above a tree stem presenting three different rooting areas and their limiting distance away from a tree. Tree rooting areas include: 1) ecological root print area; 2) critical root zone; and, 3) structural root zone (root plate).   All limiting distance measures are diameters centered on the tree in feet and calculated from tree diameter (Din) at 4.5 feet above the ground measured in inches. For example -- 20 inch diameter tree (Din = 20 inches), ecological root print distance = 80 feet in diameter; critical root zone distance = 50 feet in diameter; and, structural root zone distance = 18 feet in diameter. Each root zone limit away from a tree (root distance radius) would be 40 feet for the ecological root print area; 25 feet for the critical root zone area; and, 9 feet for the structural root zone area.

Figure 10 is an estimate of the ecological root print area for any tree in the area. This ecological root print distance is based upon root colonization distances away from the tree stem in an unconstrained landscape setting. This is a minimum ecological root print distance away from a tree for encroachment under ideal conditions.

For example, a tree with a 20 inch diameter stem (DBH) would have a ecological root print distance of 80 feet in diameter or 40 feet away from the tree stem all the way around (radius). For long term sustainability of the tree and soil health, the ecological root print area should be protected.

Figure 11 is an estimate of critical rooting distance for any tree in the area. This critical rooting distance is based upon the light resources available for each given area of soil, and forestry stocking guides in which 920 square feet of healthy, open soil surface is required per square foot of a tree's cross-sectional area. This is a minimum biological distance away from a tree for encroachment under ideal conditions. For example, a tree with a 20 inch diameter stem (DBH) would have a critical rooting distance of 50 feet in diameter or 25 feet away from the tree stem all the way around (radius).

Figure 12 is a diagram demonstrating acceptable packing density of tree root systems, or the amount of critical rooting area overlap allowed for a tree (A) when surrounded by 2, 3, 4, or 5 other trees with, in these examples, a similar sized rooting area. The percentage given is the maximum overlap of a tree's calculated critical rooting area in percent. Trees directly surrounded by six or more trees should not be allowed any critical rooting area overlap in planning. This packing density percentage is designed to minimize interference impacts of each tree on the others within the same soil area.

Figure 13 is the allowable joint rooting area percent or overlap of critical rooting areas. Rooting area overlap values per tree are based upon critical rooting area values (4.91 X (tree diameter in inches)^2 = critical rooting area in square feet). These joint rooting area overlap values should be used where trees share common soil space in linear, island or clump plantings.

Figure 14 is the calculated critical rooting distance radius values in feet for use in minimizing any type of encroachment on essential tree rooting space. Tree critical rooting radial distance given here is the essential root colonization area surrounding a tree for sustaining tree health. The values listed are the minimum distance away from a tree to exclude potential damaging activities. Do not trespass or work closer to the tree trunk than the critical rooting distance listed in feet of radius.

Figure 15 provides the percent tree rooting area disrupted when soil and roots are damaged on one side. Damaged root percents are provided by 1/5s along the radius from the stem. If the critical rooting area distance is calculated and then divided into 1/5s, the amount of active roots (in percent) destroyed are given, as damage is located closer to the tree stem base.

Figure 16 provides the percent tree rooting area disrupted when soil and roots are damaged all around a tree. Damaged root percents are provided by 1/5s along the radius from the stem. If the critical rooting area distance is calculated and then divided into 1/5s, the amount of active roots (in percent) destroyed are given, as damage is located closer to the tree stem base.

Figure 17 provides the percent of critical rooting area disrupted by development activities approaching tree and impacting soil. The whole area impacted is any activity which disrupts rooting surrounding a tree on all sides, like a cut or fill process. Half area impacted is any activity which disrupts rooting surrounding a tree on any side, like trenching.

Root Plates & Structure Assessment Tools --

Figure 18 shows a side view of a tree root plate area showing root plate depth and location of its hinge point. The decimal values are the multiplier of tree diameter inches yielding diameter of root plate in feet or radial dimensions in feet: root plate diameter = 0.9; hinge point radius = 0.15; root plate depth = 0.3.

Figure 19 provides a view from above of a tree root plate surrounding a tree of a set diameter (DBH_{in}). The decimal values are the multiplier of tree diameter inches yielding diameter of root plate in feet or radial dimensions in feet: root plate diameter = 0.9; hinge point (90^o to leeward, arc radius A-B) = 0.15.

Figure 20 is an estimate of the structural rooting area distance for any tree in the area. This structural rooting area distance limit is based upon biomechanical models of tree root strength and root plate resistance to wind loads. This is a minimum structural distance away from a tree for any type of encroachment under ideal conditions. For example, a 20 inch diameter tree would have a structural rooting area or a root plate of 18 feet in diameter or 9 feet out from the stem on all sides (radius).

Figure 21 gives the structural rooting distance in feet of radius, or root plate radius distance, used to minimize damage to tree structural base and minimize catastrophic tree failures due to root damage. The structural rooting area or root plate (i.e. pedestal roots or roots holding the tree erect under compression) should be protected from all disruption. Significant risk of catastrophic tree failure exists if structural roots within this given radius are destroyed or severely damaged.

Stem & Branch Damage Assessment Tools

Figure 22 shows how to determine the extent and severity of mechanical injuries to trees on development sites. Figure 23 provides the individual steps in determining the Damage Assessment Value for a tree injury. Figure 24 provides a diagram showing areas of a tree where load forces are concentrated and where the tissues around injuries have holding forces concentrated. Score values for different injury locations within critical tree structural zones for use in assessing damage.

Figure 25 presents the Coder Crown Raising Dose Assessment per pruning cycle for demonstrating potential crown raising abuse around a development site. Graph is the percent of live crown (height basis) that can be removed, if warranted. On many development sites, a first tree management step (or tree abuse step) is pruning up the bottom few branches of a tree to gain access, prevent damage to equipment and tree, and provide more storage space. Crown raising in small amounts may be needed and warranted. Too much pruning will lead to tree decline and death.

Figure 26 is a diagram of a tree stem cross-section showing sapwood and heartwood (shaded). Construction damage to major branches is judged after the injuries have been properly cleaned-up and a standard pruning cut is made. Only after the final pruning cut is completed can full branch damage be assessed. Additional damage can occur after the construction pruning injury as a result of improper pruning tools, techniques, and skills. In this assessment it is assumed proper standard pruning practices will be followed. Within standard pruning practices, heartwood and decay column exposure will be used to estimate damage to the health and structure of a tree now, and into the future.

Figure 27 presents the Coder Heartwood Exposure on Pruning Wounds Assessment for trees pruned, tipped or topped during development. Heartwood exposure is a deep cut into and across tree defensive systems. The more heartwood exposed, regardless of the size and age of a stem or branch, the greater potential damage to a tree.

This assessment system provides a user with the maximum number of cuts per wound damage class that should be made without significant damage to a tree. The basis of this system is examination of the cross-section of the living base of any properly pruned branch. It is critical assessors differentiate between heartwood, sapwood, and chemically altered wood areas (decay, discoloration, and defensive responses) in order to determine types and number of branch pruning cuts remaining after a tree is cleaned-up from construction injuries. Remember significant damage and liability risks exist for injured trees on development sites now and into the future.

Figure 28 shows the maximum number of pruning wounds applied to a single tree by heartwood exposure wound type on a development site. Exceeding this count magnifies tree damage significantly.

Soil Health & Strength Assessment Tools

Figure 29 represents the number of passes over the same square inch of soil to increase bulk density (compact soil) to 95% of what it can be compacted.

Soil textures classifications based upon sand and clay proportions, and dotted lines showing root-limiting bulk densities (g/cc) are given is Figure 30. Values equal to or greater the listed density value (to the right of) will significantly constrain tree root growth.

Figure 31 shows soil compaction limitations on tree root growth and survival. Listed are soil physical attributes (soil bulk density in g/cc and soil air pore space percent) by soil texture class, where tree root growth becomes severely limiting. General tree root growth limits include a physical limit on root growth as soil density reaches and exceeds > 1.7 g/cc bulk density, and an aeration pore space limit on root growth when < 15% aeration pore space remains in a soil.

Figure 32 provides effective soil depth in soils of various textures under compacted and non-compacted conditions. Deep soil under limited aeration, poor drainage, or severe compaction do not allow soil ecological systems (aerobes), (including tree roots) to function too far below the soil surface. Soil depth provided is not nearly as important as wide-spreading, shallow, open soil surface area around a tree.

Figure 33 demonstrates soil rutting potential on wet soils under development activities. Rutting causes root crushing and severing. Maintenance equipment can seriously damage soil health through driving over the same place over time. Ground pressure (psi) for vehicles: rubber tires = 20+; crawler track = 12+; and, floatation tires = 6+.

Soil fill or lifts impacts on trees are presented in Figure 34. Approximate amount of soil fill, by texture class, which can be applied before having significant negative impacts on tree root health and growth is shown. These are highly variable values depending upon crusting, compaction, aeration/drainage, native soil attributes, residual structure, application method, organic matter content, and other compounding soil / site problems. All types and quantities of fill can lead to root suffocation and other acute and chronic problems which permanently damage trees. Judging the threshold of potential damage is a professional decision beginning with site management objectives.

Soil cut values are given in Figure 35. Approximate amount of soil removal, by texture class, which can be taken away before having significant negative impacts on tree root health and growth are shown. These are highly variable values depending upon compaction, aeration/drainage, native soil attributes, residual structure, removal method, organic matter content, and other compounding soil / site problems. All soil removal can mechanically disrupt root tissue leading to acute and chronic problems which permanently damage a tree. Judging the threshold of potential damage is a professional decision beginning with site management objectives.

Failure Risk Assessment Tools

Figure 36 provides a simple Tree Structural Risk Assessment process. This assessment helps formulate a potential risk for catastrophic tree failure. A tree is most likely to fail where it is weakest and under the greatest mechanical load. Liability issues arise where people and property are under or near the tree when it could fail. A risk assessment to determine whether a tree is hazardous is a key part of tree management on a development site. Figure 37 is a sample Tree Structural Risk Assessment Form. This form lets you record your observations and develop a record for trees at risk of failure.

Obstructions & Microsites Assessment Tools

Figure 38 is a diagram showing how heat loading can be estimated on a site using a combined and averaged view-factor from 10 equal (36^{o}) observation angles. Distances given are based upon an observation height of 5.5 feet.

Figure 39 provides heat load multiplier values for various non-evaporative, dense surface view-factors (nearest 10% class) for a site or tree. Use heat load multipliers to estimate increased water use and carbohydrate use in trees under various heat loads. Trees with hardscape view-factors greater than 30% will have increased stress and adjustment issues into the future.

Exposure & Recovery Assessment Tools

Figure 40 demonstrates calculating tree damage exposure value using a tree growth season counter. One of the most important aspects of assessing site development damage to trees is the amount of time development activities occur on a site. Both the absolute time span and the timing of damage in comparison to tree growth patterns are critical to assessing potential tree damage and estimating recovery times. Use of a construction damage timing table is both a method of training new assessors and a means of quantifying the potential extent of damage to trees.

This assessment process can help drive various scenarios in the planning process to minimize the “Tree Damage Exposure Value.” The Tree Damage Exposure Value is determined by establishing a time-line for beginning and ending construction activities on a site. Components of the Tree Damage Exposure Value include the number of different tree growth seasons construction activities have spanned, which tree growth season construction activities began within, which tree growth season construction activities ended within, and how many full years have been involved in the construction process.

Tree Damage Exposure Value process is defined in Figure 41. The extent and severity of development site damage to trees is in-part dependent upon how many individual growth periods to which a tree has been subjected. The principle four tree growing seasons are dormancy (DORM), the first part of the growing season from bud break to when leaves are fully expanded (GS1), the second part of the growing season which ends when approximately 80% of the growing season has been completed or trees are starting to enter fall senescence (GS2), and senescence when trees just begin to generate a leaf color change in fall (first darker green then paler green) until leaves are dead and fall (SENC). These tree growth periods will be used to help estimate duration and severity of development site damage. The components of this assessment are given in Figure 42.

Figure 43 shows calculated tree damage exposure values. To determine a Tree Damage Exposure Value, begin at the top of the table and identify when construction activities began on the site (by tree growth season). Next move downward in the appropriate starting column until you reach the row representing the end of construction activities on the site. The number presented is the relative "Tree Damage Exposure Value."

Figure 44 provides tree recovery time determinations. Recovery timing is based upon each tree growth period impacted by site development activities (running concurrently). Recovery time commences when construction activities end on a site. Landscape disruption and installation are the final parts of site development and can be extremely damaging, especially to any mature trees present. When the last machinery has left the site and the landscape and hardscape are completely installed, recovery timing can begin. Recovery timing uses the same time-line and four tree growth periods as does the development activities tree damage exposure value calculation. For each tree growth period affected by site development activities, a specific length of recovery should be observed. Because of tree biology, recovery time periods are not additive, but run concurrently as each tree growth season is affected and grown past.

Figure 45 provides a site development and construction damage event horizon for trees. Although severe damage can cause an immediate death of a tree, site changes and cumulative injury and stress cycles caused by site development activities can still be the primary cause of tree decline and death a number of years after construction. This figure points out the normal five year damage event horizon for trees after development activities have ended.

COMPONENT #5:
Post-Development Treatments

Post-development tree quality management primarily concerns identification of problems and associated treatments which do not accentuate tree quality losses or further destroy site resources. In addition, sorting out living trees from dead, and soon to be dead, is required. Severely damaged trees should be quickly removed and replaced with plantings, if warranted.

Cultural treatments for a post-development site can include:

-weekly water/drainage management (the most important item!);
-fertilizing with essential elements shown to be deficient in tree tissue tests;
-wait one growing season for minimal nitrogen applications, then maintain minimal levels for 3-5 years;
-if in doubt about the structural integrity or survival of a tree, remove it immediately; and,
-watch closely for pests and changes in tree structure -- preventative treatments may be advisable.

CONCLUSIONS

The quality of life of a tree and tree owner is dependent upon design and development processes being tree-affirming and tree-literate. Figure 46. Tree quality also depends upon timely treatments prescribed which attack the casual agents of problems (NOT symptoms). Tree quality can be preserved, maintained and restored around development sites if we give trees a biological and ecological chance.

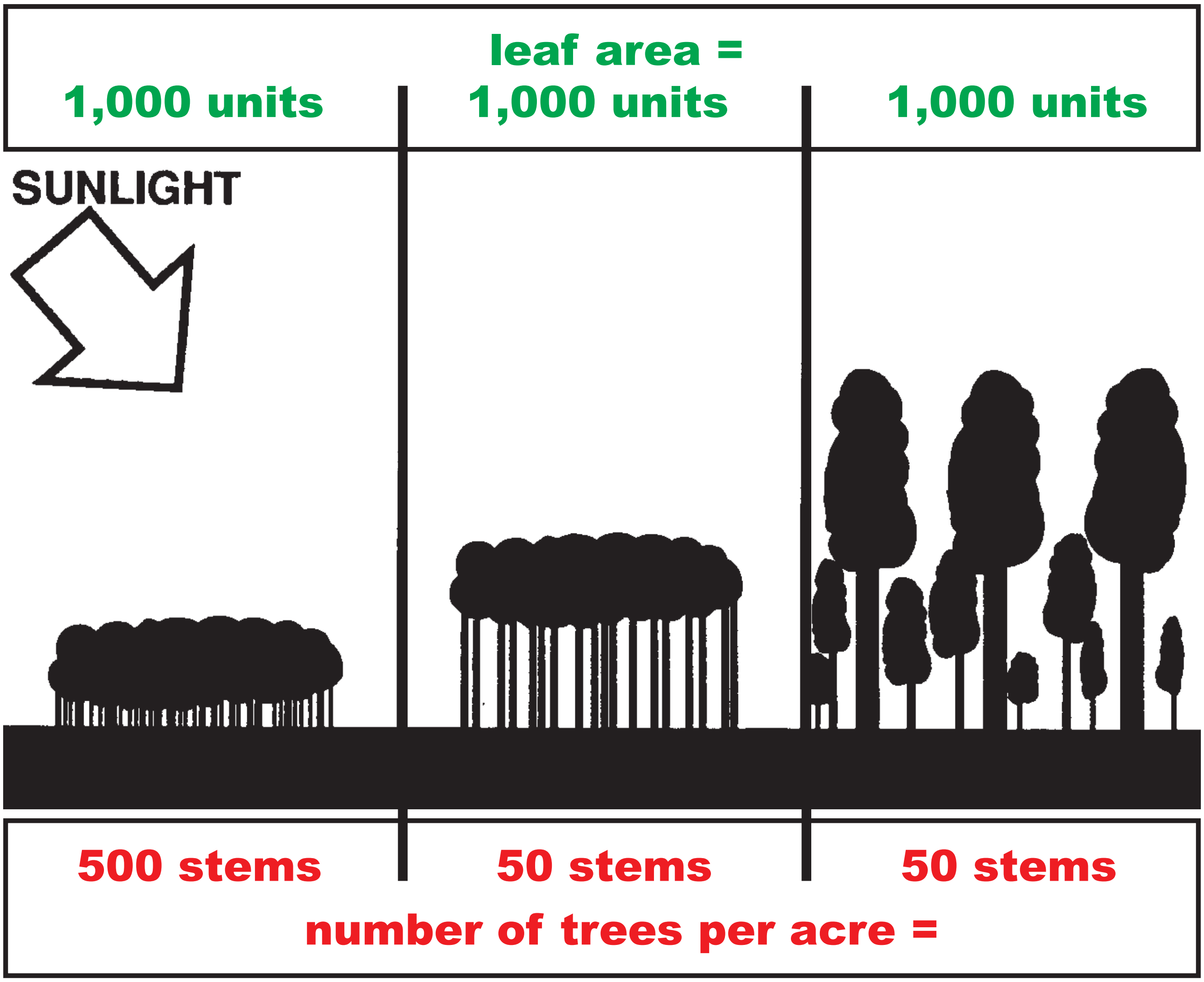

Figure 1: All sites recieve the same amount of sunlight energy per acre to power all trees. Managers can divide this energy into a few big trees or many small trees. The leaf area at full stocking will always be similar.

Figure 2: List of tree species and tolerance to site development activities.

KEY

tolerance: "g" = good; "m" = medium; "p" = poor.

limitations:
- "I" physical injury (compartmentalization and decay problems);
- "P" pest complications (chronic and acute attacks);
- "S" soil constraints (aeration, compaction, and water availability attributes);
- "C" limited climatic tolerances (native range, hardiness, and micro-climatic change problems); and,
- "A" all of these reactions combined "I + P + S + C = A."

scientific name	common name	tolerance	limitations
Acer barbatum	Florida maple	m	IS
Acer leucoderme	chalk maple	p	A
Acer negundo	boxelder	g	
Acer pensylvanicum	striped maple	m	IC
Acer rubrum	red maple	g	
Acer saccharinum	silver maple	p	A
Acer spicatum	mountain maple	m	IC
Aesculus octandra	yellow buckeye	p	IS
Aesculus pavia	red buckeye	m	I
Alnus serrulata	hazel alder	g	
Amelanchier arborea	downy serviceberry	m	IS
Aralia spinosa	devil's walking stick	m	I
Asimina triloba	pawpaw	g	
Baccharis halimifolia	Eastern baccharis	g	
Betula alleghenensis	yellow birch	m	ISC
Betula lenta	sweet birch	m	IC
Betula nigra	river birch	g	
Bumelia lanuginosa	gum bumelia	m	IS
Bumelia lycioides	buckthorn bumelia	m	IS
Carpinus caroliniana	American hornbeam	m	SC
Carya aquatica	water hickory	g	
Carya cordiformis	bitternut hickory	p	S
Carya glabra	pignut hickory	m	S
Carya ovata	shagbark hickory	p	S
Carya pallida	sand hickory	m	
Carya tomentosa	mockernut hickory	mp	S
Castanea alnifolia	Florida chinkapin	m	P
Castanea pumila	Allegheny chinkapin	p	P
Catalpa bignonioides	Southern catalpa	g	
Celtis laevigata	sugarberry	g	I

Figure 2: List of tree species and tolerance to site development activities. (continued)

KEY

tolerance: "g" = good; "m" = medium; "p" = poor.

limitations:
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- "P" pest complications (chronic and acute attacks);
- "S" soil constraints (aeration, compaction, and water availability attributes);
- "C" limited climatic tolerances (native range, hardiness, and micro-climatic change problems); and,
- "A" all of these reactions combined "I + P + S + C = A."

scientific name	common name	tolerance	limitations
Celtis tenuifolia	Georgia hackberry	m	IS
Cephalanthus occidentalis	buttonbush	g	I
Cercis canadensis	redbud	m	S
Chionanthus virginicus	fringetree	m	IS
Cladrastis kentukea	yellowwood	p	A
Clethra acuminata	cinnamon clethra	m	IS
Cliftonia monophylla	buckwheat tree	m	IS
Cornus alternifolia	alternate-leaf dogwood	m	I
Cornus florida	dogwood	m	IP
Cornus stricta	swamp dogwood	g	I
Corylus cornuta	beaked hazel	g	
Cyrilla racemiflora	swamp cyrilla	m	I
Diospyros virginiana	persimmon	g	P
Erythrina herbacea	Eastern coralbean	m	I
Euonymus atropurpureus	Eastern wahoo	m	I
Fagus grandifolia	American beech	p	A
Forestiera acuminata	swamp-privet	g	
Fraxinus americana	white ash	m	IS
Fraxinus caroliniana	Carolina ash	g	
Fraxinus pennsylvanica	green ash	g	
Gleditsia aquatica	waterlocust	g	
Gleditsia triacanthos	honeylocust	g	
Gordonia lasianthus	loblolly-bay	g	
Halesia carolina	Carolina silverbell	m	ISC
Halesia diptera	two-wing silverbell	m	IS
Halesia parviflora	little silverbell	m	IS
Hamamelis virginiana	witch-hazel	m	IS

Figure 2: List of tree species and tolerance to site development activities. (continued)

KEY

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limitations:
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- "P" pest complications (chronic and acute attacks);
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- "C" limited climatic tolerances (native range, hardiness, and micro-climatic change problems); and,
- "A" all of these reactions combined "I + P + S + C = A."

scientific name	common name	tolerance	limitations
Ilex ambigua	Carolina holly	g	
Ilex cassine	dahoon	g	
Ilex coriacea	large gallberry	g	
Ilex decidua	possumhaw	g	
Ilex montana	mountain winterberry	gm	C
Ilex myrtifolia	myrtle dahoon	g	
Ilex opaca	American holly	g	
Ilex verticellata	common winterberry	g	
Ilex vomitoria	yaupon holly	g	
Juglans nigra	black walnut	p	IS
Juniperus virginiana	Eastern redcedar	m	IS
Kalmia latifolia	mountain laurel	g	
Liquidambar styraciflua	sweetgum	g	
Liriodendron tulipifera	yellow-poplar	p	IS
Magnolia acuminata	cucumbertree	m	I
Magnolia fraseri	Fraser magnolia	p	IC
Magnolia grandiflora	Southern magnolia	m	I
Magnolia pyramidata	pyramid magnolia	p	IC
Magnolia virginiana	sweetbay	g	
Malus angustifolia	Southern crabapple	m	ICP
Malus coronaria	sweet crabapple	m	ICP
Morus rubra	red mulberry	g	
Myrica cerifera	Southern bayberry	g	
Myrica heterophylla	evergreen bayberry	g	
Nyssa aquatica	water tupelo	g	
Nyssa ogeche	Ogeechee tupelo	m	IS
Nyssa sylvatica	blackgum	g	

Figure 2: List of tree species and tolerance to site development activities. (continued)

KEY

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- "P" pest complications (chronic and acute attacks);
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- "C" limited climatic tolerances (native range, hardiness, and micro-climatic change problems); and,
- "A" all of these reactions combined "I + P + S + C = A."

scientific name	common name	tolerance	limitations
Osmanthus americana	devilwood	m	I
Ostrya virginiana	Eastern hophornbeam	m	S
Oxydendrum arboreum	sourwood	p	A
Persea borbonia	redbay	g	
Pinckneya pubens	pinckneya	m	I
Pinus echinata	shortleaf pine	gm	P
Pinus elliottii	slash pine	g	
Pinus glabra	spruce pine	g	
Pinus palustris	longleaf pine	gm	C
Pinus pungens	table-mountain pine	gm	C
Pinus rigida	pitch pine	g	
Pinus serotina	pond pine	g	
Pinus strobus	Eastern white pine	m	A
Pinus taeda	loblolly pine	g	
Pinus virginiana	Virginia pine	g	
Planera aquatica	planer-tree	g	
Platanus occidentalis	American sycamore	g	
Populus deltoides	Eastern cottonwood	g	
Prunus americana	American plum	m	IS
Prunus angustifolia	chickasaw plum	m	IS
Prunus caroliniana	Carolina laurelcherry	g	
Prunus pensylvanica	fire cherry	m	I
Prunus serotina	black cherry	m	I
Prunus umbellata	flatwoods plum	m	I
Ptelea trifoliata	hoptree	m	I
Quercus alba	white oak	gm	S
Quercus coccinea	scarlet oak	g	
Quercus durandii	Durand oak	g	
Quercus falcata	Southern red oak	g	
Quercus falcata var. pagodaefolia	cherrybark oak	g	

Figure 2: List of tree species and tolerance to site development activities. (continued)

KEY

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limitations:
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- "P" pest complications (chronic and acute attacks);
- "S" soil constraints (aeration, compaction, and water availability attributes);
- "C" limited climatic tolerances (native range, hardiness, and micro-climatic change problems); and,
- "A" all of these reactions combined "I + P + S + C = A."

scientific name	common name	tolerance	limitations
Quercus incana	bluejack oak	g	
Quercus laevis	turkey oak	g	
Quercus laurifolia	laurel oak	g	
Quercus lyrata	overcup oak	g	
Quercus marilandica	blackjack oak	g	
Quercus michauxii	swamp chestnut oak	g	
Quercus muehlenberrgii	chinkapin oak	g	
Quercus nigra	water oak	g	
Quercus phellos	willow oak	gm	S
Quercus prinus	chestnut oak	gm	S
Quercus rubra	Northern red oak	gm	SC
Quercus shumardii	Shumard oak	g	
Quercus stellata	post oak	g	
Quercus velutina	black oak	g	
Quercus virginiana	live oak	gm	C
Rhamnus caroliniana	Carolina buckthorn	m	IS
Rhododendron catawbiense	catawba rhododendron	m	I
Rhododendron maximum	rosebay rhododendron	m	I
Rhus coppalina	shining sumac	m	I
Rhus glabra	smooth sumac	m	I
Robinia pseudoacacia	black locust	g	P
Salix caroliniana	Coastal Plain willow	g	
Salix nigra	black willow	g	
Salix sericea	silky willow	g	
Sambucus canadensis	American elder	p	A
Sassafras albidum	sassafras	g	
Staphylea trifolia	American bladdernut	g	
Stewartia malacodendron	Virginia stewartia	g	
Stewartia ovata	mountain stewartia	g	
Styrax americana	American snowbell	m	IS

Figure 2: List of tree species and tolerance to site development activities. (continued)

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limitations:
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- "C" limited climatic tolerances (native range, hardiness, and micro-climatic change problems); and,
- "A" all of these reactions combined "I + P + S + C = A."

scientific name	common name	tolerance	limitations
Styrax grandifolia	bigleaf snowbell	m	IS
Symplocos tinctoria	sweetleaf	g	I
Taxodium distichum	baldcypress	g	
Taxodium distichum var. nutans	pondcypress	g	
Tilia caroliniana	Carolina basswood	p	A
Tilia heterophylla	white basswood	p	A
Toxicodendron vernix	poison sumac	m	I
Tsuga canadensis	Eastern hemlock	p	A
Ulmus alata	winged elm	g	
Ulmus americana	American elm	m	P
Ulmus rubra	slippery elm	m	P
Vaccinium arboreum	tree sparkleberry	m	A
Viburnum nudum	possumhaw viburnum	g	
Viburnum obovatum	Walter viburnum	g	
Viburnum rufidulum	rusty blackhaw	g	
Zanthoxylum clava-herculis	Hercules-club	m	I

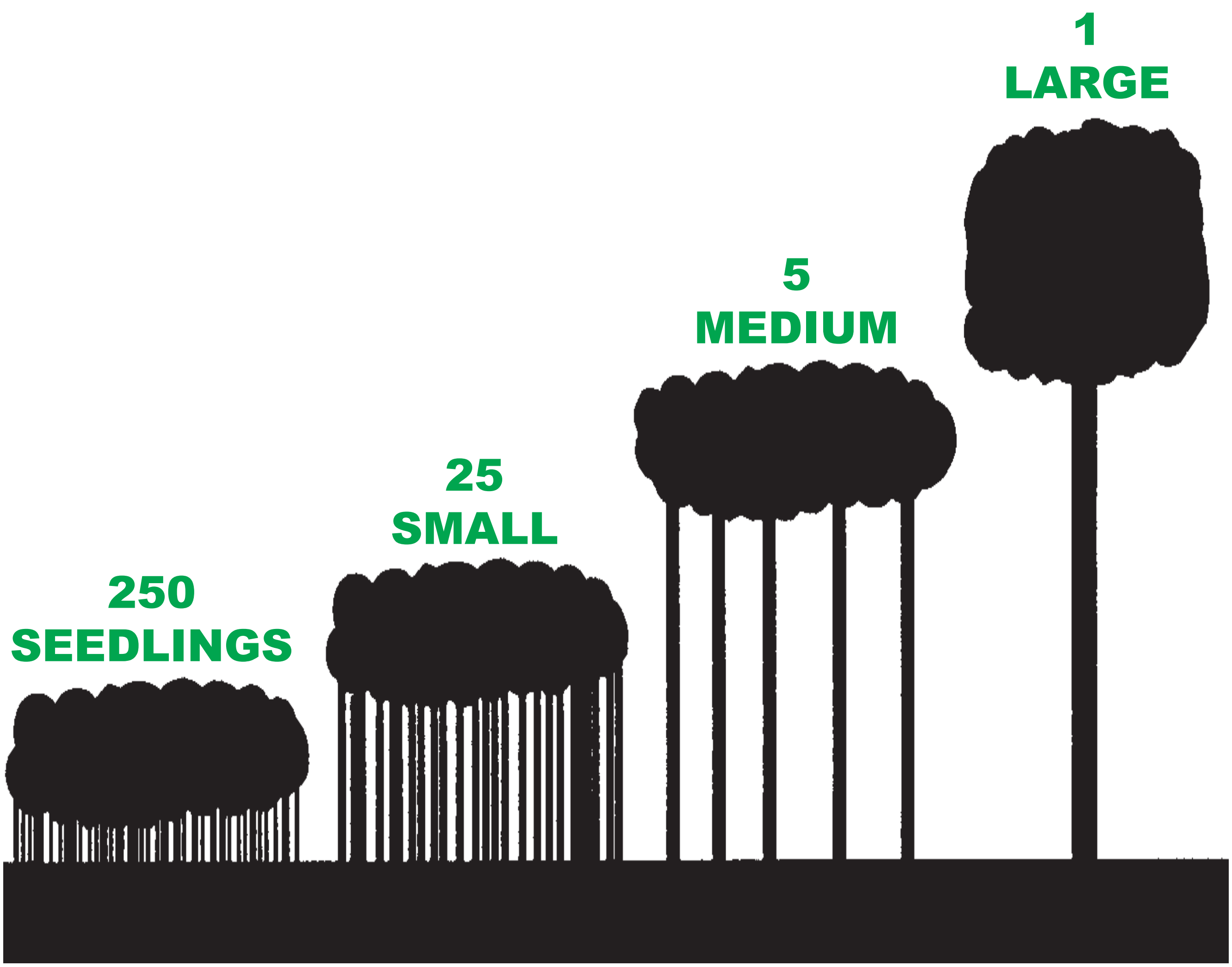


Figure 3: An ideal size distribution for a wooded appearance on a development site.

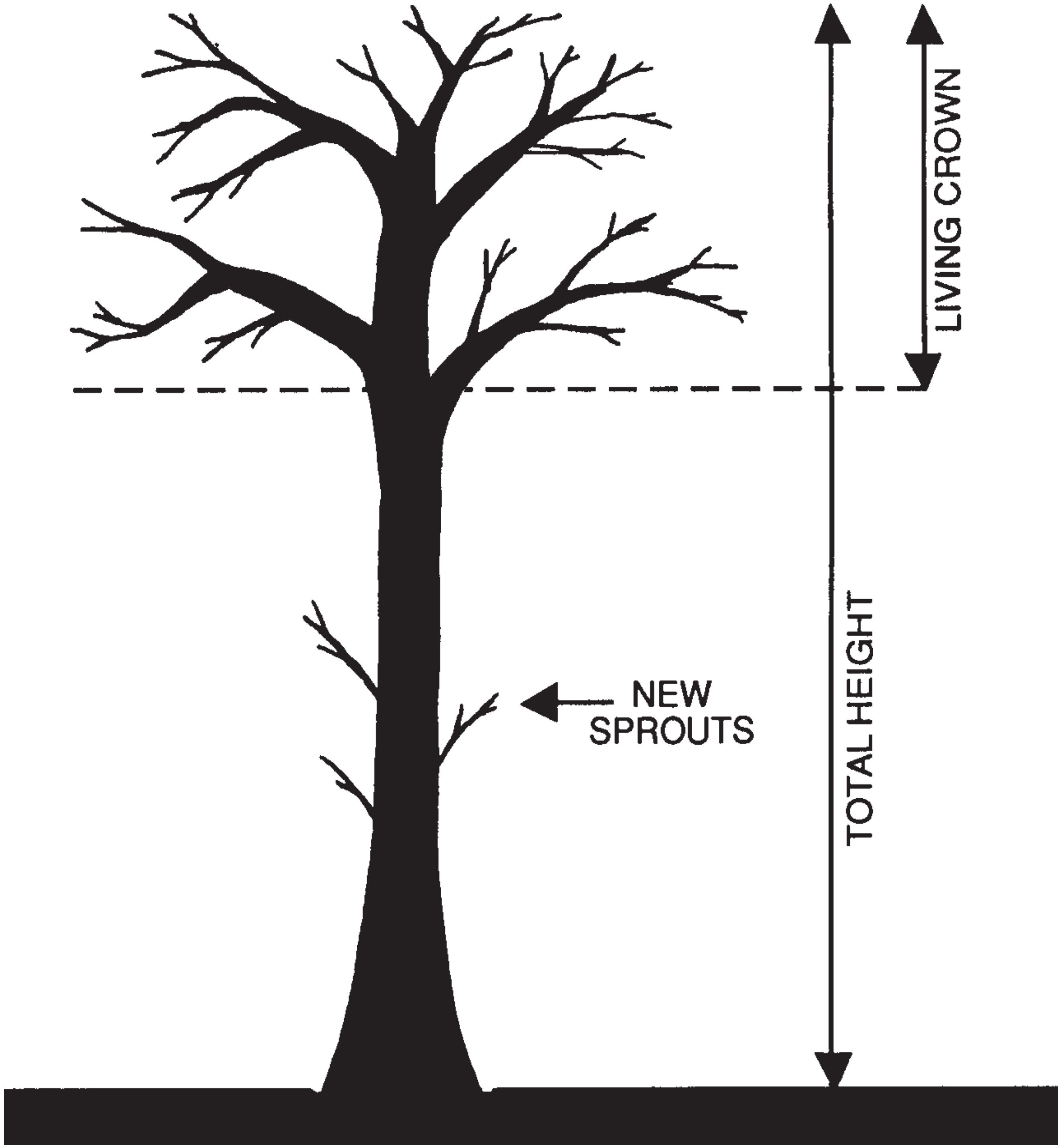


Figure 4: Live crown height is measured upward from where the first main live branches grow from a stem, and does not include consideration of incidental sprouts.

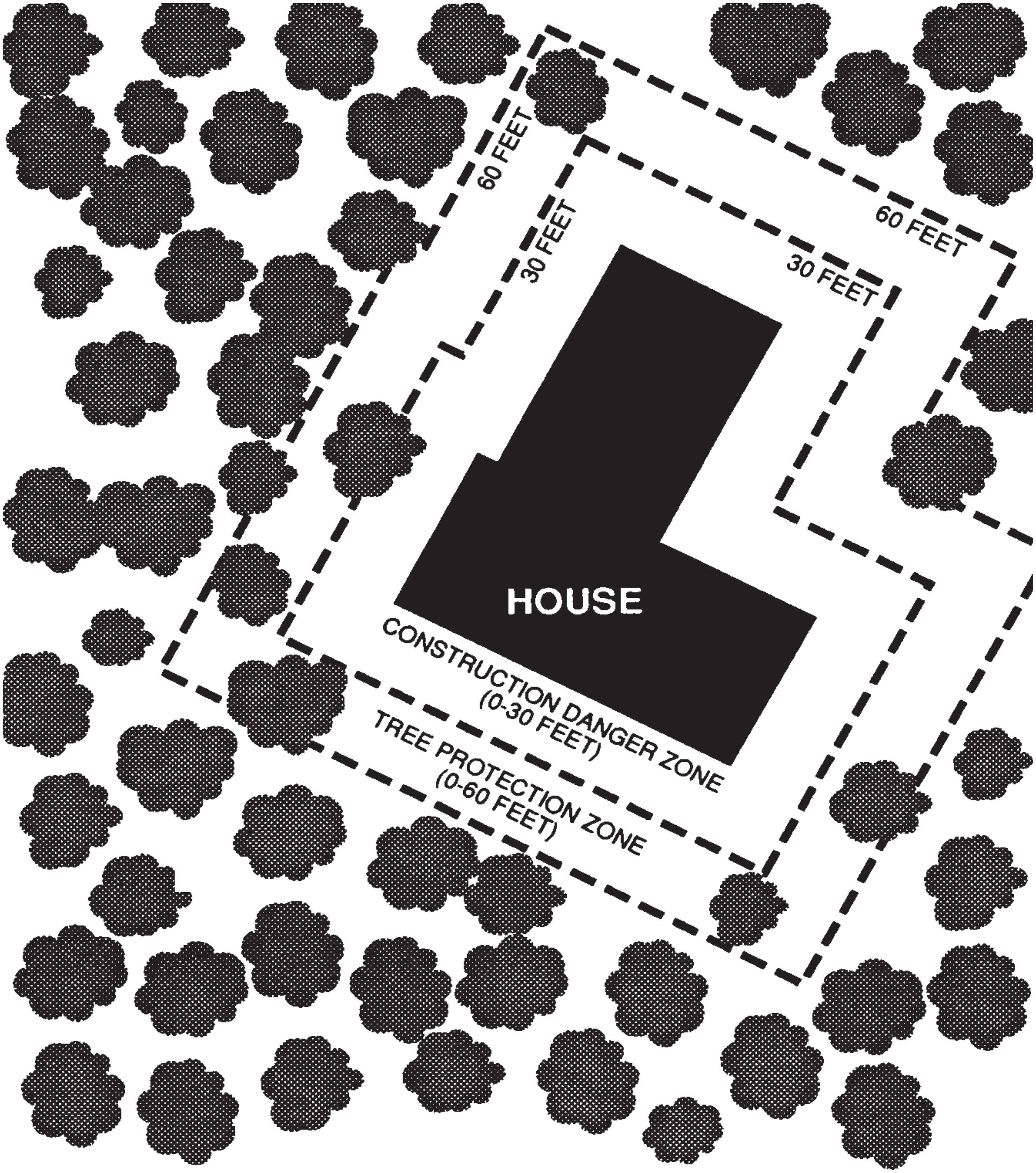


Figure 5: Diagram of a construction danger zone (CDZ) and a tree protection zone (TPZ) around a house foot print. Note two access routes onto the site are not shown.

1) **Know site development & building regulations concerning trees in your area.**

2) **Establish fenced tree protection areas. For trees in harm's way, use tree protection barriers, wraps, & pads.**

3) **Include contractual penalties in real dollars for tree protection area violations & tree barrier damage.**

4) **Plan for a cement wash-out pit & designate a chemical holding area, both away from tree protection areas.**

5) **Limit site parking & material storage to already damaged areas.**

6) **Allow no site-offices, equipment, or material storage in tree protection areas.**

7) **Keep refueling & equipment maintenance areas away from trees and native soils.**

8) **Control toilet, lunch, break and burn areas, and associated refuse.**

9) **Control & limit on-site soil storage.**

10) **Control and minimize grade changes, and prevent significant water & soil flow / accumulation changes on-site across tree protection areas.**

11) **Allow only two construction access drives into site – one in, one out.**

12) **Control utility over-head and under-ground corridors.**

13) **Be careful of fire dangers to site and surrounding woods.**

Figure 6: Best Management Practices (BMPs) Checklist

Class 1 -- General root system destruction and rooting space loss.
Figures 8-17.

Class 2 -- Root collar and structural support root damage.
Figures 18-21.

Class 3 -- Mechanical / structural damage to stem and branches.
Figures 22-28.

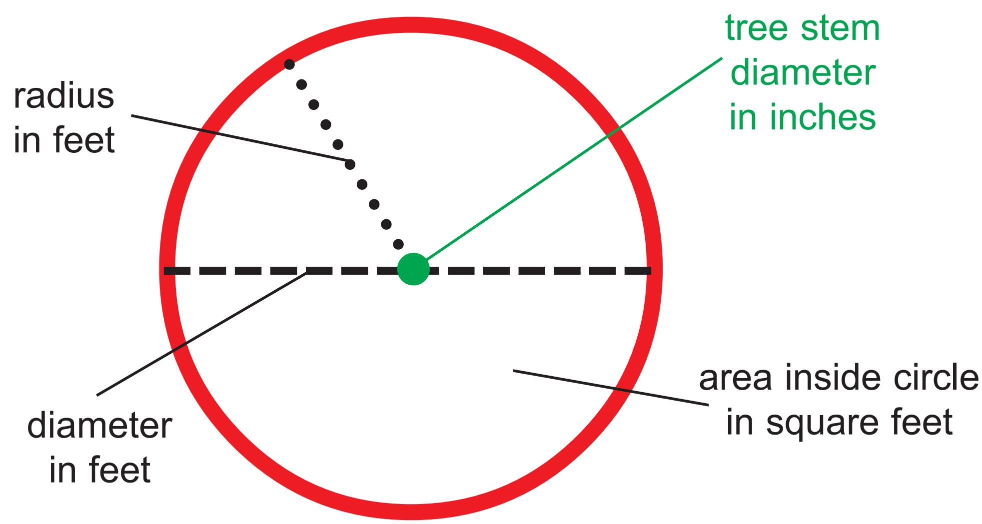
Class 4 -- Soil problems.
Figures 29-35.

Class 5 -- Wind load changes (tree failures under wind loading) -- Note this class affects edge or island trees where clearing or thinning has left trees prone to windthrow. This is the only damage class not necessarily a result of direct mechanical or soil damage.
Figures 36-37.

Class 6 -- Instituting obstructions & new microsite attributes -- changes in surroundings which will modify growth success and management activities now and into the future (growing space interference -- new lines, barriers, hardscapes, advected heat, heat loading, buildings, trees).
Figures 38-39.

Summary Assessments --
Determining Total Tree Damage Exposure & Recovery Time
Figures 40-45.

Figure 7: Site development damage classes and associated assessment tools for trees and soils.



Tree Rooting Distance

(in feet away from or around tree stem)

Diameter of Rooting Distance in feet =
2.0 X Radius of Rooting Distance in feet

Radius of Rooting Distance in feet =
0.5 X Diameter of Rooting Distance in feet

Tree Rooting Area

(in square feet of soil surface area away from tree stem)

Rooting Area in square feet =
0.785 X (Diameter of Rooting Distance in feet)^2

Rooting Area in square feet =
3.14159 X (Radius of Rooting Distance in feet)^2

Figure 8: Calculating rooting area diameter, radius, and soil surface area around a tree.

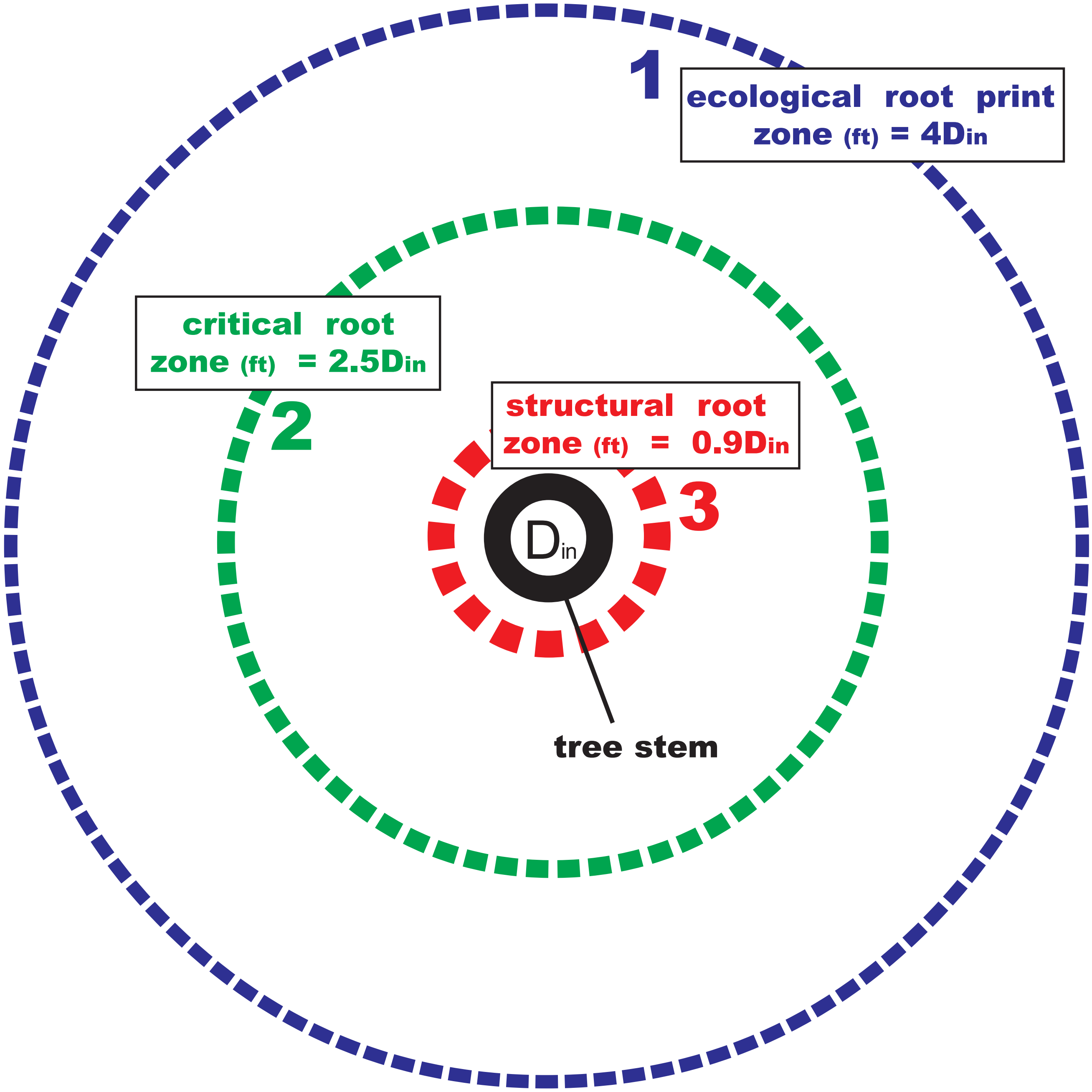
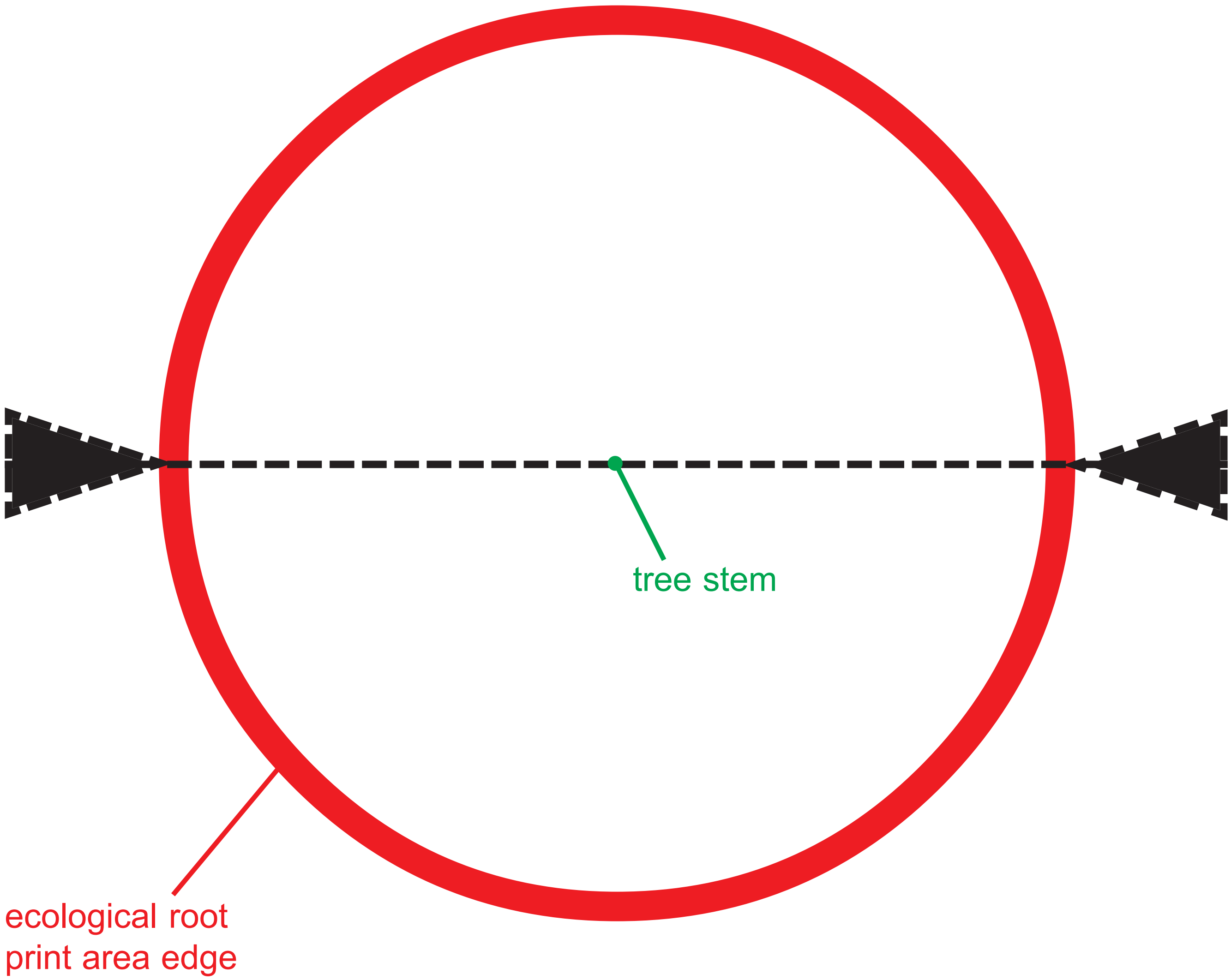


Figure 9: Site view from above a tree stem showing three different rooting areas and their limiting distance away from a tree.

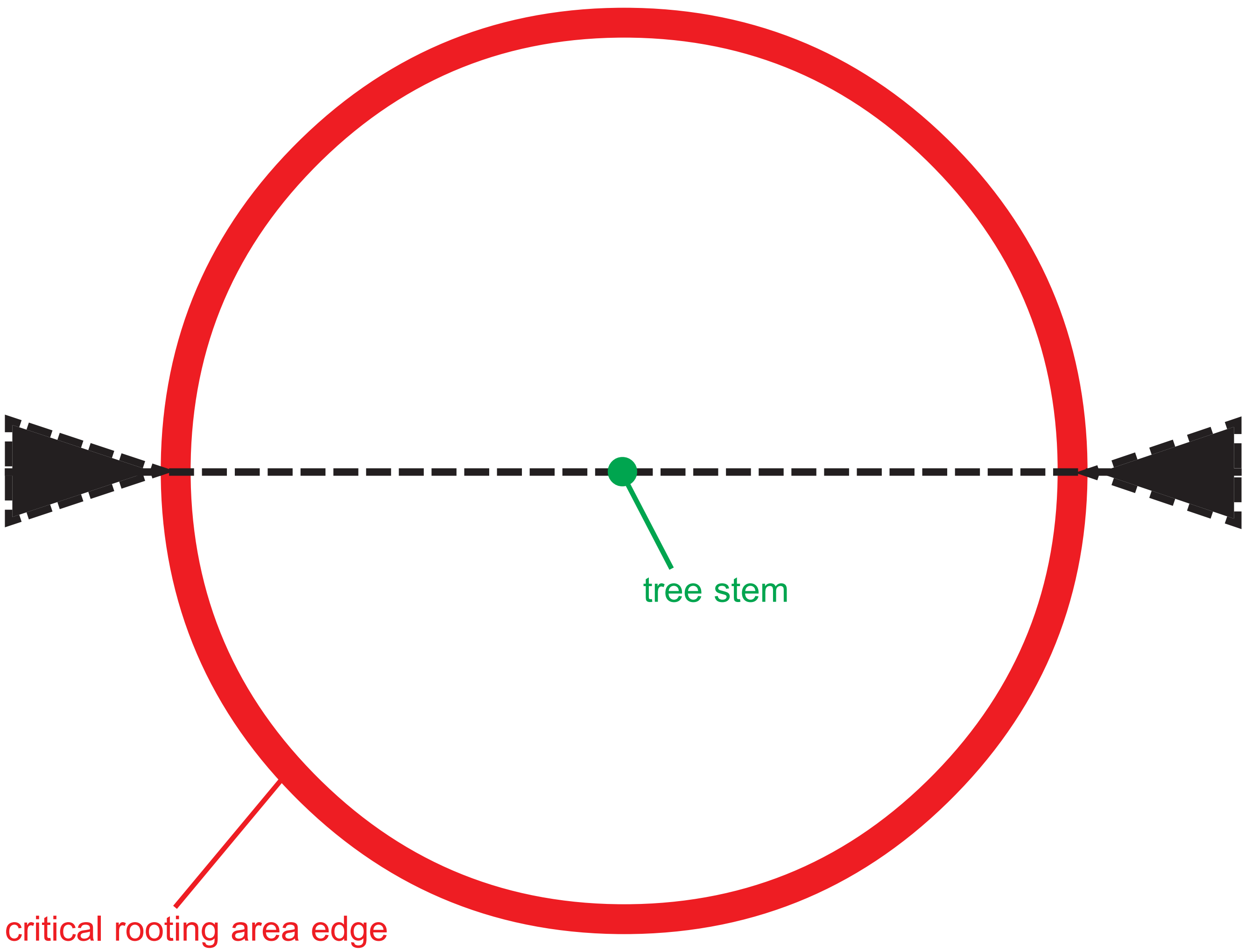


4.0 X DIAMETER OF TREE
(DBH in inches)

=

ECOLOGICAL ROOT PRINT DIAMETER (in feet)

Figure 10: Estimated ecological root print area for any tree.



2.5 X DIAMETER OF TREE
(DBH in inches)
=
CRITICAL ROOTING AREA DIAMETER (in feet)

Figure 11: Estimated critical rooting distance for any tree.

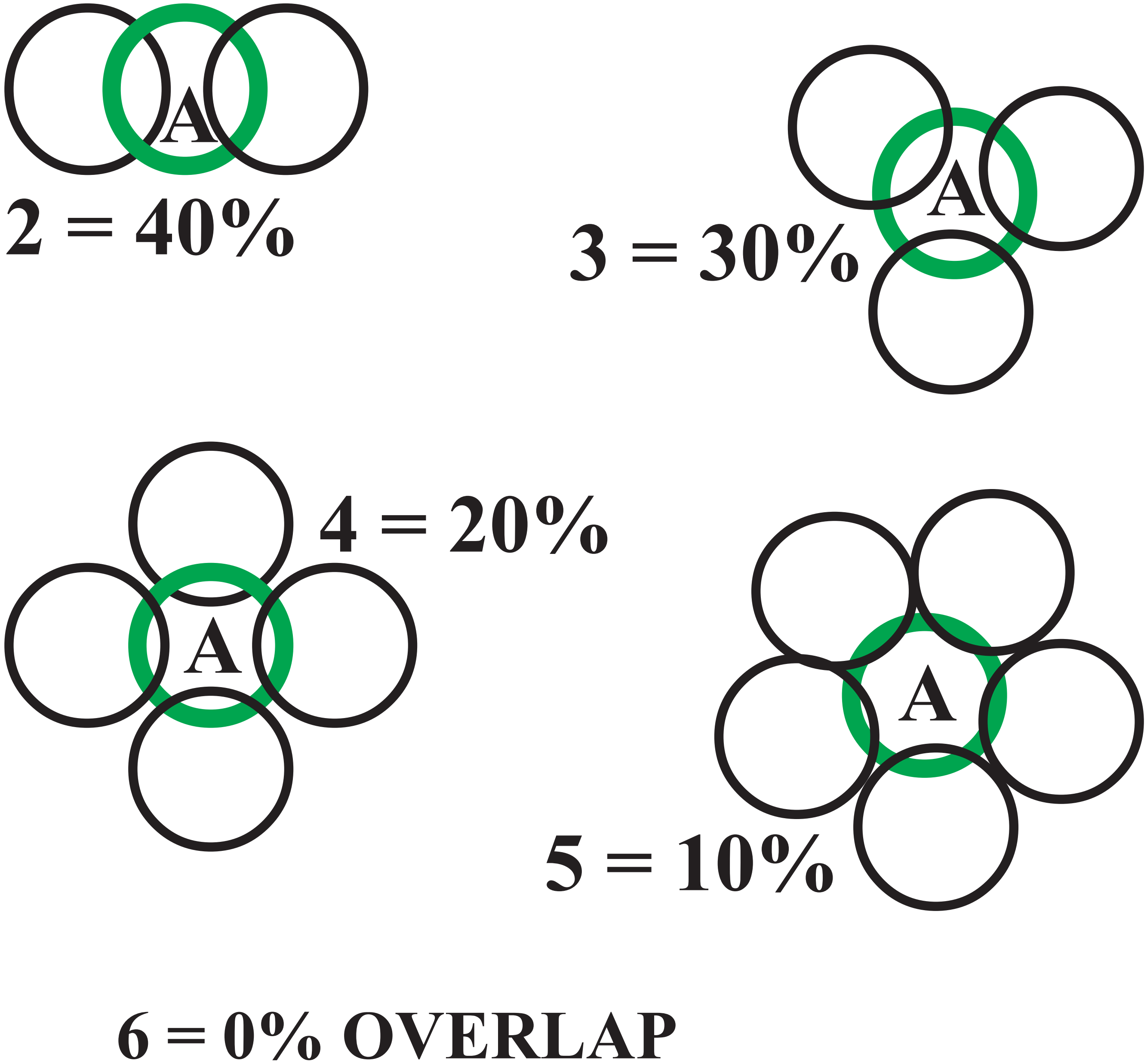


Figure 12: Diagram demonstrating acceptable packing density of tree root systems, or the amount of critical rooting area overlap allowed for a tree (A) when surrounded by 2, 3, 4, or 5 other trees with, in these examples, a similar sized rooting area.

number of neighbor trees to tree A	allowed critical rooting area overlap with tree A
1	50%
2	40%
3	30%
4	20%
5	10%
>6	0%

Figure 13: Allowable joint rooting area percent or overlap of critical rooting areas.

TREE DIAMETER (inches)	CRITICAL ROOTING DISTANCE (feet of radius)	TREE DIAMETER (inches)	CRITICAL ROOTING DISTANCE (feet of radius)
1	1.25	26	33
2	2.5	27	34
3	4	28	35
4	5	29	36
5	6	30	38
6	9		
7	9	31	39
8	10	32	40
9	11	33	41
10	13	34	43
		35	44
11	14	36	45
12	15	37	46
13	16	38	48
14	18	39	49
15	19	40	50
16	20		
17	21	45	56
18	23	50	63
19	24	55	69
20	25	60	75
		65	81
21	26	70	88
22	28	75	94
23	29	80	100
24	30	85	106
25	31	90	113

Figure 14: Calculated critical rooting distance radius values in feet for use in minimizing any type of encroachment on essential tree rooting space.

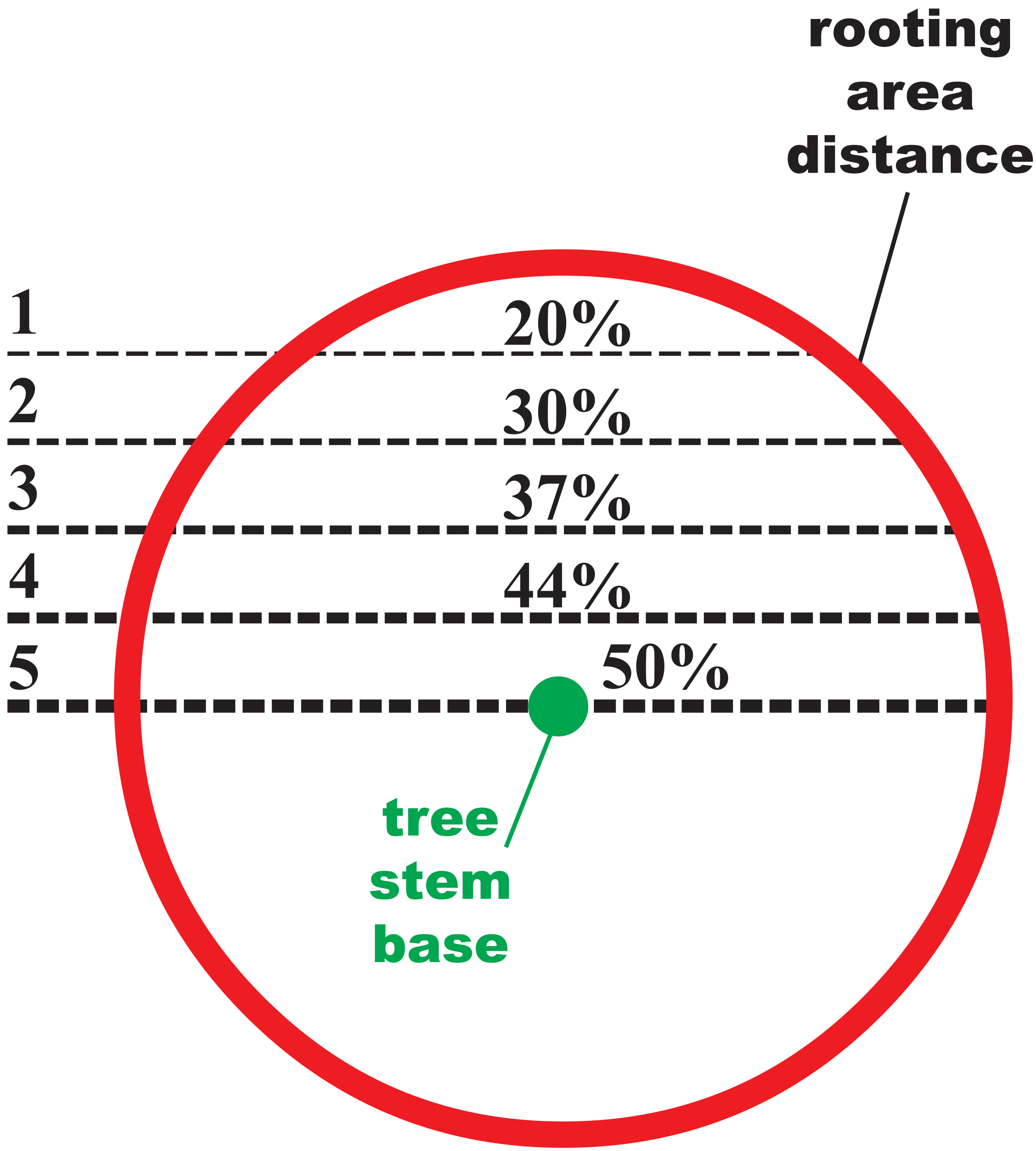


Figure 15: Percent tree rooting area disrupted when soil and roots are damaged on one side, divided into 1/5s.

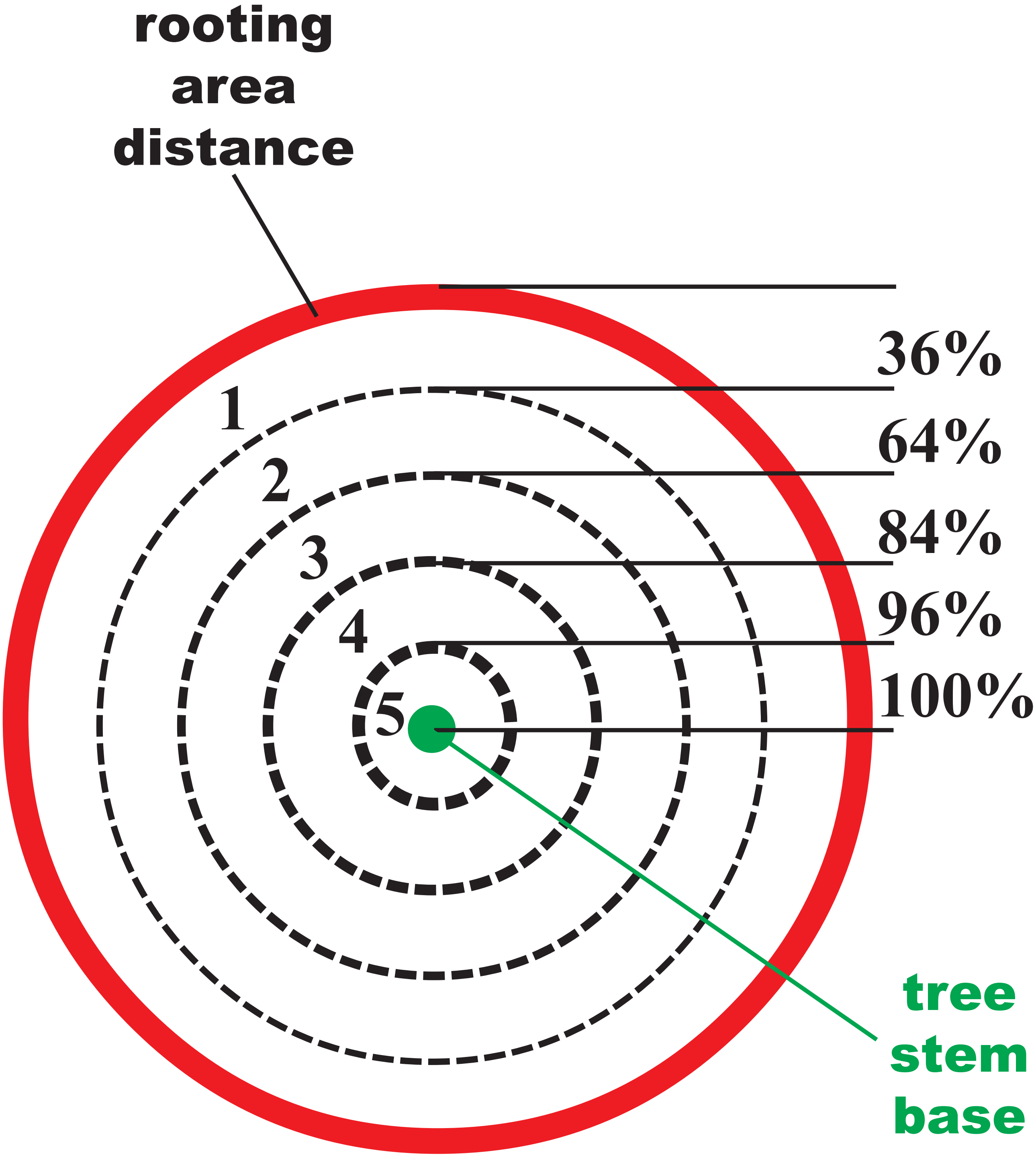


Figure 16: Percent tree rooting area disrupted when soil and roots are damaged all around a tree, divided into 1/5s.

fifths of tree critical rooting area encroached	whole area	half area
1/5	36%	20%
2/5	64%	30%
3/5	84%	37%
4/5	96%	44%
5/5 (all soil)	100%	50%

Figure 17: Percent of critical rooting area disrupted by development activities approaching tree and impacting soil.

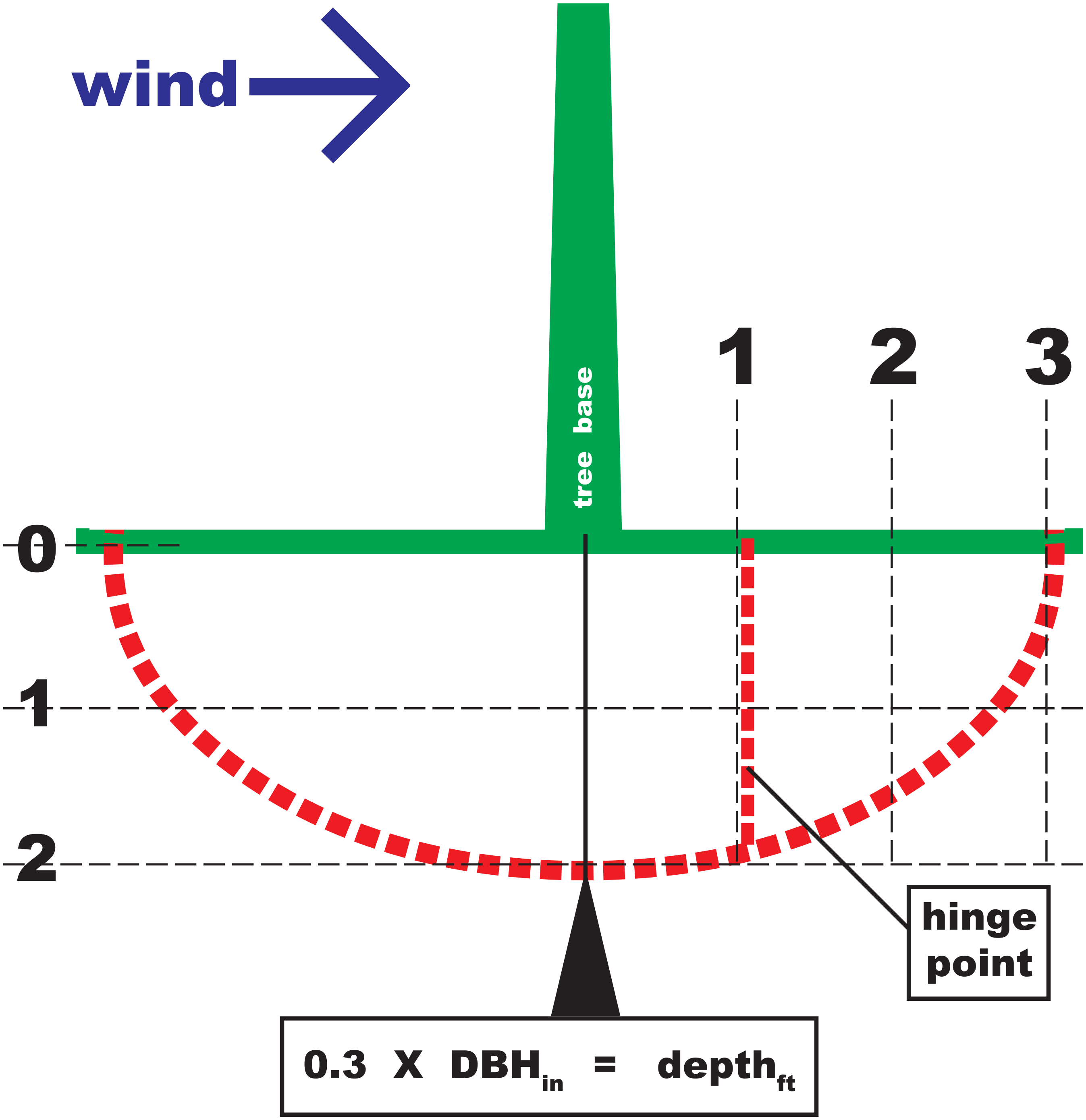


Figure 18: Side view of a tree root plate area showing root plate depth and location of hinge point in an unconstraining soil.

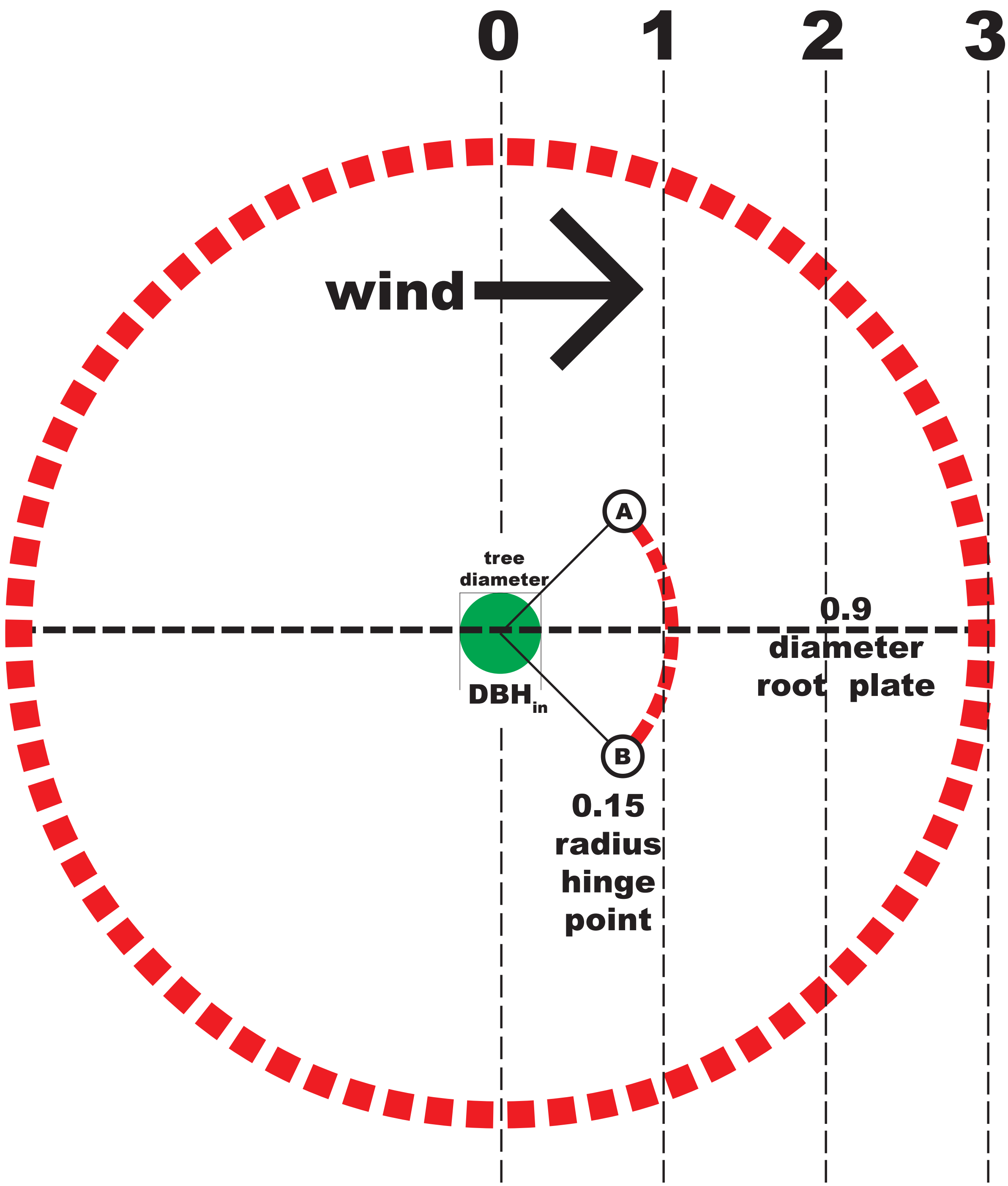
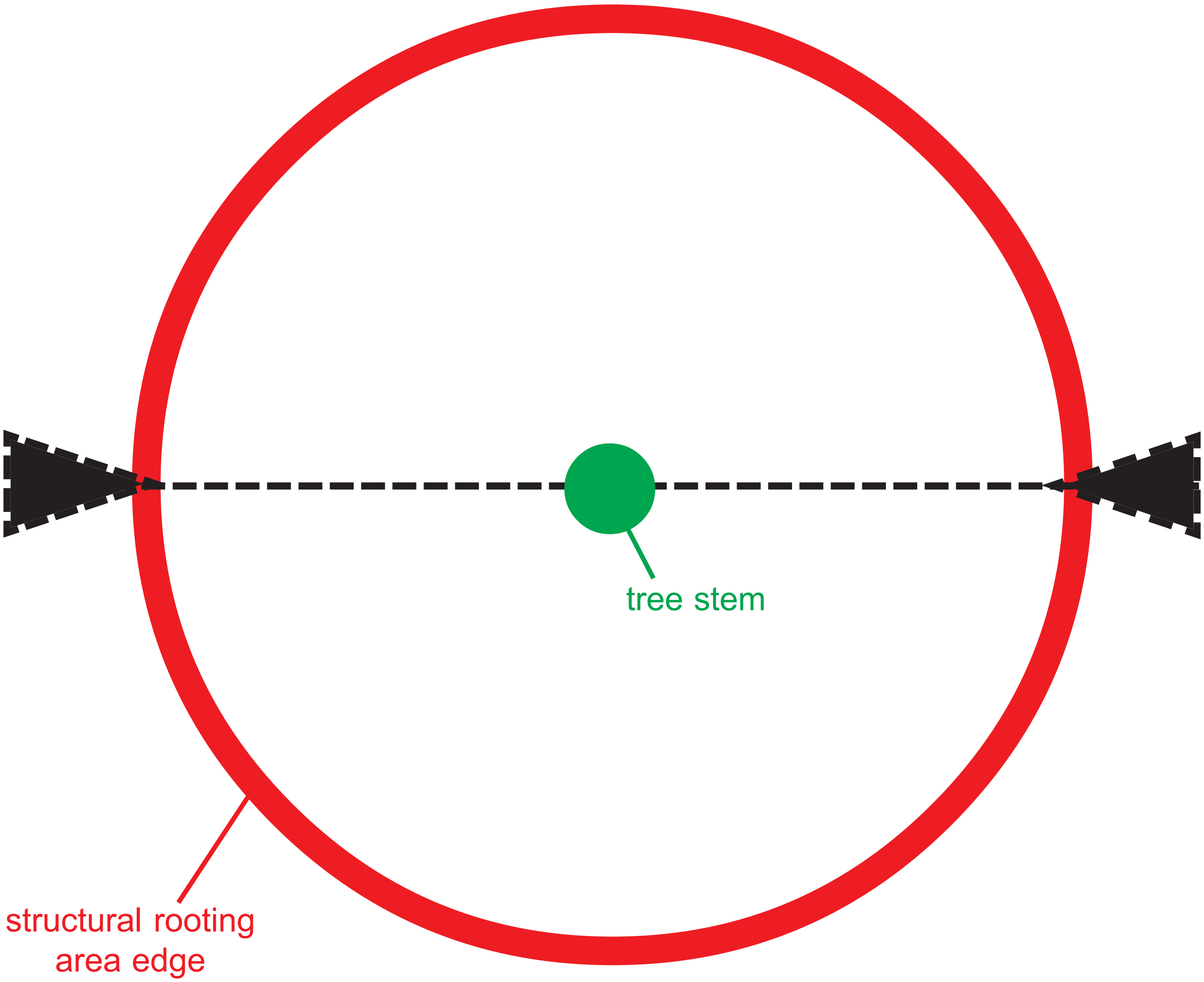


Figure 19: View from above of a tree root plate surrounding a tree of a set diameter (DBH_{in}).



0.9 X DIAMETER OF TREE
(DBH in inches)

=

STRUCTURAL ROOTING AREA DIAMETER
(in feet)

Figure 20: Estimated structural rooting area (root plate) distance for any tree.

TREE DIAMETER (inches)	STRUCTURAL ROOTING DISTANCE (feet of radius)	TREE DIAMETER (inches)	STRUCTURAL ROOTING DISTANCE (feet of radius)
1	0.5	26	12
2	1.0	27	12
3	1.5	28	13
4	2	29	13
5	2	30	14
6	3		
7	3	31	14
8	4	32	14
9	4	33	15
10	5	34	15
		35	16
11	5	36	16
12	5	37	17
13	6	38	17
14	6	39	18
15	7	40	18
16	7		
17	8	45	20
18	8	50	23
19	9	55	25
20	9	60	27
		65	29
21	10	70	32
22	10	75	34
23	10	80	36
24	11	85	38
25	11	90	41

Figure 21: Structural rooting distance in feet of radius, or root plate radius distance, used to minimize damage to tree structural base and minimize catastrophic tree failures due to root damage.

Determine & record the following items in the field —

1. Diameter of stem or branch at site of recent injury:
   - A. If the stem / branch area including the injury has little or no taper along its longitudinal axis then measure mid-injury diameter of the stem / branch. (midDIAMETER)

     OR

   - B. If the stem / branch area including the injury area has significant taper along its longitudinal axis, from injury top to bottom, then measure the diameter of the stem / branch at the top and bottom of injury. (topDIAMETER & bottomDIAMETER)

2. Dimensions of injury:
   - A. Total linear height or length (along longitudinal axis) of injury on stem / branch. (injuryHEIGHT)
   - B. Total linear width (perpendicular to longitudinal axis) of injury — not circumference of injury area. (injuryWIDTH)
   - C. Depth of injury at deepest point (as best as can be determined or estimated). (injuryDEPTH)

3. Estimate number of annual rings and tissue types breached with injury.

4. Location of injury section in tree.

5. Species of tree —
   attempt to gauge effectiveness & efficiency of tree's reaction to injury.

Figure 22: Extent and severity of mechanical injuries to trees on development sites.

STEP 1A: Determine stem / branch whole segment volume (no taper) =
injuryHEIGHT * 0.785 * $(\text{midDIAMETER})^2$

OR

STEP 1B: Determine stem / branch whole segment volume (taper) =
injuryHEIGHT * 0.262 * $(\text{topDIAMETER})^2$ +
0.785 * $(\text{bottomDIAMETER})^2$ +
SQUARE ROOT (0.616 * $(\text{topDIAMETER})^2$ * $(\text{bottomDIAMETER})^2$).

STEP 2: Determine injury segment volume (ellipsoidal shape factor) =
0.5 * injuryHEIGHT * injuryWIDTH * injuryDEPTH.

STEP 3: Determine DAMAGE EXTENT SCORE =
((VOLUME of injury segment (STEP 2) /
VOLUME of whole segment (STEP 1)) * 100

STEP 4: Determine DAMAGE SEVERITY SCORE.
Estimate number of annual rings & tissue types breached in injury.

Select one description which most fully matches depth of injury:

1. Bark to xylem (score = 0)
2. Expanded growing points, one, or two year old xylem (score = 1)
3. Three to seven year old xylem -- 100% sapwood (score = 2)
4. Seven year old xylem to end of sapwood -- 100% sapwood (score = 5)
5. Heartwood (score = 11)
6. Existing damage-modified heartwood and discoloration / decay columns (score = 23)

Figure 23: Steps in determining Damage Assessment Value for a tree injury.

(continued on next page)

STEP 5: Determine DAMAGE LOCATION SCORE.

1. Root collar / stem base area — two feet out and four feet up (score = 7)
2. Root plate area -- structural rooting zone supporting tree under compression (score = 6)
3. Base of live crown (score = 5)
4. Stem / trunk (score = 4)
5. Injury into reaction wood on basal 1/4 of the length of primary scaffold branches -- upper side tension wood in angiosperms & lower side compression wood in non-angiosperms (score = 3)
6. Ground contact / rain splash / direct irrigation wetting area (score = 2)
7. South and Southwest exposure with full sun (score = 1)

Locations numbers 1-5 above are unique positions and are non-additive. Locations numbers 6 & 7 are additive with other location scores.

STEP 6: Determine DAMAGE ASSESSMENT VALUE.

DAMAGE ASSESSMENT VALUE =
DAMAGE EXTENT SCORE +
DAMAGE SEVERITY SCORE +
DAMAGE LOCATION SCORE.

Species and individual tree differences play a critical role in setting management objectives for an area, risk acceptance levels, and tree removal decisions using the DAMAGE ASSESSMENT VALUE.

For long-term tree quality, suggested DAMAGE ASSESSMENT VALUES generated where managerial notice should particularly occur are at 15, 22.5, and greater than 30. Removal should be considered at a DAMAGE ASSESSMENT VALUE of 31 and above.

Figure 23: Steps in determining Damage Assessment Value for a tree injury. (continued)

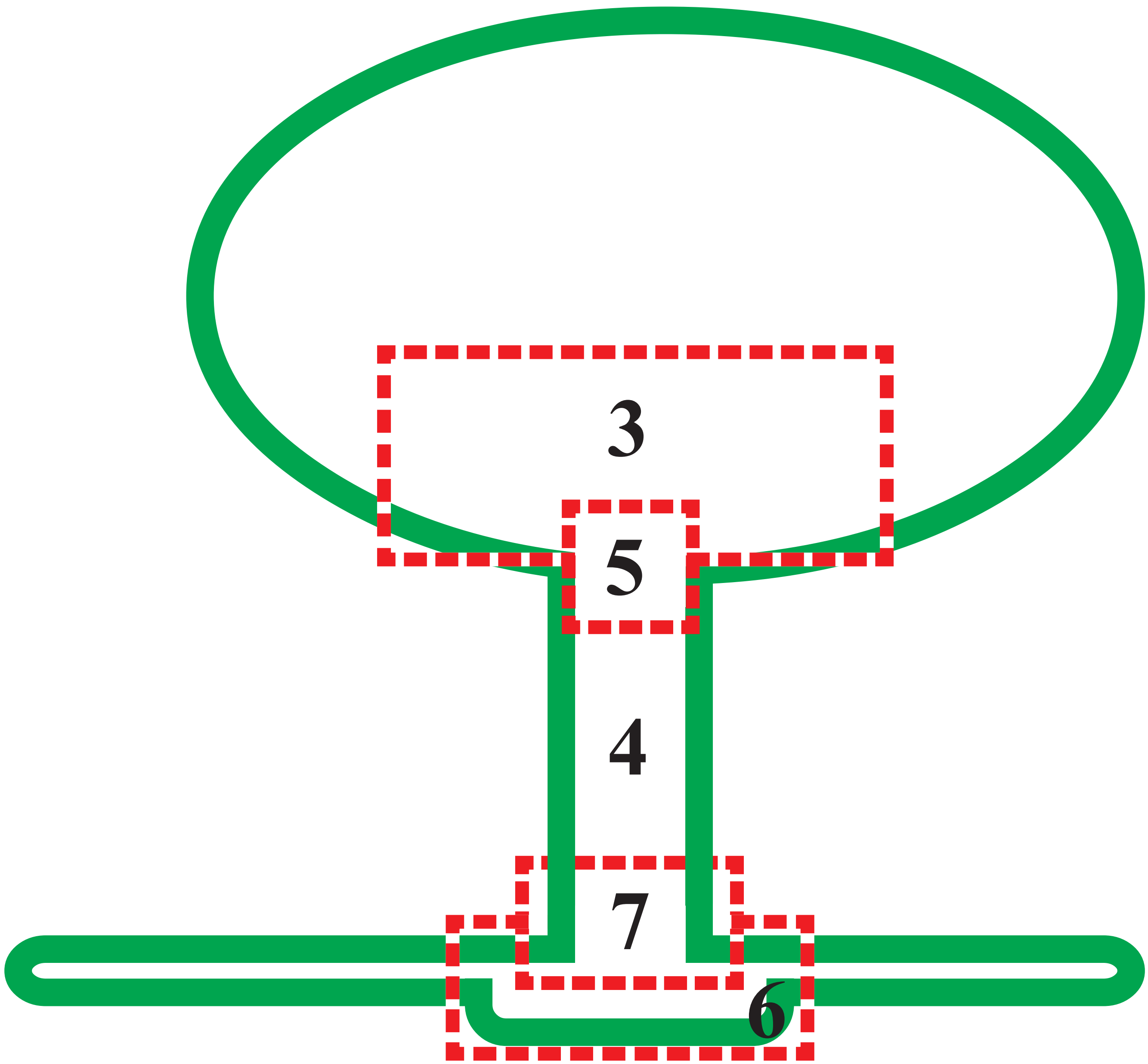


Figure 24: Score values for different injury locations within critical tree structural zones for use in assessing damage.

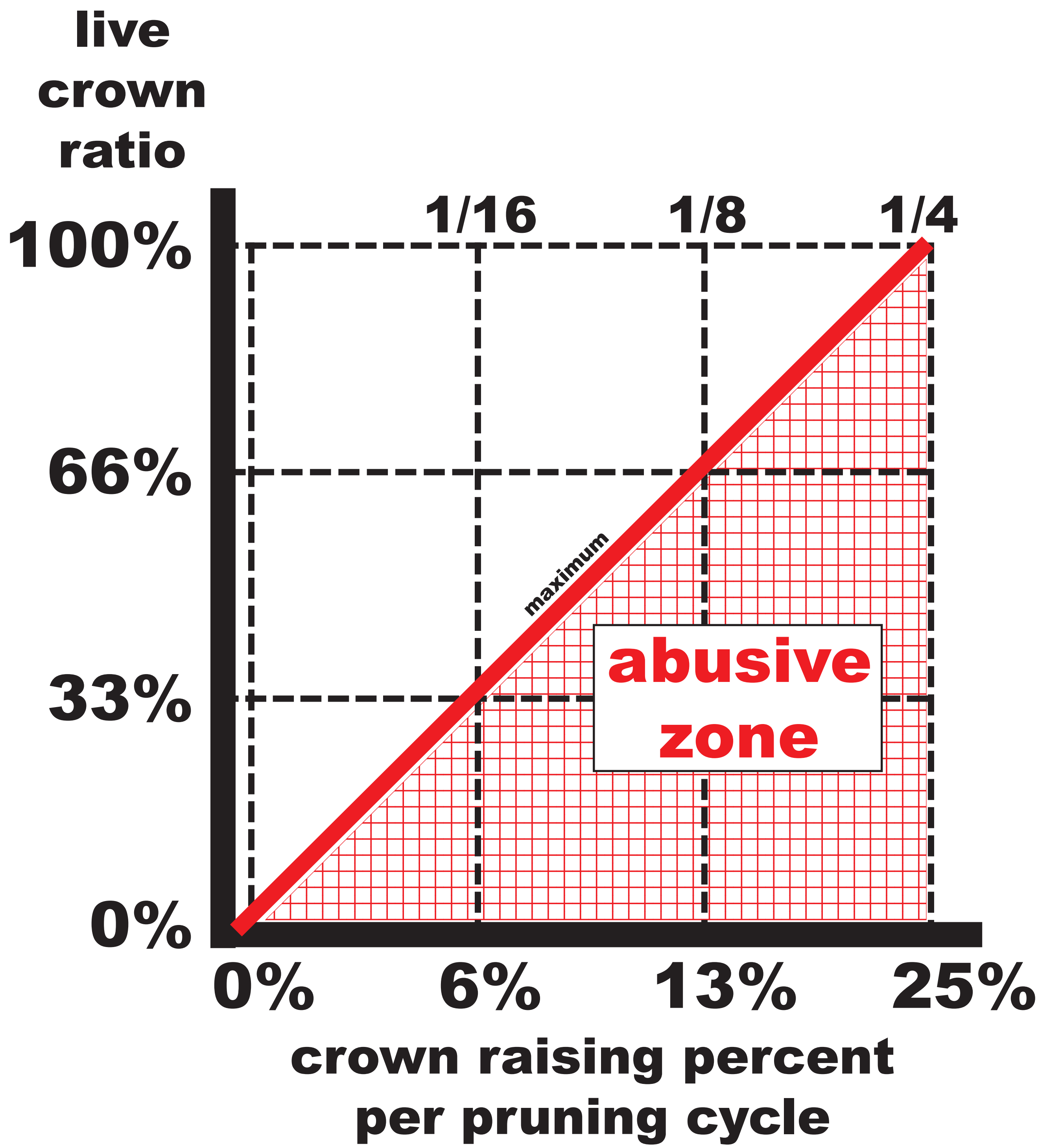


Figure 25: Coder Crown Raising Dose Assessment per pruning cycle for demonstrating potential crown raising abuse around a development site. Graph is the percent of live crown (height basis) which can be removed, if warranted.

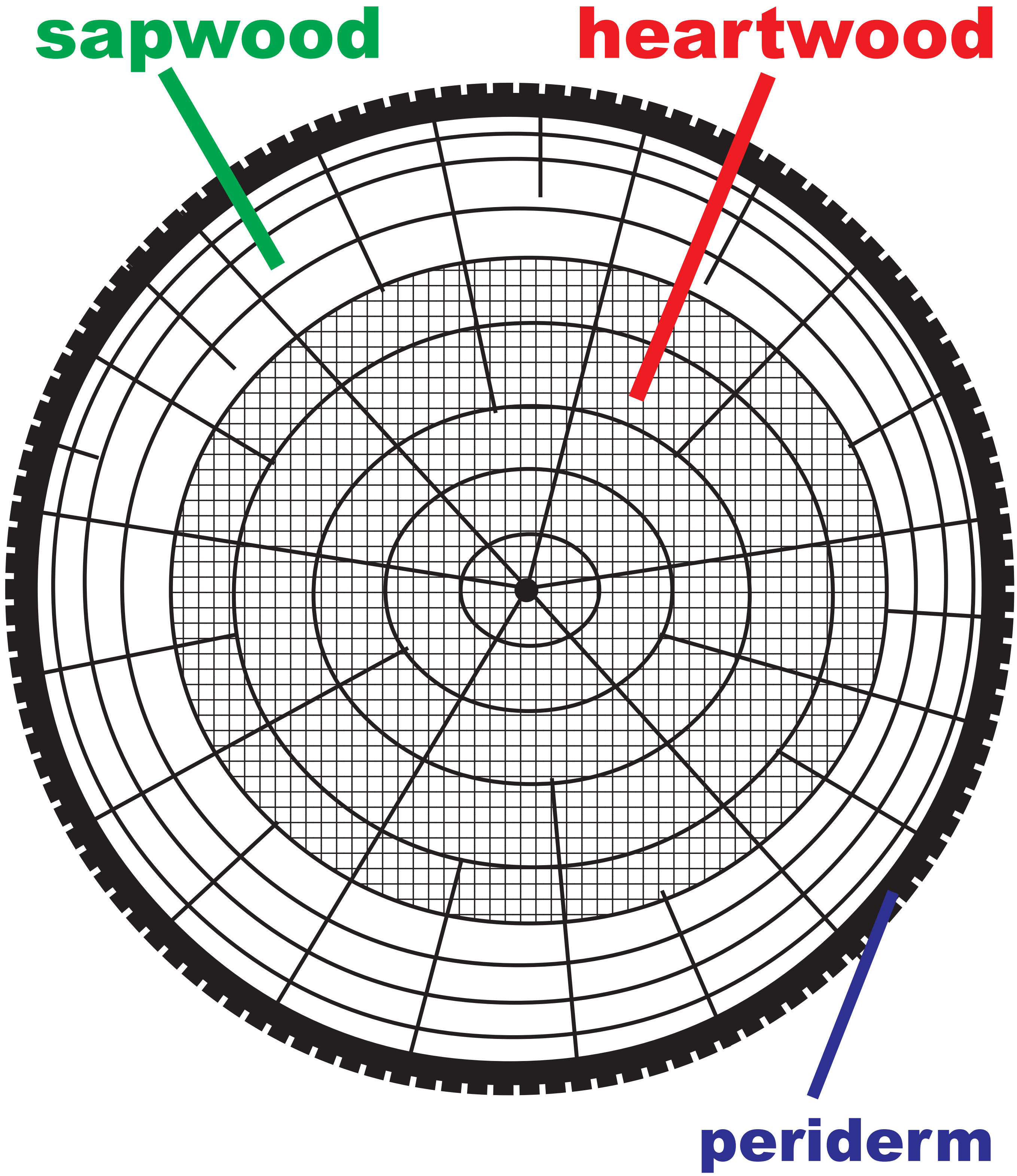


Figure 26: Diagram of a tree stem cross-section showing sapwood and heartwood (shaded).

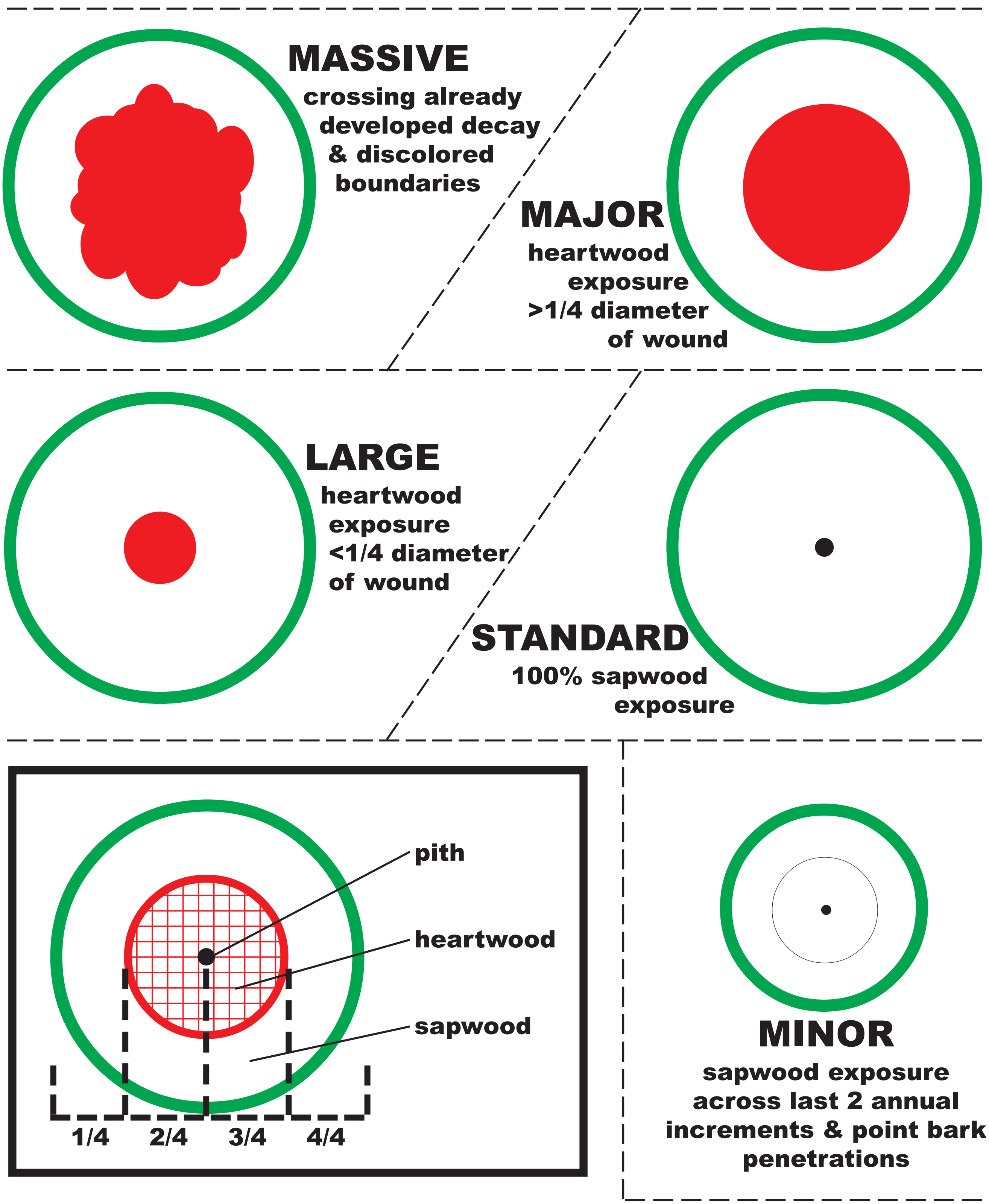


Figure 27: Coder Heartwood Exposure on Pruning Wounds Assessment for trees pruned, tipped or topped during development.

pruning wound type	maximum number of pruning wounds to single tree
massive	1
major	3
large	7
standard	15
minor	31

Figure 28: Coder Heartwood Exposure on Pruning Wounds Assessment -- Maximum number of pruning wounds applied to a single tree by wound type. Exceeding this count magnifies tree damage significantly.

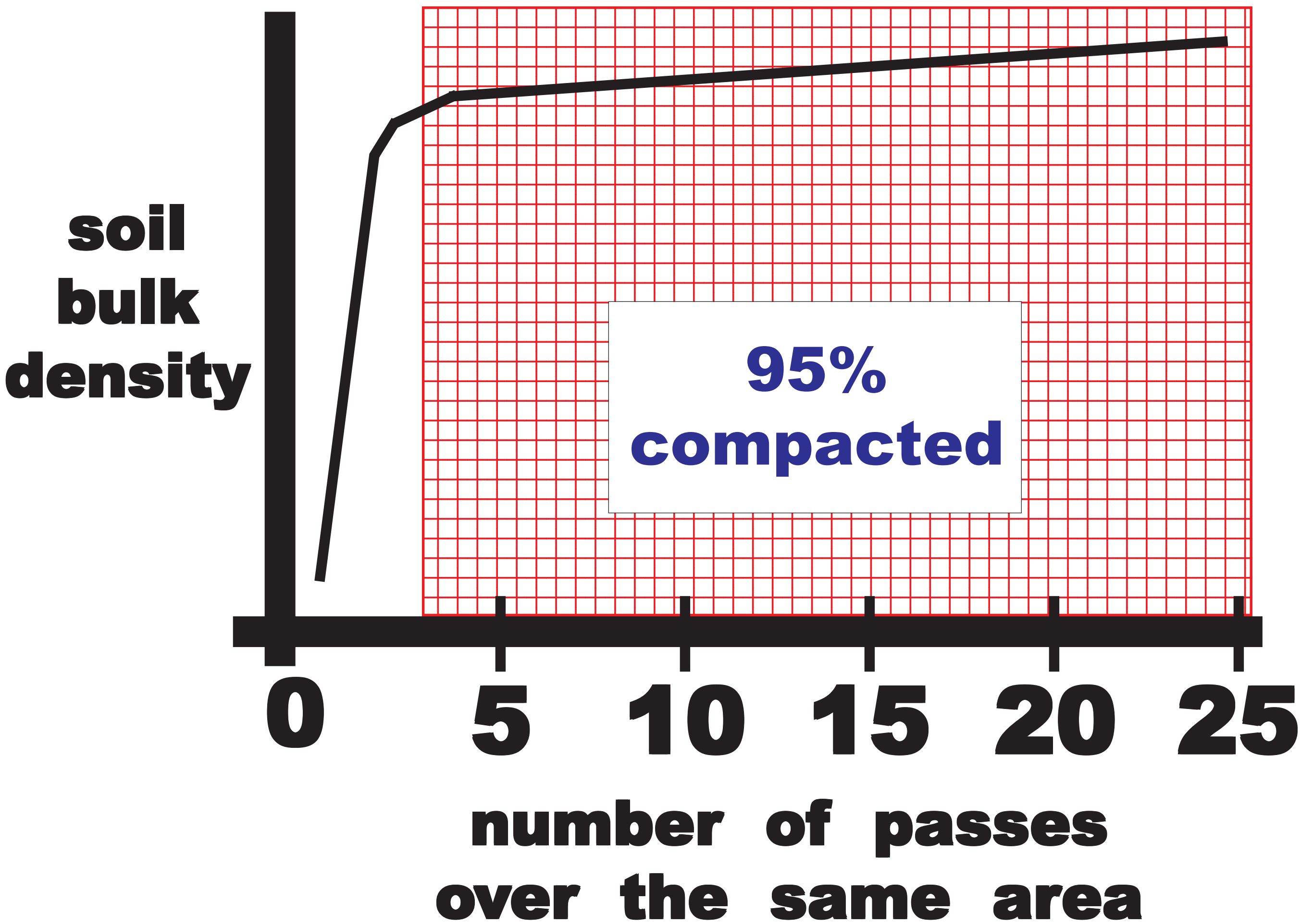


Figure 29: The number of passes over the same square inch of soil to increase bulk density (compact soil) to 95% of what it can be compacted.

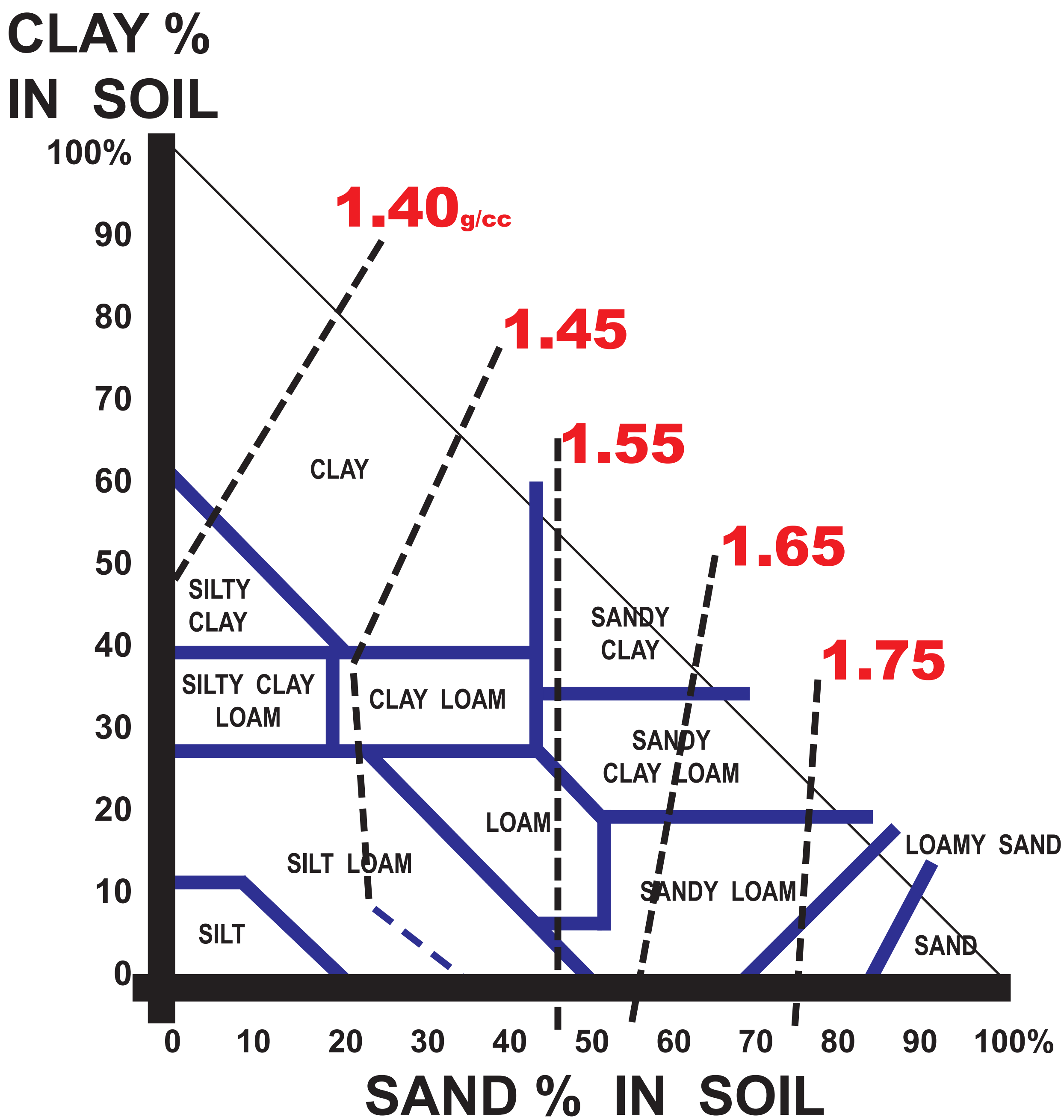


Figure 30: Soil textures classifications based upon sand and clay proportions, and dotted lines showing root-limiting bulk densities (g/cc). Values equal to or greater than listed density value (to the right of) will significantly constrain tree root growth.

soil texture	root-limiting bulk density (g/cc)	root-limiting % air pores
sand	1.8	24
fine sand	1.75	21
sandy loam	1.7	19
fine sandy loam	1.65	15
loam	1.55	14
silt loam	1.45	17
clay loam	1.5	11
clay	1.4	13

Figure 31: Soil compaction limitations on tree root growth and survival. Listed are soil physical attributes (soil bulk density in g/cc and soil air pore space percent) by soil texture class, where tree root growth becomes severely limiting.

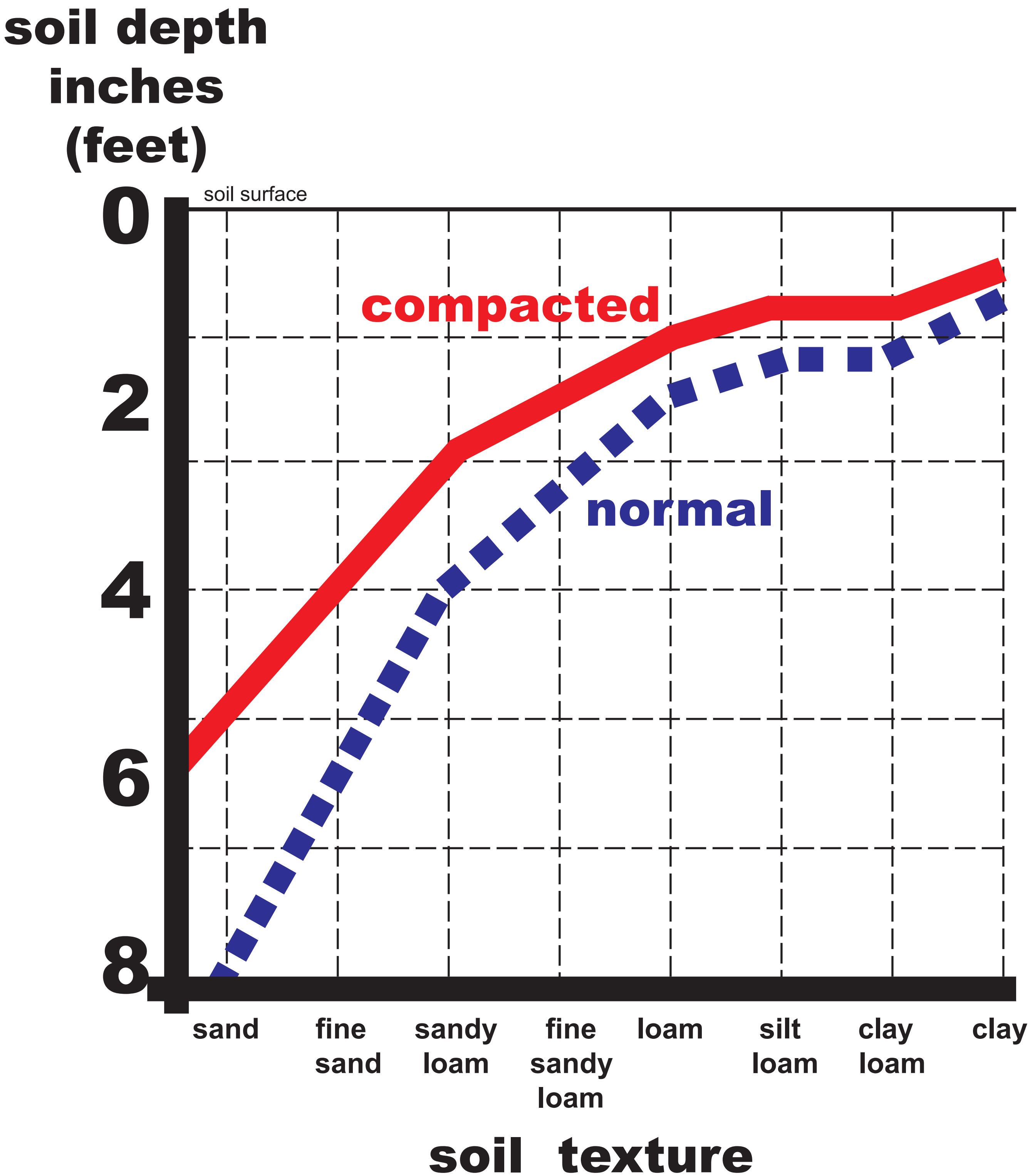


Figure 32: Effective soil depth in soils of various textures under compacted and non-compacted conditions.

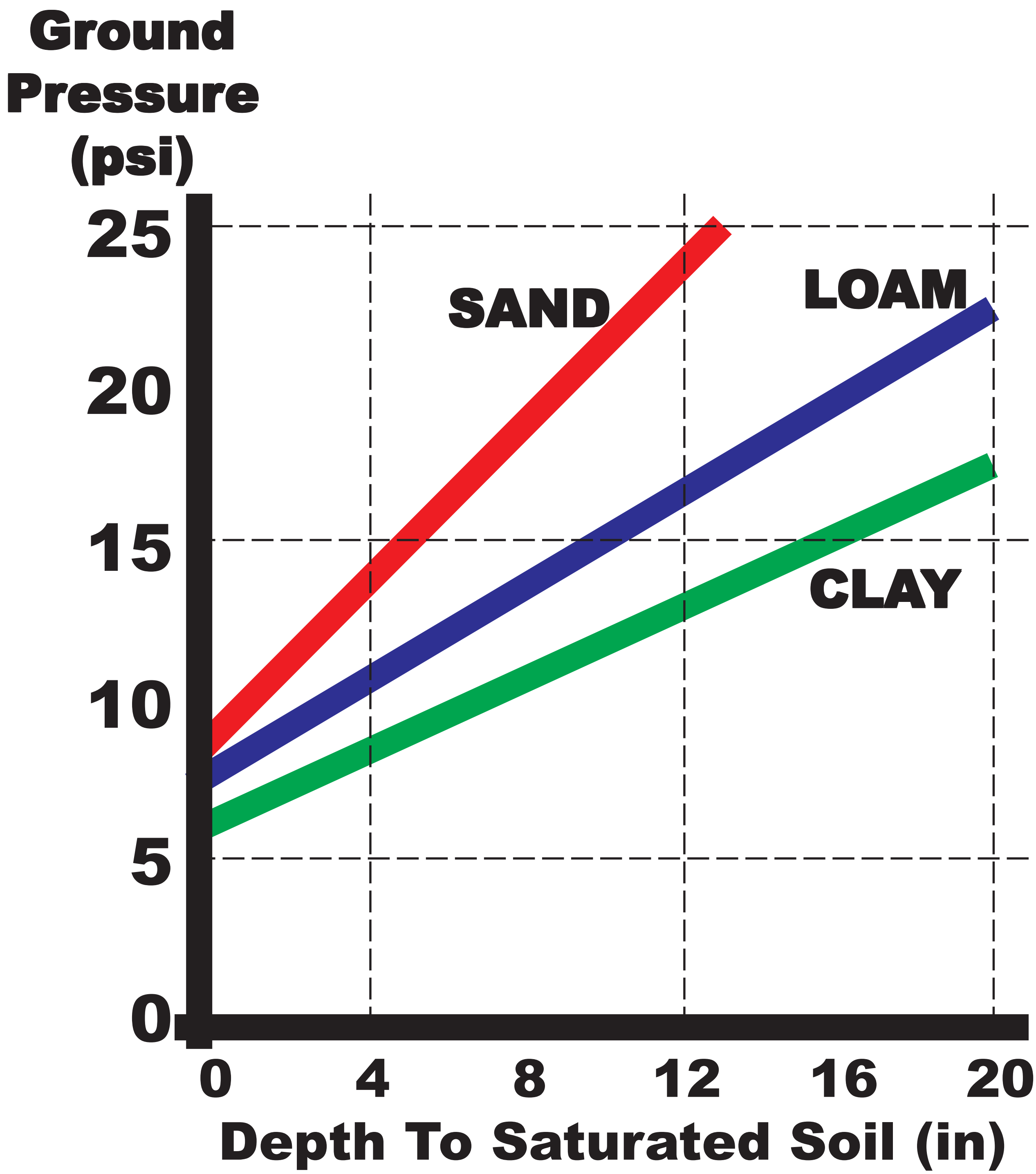


Figure 33: Soil rutting potential on wet soils under development activities. Ground pressure (psi) for vehicles: rubber tires = 20+; crawler track = 12+; and, floatation tires = 6+.

soil texture	initiation of root damaging soil fill	massive root damaging soil fill
sand	8 in.	24 in.
fine sand	6	18
sandy loam	4	12
fine sandy loam	3	9
loam	2	6
silt loam	1.5	4.5
clay loam	1.5	4.5
clay	1	3

Figure 34: Soil fill or lifts.

soil texture	significant root damaging soil removals
sand	10 in.
fine sand	8.5
sandy loam	7
fine sandy loam	5.5
loam	4
silt loam	3
clay loam	3
clay	2

Figure 35: Soil cuts.

Assessment Criteria: When three significant simple faults potentially leading to catastrophic loss are identified (in zone order), or one significant compound fault potentially leading to catastrophic loss is identified, stop and assess targeting aspects of the area, and reexamine site management objectives to determine risk designation (and removal priority if warranted). Examine tree from at least three sides.

ZONE 1: STEM / ROOT BASE (4 feet up and out) -- Bottom four feet of main stem and zone of rapid taper (ZRT) in roots stretching out four feet.

NO COMPROMISE -- NO DOUBT

ZONE 2: MAIN STEM (up to live crown and base of scaffold branches)
ZONE 3: PRIMARY ROOT SUPPORT (out to 1/2 drip line)
ZONE 4: PRIMARY BRANCH SUPPORT (major branch base area plus basal 1/3 of their length) Faults in zones two, three, and four are correctable with large inputs of time, money, materials and technical maintenance. Corrective measures may represent a notification of problems.

ZONE 5: REMAINDER OF WOODY ROOTS (out to 1.5 times dripline)
ZONE 6: REMAINDER OF CROWN
Zones five and six are not of primary structural concern but any faults still represent significant risks

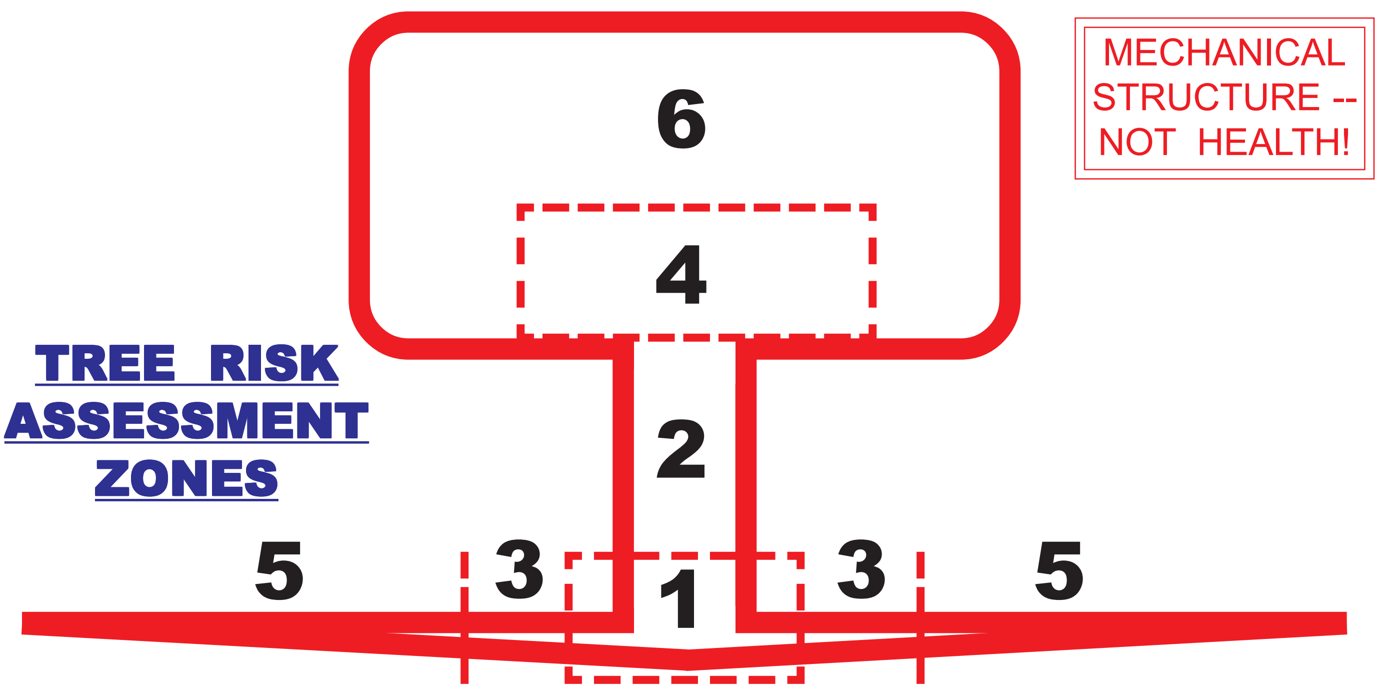


Figure 36: Tree Structural Risk Assessment.

TREE NUMBER: DATE:
ASSESSOR'S NAME:

TREE SPECIES: TREE DIAMETER:
SPECIFIC TREE LOCATION:

OWNERSHIP:

BOUNDARY LINE TREE _____ SINGLE OWNER TREE _____
OWNER'S NAME(S): PHONE(S):

TREE HEIGHT: DISTANCE FROM OTHER OWNERSHIP:

RISK ASSESSMENT:

MAJOR STRUCTURAL FAULTS (describe type and location):

FAULT #1 (ZONE=):

FAULT #2 (ZONE=):

FAULT #3 (ZONE=):

OTHER STRUCTURAL FAULTS:

MINOR RISKS:

TARGETING (people / property / resources over space and time):

RISK ACCEPTANCE BY OWNER GIVEN MANAGEMENT OBJECTIVES:
(hazard threshold)

ACTIONS RECOMMENDED: (ALWAYS MANAGERIAL / OWNER NOTICE OF RISKS)

______NO REMOVAL / NO RISK REDUCTION ACTION
______CORRECTIONS OF MINOR FAULTS / RISK REDUCTION
______REMOVAL

Figure 37: Sample Tree Structural Risk Assessment Form.

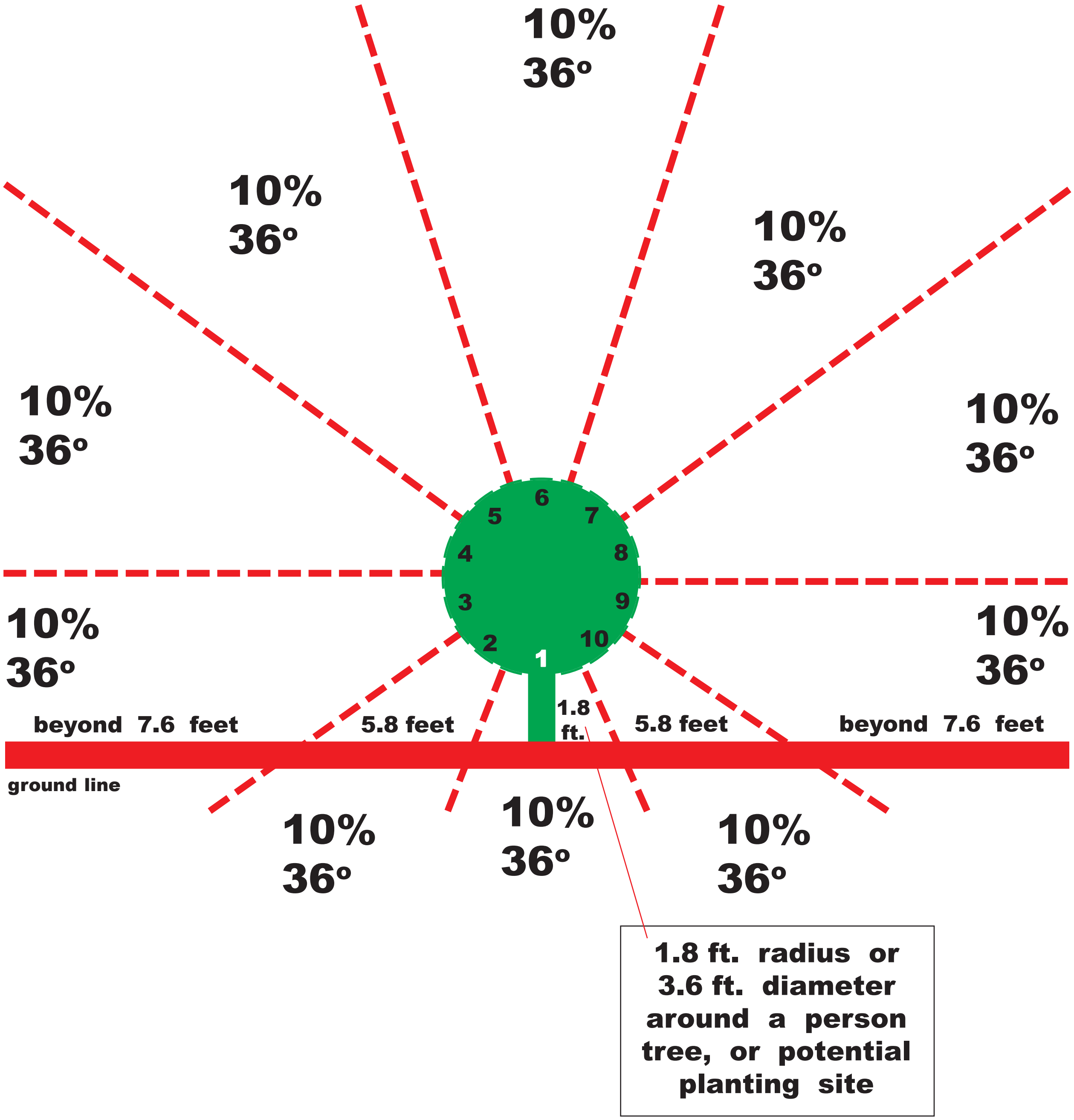


Figure 38: Diagram showing how heat loading can be estimated on a site using a combined and averaged view-factor for hardscapes / non-evaporative surfaces from 10 equal (36°) observation angles.

view-factor percent of non-evaporative, dense surfaces facing site	heat load multiplier
100%	3.0
90%	2.7
80%	2.4
70%	2.1
60%	1.9
50%	1.7
40%	1.5
30%	1.3
20%	1.2
10%	1.1
0%	1.0

Figure 39: Coder heat load multiplier values for various non-evaporative, dense surface view-factors (nearest 10% class) for a site or tree. Use heat load multiplier to estimate increased water use and carbohydrate use in trees under various heat loads.

Four Tree Growth Periods			
YEAR #1: dormancy **DORM**	first portion of growing season **GS1**	second portion of growing season **GS2**	senescence **SENC**
YEAR #2: dormancy **DORM**	first portion of growing season **GS1**	second portion of growing season **GS2**	senescence **SENC**
YEAR #3: dormancy **DORM**	first portion of growing season **GS1**	second portion of growing season **GS2**	senescence **SENC**
YEAR #4:	--(etc.)--		

Figure 40: Tree Growth Season Damage Exposure.

TREE DAMAGE EXPOSURE VALUE

=

(SEASONS INFLUENCED NUMBER +

SEASONAL STARTING PENALTY NUMBER +

SEASONAL ENDING PENALTY NUMBER) X

MULTIPLE-YEAR PENALTY FACTOR

Figure 41: Calculation of Tree Damage Exposure Value.

TREE DAMAGE EXPOSURE VALUE COMPONENTS

1) **SEASONS INFLUENCED**
(tree growth periods impacted by site development activities)

full year (GS1 + GS2 + SENC + DORM)= 25
- dormant season (DORM) = 1
- full growing season (GS1 + GS2 + SENC) = 24
  - first portion growing season (GS1) = 12
  - second portion growing season (GS2) = 9
  - senescence season (SENC) = 3

2) **SEASONAL STARTING PENALTY**
(tree growrth period when construction began)

dormant season (DORM)	= 0
first portion growing season (GS1)	= 6
second portion growing season (GS2)	= 4
senescence season (SENC)	= 2

3) **SEASONAL ENDING PENALTY**
(tree growth period when construction ended)

dormant season (DORM)	= 0
first portion growing season (GS1)	= 6
second portion growing season (GS2)	= 0
senescence season (SENC)	= 0

4) **MULTIPLE-YEAR PENALTY** (number of dormant period lay-overs)

-- multiply the summed results of preceding three steps by (1.05^{years})

examples: 2 years = 1.05^2 = 1.10X; 3 years = 1.05^3 = 1.16X.

5) YOU HAVE NOW COMPLETED THE FOLLOWING FORMULA:

TREE DAMAGE EXPOSURE VALUE =
(SEASONS INFLUENCED NUMBER +
SEASONAL STARTING PENALTY NUMBER +
SEASONAL ENDING PENALTY NUMBER) X
MULTIPLE-YEAR PENALTY FACTOR.

Figure 42: Tree Damage Exposure Value calculation.

ACTIVITIES END	ACTIVITIES BEGIN YEAR 1 DORM	YEAR 1 GS1	YEAR 1 GS2	YEAR 1 SENC
YEAR 1 DORM	1	---	---	---
YEAR 1 GS1	18	24	---	---
YEAR 1 GS2	22	27	13	---
YEAR 1 SENC	25	30	16	5
YEAR 2 DORM	29	34	19	7
YEAR 2 GS1	48	54	39	26
YEAR 2 GS2	52	57	42	30
YEAR 2 SENC	55	61	45	33
YEAR 3 DORM	59	65	60	36

Figure 43: Calculated Tree Damage Exposure Values

Minimum Recovery Times

-- Dormant season (DORM)
= 1 year

-- Senescence season (SENC)
= 2 years

-- Second portion of growing season (GS2)
= 3 years plus time to end of growing season

-- First portion of growing season (GS1)

diffuse porous trees
= 3 years plus time to end of growing season

ring porous / gymnosperm trees
= 4 years plus time to end of growing season

Figure 44: Tree Recovery Times based upon each tree growth period impacted by site development activities (running concurrently).

TREE DAMAGE IMPACTS

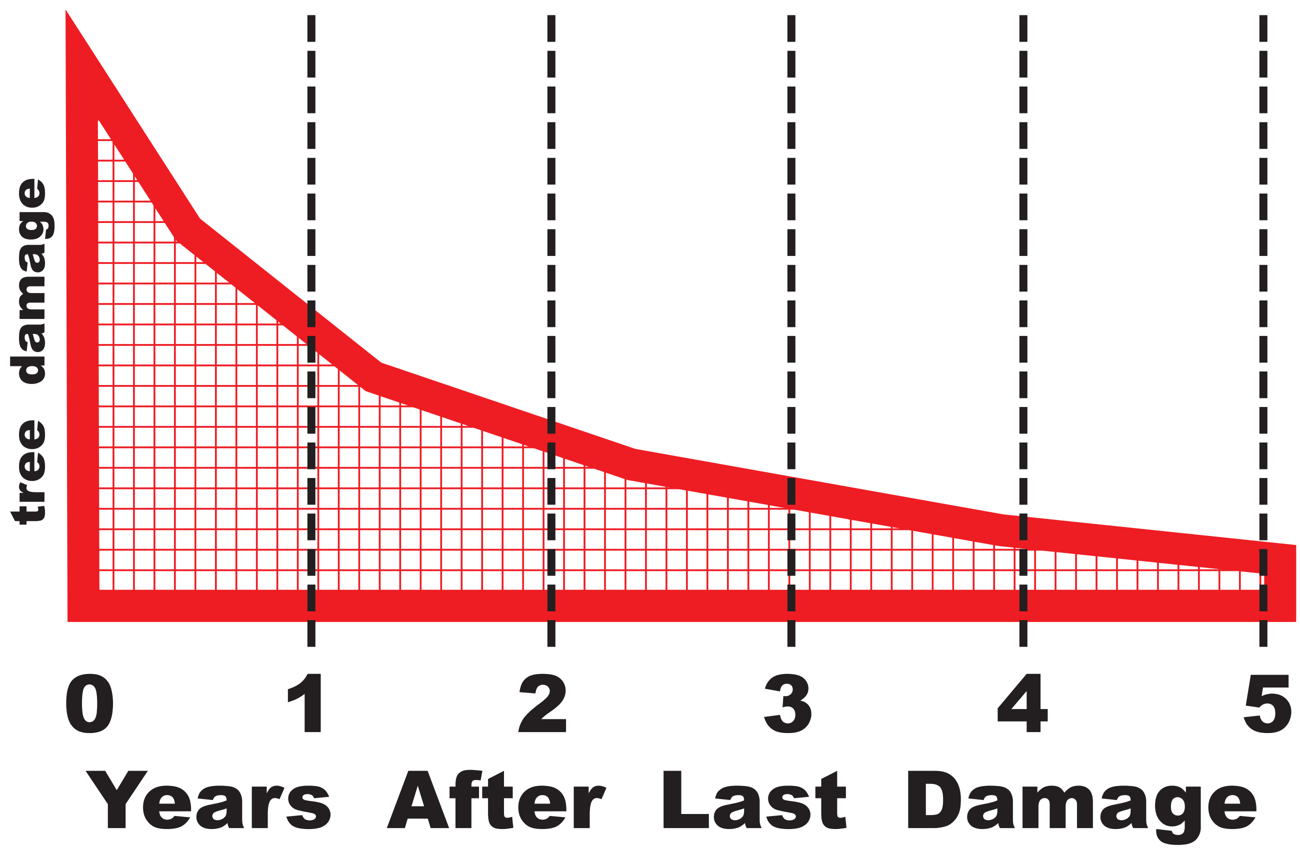
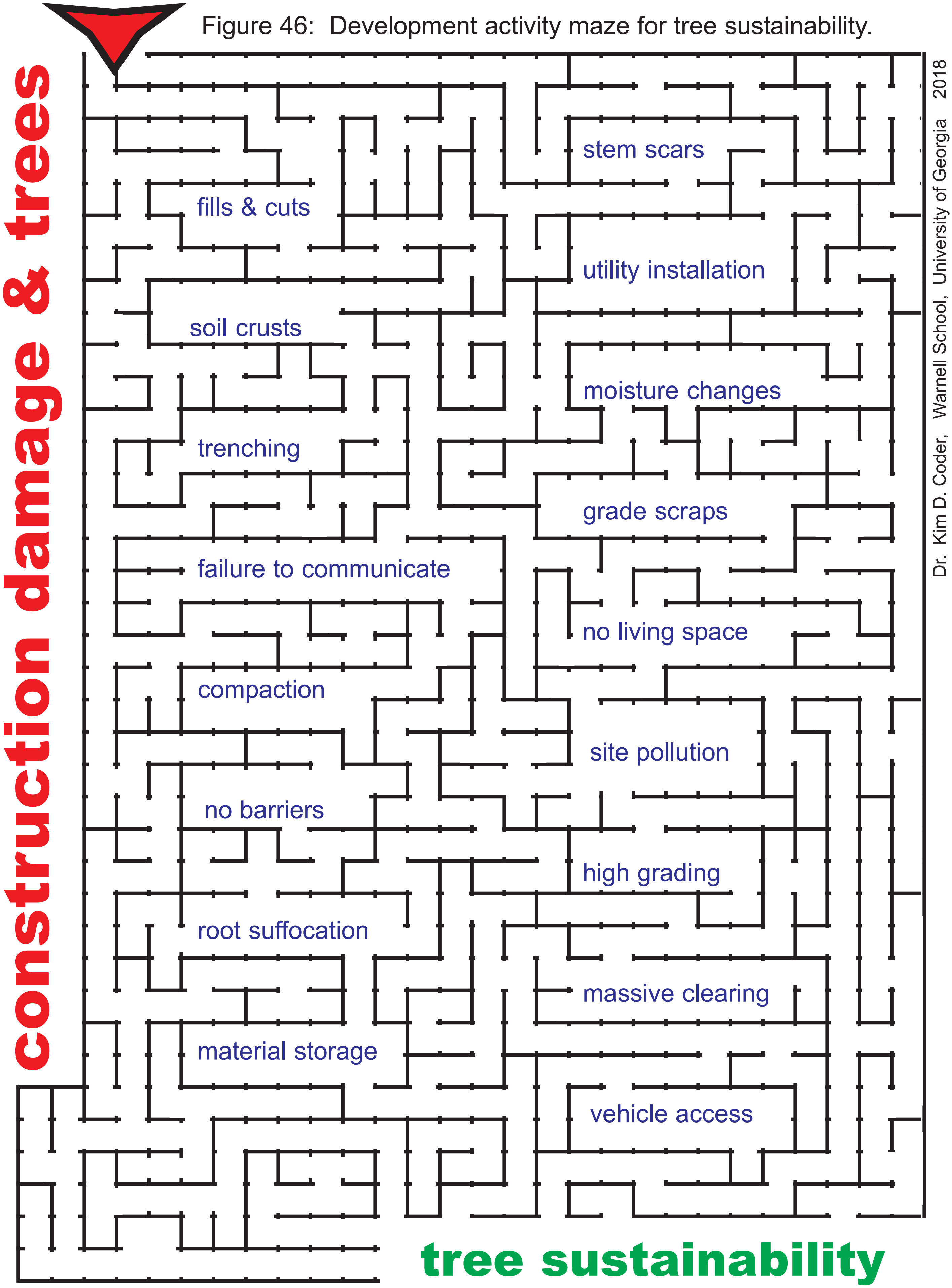


Figure 45: Site development and construction damage event horizon for trees.

Figure 46: Development activity maze for tree sustainability.



Development Site Damage Assessment Form:
Single Tree Examination and Prescription

project name:

---

assessor:
date:
tree location:
area: site strata number:
location description:

tree number:

ownership confirmation -- full ______ boundary _______

---

tree attributes
species:
trunk diameter (inches at 4.5 feet along axis):
crown radius (feet) 0° : 180° :
60° : 240° :
120° : 300° :
nearest touch (feet and azimuth):
live crown ratio (10% classes):

---

critical rooting distance (feet in radius away from stem):
nearest touch (feet and azimuth or side direction):
structural root plate distance (feet in radius away from stem):
nearest touch (feet and azimuth or side direction):
exposed roots extent (root flair / large surface roots):

---

primary branch height (feet above surface)
lowest primary branch size (one foot from trunk):
direction of growth:
second lowest branch size (one foot from trunk):
direction of growth:
other branches of concern:

---

structural faults:

---

health problems:

---

site attributes
topographic location / position: slope: aspect:
soil characterization
texture: bulk density: depth:
surface features:
major limitations:

cuts / fills / water and oxygen availability:

---

tree number:

damage class(es) -- describe damage

______Class 1 -- General root system destruction & rooting space loss:

______Class 2 -- Root collar and structural support root damage:

______Class 3 -- Mechanical / structural damage to stem and/or major branches:

______Class 4 -- Soil problems:

______Class 5 -- Wind load changes:

______Class 6 -- Potential obstructions:

Tree Damage Exposure Value: ______ Recovery Time: ______ years

---

recommendations

PRIORITY removal: ________ removal: ________ do not remove: ________

immediate treatments:

future treatments:

potential storm damage risk 1° -- 2° -- 3°
managerial notice points:

pre-construction appraised value ($):

post-construction appraised value ($):

expected life-span and prognosis:

Outreach
Warnell School of Forestry & Natural Resources
UNIVERSITY OF GEORGIA

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