Ecological Solutions Inc.

National Grid ROW Side Line Tree Risk Assessment & Mitigation

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Side Line Tree Risk Background

- National Grid transmission facilities in NY, MA, RI, NH, VT
- Centralized, cyclic program on ROW floor with hazard trees outside ROW identified and removed as part of routine maintenance
- Maintain floor by holding vegetation in early stages of succession – low growing plants
- Interruptions from ROW floor have become rare
- Primary source of tree-caused interruptions – tree failures from outside ROW

Side Line Tree Interruption Experience

- **National Grid system – 1.7 yr^{-1} per 1000 miles ROW**
- **NE transmission – 4.1 yr^{-1} per 1000 miles ROW**
- **50% of NE tree-caused incidents occurred over only 5.5% of the system**
- **42.5% of NE incidents involve White Pine**

2002 data

Opportunity

- Floor has been addressed & not the source for major reductions in tree-caused incidents
- Major reliability gains possible if nature of side line tree risk better defined and understood

Side Line Tree Risk Project Objectives

- **Quantify the risk to the transmission system from tree failure / line strike**
- **Develop mitigation strategies to reduce risk of tree failure / line strike**
- **Assess cost of mitigation options for a range of risk levels**
- **Develop guidelines for field level mitigation program implementation**

Side Line Tree Risk Project To Provide

- The percent of forested right-of-way edge
- Quantification of the extent of emergent White Pine exposure
- The total size of the outside right-of-way component of the utility forest
  - Define utility forest, hazard tree, danger tree
- The number of trees per line mile (outside right-of-way)
- Tree Risk Factor - based on line height, tree height, clear width and tree density
- Mitigation options to achieve specified levels of tree risk

Side Line Tree Risk Project Results

- The process & data collected
- High level descriptions of utility forest
- Forest composition
- Variables affecting tree risk
- Risk quantification
- Mitigation possibilities
- Chosen mitigation strategy
- Weather risk

Side Line Tree Risk Project Details

- **Initial target 400 sites, 800 edge samples each with 3 replications of forest data**
- **Intent to deliver reasonably tight statistical confidence intervals (90%)**
- **Completed 672 edge samples with over 22,200 forest data records**
- **618 edge samples transmission – difference sub-transmission**

Data Conventions

- Mean presented as 56.68 ± 0.98
  mean falls between 55.7 and 57.66
  90% of the time

Utility Forest Beyond ROW

	NE			NY		
	Miles ROW Edge	Average Ac/Mi	Total Acres	Miles ROW Edge	Average Ac/Mi	Total Acres
69 kV	500	2.01	**1003**	-	-	**-**
115 kV	1260	1.29	**1620**	4940	0.99	**4899**
230 kV	468	1.1	**517**	580	0.46	**268**
345 kV	560	0.55	**307**	884	0.07	**60**
Total	2888		**3447**	6404		**5227**

Treed Right-of-Way Edge

Operating Area/State	NE	MA	NH	RI	VT	NY
% Treed ROW Edge	**77.46 ± 3.1**	78.22 ± 3.53	81.47 ± 6.33	59.1 ± 17.08	74.38 ± 15.03	**61.83 ± 2.93**
Miles Treed ROW Edge	**2160 ± 86**					**3960 ± 188**

Conflicting Utility Forest Miles

	NE					NY				
	Miles ROW Edge	% of Edge Treed	% of Samples With Risk	Danger Trees Miles Utility Forest	% Danger Tree Miles	Miles ROW Edge	% of Edge Treed	% of Samples With Risk	Danger Trees Miles Utility Forest	% Danger Tree Miles
69 kV	500	83.81	81.03	**340**	**68**	-	-	-	**-**	**-**
115 kV	1260	76.56	50.43	**486**	**39**	4940	64.90	44.85	**1438**	**29**
230 kV	468	80.15	53.57	**201**	**43**	580	57.96	38.24	**129**	**22**
345 kV	560	75.29	30.30	**128**	**23**	884	60.24	2.00	**11**	**1**
Total	2888	78.77	53.05	**1207**	**42**	6404	63.58	38.20	**1555**	**24**

Utility Forest Outside ROW >4" dbh

As found:

- **NE 534,837**
- **NY 649,078**

At Maximum Sag:

- **NE 642,874**
- **NY 795,770**

Total side line tree exposure = 1,438,644

Trees Per Mile of Treed Edge

	Trees / Mi
69 kV	407
115 kV	201
230 kV	184
345 kV	48

At sag conditions as found

Tree Density by Operating Area (Trees/Acre)

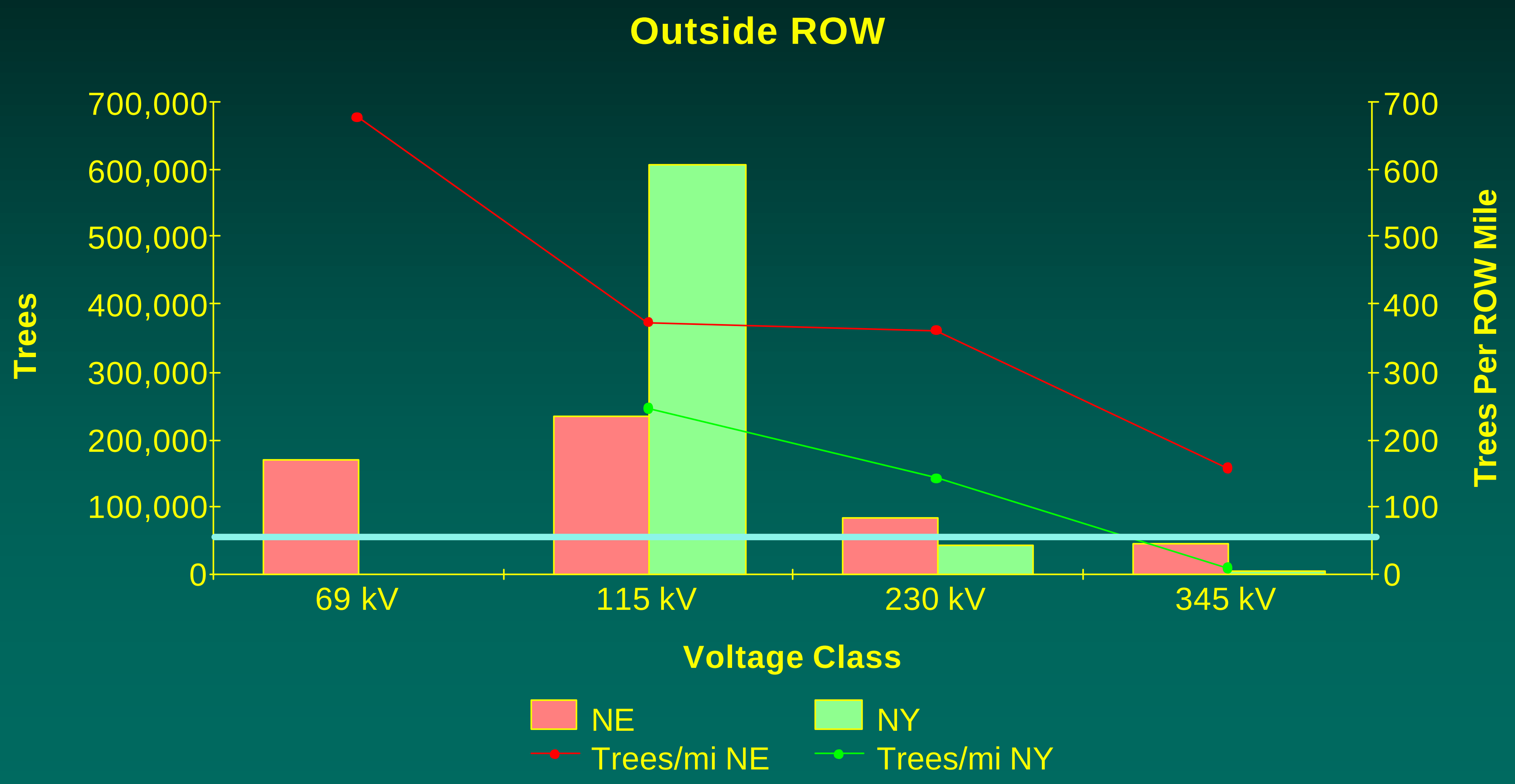
	Trees Per Acre	Trees Per Acre (>4?dbh)
NE	491 ± 50	198 ± 8
NY	433 ± 31	197 ± 7
All	456 ± 27	**198 ± 5**

Tree Exposure

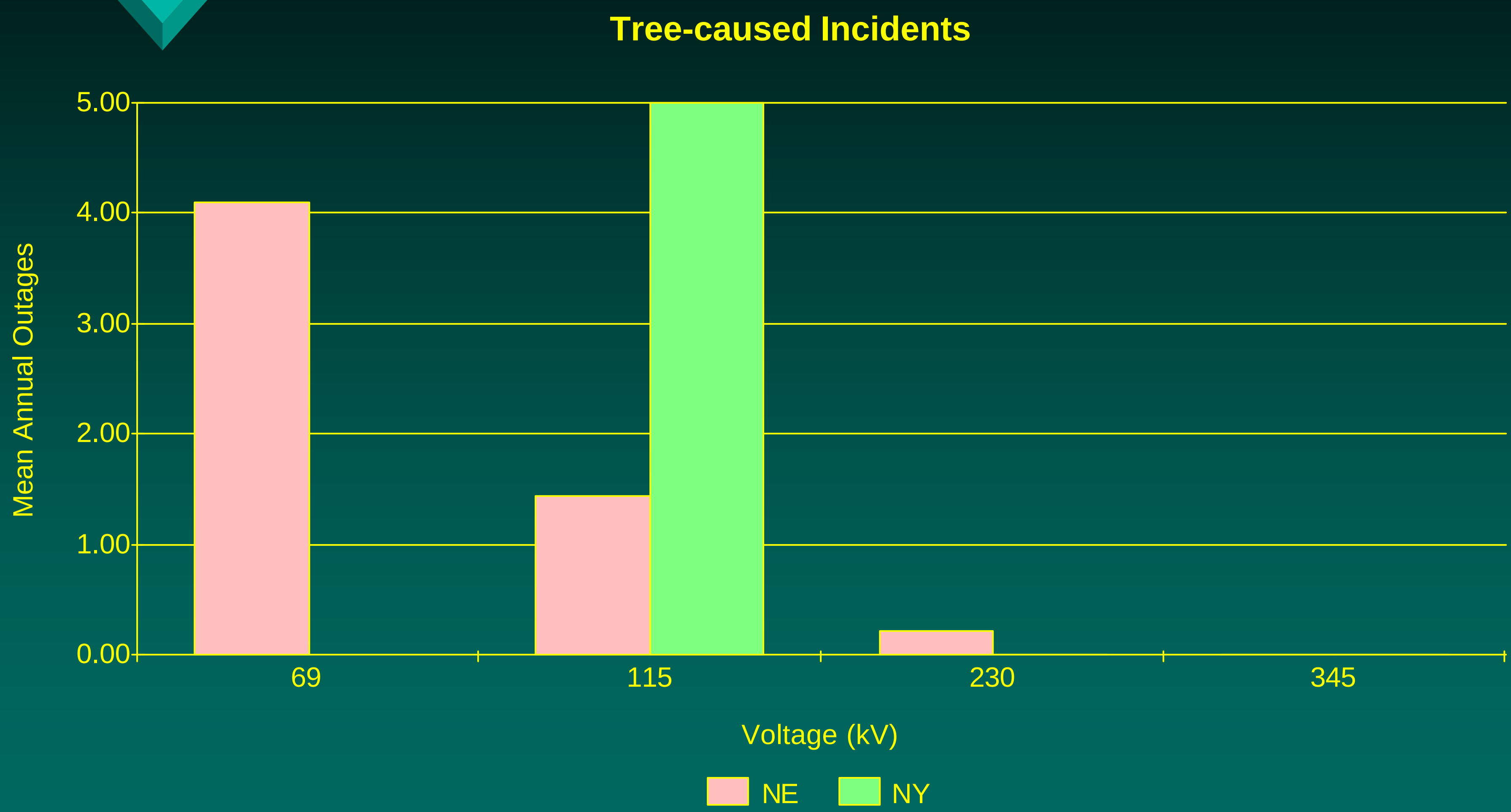
	NE	Trees/ROW Mile	NY	Trees/ROW Mile
69 kV	169,659	679		
115 kV	234,863	373	606,585	246
230 kV	84,480	361	41,182	142
345 kV	44,208	158	4,408	10
Total	533,210		652,175	

At found sag condition

Total Tree Exposure

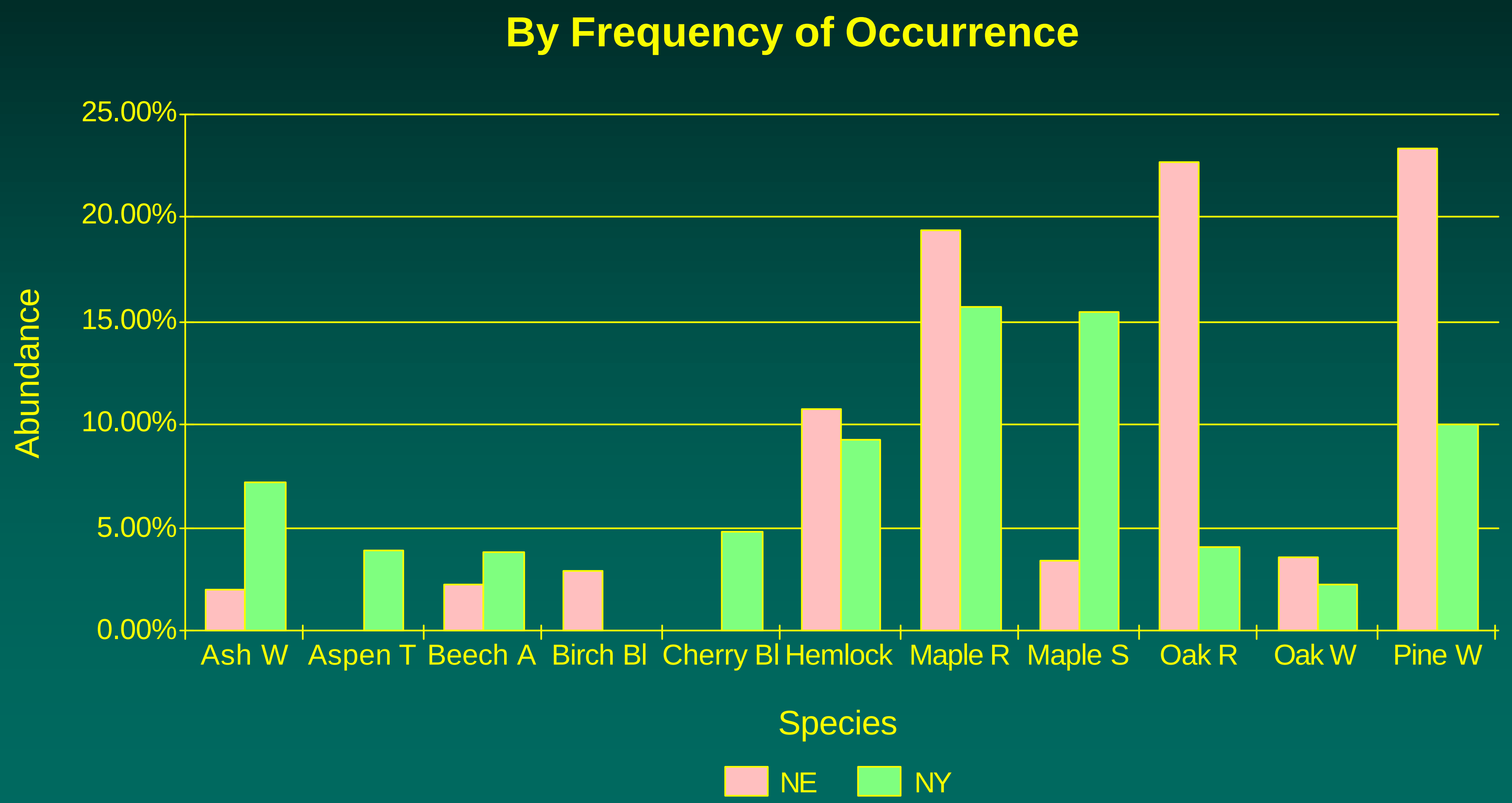


Outage History



- NE 1996 – 2004
- NY 2001 - 2004

Tree Species



Emergent Trees

	Miles Edge Emergent Species	% Edge Emergent Species	Miles Edge Emergent White Pine	% Edge Emergent White Pine
NE	372	**13.3**	346.1	**12.4**
NY	722.2	**11.3**	544.9	**8.5**

White Pine Exposure

	Miles Edge White Pine	Miles Edge	Exposure as % of Area	Exposure as % of Total System
MA	1349.2	1997	67.6	14.7
NH	338.6	460.8	73.5	3.7
RI	100.7	279.3	36.1	1.1
VT	84.6	138.4	61.1	0.9
NE	1873.1	2788	**67.2**	**20.4**
NY	2502.9	6404	**39.1**	**27.2**
Total	4376	9192	47.6	**47.6**

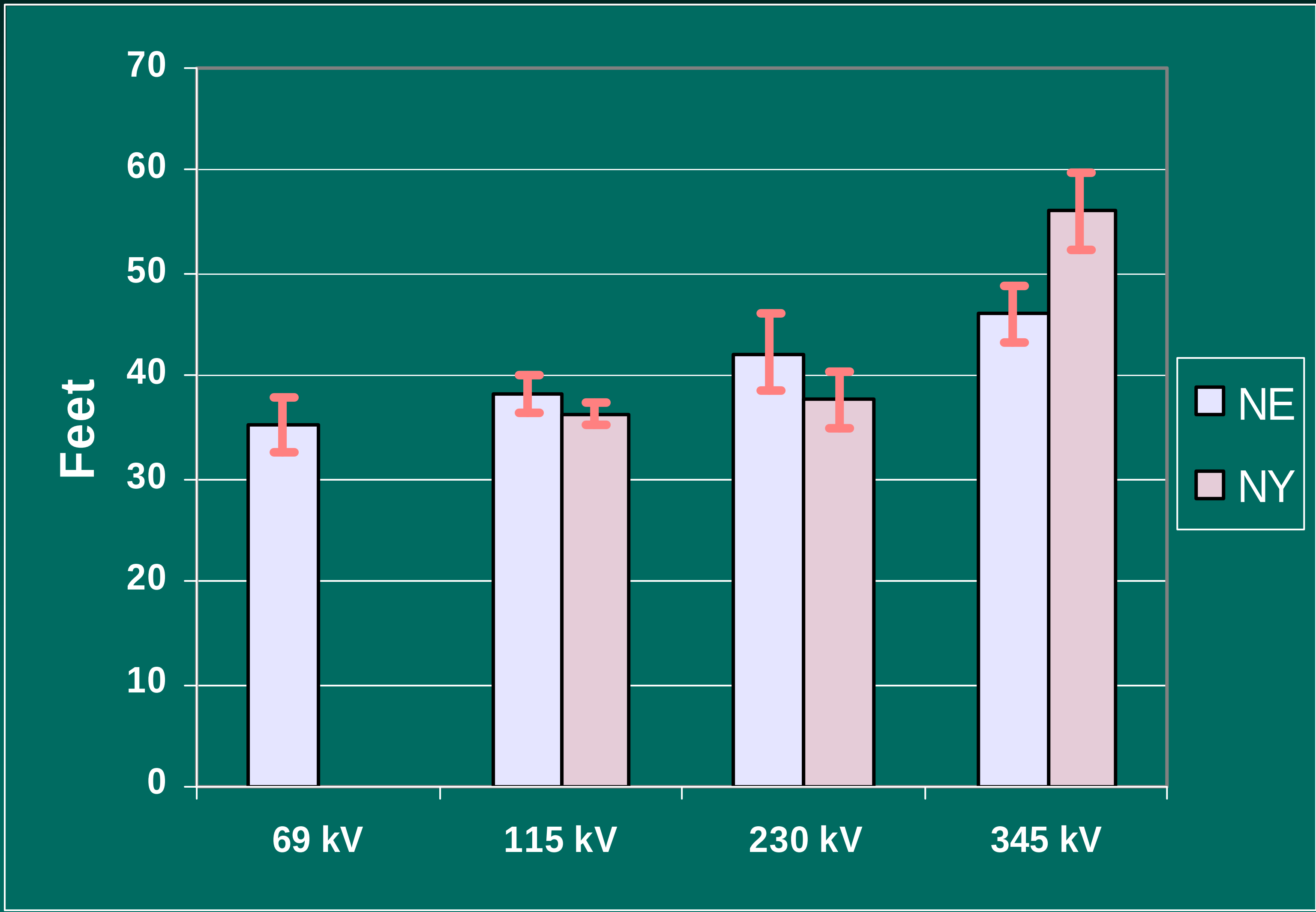
Future – Emergent White Pine

- **Emergent white pine greater problem in the future**
  - **Potential for >100% increase**
- **47.6% of system miles have white pine exposure**
- **Current emergent white pine 20.9% of system edge**
- **Current system level exposure vs. potential**
  - **NE current emergent WP 12.4%; potential 20.4%**
  - **NY current emergent WP 8.5%; potential 27.2%**
- **Emergent white pine will become a major concern in NY in future (10-30 yrs)**
  - **Dominant mean height: NE 84.6; NY 68.4**

Quantifying Tree Risk

- **Line height**
- **Tree height**
- **Clear width**
- **Tree density**
  - **198 trees/Ac**

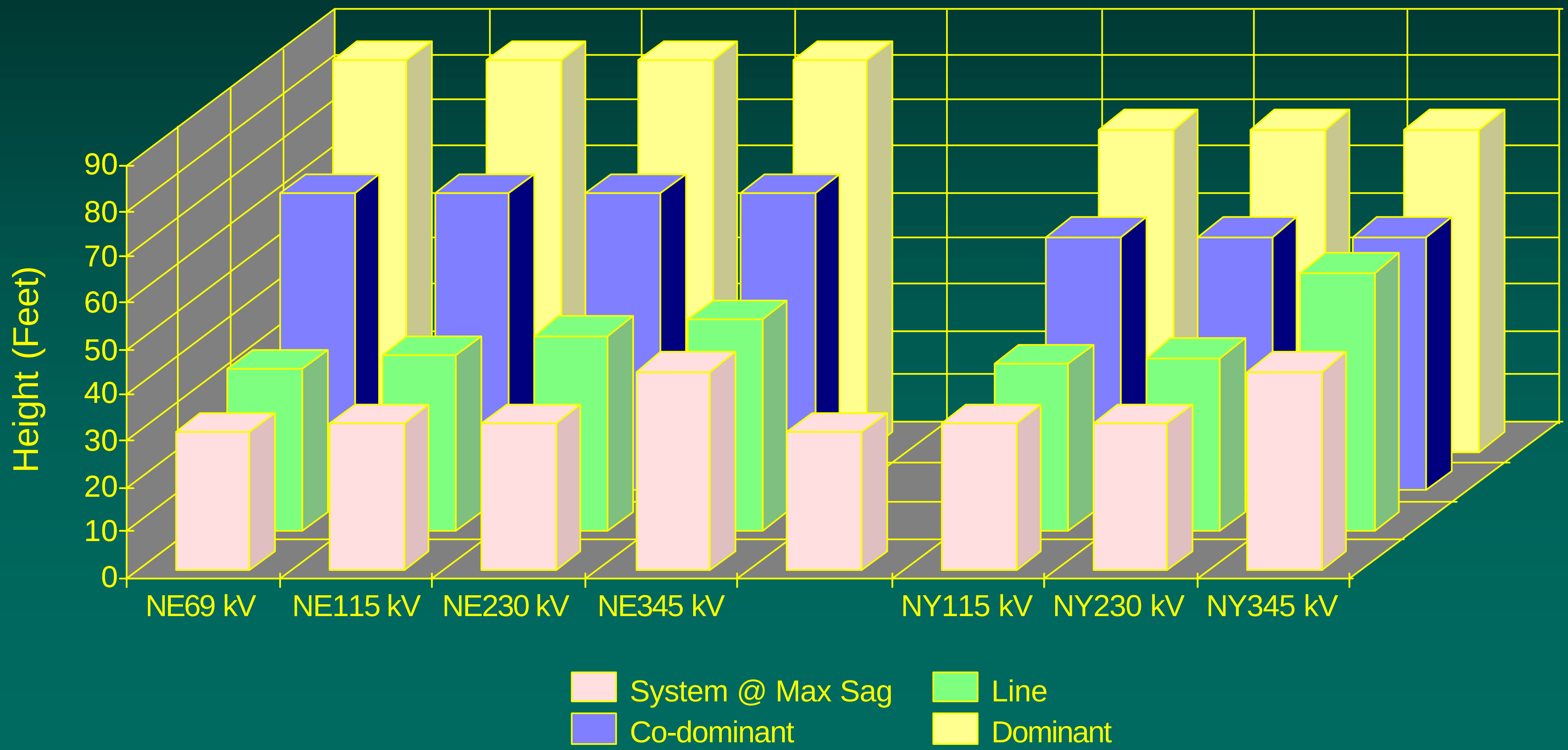
National Grid Transmission Line Heights



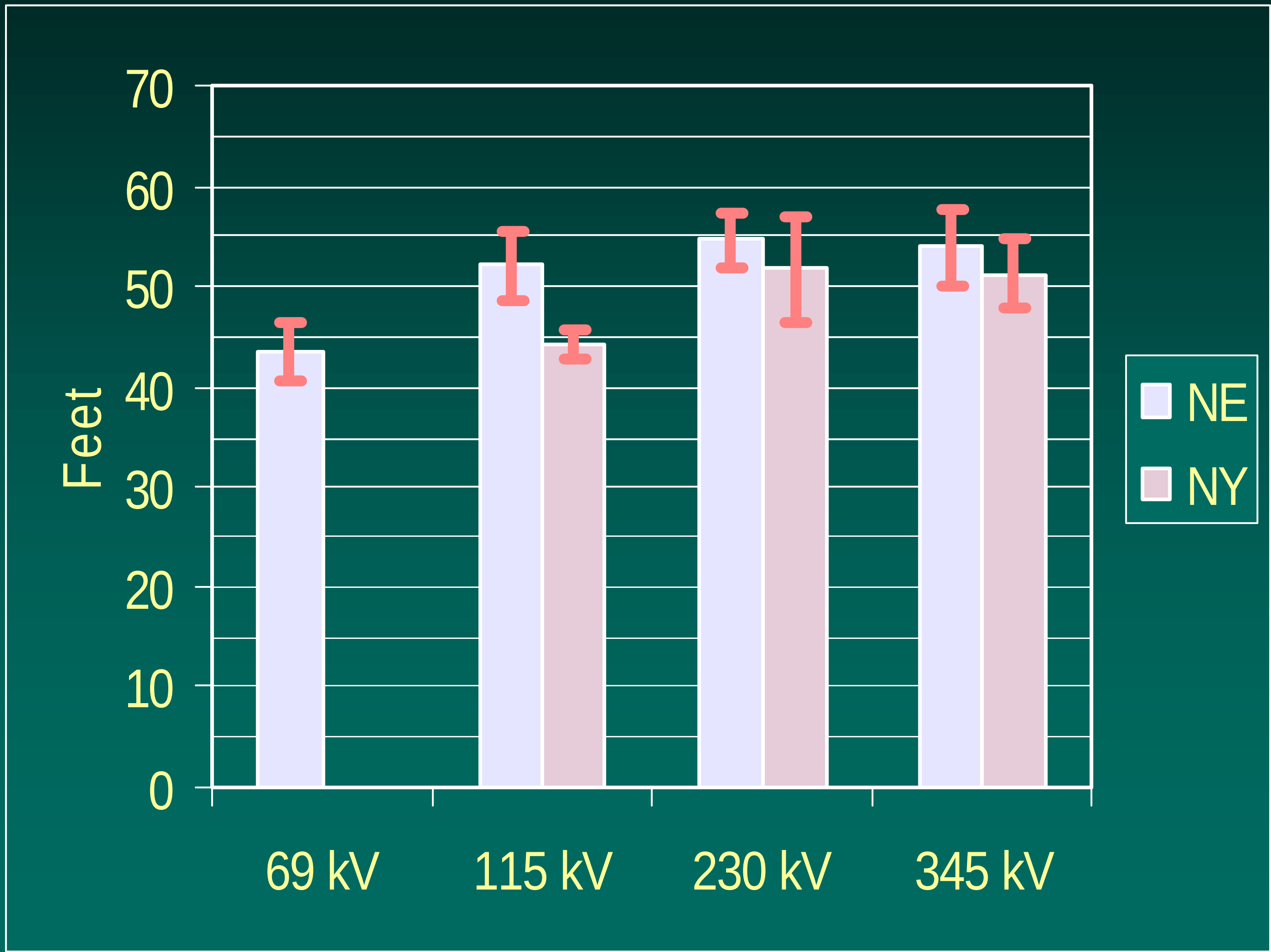
Mean Tree Height

	Co-dominant Tree Height (feet)	Dominant Tree Height (feet)
NE	65 ± 1.6	85 ± 3.8
NY	55 ± 1.1	70 ± 3.4
All	59 ± 1	77 ± 2.9

National Grid Transmission System Heights



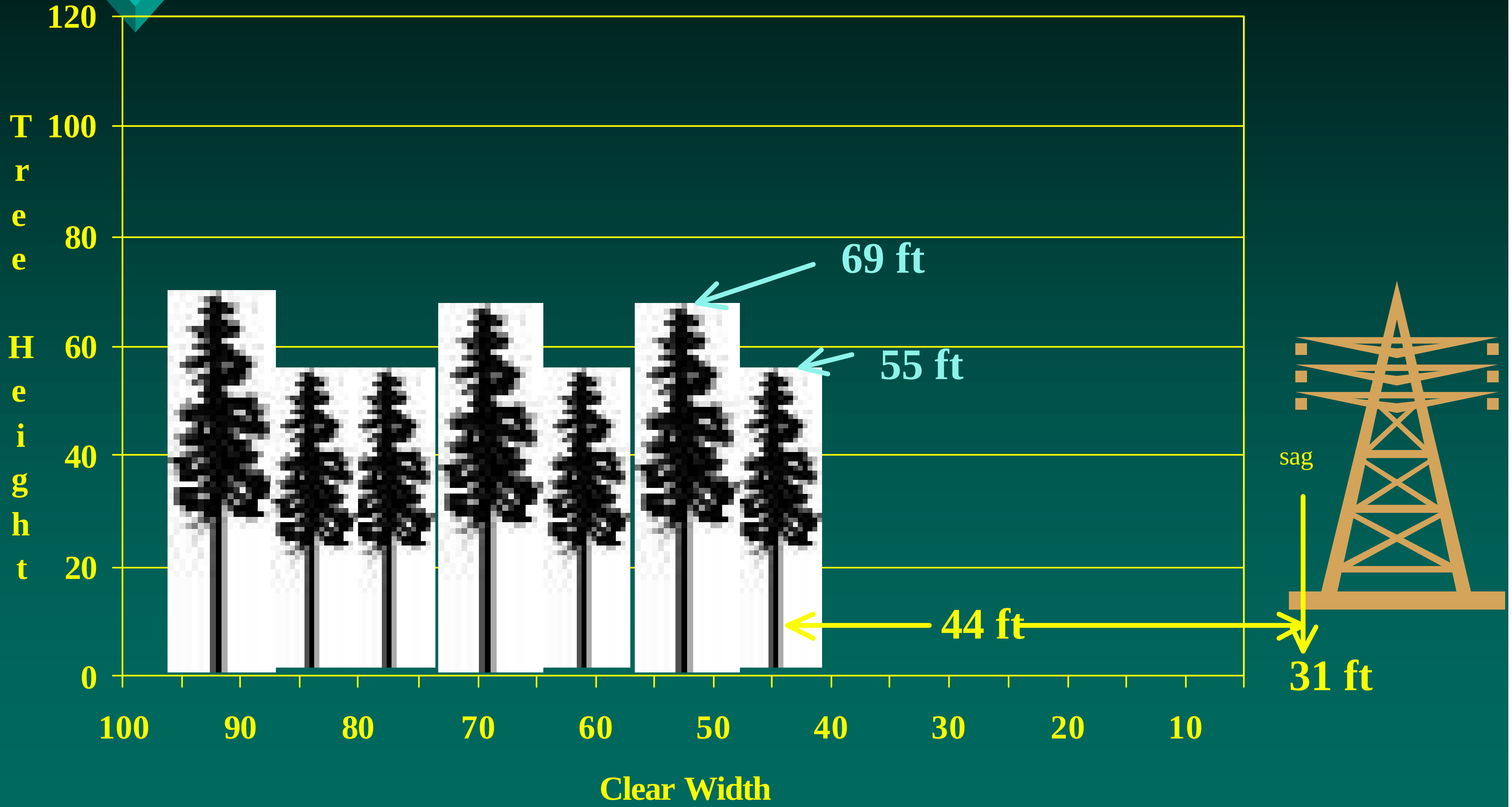
National Grid Transmission Clear Width

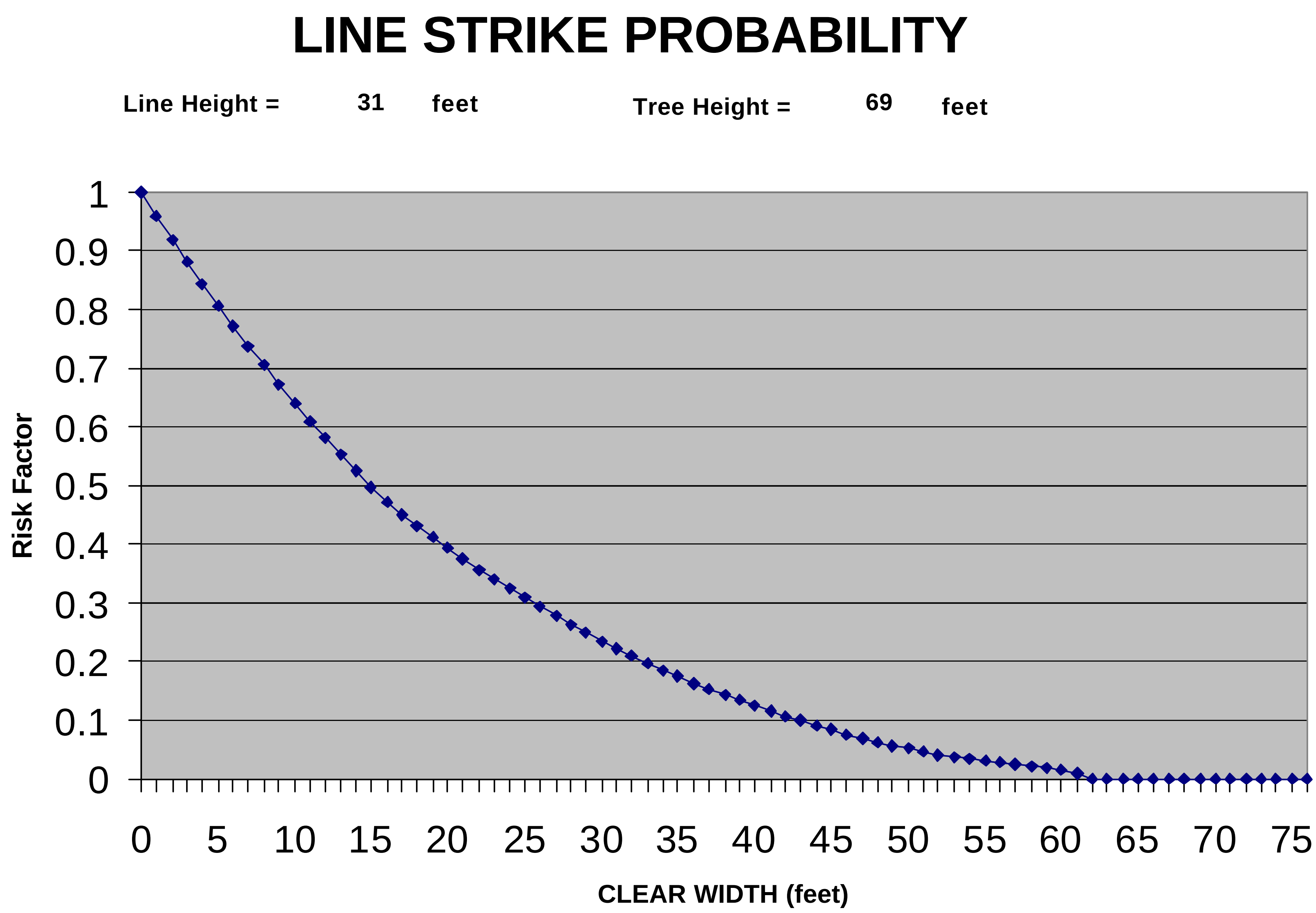


Residual Tree Risk

- Optimal Clear Width Calculator
  - Triangulation (line height, tree height, clear width) + tree exposure (tree density)
- Output = Tree Risk Factor
  - Expressed as a %
  - Clear width=0; RF=100%
  - No possible direct line strikes; RF=0%
- Basis for quantitative comparison
  - Adjusting one or more variables

NY 115 kV Mean Conditions

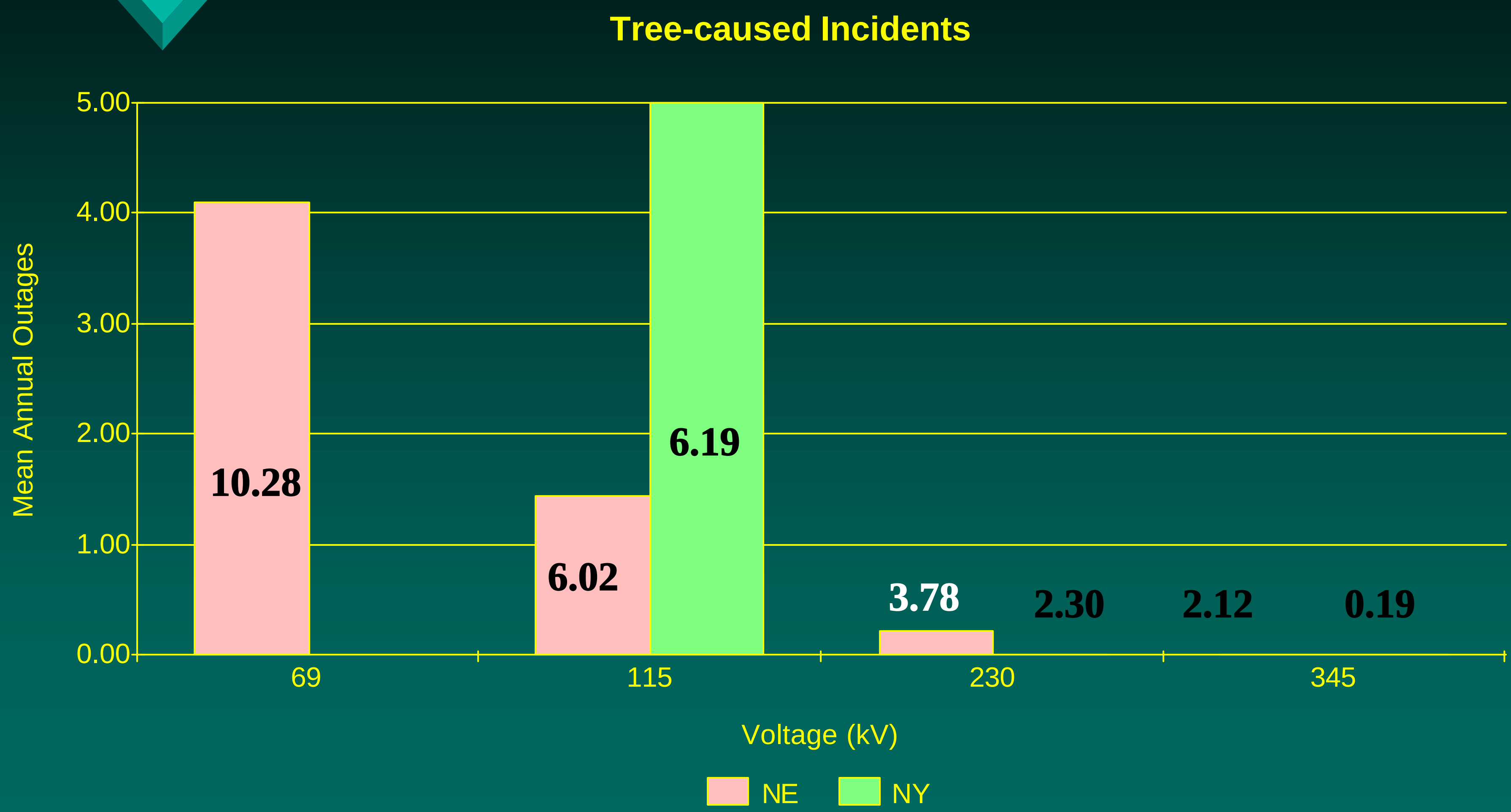



LINE STRIKE PROBABILITY
Line Height = 31 feet
Tree Height = 69 feet
Risk Factor
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75
CLEAR WIDTH (feet)

Mean Risk Factor

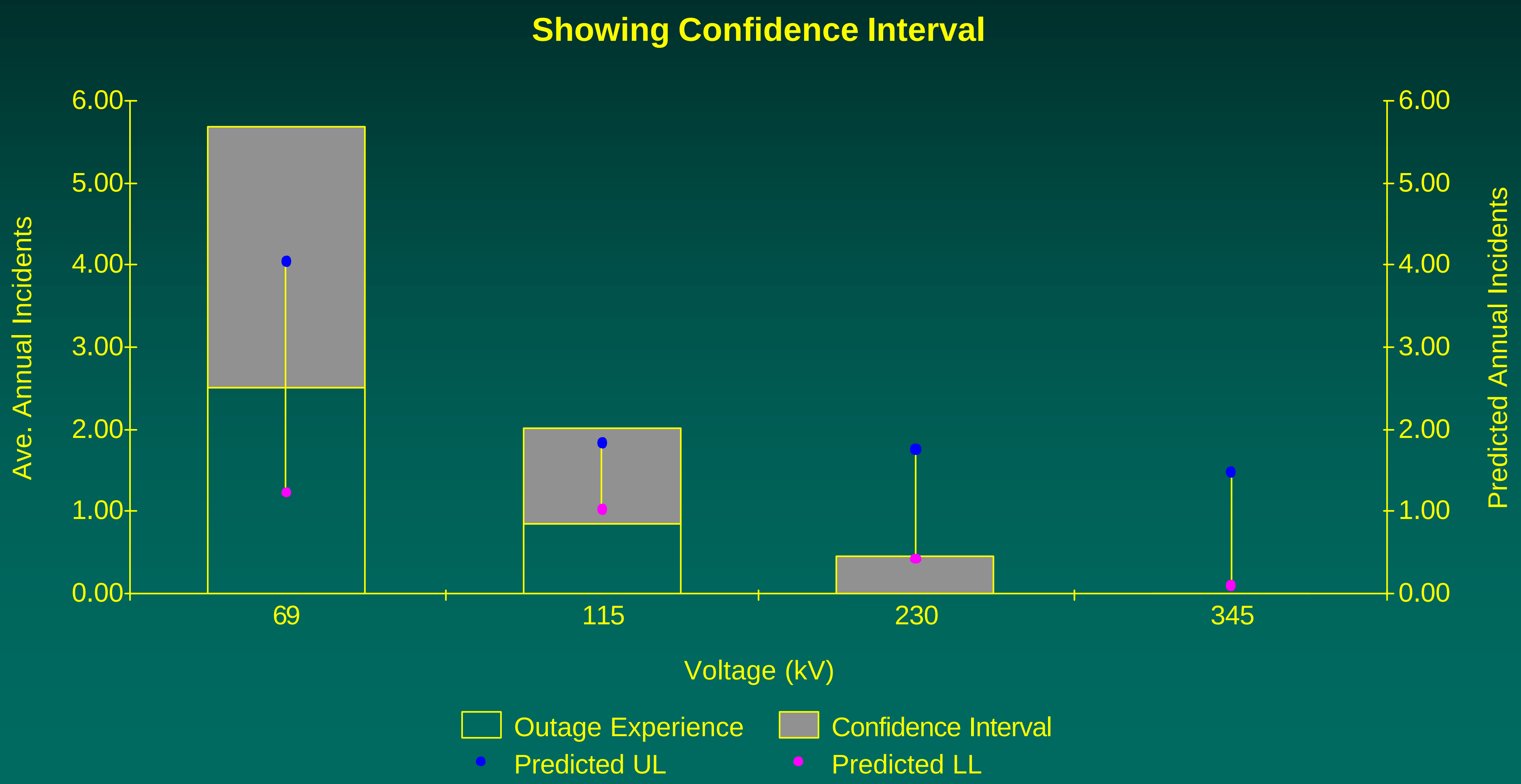
	NY			NE			
	115	**230**	**345**	**69**	**115**	**230**	**345**
Mean Risk Factor (%) As Found	6.19	**2.30**	**0.19**	10.28	6.02	3.78	**2.12**
Mean Risk Factor (%) @ Max Sag	7.52	**3.50**	0.71	11.95	7.08	**4.85**	3.21

Outage History



- NE 1996 – 2004
- NY 2001 - 2004

Using Risk Factor to Predict Tree-related Outages



Mean Risk Factor

	NY			NE			
	115	**230**	**345**	**69**	**115**	**230**	**345**
Mean Risk Factor (%) As Found	6.19	**2.30**	**0.19**	10.28	6.02	3.78	**2.12**
Mean Risk Factor (%) @ Max Sag	7.52	**3.50**	0.71	11.95	7.08	**4.85**	3.21

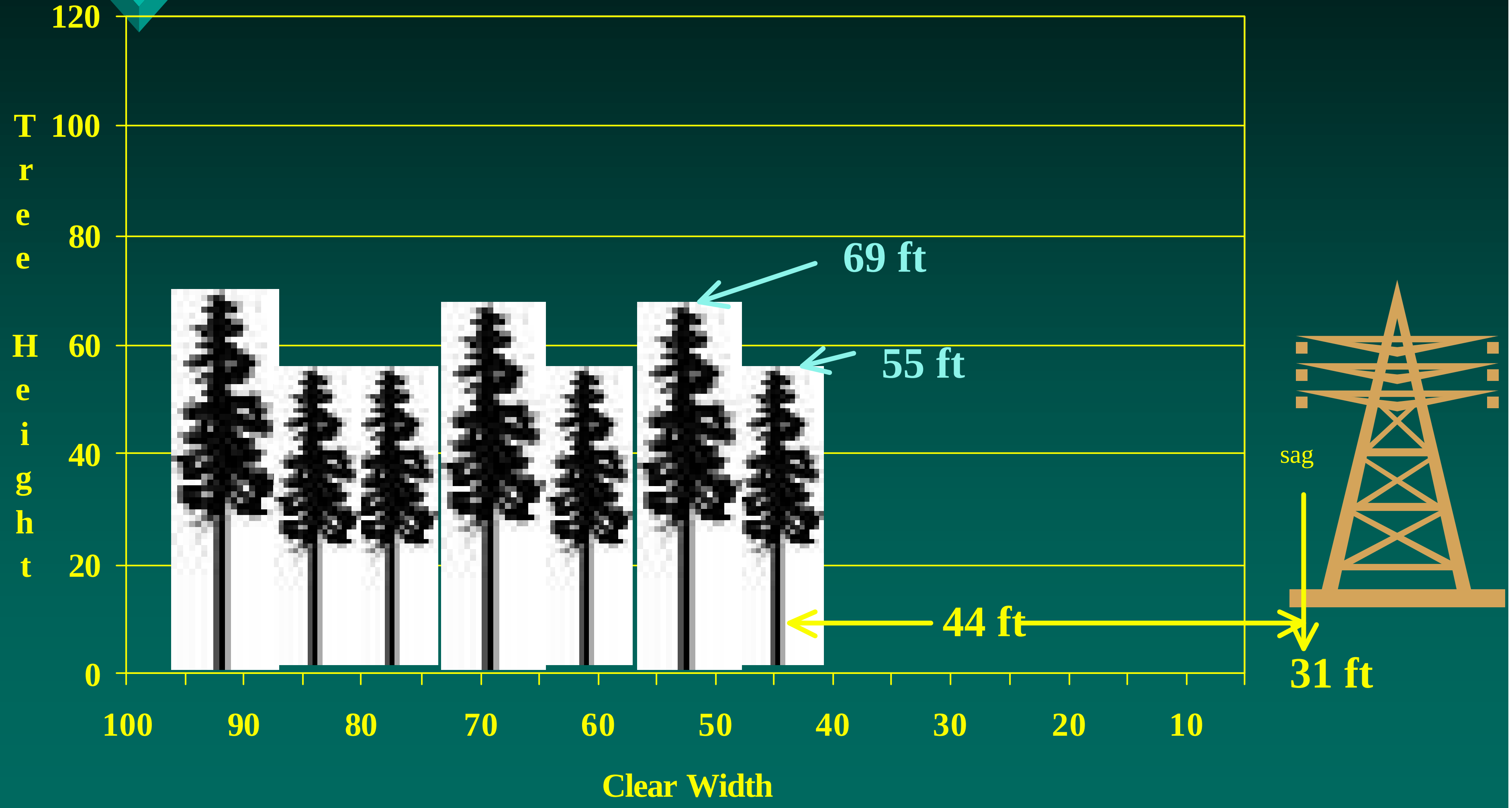
Clear Width

	NE	NY	All
69 kV	43.6 ± 2.9		43.6 ± 2.9
115 kV	**52.1 ± 3.5**	**44.2 ± 1.5**	46.4 ± 1.5
230 kV	54.6 ± 2.6	51.8 ± 5.3	53.9 ± 2.6
345 kV	53.9 ± 3.9	51.2 ± 3.5	**52.7 ± 2.6**

Tree Free Clear Width for Mean Conditions

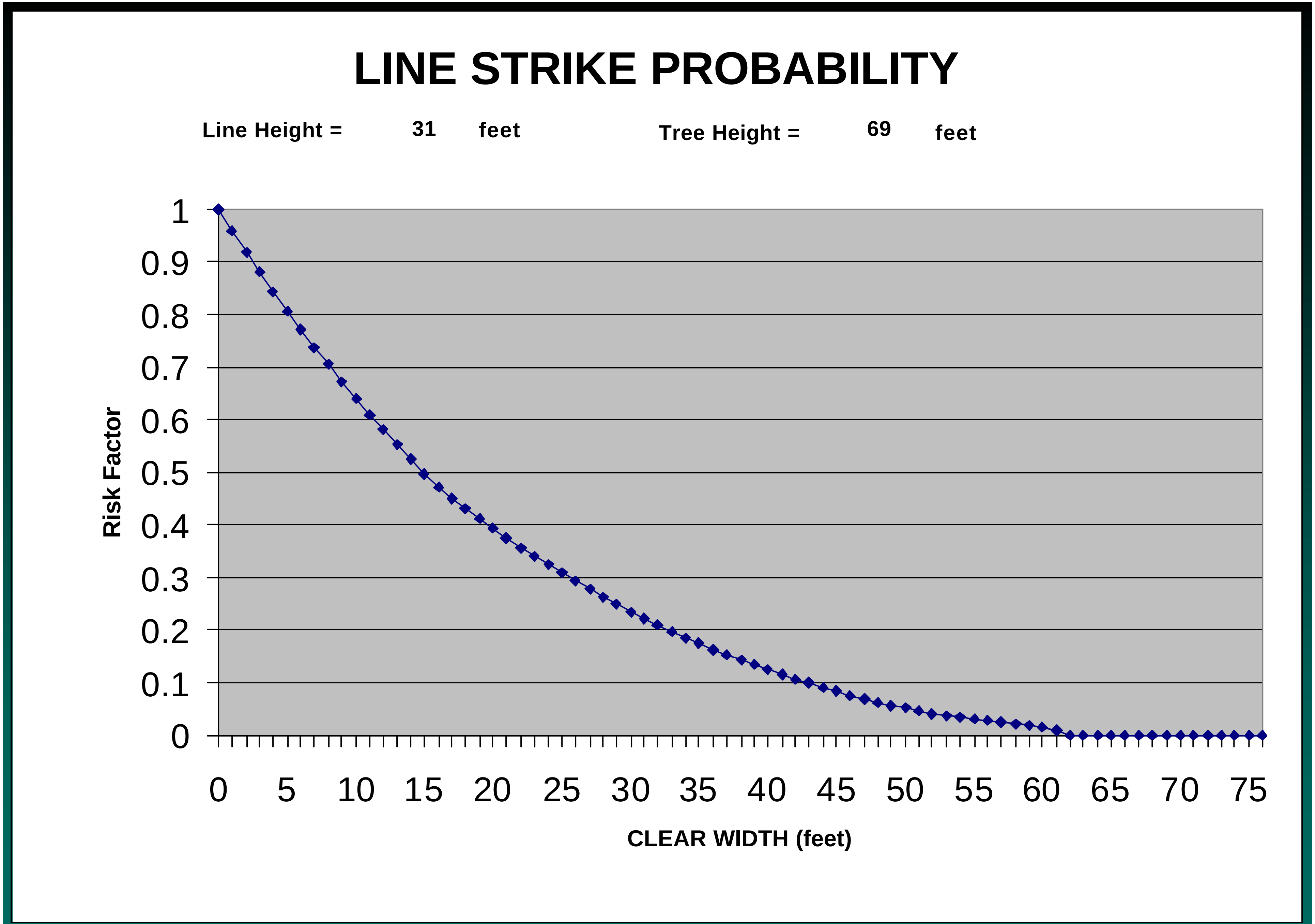
Voltage	Mean Risk Factor (%)	Current Mean Clear Width (ft)	Tree Free Clear Width (ft)	Tree Free Tallest Tree Found Clear Width (ft)
69 kV	11.95	44	84	115
115 kV	7.39	47	67	107
230 kV	4.34	54	78	98
345 kV	1.71	52	66	104

NY 115 kV Mean Conditions



What’s the Right Clear Width

- **Current mean CW 44 ft**
- **Based on mean line height, tree height, clear width and tree density: RF = 0% @ 62 ft**
- **New standard ? Ft**
- **RF @ 5% target**
  - **then clear width 3 50’ & RF = 5.17**

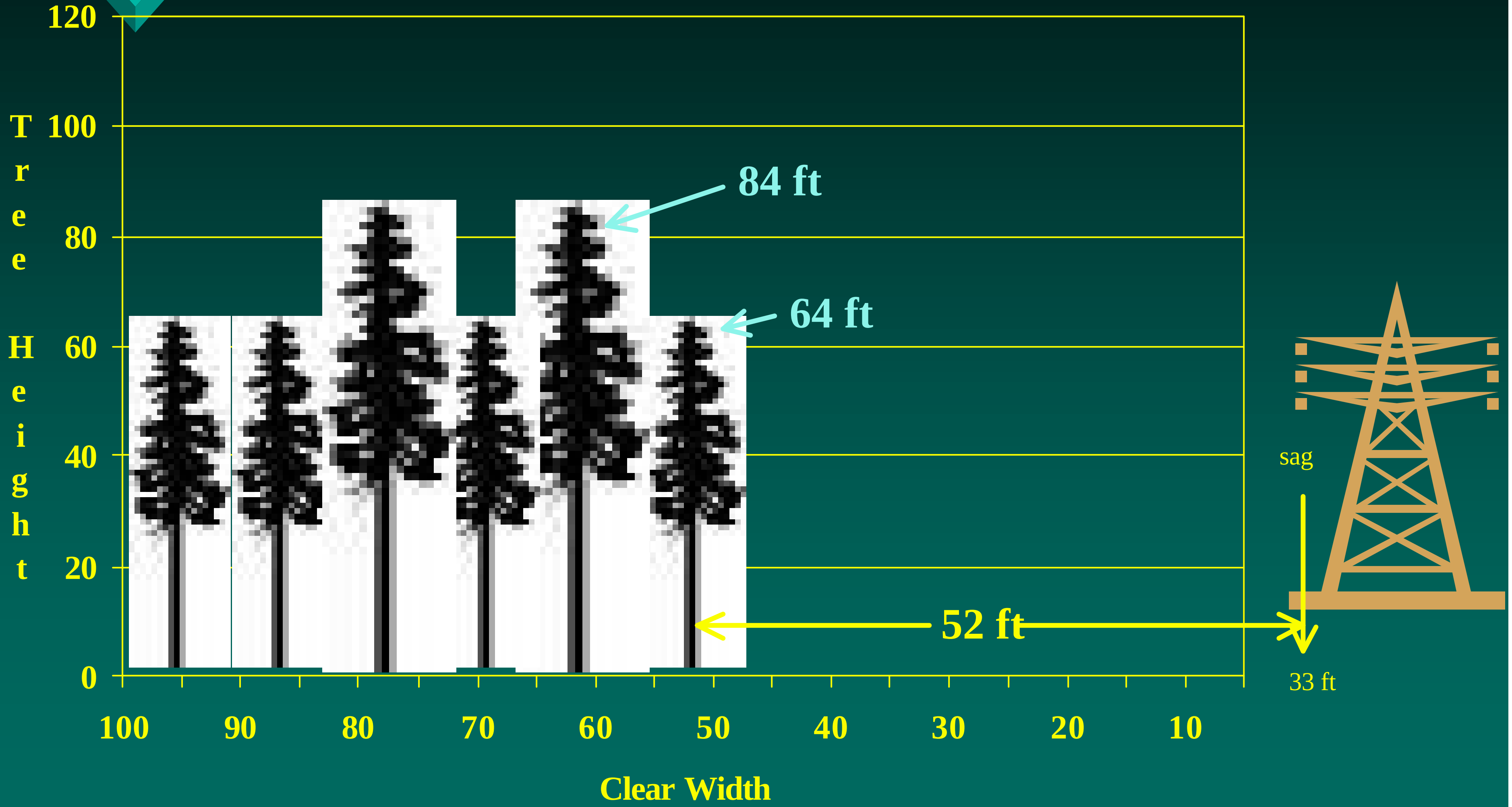


LINE STRIKE PROBABILITY
Line Height = 31 feet
Tree Height = 69 feet
Risk Factor
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75
CLEAR WIDTH (feet)

What’s the Right Clear Width

- **Current mean 44 ft**
- **Based on mean line height, tree height, clear width and tree density RF = 0% @ 62 ft**
- **New standard ? Ft**
- **RF @ 5% target**
  - **then clear width ^{3} 50’ & RF = 5.17**
- **Installing standardized 50' clear width**
  - **72% of treed edge needs work**
  - **29% widening done not necessary as RF < 5.17%**
  - **2% of system left with RF > 9%**

NE 115 kV Mean Conditions



What’s the Right Clear Width

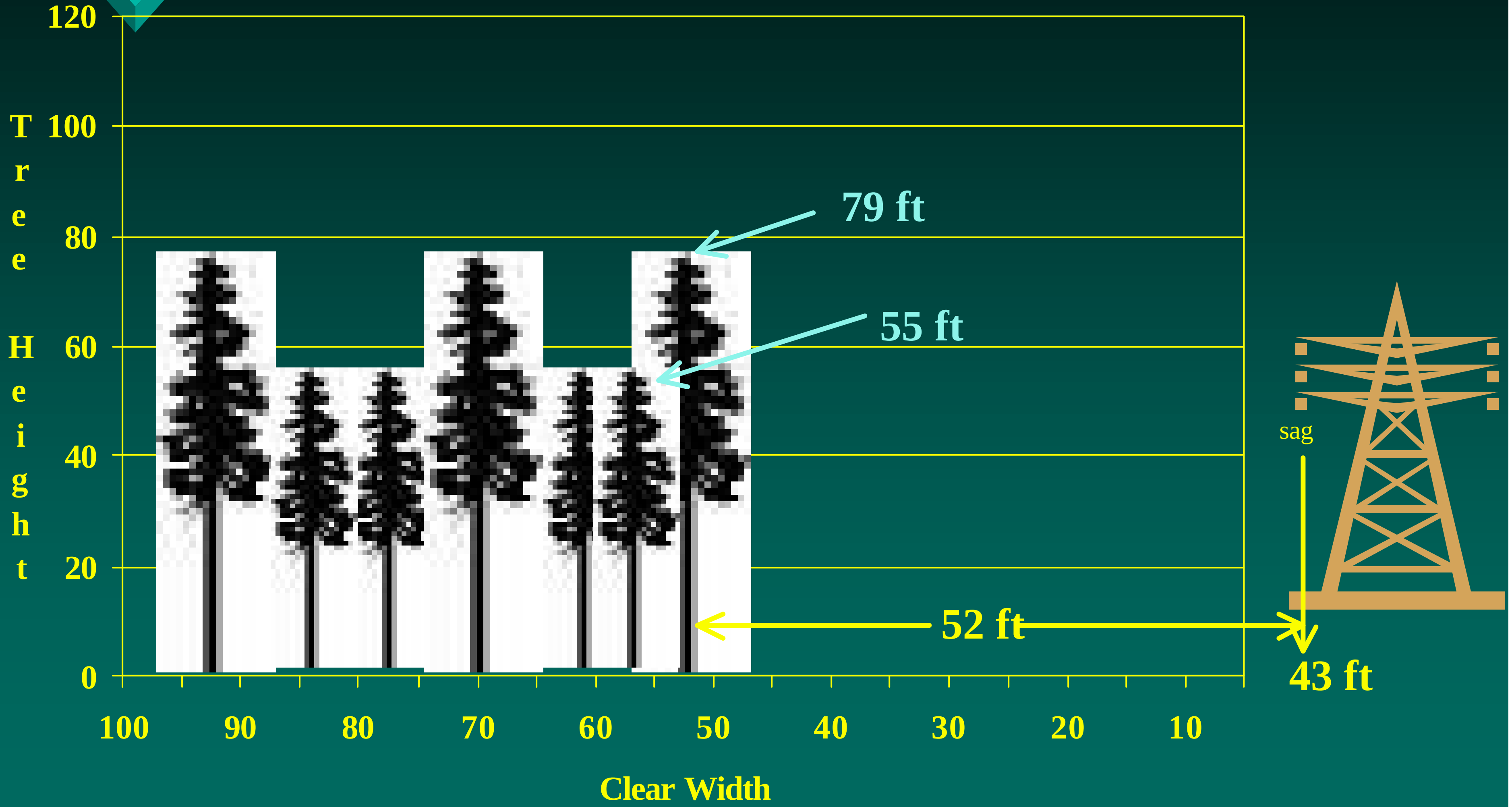
- **Current mean 52 ft**
- **Based on mean line height, tree height, clear width and tree density RF = 0% @ 77 ft**
- **New standard ? Ft**
- **RF @ 5% target**
  - **then clear width ^{3} 60’ & RF = 4.97**
- **Installing standardized 60' clear width**
  - **77% of treed edge needs work**
  - **39% widening done not necessary as RF < 4.97%**
  - **1% of system left with RF > 14%**

Use of Standard ROW Width

These two examples have shown that:

- **A tree free standard is unachievable**
- **If there is an intent to manage tree risk, standardized right of way widths cannot be used, as achieving a target RF @ 5% on 115 kV lines requires a 50' clear width in NY vs 60' in NE**
- **Installing a standardized clear width entails considerable waste of resources on work which yields no benefit in line security**
- **Use of standardized clear widths can leave areas of high residual risk**

345 kV Mean Conditions



Implications of STD Clear Width

- **Current mean Risk Factor = 1.71%**
- **Based on mean variable values RF = 0 @ 67 ft**
- **STD Clear Width 70 ft?**
  - **89% needs work**
  - **Voltage class security improvement = 78%**
  - **69% already at 0% risk**
  - **1% of system left with >0% risk**
- **To achieve tree free need to increase clear width to 104 ft**

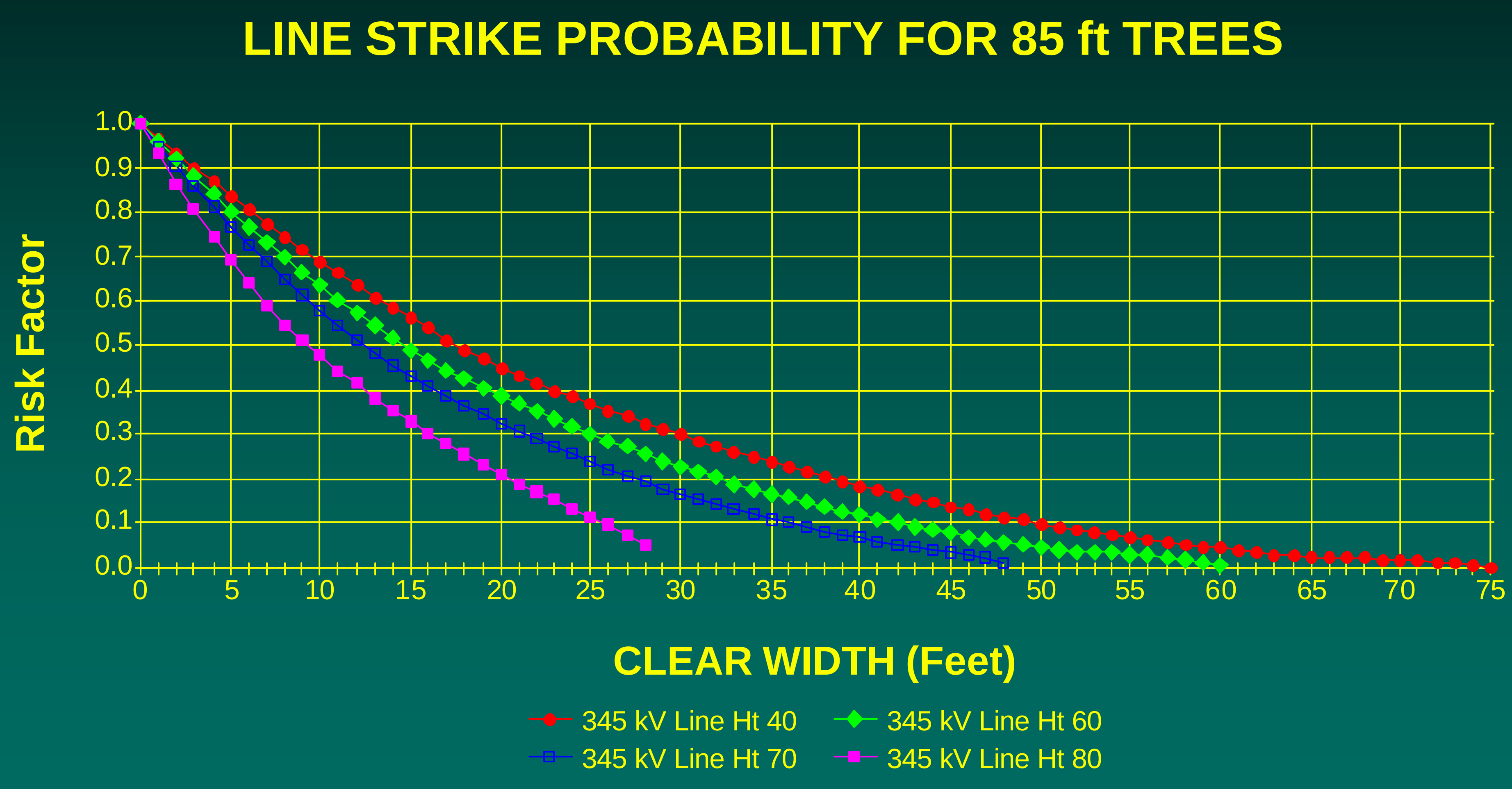
Target Risk Factor Mitigation

- Target RF = 1.71%
- 20% of system needs work
- Average RF where work required = 8.27%
- 345 kV system risk factor on completion = .36%
  - Weighted average
  - Security improvement = 79%

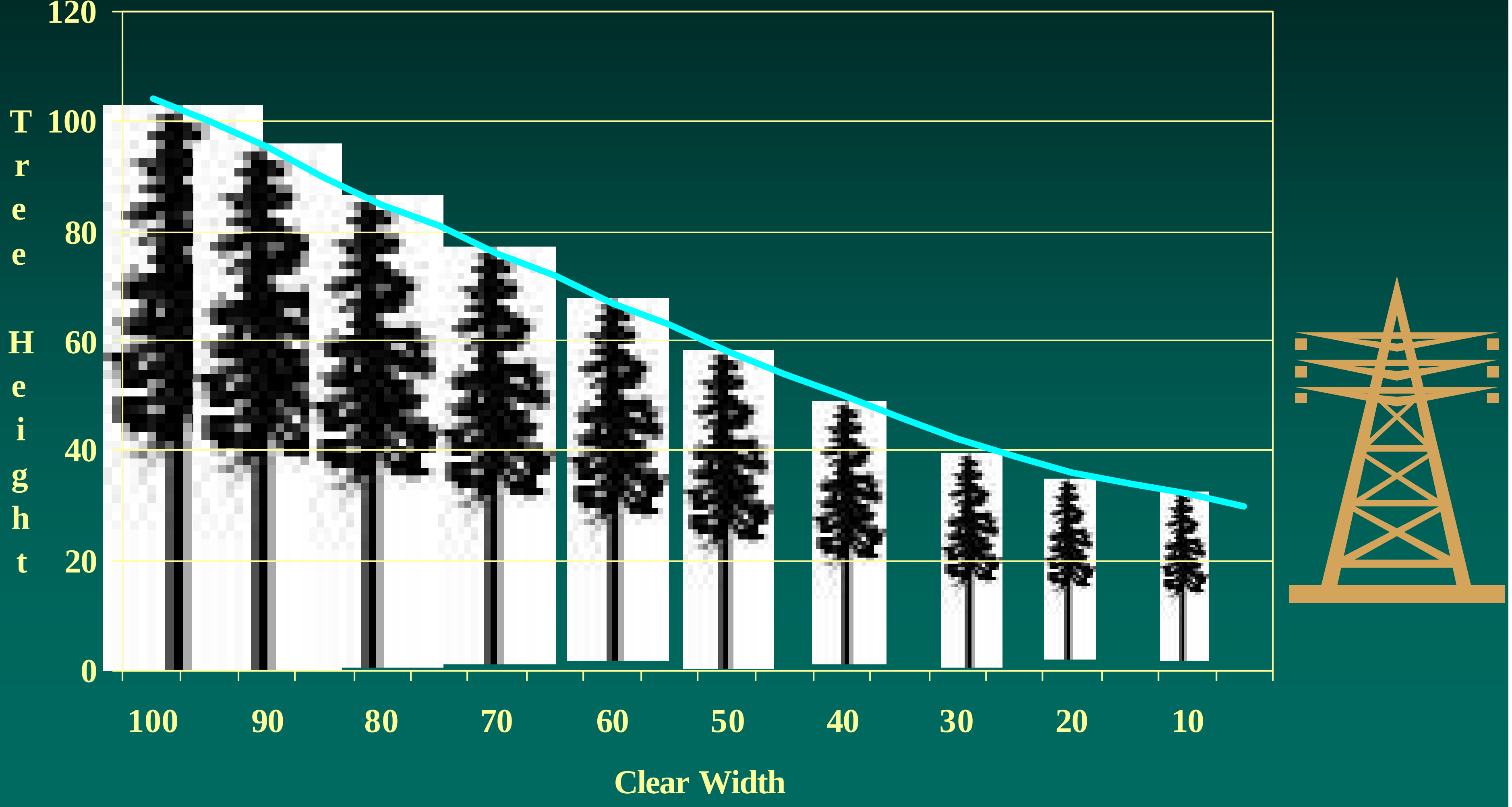
Other Options

- **Increase line height**
- **Prune trees to reduce height**

Sensitivity of Risk Factor to Line Height



Pruning



120
100
80
60
40
20
0
Tree Height
100
90
80
70
60
50
40
30
20
10
Clear Width

Mitigation Plan

- **Emergent trees – remove or prune to co-dominant height**
- **Co-dominant trees – where RF > system average RF for the voltage class adjust clear width, line height or tree height to achieve RF £ system voltage class average**

Target/Mean Risk Factors (%)

	At Maximum Sag		
	NE	NY	System
69 kV	11.95	-	11.95
115 kV	7.08	7.52	7.39
230 kV	4.85	3.50	4.34
345 kV	3.21	0.71	1.71

Does Mitigation Meet Objectives?

- **Does it address maximum tree free requirements?**
- **Does it provide the greatest return in system security for the dollar invested?**
- **Does it achieve the objective of no tree-caused interruptions?**
- **Has all tree risk been removed?**

Scope of Mitigation Implied at Maximum Sag

	No. of Records	No. Records With RF>Mean	% Requiring Mitigation
69 kV	58	24	**41**
115 kV	387	145	**37**
230 kV	90	33	**37**
345 kV	83	17	**20**

System Improvement Possible

	Tree Risk @ Maximum Sag		Tree Risk For Records With RF<Mean		Tree Risk For Records With RF=>Mean		
	No. of Records	**Ave. Risk Factor (%)**	**No. of Records**	**Ave. Risk Factor (%)**	**No. of Records**	**Ave. Risk Factor (%)**	**% Improvement (Weighted average)**
69 kV	58	11.95	34	4.42	24	22.62	**37**
115 kV	387	7.39	242	1.36	145	17.45	**51**
230 kV	90	4.34	57	0.99	33	10.14	**49**
345 kV	83	1.71	66	0.01	17	8.27	**79**

Weather Risk

- **Trees fail under weather stress**
- **Probability of a hurricane:**
  - **MA, RI .062**
  - **NY coast .093, inland @ 0.0**
- **Hurricane return period = 4.6 yrs**
- **Winter tree damaging events return period 2-3 yrs**

Annual Frequency of Tree Damaging Weather Events

State	Minor Destructive Wind Events	Major Destructive Wind Events	Winter Tree Damage Events	Total Major Tree Damage Events
MA	2.6590	0.062	0.2537	0.3157
NH	2.2833	0.0482	0.4711	0.5193
RI	1.5867	0.062	0.3178	0.3798
VT	1.98	0.021	0.3185	0.3395
NE	2.33	0.062	0.3311	0.3931
NY	3.3276	0.093	.7650	0.858

Weather & Forest Interactions

- Wind storms are a greater risk to transmission systems than ice storms as total tree failure under ice loading was pronounced in the smaller diameter classes while windthrow increased with stand age (larger diameter trees). As most ice storm damage was to the crown it indicates that branches broke under the load. The direction of this stress is predominantly downward. Trees, within the forest stand, shedding branches with little, if any, windthrow effect will not interfere with electrical service.

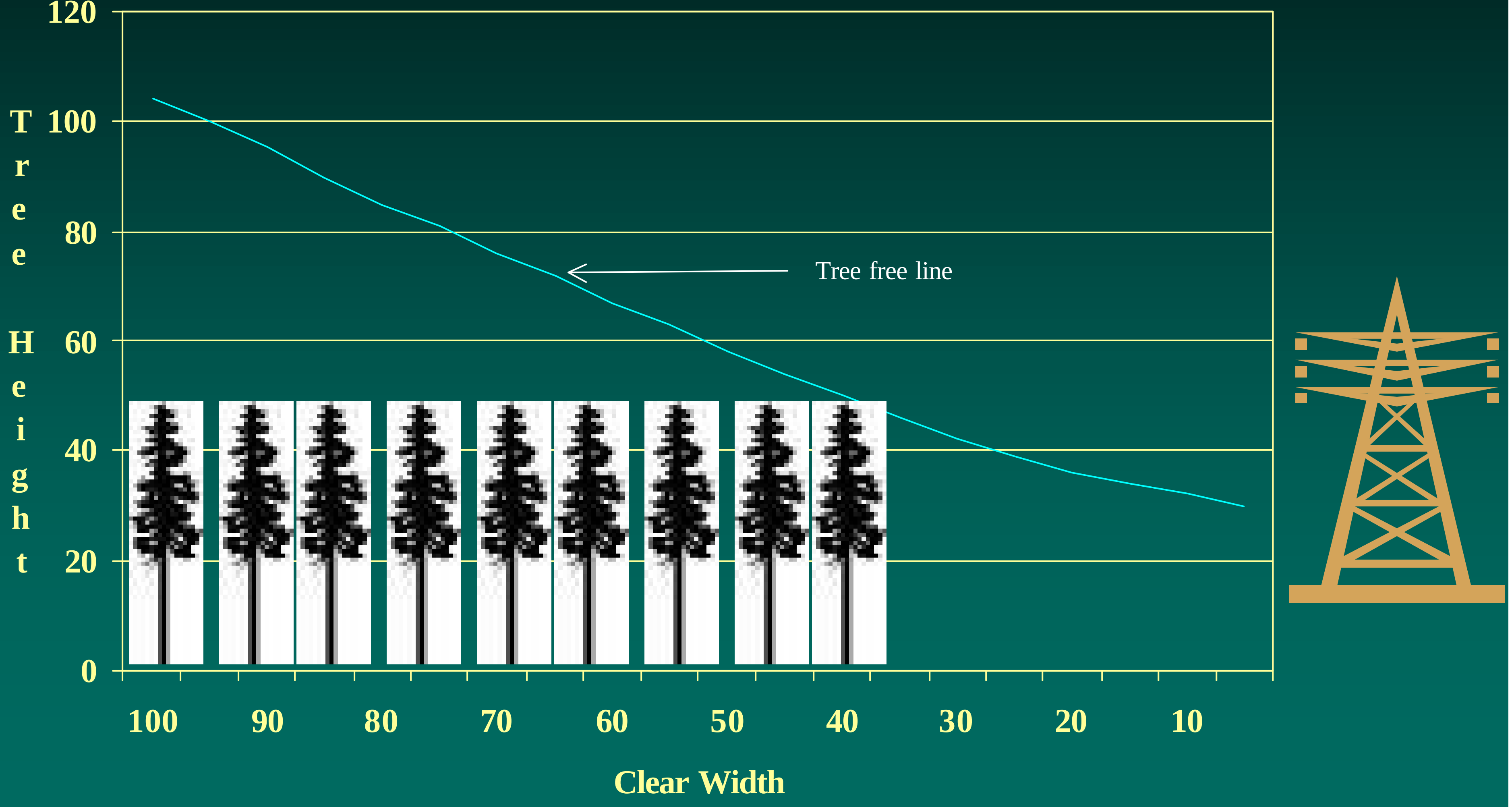
Weather & Forest Interactions

- Smaller diameter trees (5"-10") are far more susceptible to uprooting and bending under ice loading. Where right-of-way edges contain trees in this dbh range they pose a serious risk to electrical service, especially if the species are ones that tend to bend under load, such as trembling aspen.

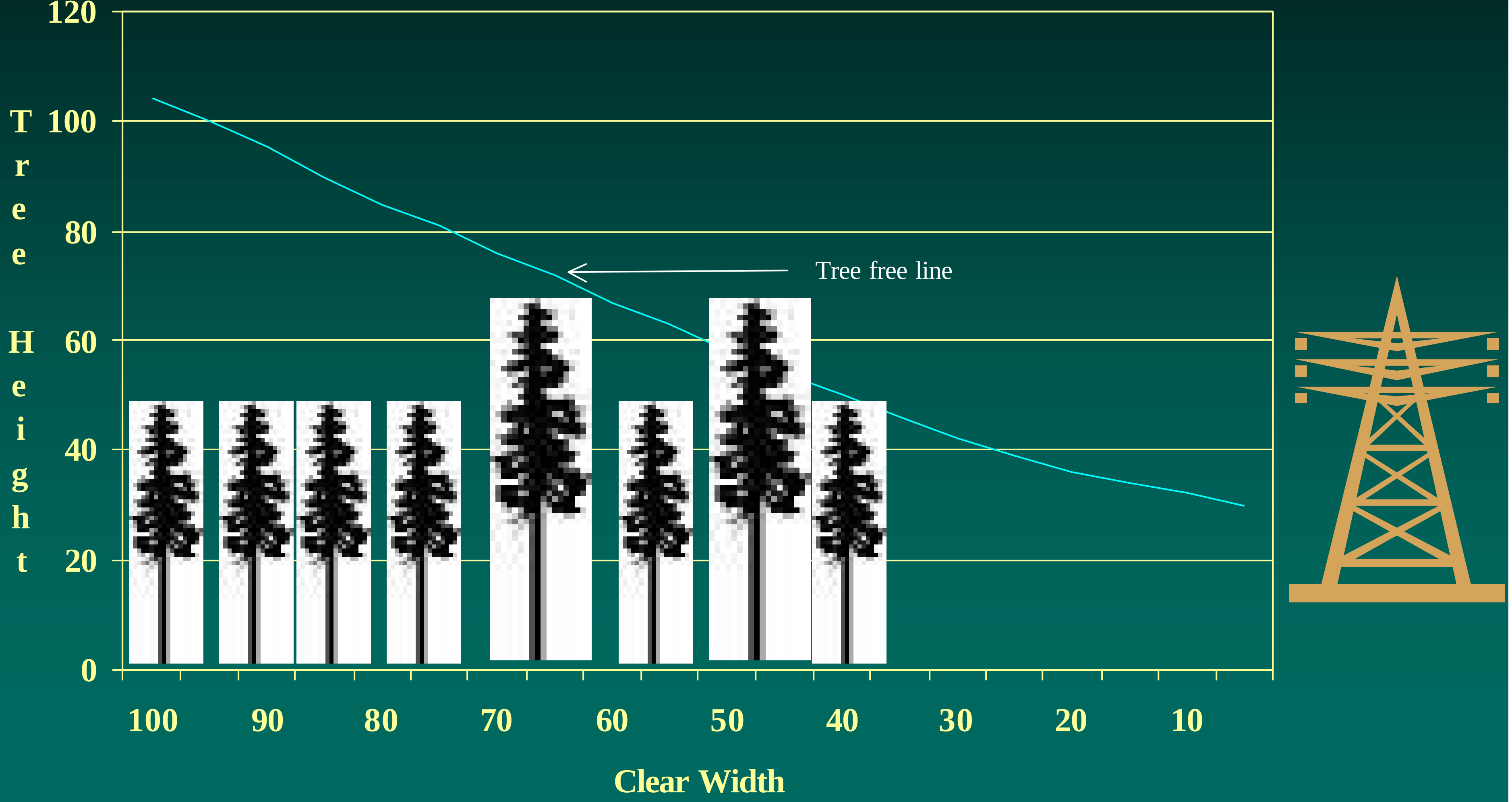
Mitigation

- **Situation that will be encountered**

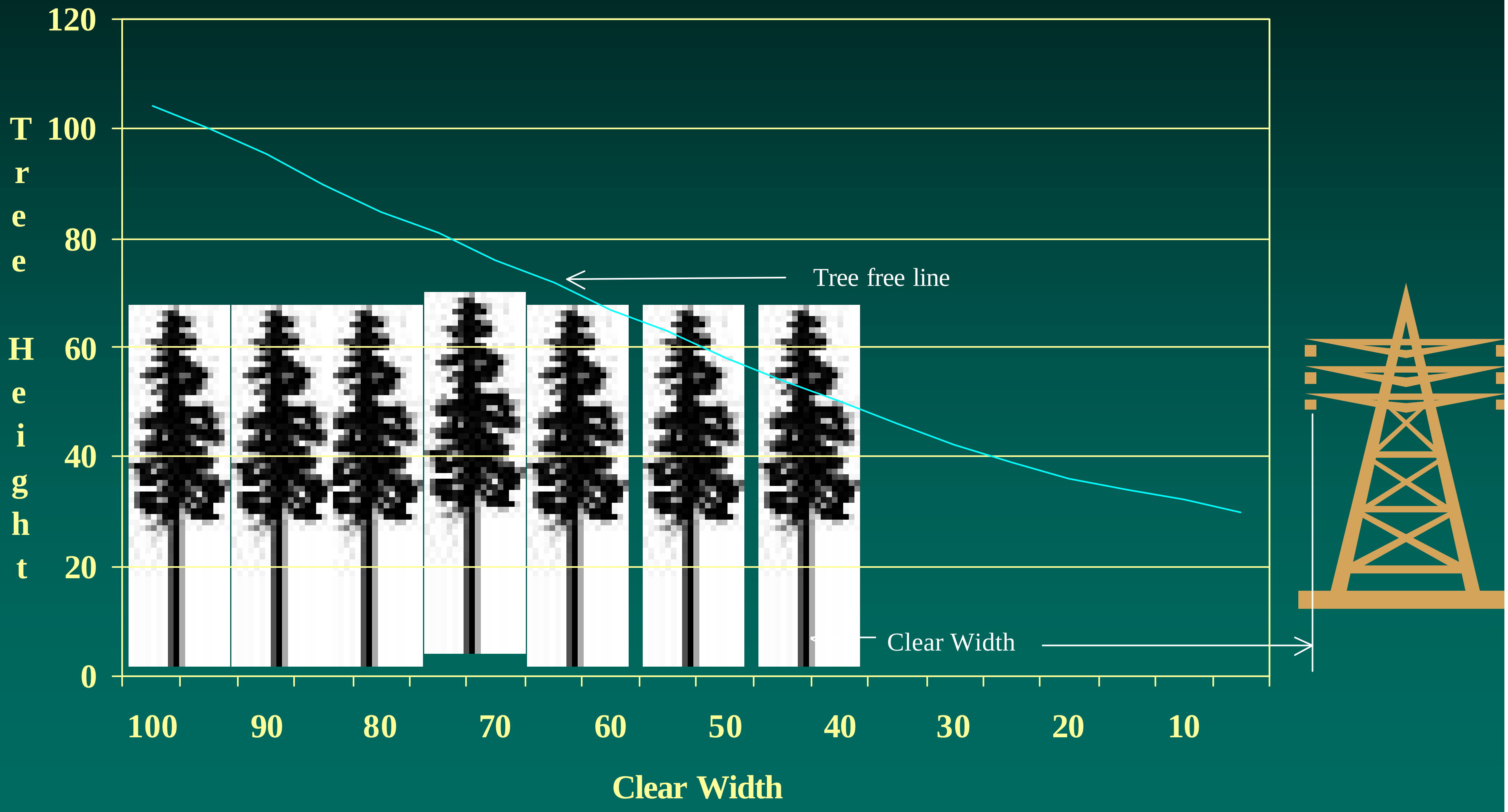
No Work Required



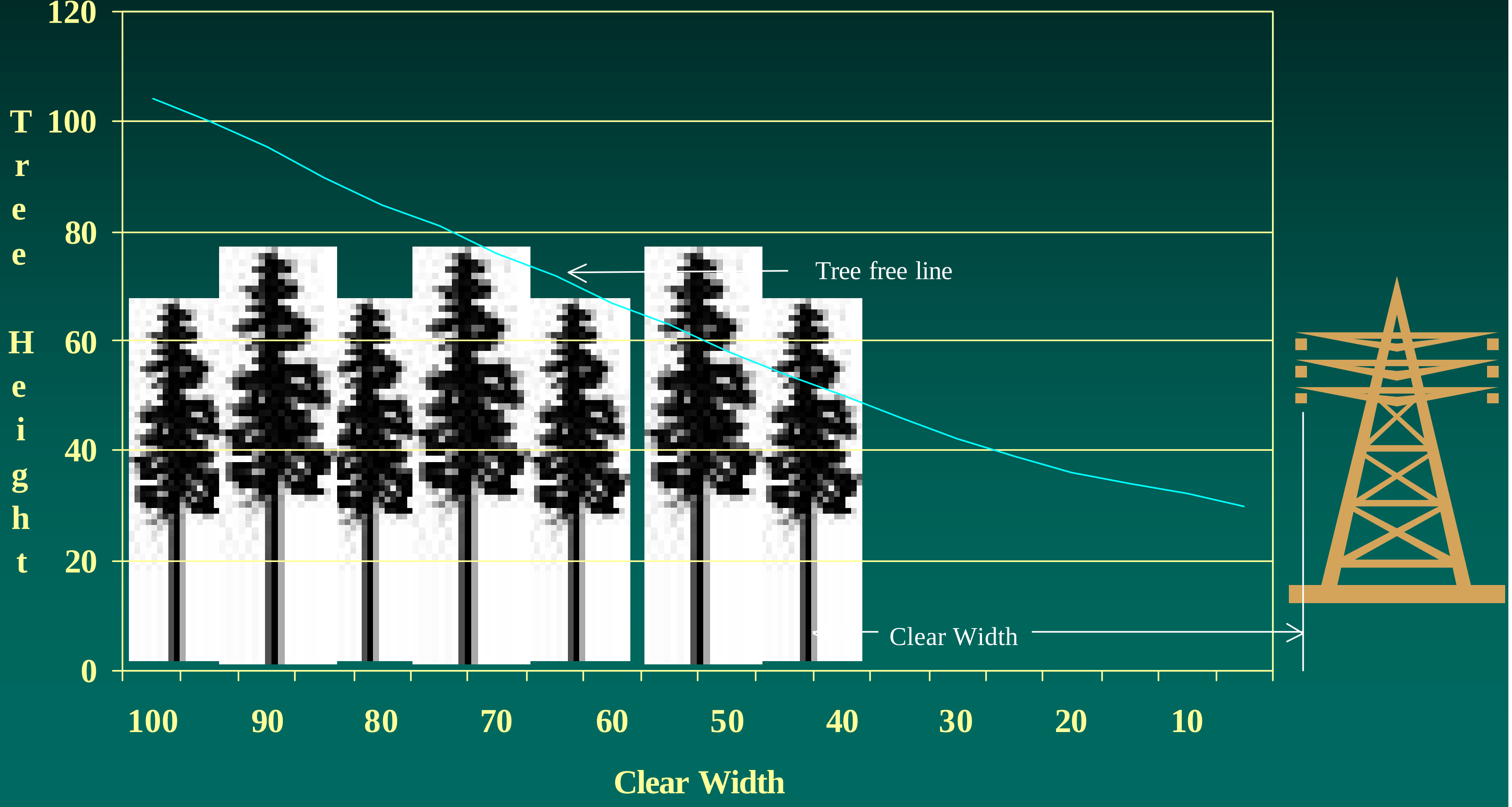
Emergent Trees Only



Co-dominant Trees Only



Dominant & Co-dominant Trees



Mitigation of Side Line Tree Risk

1) **Identify all spans where there are emergent and co-dominant danger trees**
2) **Using the Optimal Clear Width Calculator (OCWC) derive the Risk Factor by span for dominant trees and the co-dominant canopy height at maximum line sag**
3) **Using the target residual tree Risk Factor determine the minimum clear width, residual tree height or conductor height necessary for the co-dominant canopy to yield a Risk Factor <= the target residual tree Risk Factor**

Mitigation of Side Line Tree Risk

5) **Decide whether or not to exclude spans populated exclusively with low risk species from the planned treatment**
6) **Check for limits on easements that would prevent establishing the target clear width or pruning trees to an acceptable target height**
7) **Do the work**
8) **Audit the results**