UNIVERSITY OF GEORGIA
Warnell School of Forestry & Natural Resources

Publication WSFNR-22-14C

February 2022

Assessing Tree Risks Of Lightning Strikes

Dr. Kim D. Coder, Professor of Tree Biology & Health Care / University Hill Fellow
University of Georgia Warnell School of Forestry & Natural Resources

Storm clouds with the right internal conditions can generate large numbers of electric charges separated by miles of air. The ground surface mirrors the opposite charge of the cloud base with a rolling wave following below the rapidly moving storm cloud. When and where cloud leaders and ground streamers connect is impossible to precisely predict.

The strength of ground streamers (ground field enhancement) can be estimated based upon different objects or neighborhoods on the ground. Risk assessments are concentrated on ground streamer strength while leader / streamer connectivity is highly variable depending upon each storm. Ground streamer strength (field enhancement) is based upon many factors which can be increased to a point where any cloud leaders in the area (i.e. within 5 to 6 times tree height above a tree) will interconnect and exchange charges.

A tree's topographic position and height above surrounding objects or structures play crucial roles in determining where lightning will strike. Isolated, tall trees would have the potential for strong ground streamer strength and serve as a conduit of charge exchange exceeding simple random probabilities. Valuable trees along the path of potential lightning strikes, where risk is based upon ground streamer strength factors, should be evaluated.

Three simple and quick risk analysis methods are presented here. They are based on an educational summary of lightning risk factors in trees and none should be used as a single source in determining lightning conduction system requirements for trees.

Height Method

The first assessment method for gauging lightning risk to trees is the Coder Tree Height Assessment for Lightning Risk used to help tree health care providers in discussions with clients as to whether a tree lightning conduction system should be installed. This risk assessment process is based only upon historic lightning ground strike information for the tree location (i.e. annual lightning ground strike density per square mile), and tree height. (derived from Bazelyan & Raizer 2000)

Figure 1 is a graph comparing tree heights in feet with lightning ground strike per square mile per year at four different risk levels. Risk levels are provided for 1 in 25 years (4%), 1 in 50 years (2%), 1 in 100 years (1%), and a 1 in 200 years (0.5%) chance of a lightning strike. Higher risk values, like 1 in 10 years (10%) and 1 in 5 years (20%), are considered so likely to occur, risk assessment is not required. The fewer lightning strikes per year at any location, the greater tree height at which various risk levels of a strike occur.

Figure 2 shows the great risk variation in tree heights. Notice above a lightning strike density of about 18 ground strikes per square mile per year, there is little difference in tree risk based upon tree height. Below this strike density, tree height differences do differentiate risk levels more clearly.

Figure 3 provides heights (in feet) for single, isolated trees at the greatest risk for lightning strikes depending upon tree location (i.e. lightning ground strike density per square mile per year.) For example, if your location sustains 15 lightning ground strikes per square mile per year, an 81 foot tall single isolated tree would fall into the 10% annual risk category and is considered a severe risk of a lightning strike. If a similar 80 foot tall tree in the same area is at least 35 feet above surrounding structures and other trees, then this tree would fall into a 2% annual risk category and is considered only a moderate risk of a lightning strike.

Uman Ground Collection Method

Figure 4 provides a second way of considering how tree height impacts the number of lightning strikes for a given strike density. This method represents the collection area of a tree, or the enhanced area for lightning strikes based upon added tree height. Figure 5 illustrates how the tree collection area is calculated using tree height and crown diameter.

Four times (4X) tree height is used traditionally for estimating lightning strikes to trees under 50 feet tall. Six times (6X) tree height is used as an area calculation for international lightning protection standards and trees over 50 feet. Figure 6 provides an example probability of tree lightning strikes using N=15 lightning strikes per square mile per year, and a crown diameter of 30 feet. (derived from Uman 2008). Note how lightning strike potential greatly increases with tree height above 45 feet.

Coder-Cripe Method

The third assessment method for gauging lightning risk to trees is the Coder-Cripe Ground Effects Lightning Risk Assessment method. This assessment uses a number of lightning strike risk factors (i.e. enhanced electric field -- ground streamer strength factors) associated with trees. Tree height, relative height of a tree within its surroundings, location on landscape, closeness of neighboring trees and structures, and historic number of ground strikes per square mile per year are all incorporated. The result is a simple assessment for determining if a lightning conduction system is warranted. It does not (can not) include tree values or benefit / cost analysis. This assessment is a training guide for determining potential lightning strike probabilities on trees. (based partially on Robert E. Cripe's work).

Determinations

To use this assessment aid, you will need several pieces of information about the assessed tree and site. An accurate tree height and neighboring structure height are essential. Use a clinometer, hand altimeter, or height stick with a 100 feet tape to record height and distance measures.

Figure 7 represents risk factor #1 -- where is the tree located topographically in the landscape. Higher locations, compared with lower growth sites are more likely to have strong ground streamer strengths. Large scale, landscape level positions which accentuate a tree's effective height and ground streamer strength carry higher risks. Trees on hilltops will usually have stronger ground streamer strength than trees in valley bottoms. Determine the risk percentage closest to the assessed tree's topographic location.

Figure 8 represents risk factor #2 -- relative height of the tree crown. Determine relative tree height compared with neighboring trees. The more a tree crown rises above neighboring trees, the stronger its potential ground streamer strength. This figure shows tree crowns and names of crown classes (relative height values). The classic forest crown class descriptions are used to determine if the assessed tree is taller (an emergent crown class) than its surrounding tree neighbors. Pick the risk percentage closest to the assessed tree's crown class. Single isolated trees with no surrounding trees would be assessed at 100%.

Figure 9 represents risk factor #3 -- tree crown openness or view aspect. Determine how open a tree crown is from the sides. Trees open to water, fields, large open spaces, or facing areas with vegetation significantly shorter in height, will leave the sides of their crowns open and more likely to produce strong ground streamers. This figure shows tree crowns from above clustered around the assessed tree (i.e. the darkest circle) and various levels of openness of the assessed tree crown. Risk percent is equal to degrees of openness between 0^o & 360^o divided by 3.6. Figure 10. Single trees standing alone are open on all sides and tend to have the strongest ground streamer strength. As neighboring trees close in on different sides, the openness risk factor declines. A risk percentage for the degree of tree crown openness should be determined.

Figure 11 represents risk factor #4 -- relative height of other structures in the neighborhood. A direct measure of the single tallest structure or tree in the neighborhood is compared to the assessed tree. The neighborhood distance on the ground is a radius three times assessed tree height (3 X tree height) away from the assessed tree. Within this neighborhood distance, calculate the relative height difference for the single tallest structure or tree. The taller the tree is in its neighborhood, the stronger its potential ground streamer strength. Figure 12. A risk percentage for how tall the assessed tree is compared to the tallest structure in the neighborhood should be determined.

Figure 13 represents risk factor #5 -- proximity of human or property targets. When lightning strikes a tree, collateral damage can result. The risk of a tree lightning strike impacting structures, electronics, animals and humans in the vicinity is a major concern. A risk assessment must determine the spacial relationship between trees and these targets. The closer and taller the assessed tree is to a target, the stronger ground streamer potential, and the more likely target damage and injuries (possibly death) may occur if lightning strikes.

Structures surrounded by, or overhung with, tree branches should have their own lightning protection system. The distances listed for risk assessment are based upon radial distances away from the base of the assessed tree stem at the ground surface. A risk percentage for collateral damage to targets close to the assessed tree should be determined.

Summing Up

Once the first five risk factors have been determined, the percentage numbers (not decimal percents) should be added together. The total sum should be divided by 500 yielding a value < 1.0. The result is called a Composite Risk Factor since it combines or averages the first five risk factors together. Figure 14.

Taking Chances

Figure 15 represents risk factor #6 -- annual lightning strike probability. Different places across globe have different lightning strikes per square mile per year. The map represents the number of lightning strikes per square mile per year for the Southeastern United States. This map provides the lightning strike number to be used in the calculation for Risk Factor #6. The other value needed is the height of the tree. These two values are placed in the following formula:

Annual Lightning Strike Probability =

$$\textbf{lightning strike number} \;\; \textbf{X} \;\; [3.142 \;\; \textbf{X} \;\; ((\textbf{tree height in feet}) \;\; \textbf{X} \;\; 3)^2 \; / \; (5{,}280)^2\,]$$

The Annual Lightning Strike Probability value represents a risk value for a single tree standing alone in a flat landscape with nothing taller in its neighborhood. An Annual Lightning Strike Probability risk factor should be determined.

The Composite Risk Factor (determined from Risk Factors #1 - #5) should be multiplied by the Annual Lightning Strike Probability (Risk Factor #6). The result is the Total Tree Lightning Strike Risk Value. Figure 16. If the Total Tree Lightning Strike Risk Value is greater than 0.05, then there is greater than a 1 in 20 chance a tree may be struck by lightning each year. This is considered a severe risk of tree damage. If the Total Tree Lightning Strike Risk Value is 0.01, a 1 in 100 chance exists a tree may be struck by lightning each year. This is considered a low risk. Figure 17.

Unfortunately this risk assessment does not include expected tree life-span, or historic / cultural values of the tree. A tree expected to live another 300 years, and culturally valuable, would have a much greater risk, and much higher human remorse factor if lost, than this assessment tool would determine. A Tree Lightning Risk Assessment Worksheet is provided in Figure 18.

Fighting Myths

There has developed over many years a series of tree associated lightning protection concepts. Figure 19 shows the work of Makela's team in field testing these traditional ideas. The two fundamental ideas are: 1) when trees are most likely to be struck; and, 2) lightning attributes which cause more tree damage. Some of these traditional concepts are supported by field observations. One specifically requires more research -- in a forest landscape, the tallest tree is not most likely to be struck.

Citation:

Coder, Kim D. 2022. Assessing tree risks of lightning strikes. Warnell School of Forestry & Natural Resources, University of Georgia, Outreach Publication WSFNR-22-14C. Pp.23.

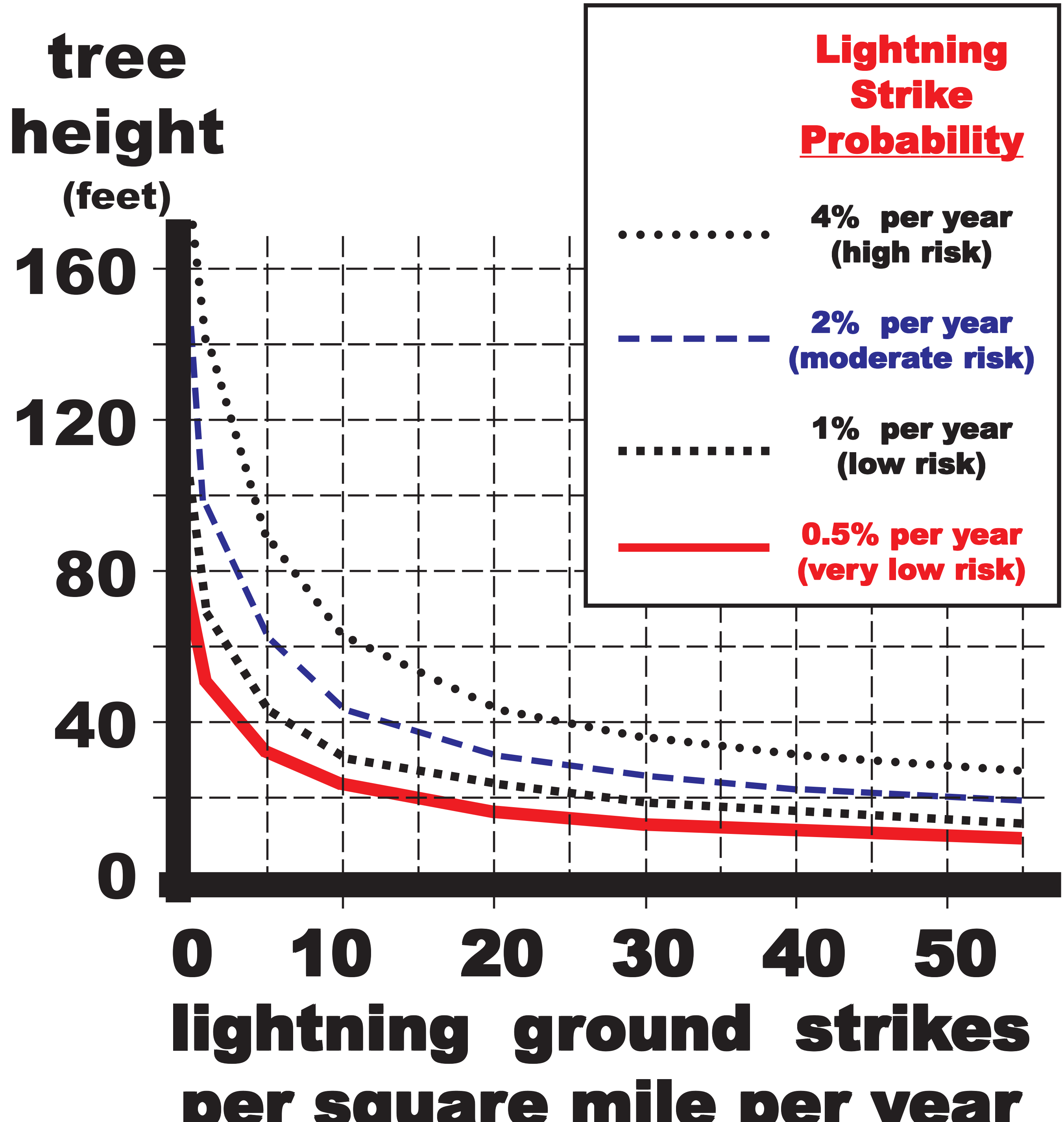


Figure 1: Risk level for tree lightning strikes based on tree height in feet across lightning density values measured as ground strikes per square mile per year.
(derived from Bazelyan & Raizer 2000)

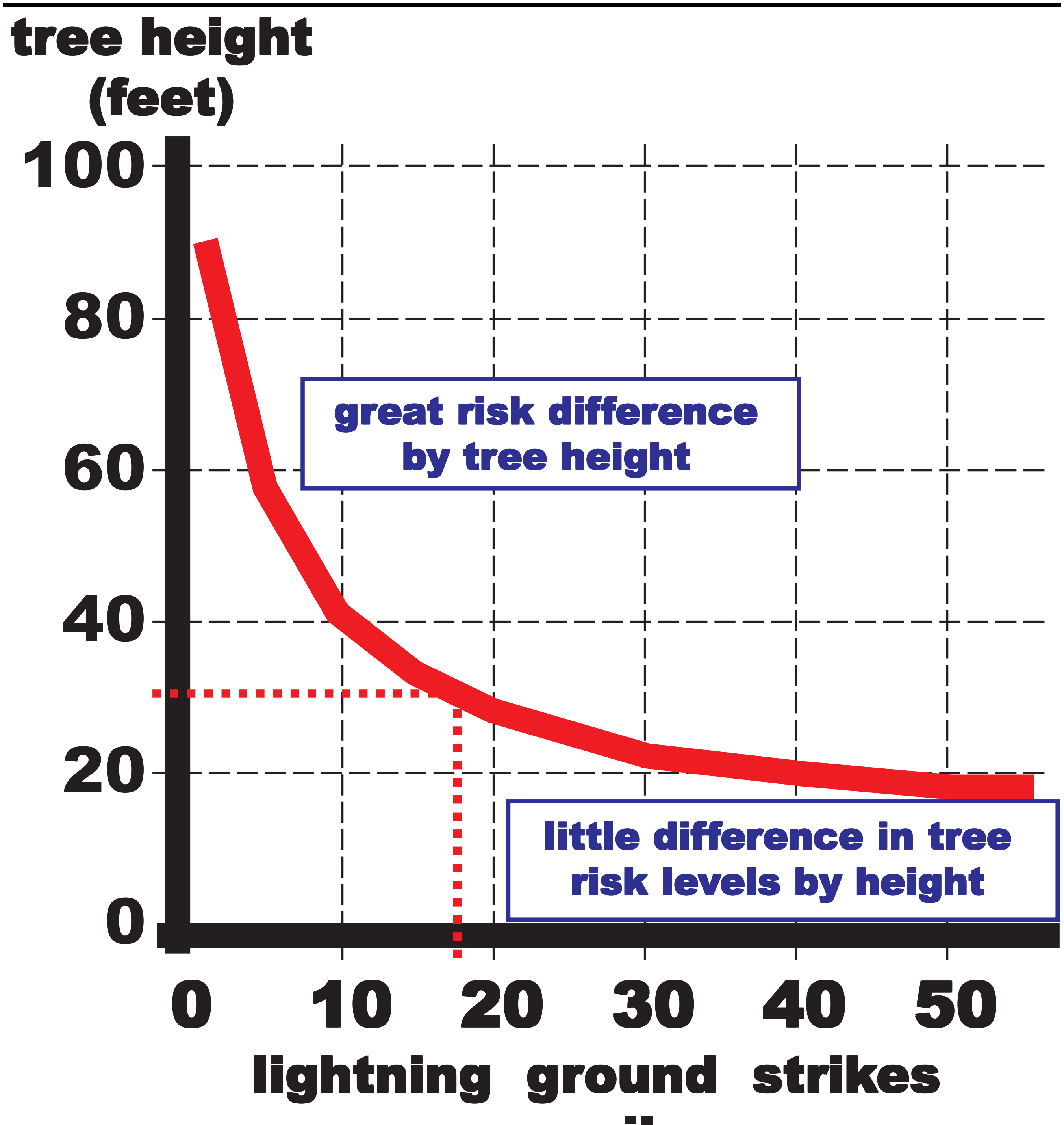


Figure 2: Average risks for tree heights (between high and very low risk) across lightning density value measured as ground strikes per square mile per year. Dotted lines represent 30 feet height and 18 ground strikes.
(derived from Bazelyan & Raizer 2000)

UNIVERSITY OF GEORGIA
Warnell School of Forestry & Natural Resources

Coder Tree Height Assessment For Lightning Risk

lightning strike density (mile²/year)	lightning strike annual risk level 20%	10%	4%	2%
2	--	--	140	95
5	--	140	85	60
10	140ft	95	60	40
15	110	80	50	35
20	95	70	40	30
25	85	60	35	25
30	80	55	35	25
35	70	50	30	20
40	65	45	30	20
45	65	45	25	20
risk levels =	extreme	severe	high	moderate

Figure 3: Single, isolated tree heights in feet within the greatest risk catagories for lightning strikes depending upon tree location (lightning ground strike density per square mile per year.)

Collection Area of Tree =

CA in square miles =

$$\frac{((\text{tree height}_{ft} \times Z) + \text{crown diameter}_{ft})^2}{35{,}514{,}000.}$$

Z = 4 (traditional value & trees <50ft tall)
Z = 6 (international standards & trees >50ft tall)

$$CA_{sq.mi.} \times N_{sq.mi.\ per\ year} =$$

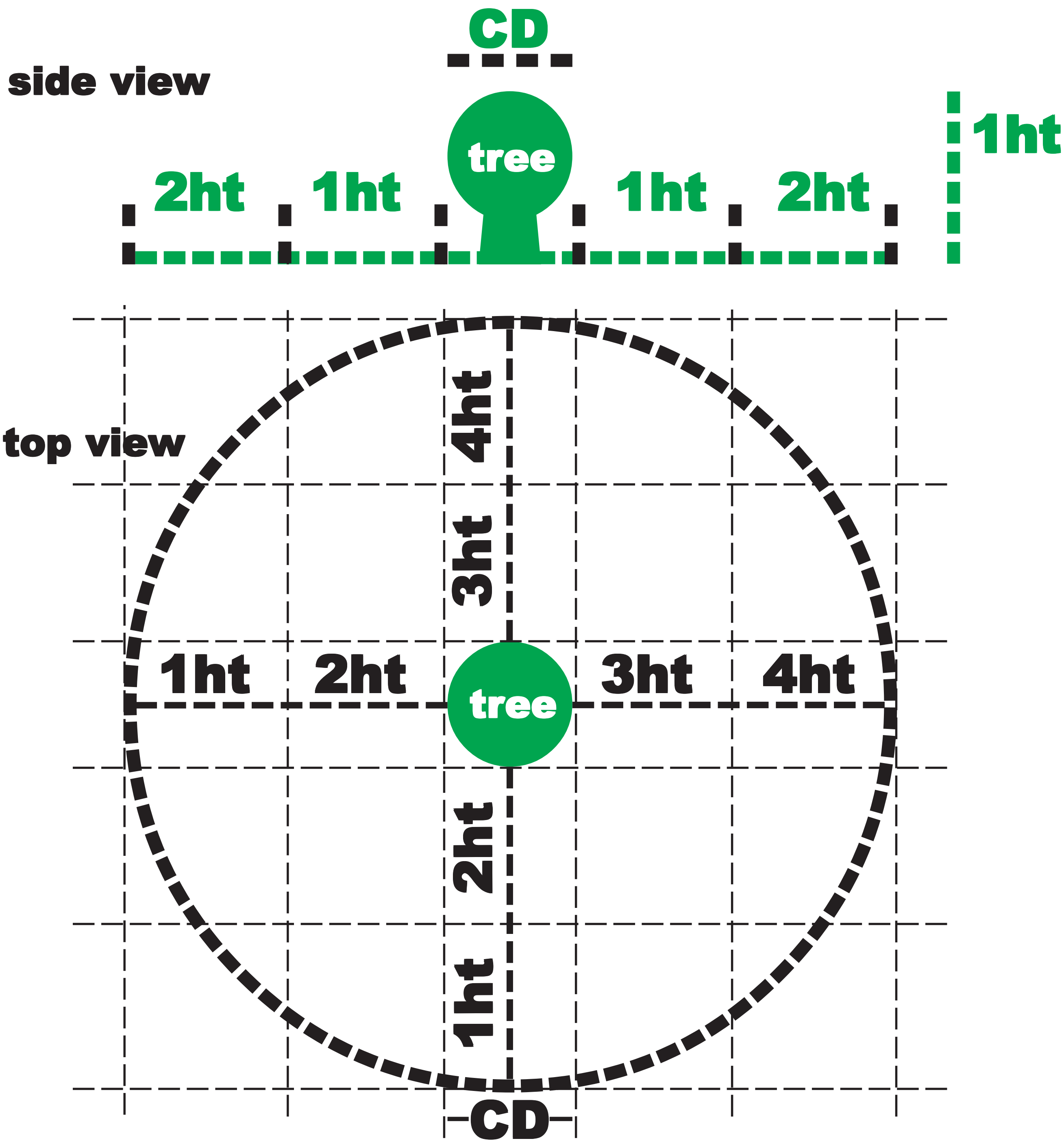
tree strikes per year.

N = annual number of lightning strikes per mile^2

1 / tree strikes per year =

years between tree strikes.

Figure 4: Tree collection area for estimating number of lightning strikes to trees of different heights over time.
(derived from Uman 2008)



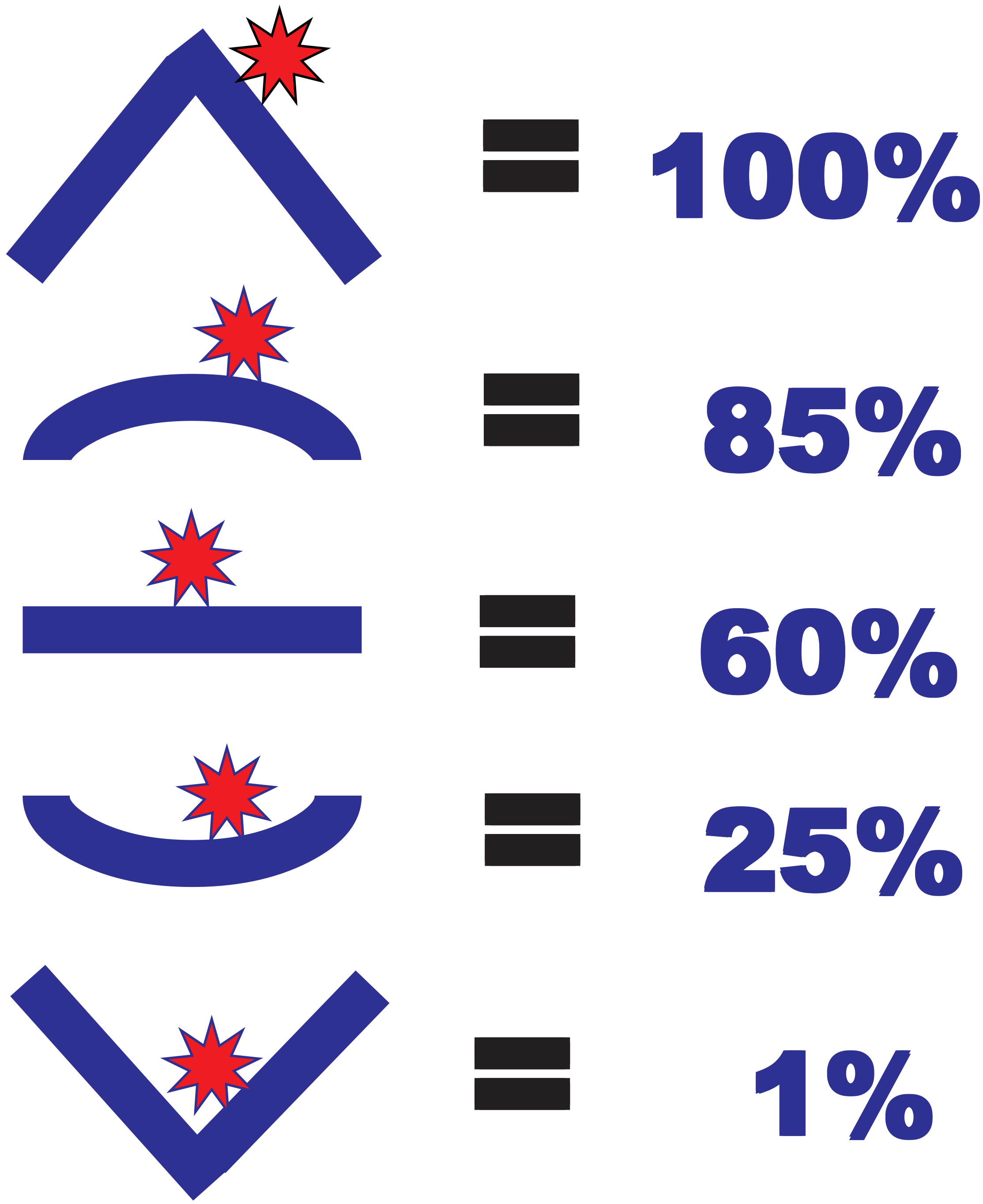
$(4ht_{ft} + CD_{ft})^2 \;/\; 35{,}514{,}000 =$ tree collection area$_{\text{sq. miles}}$

Figure 5: Diagram of tree collection area for estimating number of lightning strikes to trees of different heights. Z = 4.

(derived from Uman 2008)

tree height (feet)	number of strikes per year	years between strikes
10	0.002	483
20	0.005	196
30	0.009	105
40	0.015	66
50	0.022	45
60	0.064	16
70	0.086	12
80	0.11	9
90	0.14	7
100	0.17	6
110	0.20	5
120	0.24	4

Figure 6: Tree lightning strikes determined by tree collection area for various tree heights using 15 annual lightning strikes per square mile and crown diameter of 30 feet. (derived from Uman 2008)



= topographic position of tree in landscape

Figure 7: Risk Factor #1 --
<u>Topographic Location in Landscape</u>.
Determine where on the landscape a tree is growing. Select risk percentage closest to assessed tree's topographic location.

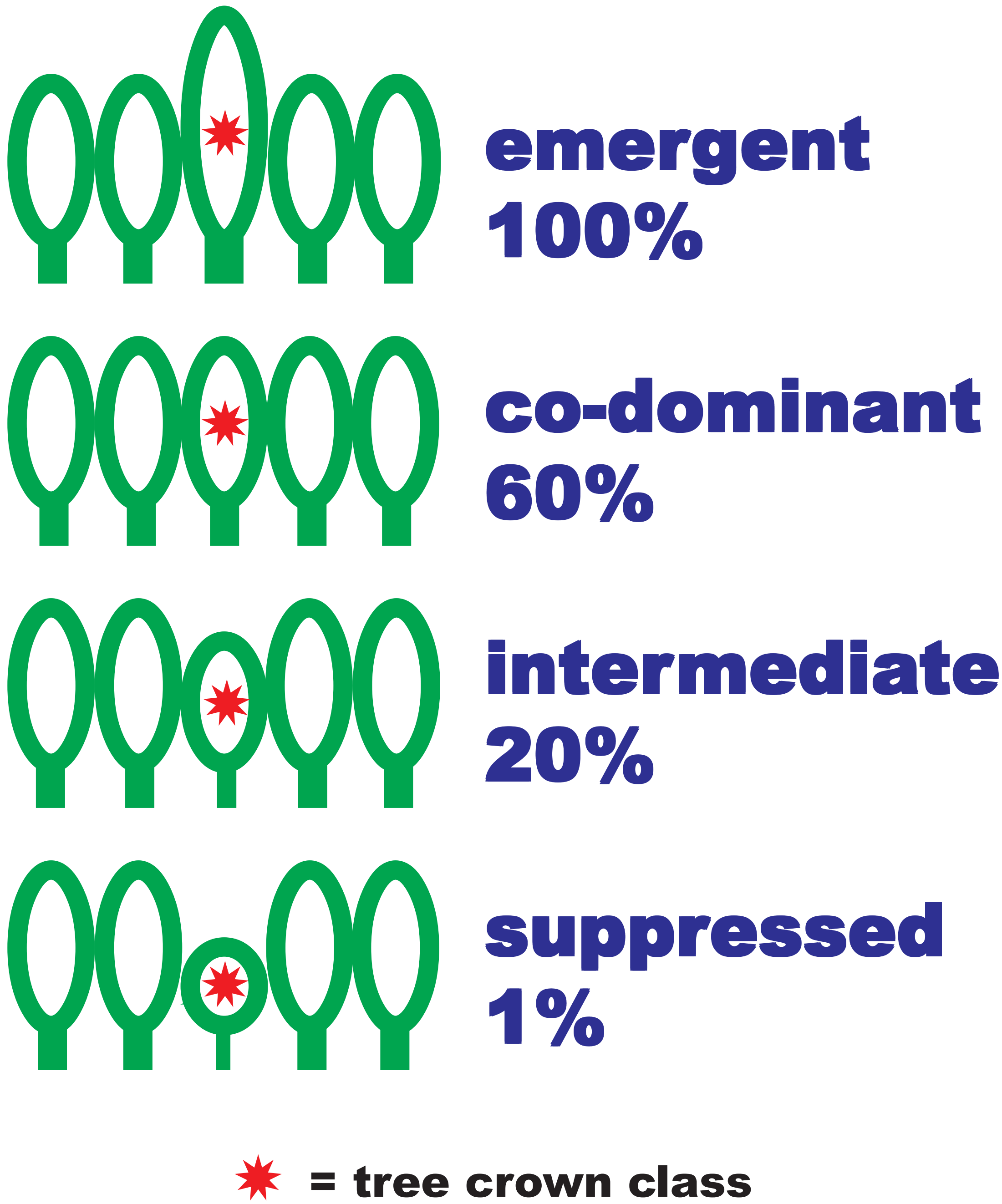


Figure 8: Risk Factor #2 --
<u>Relative Tree Height</u>
Determine relative tree height compared with neighboring trees. Select risk percentage closest to assessed tree's crown class.

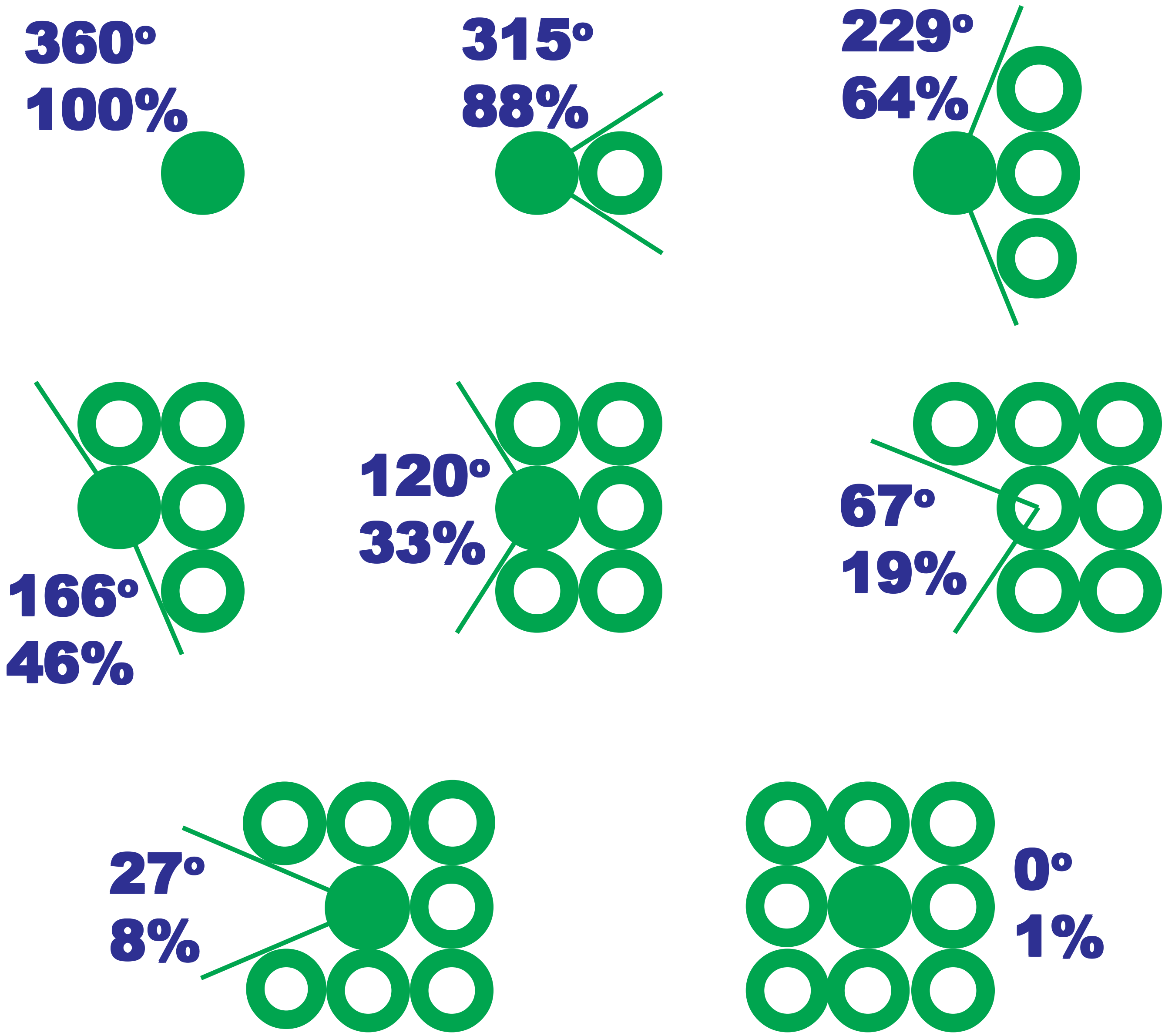


Figure 9: Risk Factor #3 --
<u>Tree Openness</u>

Determine how open a tree crown is on its sides compared with other surrounding trees. Shown are tree crowns viewed from above with assessed tree (filled circle) and neighboring trees (open circles). Select risk percentage closest to assessed tree's crown openness.

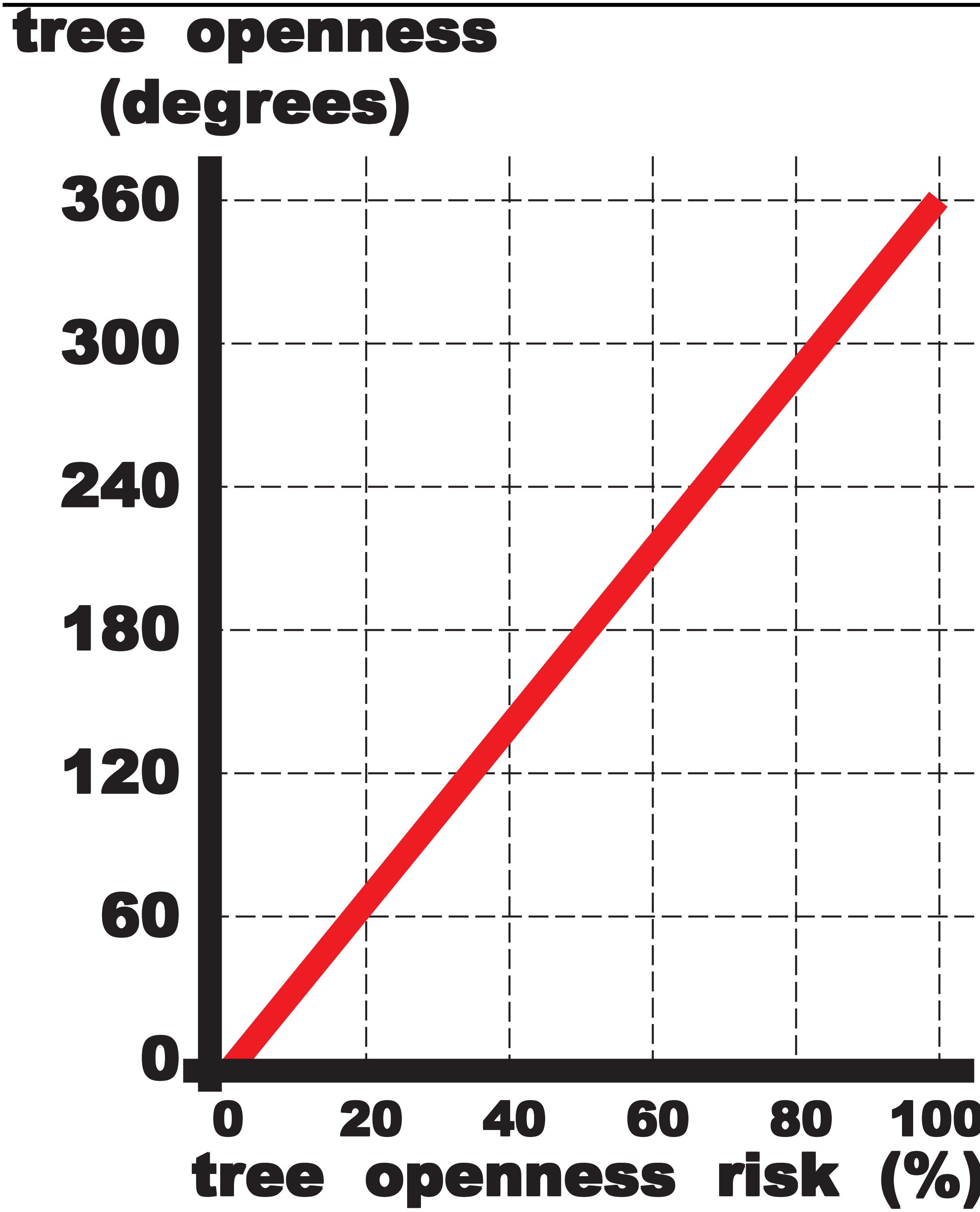


Figure 10: Risk Factor #3 - Tree Openness
Graphical determination of tree crown openness and risk of lightning strike.

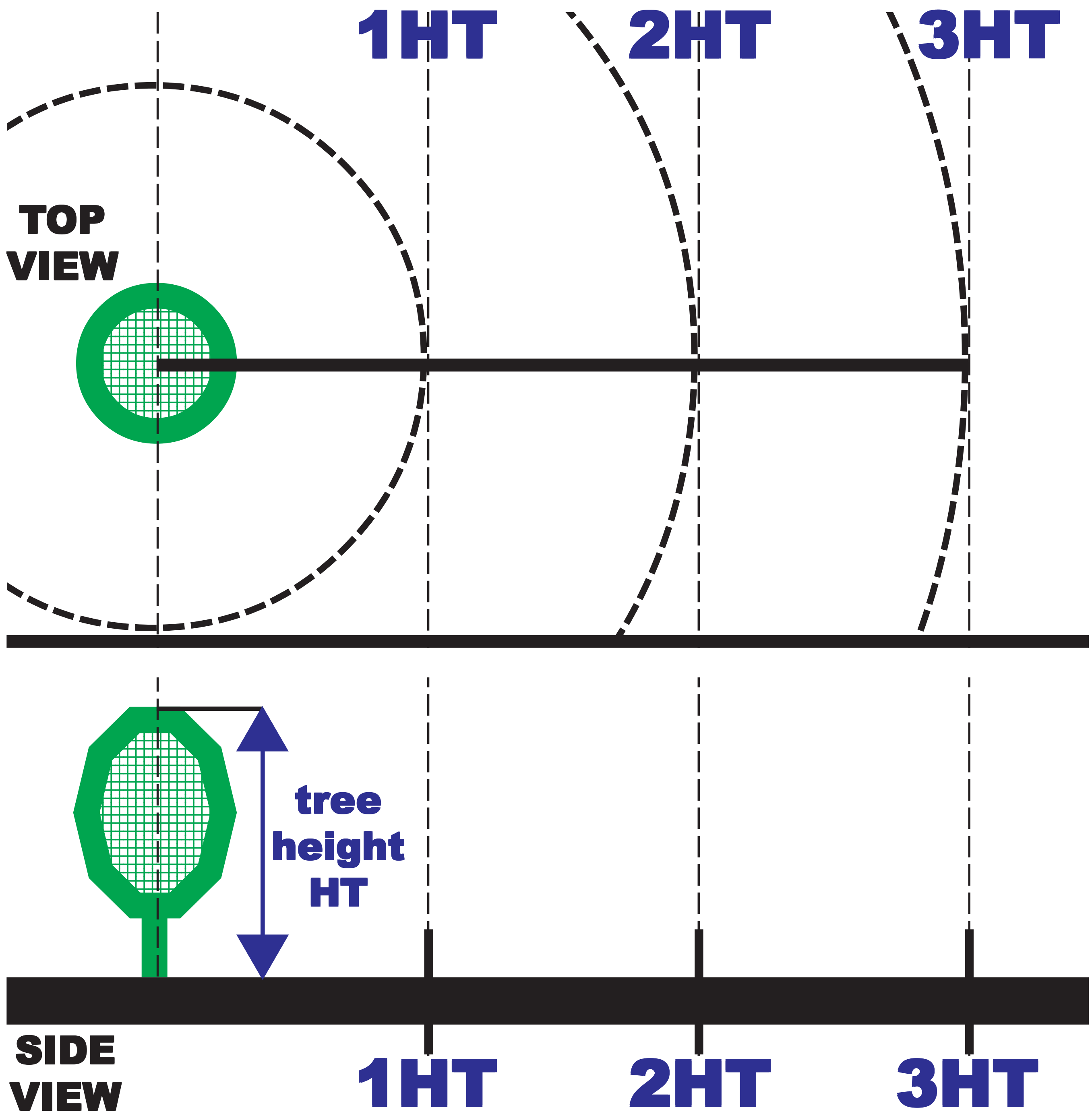


Figure 11: Risk Factor #4 --
Relative Neighborhood Height Differences
Measure height of single tallest structure or tree within three (3) tree heights of assessed tree. The taller a tree is in its neighborhood, the stronger its ground streamer strength.

number of times structure is taller than assessed tree	risk assessment value (%)
2.5 times taller	2%
2.0 times taller	10%
1.5 times taller	20%
1.25 times taller	40%
same height	65%
shorter	100%

Figure 12: Risk Factor #4 --
Relative Neighborhood Height Differences
Measure height of single tallest structure or tree within three (3) tree heights of assessed tree. The taller a tree is in its neighborhood, the stronger its ground streamer strength.

tree position relative to target	assessed risk value (%)
tree as tall / taller & touching	100%
overhanging target	95%
within 1/2 tree height	90%
within 1 tree height	80%
within 2 tree heights	65%
within 3 tree heights	30%
beyond 3 tree heights	2%

Figure 13: Risk Factor #5 --
Tree Target Proximity

Risk of lightning strike impacting structures, electronics,animals and humans in vicinity. Risk assessment must determine spatial relationship between trees and potential targets. Height distances listed are based upon radial distances away from base of assessed tree stem.

A) Record assessed values for risk factors #1 through #5 below. Risk factor values will range from 1% -100%. Note: Use percents in whole numbers not decimal percent values (i.e. use 90% NOT 0.90).

RISK FACTOR #1: __________% +

RISK FACTOR #2: __________% +

RISK FACTOR #3: __________% +

RISK FACTOR #4: __________% +

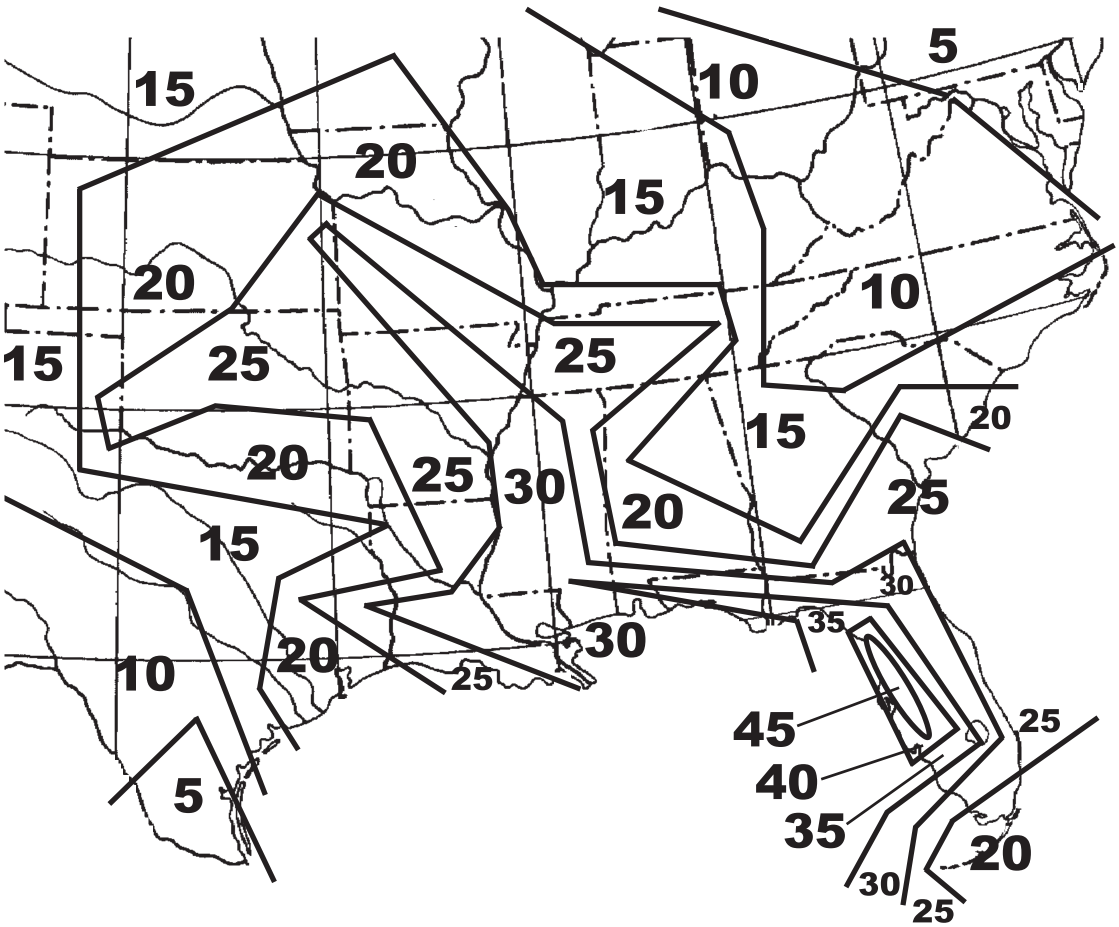
RISK FACTOR #5: __________% =

ADD RISK FACTORS #1 - #5: _________ / 500 =

COMPOSITE RISK FACTOR =

____

Figure 14: Tree Lightning Risk Assessment
(Part A of three calculations)



Annual Lightning Strike Probability =

lightning strike number from map X
[3.142 X ((tree height in feet) X 3)^2 / (5,280)^2]

Figure 15: Risk Factor #6 --
<u>Annual Lightning Strike Probability</u>
From map above (or using any other map source) select a lightning strike number per year per square mile value for your site. Insert this value into the annual lightning strike probability formula given above.

B) Record risk factor #6, the annual lightning strike probability below.

RISK FACTOR #6:

ANNUAL LIGHTNING STRIKE PROBABILITY =

____

C) Multiply composite risk factor (Part A) & annual lightning strike probability (Part B).

COMPOSITE RISK FACTOR X
ANNUAL STRIKE PROBABILITY =

TOTAL TREE LIGHTNING STRIKE RISK VALUE

______________________ **X** ______________________ **=**

COMPOSITE RISK FACTOR | **ANNUAL LIGHTNING STRIKE PROBABILITY**

____

TOTAL TREE LIGHTNING STRIKE RISK VALUE

Figure 16: Tree Lightning Risk Assessment
(part B & C of three calculations)

CALCULATED TOTAL TREE LIGHTNING STRIKE RISK VALUE	RISK DESCRIPTION
> 0.05	severe risk (installation recommended)
> 0.03	high risk
> 0.02	moderate risk (consider installation)
> 0.01	low risk
< 0.005	very low risk (no installation)

Remember risks can be low, not zero, and lightning strikes, especially smaller current strikes, can still occur.

Figure 17: Tree Lightning Risk Assessment Response
(based on calculations of risk in Part A, B, & C)
Risk description suggests whether a lightning conduction / tree protection system should be installed.

Figure 18: Field worksheet.

TREE LIGHTNING RISK ASSESSMENT WORKSHEET

Dr. Kim D. Coder, Warnell School of Forestry & Natural Resources, University of Georgia, 2/2022

RISK FACTOR #1:
TOPOGRAPHIC LOCATION IN LANDSCAPE = ____________%

RISK FACTOR #2:
RELATIVE TREE HEIGHT = ____________%

RISK FACTOR #3:
TREE OPENNESS = ____________%

RISK FACTOR #4:
RELATIVE NEIGHBORHOOD HEIGHT DIFFERENCES = ____________ %

RISK FACTOR #5:
TREE TARGET PROXIMITY = ____________ %

ADD RISK FACTORS #1 - #5 TOGETHER **TOTAL** = ____________

DIVIDE TOTAL BY 500 = COMPOSITE RISK FACTOR = ____________

RISK FACTOR #6:
ANNUAL LIGHTNING STRIKE PROBABILITY = ____________
(map value + formula)

COMPOSITE RISK FACTOR X
ANNUAL LIGHTNING STRIKE PROBABILITY =
TOTAL TREE LIGHTNING RISK VALUE

____________________ X ________________ = [ ]

COMPOSITE RISK FACTOR | ANNUAL LIGHTNING STRIKE PROBABILITY | **TOTAL TREE LIGHTNING RISK VALUE**

TOTAL TREE LIGHTNING RISK VALUE	
> 0.05	severe risk
> 0.03	high risk
> 0.02	moderate risk
> 0.01	low risk
< 0.005	very low risk

Tree most likely struck:

-TRUE-

-- open grown or edge trees
-- growing under dry soil conditions
(soil moisture & wet surfaces protect tree)

-FALSE-

-- tallest ***
-- growing in high resistance soil
-- certain species
-- close to other grounds

Causes more damage:

-TRUE-

-- positive polarity lightning strikes
-- higher peak current

-FALSE-

-- strikes with more strokes
-- continuous current

Figure 19: Field tests of traditional lightning -- tree concepts.
(Makela et.al. 2009)