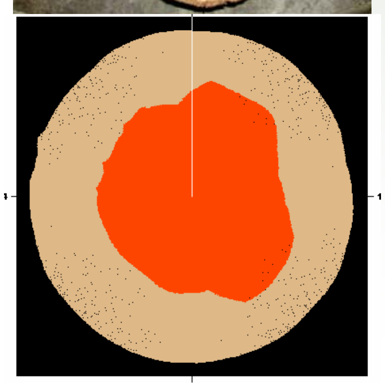
TREERADAR, Inc

MRI for TREES

RADAR IMAGING FOR NON-INVASIVE ASSESSMENT OF TREE AND ROOT HEALTH

Non-Invasive Assessment of Tree and Root Structural Integrity

Features of TRU System



- **Non-Invasive**
- **Portable, via Battery Supply**
- **Minimal Set-Up, Easy to Use**
- **Same System can Scan both Trunk and Roots**
- **Rapid Scan – Less than 1 minute per Horizontal Circumferential Section**
- **Multi-Elevations Scanned to Track Decay**
- **High-Resolution 360° Cross-Sectional Image – “Virtual Drill”**
- **Quantitative Table of Remaining Solid Wood**
- **Subsurface Images of Structural Roots – Location and Depth – “Virtual Excavator”**

TRU™ (Tree Radar Unit) System Components

Field Computer

- Trans Reflective Display
- No Internal Hard Drive
- Compact Flash Card for Recorded Digital Waveforms
- Windows Cnet O/S

Radar Antenna

- Non-Invasive Trunk Inspection
- Encoder Wheel Automatically Triggers Digital Waveform Collection

Semi-Automated Roots Scanning

- Used in Narrow Pathways
- Encoder Wheel trails Tub and Automatically triggers Digital Data Collection

Automated Roots Scanning

- Fully Automated
- Encoder Wheel rubs against Rear Wheel to Automatically Trigger Digital Data Collection

Trunk (Stem) Inspection

“Virtual Saw Cut”

"How Could It Fall Down…It Looked So Healthy?"






Stem Scanning Protocol

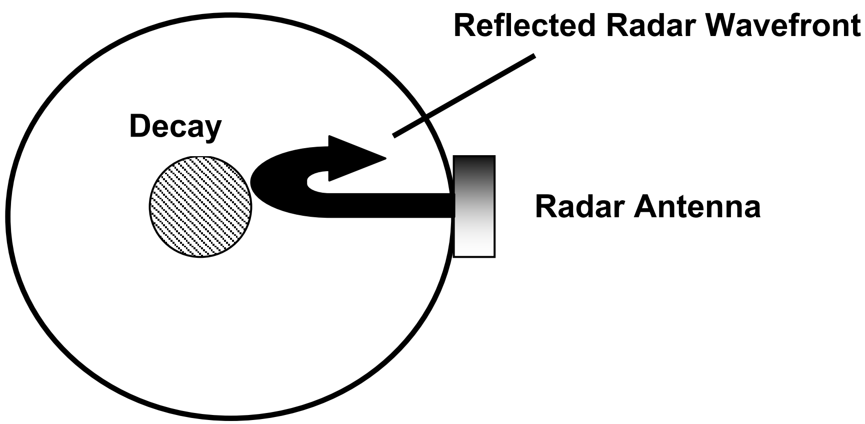
Single T/R Antenna - Reflection Mode

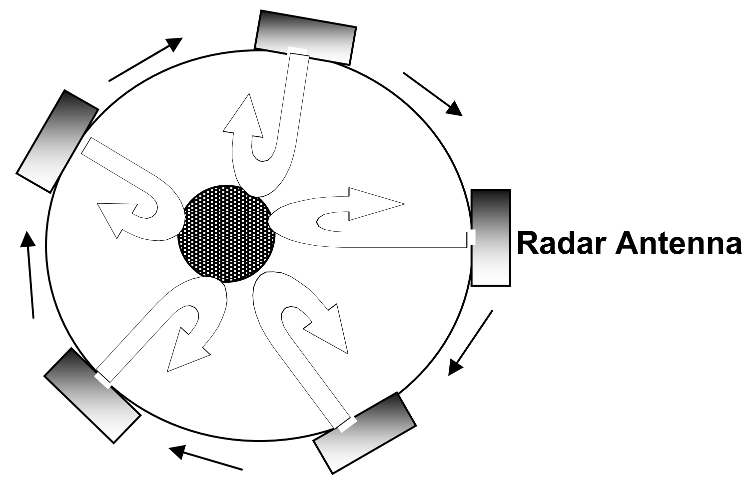
Scan proceeds Clockwise from Start/Stop Point

Radar Digitized Waveforms automatically recorded at every 0.2 in. (5 mm) of Movement around the complete Circumference

Off-Line Signal Processing Software determines the Distance from Bark Surface to Decay for every 0.2 in (5 mm) Location around the Circumference

Plots of the Predicted Cross-Sectional Geometry and the Remaining Solid Wood around the Circumference are Created





Reflection Mode
Single T/R Antenna

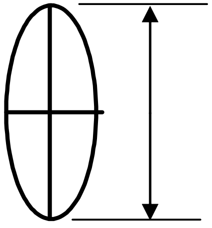
Radar Antenna Parameters

Dimensions: 14in (36cm) x 7in (18cm) x 2in (5cm)

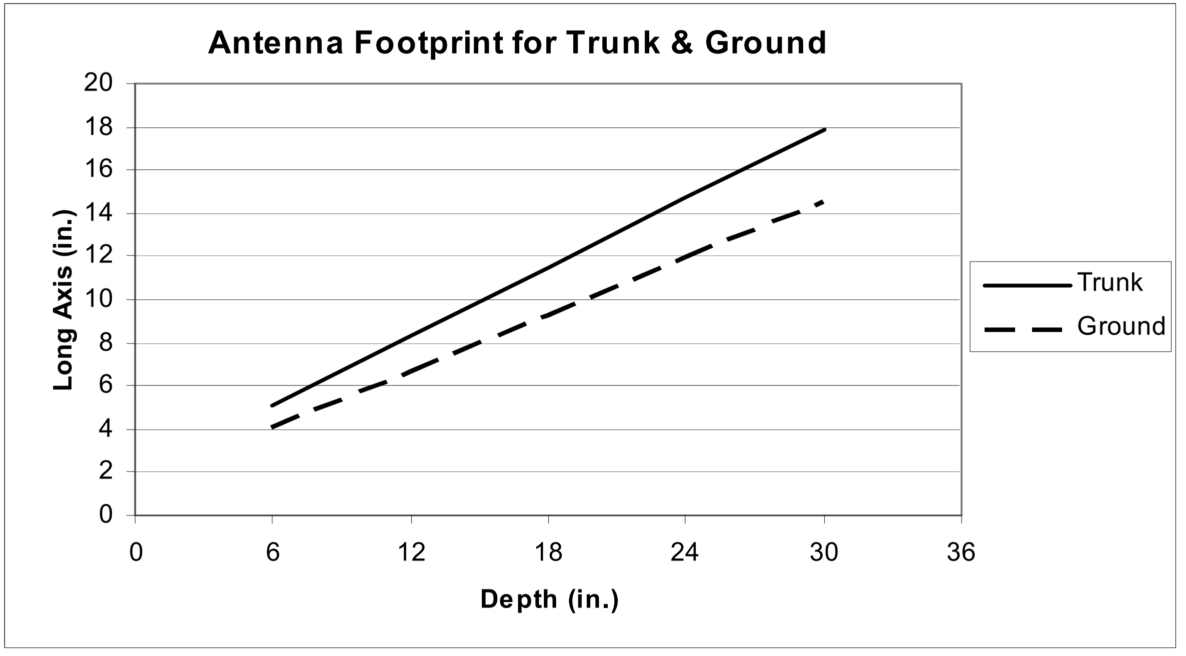
Weight: 5 Lbs (2.3 kg)

Center Frequency: 900 MHz (0.9 GHz)

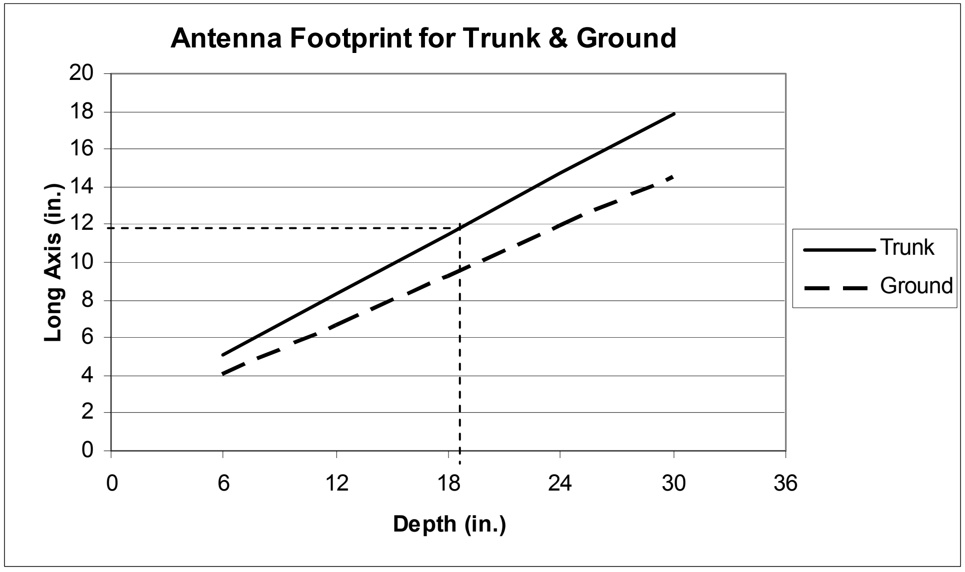
Material	Wavelength	Resolution	Penetration Depth
Wood	3.7 in (9cm)	1.2 in (3cm)	1 meter
Soil	2.3 in (5.8cm)	0.7 in (1.2cm)	1 meter



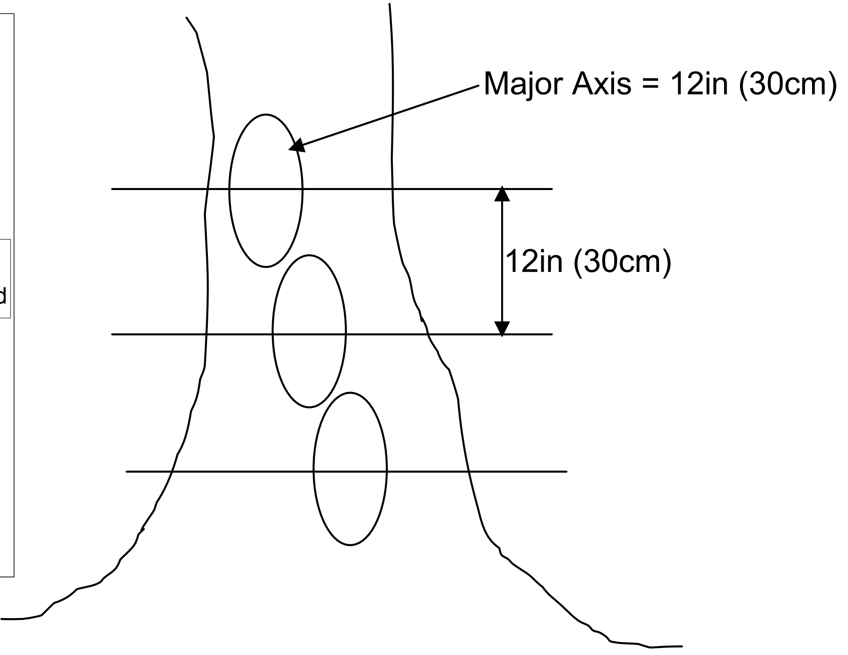
Antenna Elliptical Footprint
Long Axis denotes Beam Spread in the Vertical Direction for Trunks & Perpendicular to the Roots for Subsurface Inspection



Example of the Advantage Sensor Beam Spread offers for Trunk Overlapping Coverage



100% Horizontal & Vertical Coverage due to Sensor Beam Spread

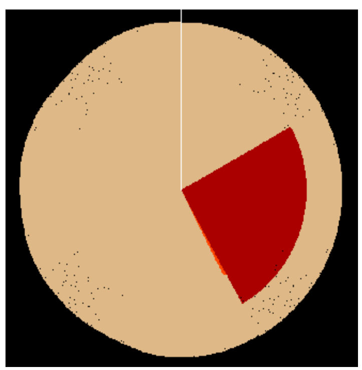


TRU™: Tree Radar Unit

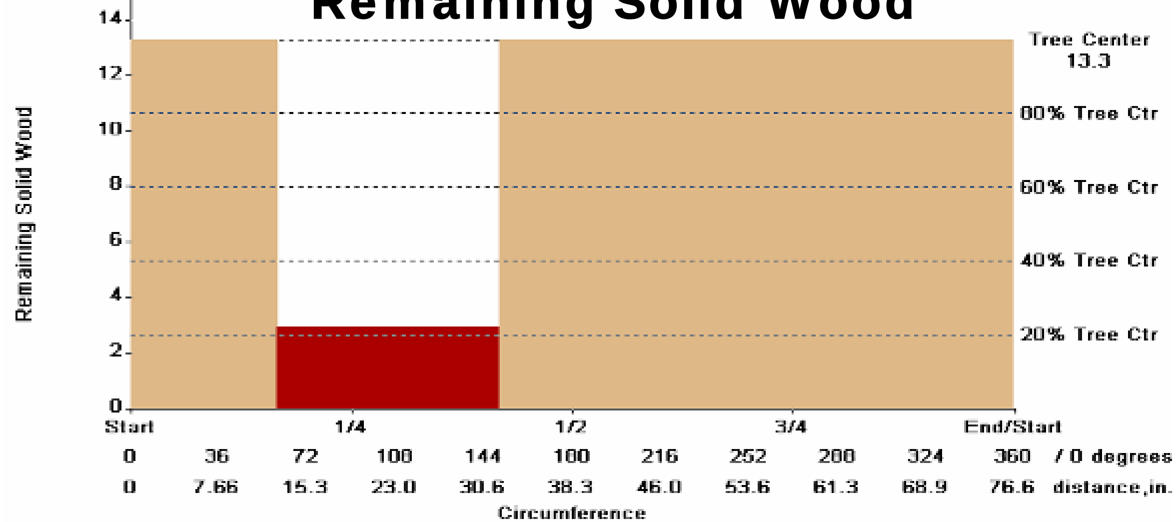
- Innovative *Non-Invasive* system provides a cross-sectional image with 100% coverage of the tree trunk at multiple elevations – "Virtual Saw Cut"
- Thickness plot showing a 360-degree plot of remaining solid wood – "Virtual Drill" – is generated and analyzed for each elevation scanned

Actual Cross-Section

Predicted Cross-Section



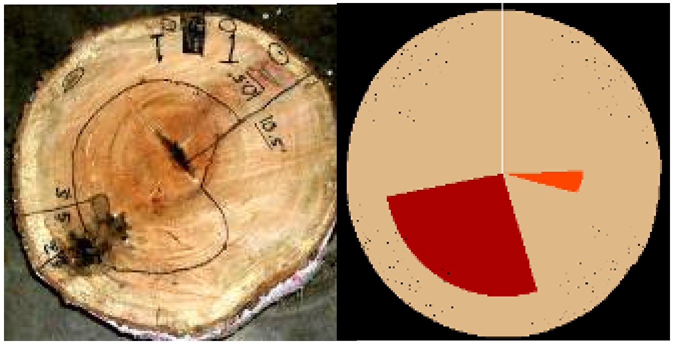
Predicted Remaining Solid Wood

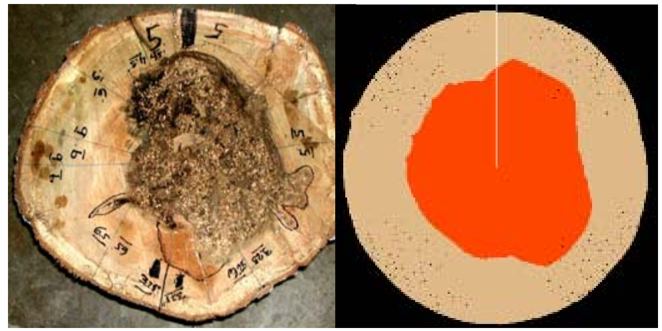


Actual vs. Predicted Cross-Sections for Five Different Hardwoods

Near-Surface Decay with 0 to 3in (7.5cm) RSW

Decay with > 3in (7.5cm) RSW





TreeHenge II

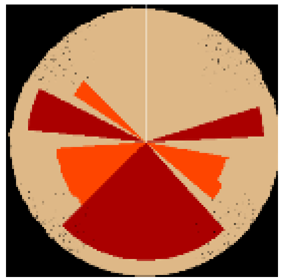
Five Recently Felled Hardwoods

Tracking Decay Progress down the Trunk

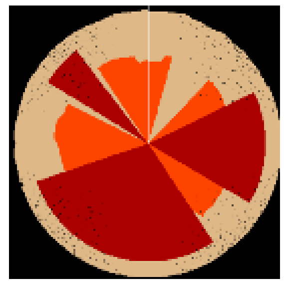
Silver Maple   dbh = 48in (122cm)

Open Cavity at 20ft (6m) + Significant Problems at base

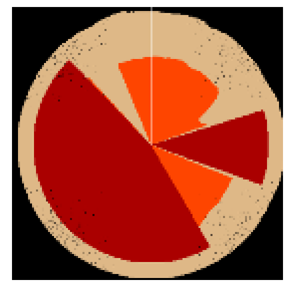
Scanned at 5 Elevations



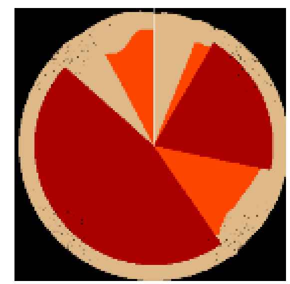
6ft (1.8m)



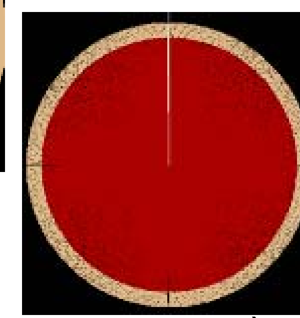
5ft (1.5m)



4ft (1.2m)



3ft (0.9m)



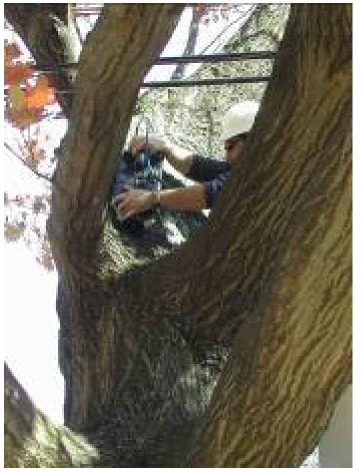
2ft (0.6m)

TRU at High Elevations

Urban Forest Limbs & Canary Island Date Palms









TRU in the Forest

- Climbers using TRU to perform complete 360-deg circumferential scans of large conifers at high elevations
- The two climbers are shown handing off the antenna from one to another to perform the complete scan
- The field computer is being operated by a third individual in a gondola of a 285ft (87m) tall crane, located 20ft (6m) from the climbers, with a 100ft (30m) cable attaching the field computer to the scanning radar antenna
- Douglas Fir, 210ft (64m) tall, scanned from top to bottom at 20 different elevations



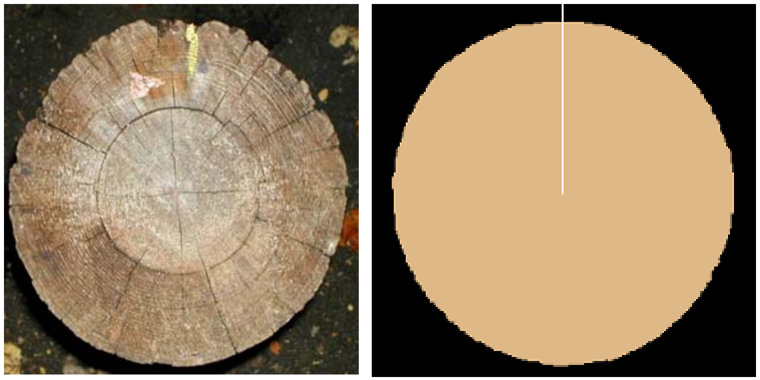
TRU Radar Scanning of Utility Poles

Small 1500MHz High-Resolution Antenna

TRU Radar Scanning of Utility Poles

Four Pole Samples

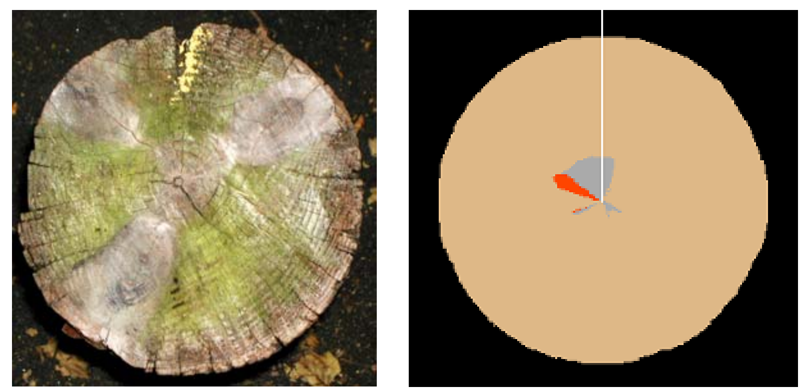
TRU Radar Scanning of Utility Poles



Pole A Dia = 9.25in (23.5cm)

Pole B Dia =10in (25.4cm)

Pole C Dia = 9.5in (24cm)



Pole D Dia = 8.5in (21.6.5cm)

Point Data Acquisition Mode

- ■ Lowest Elevation (base) Radar Waveform Recording where Surface is very bumpy
- ■ Single Waveform Recording at any Desired Location - "Virtual Drill"
- ■ Beam Spread Averages over an Elliptical Area for Single Shot – advantage over Drill

Single Point Data Collection on Base of Silver Maple

Structural Roots Inspection

“Virtual Excavator”

Most Trees Fall Because of Compromised Roots – mainly due to Construction or Fungal Attack

- Two roots emerging from buttresses of an English Oak
- Both curve away from a radial direction
- Root on the left changes from a radial direction to tangential
- The roots then cross and partially graft with each other
- So the root further from the tree is thicker than the root closer to the tree
- One root divides so it continues its original direction as well as grafting and fattening another root

Subsurface Structural Roots Inspection

Same Equipment – used for Roots:

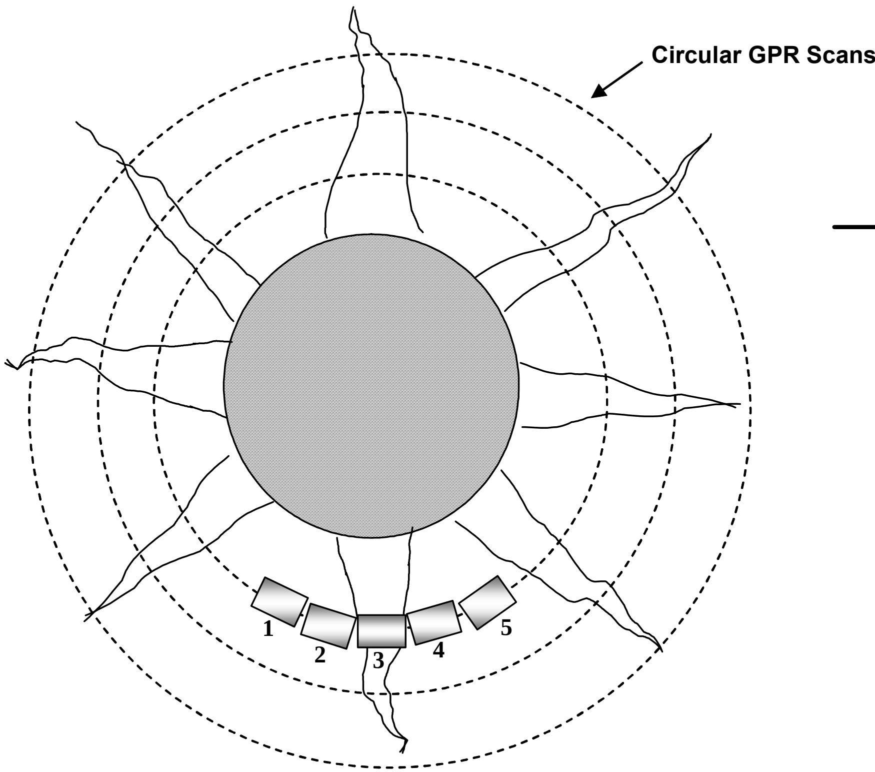
- **Detection & Mapping**
- **Sizing (diameter)**
- **Decay Inference**

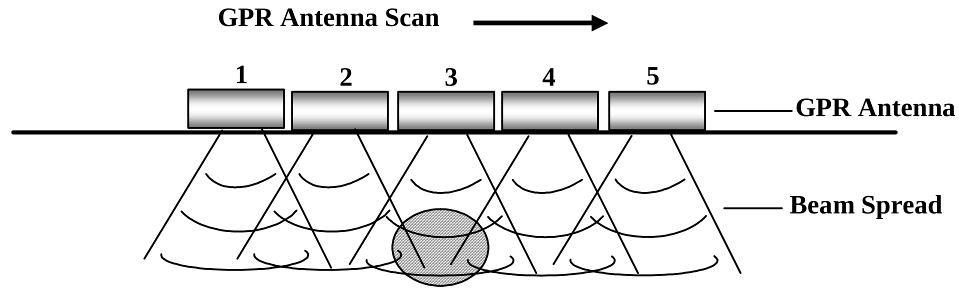
Subsurface Structural Roots Inspection

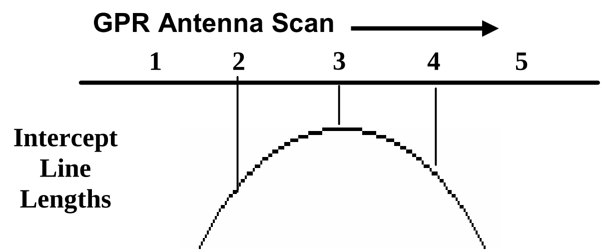
- **Detection & Mapping**
- **Sizing (diameter)**
- **Decay Inference**

Root Scanning Protocol

TRU Subsurface Radar Root Biomass Imaging





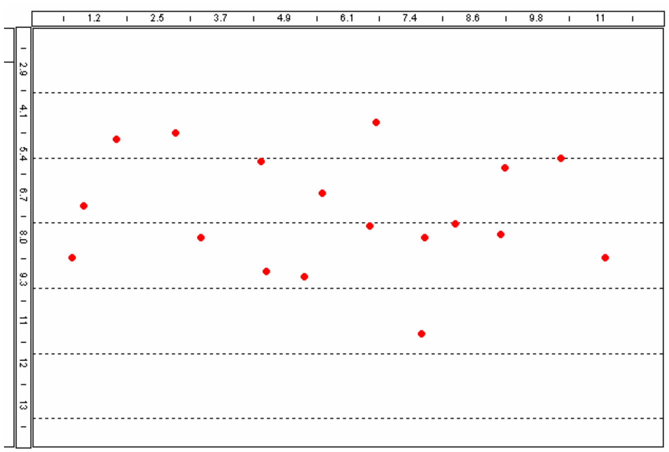


Beam Spread caused the Root Radar Image to appear as a "Reflection Hyperbola" whose shape is correlated with the Root Geometry

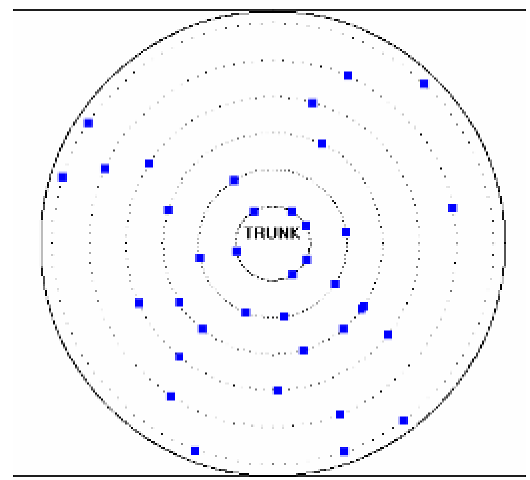
Resolution = 0.5in (1.25cm)

TRU™: Tree Radar Unit

- Soil scans to determine subsurface structural root location, depth, and size– "Virtual Excavator"
- Radar waves can penetrate covered soil to find roots under brick, concrete, and asphalt



Virtual Trench – 2D Planar Depth Image of Root Location and Depth for One Scan Line



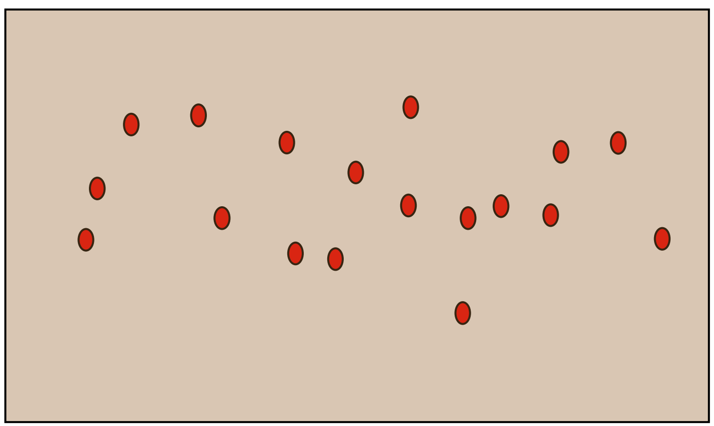
3D Top-Down Image of Root Layout and Density

2D Planar Image – "Virtual Excavator"

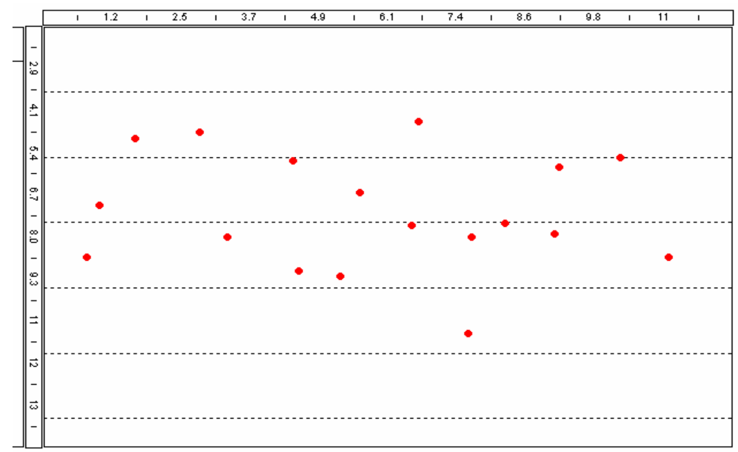
Actual Trench Excavation

Virtual Trench Excavation

Actual Root Locations (Hor) & Depth (Vert)

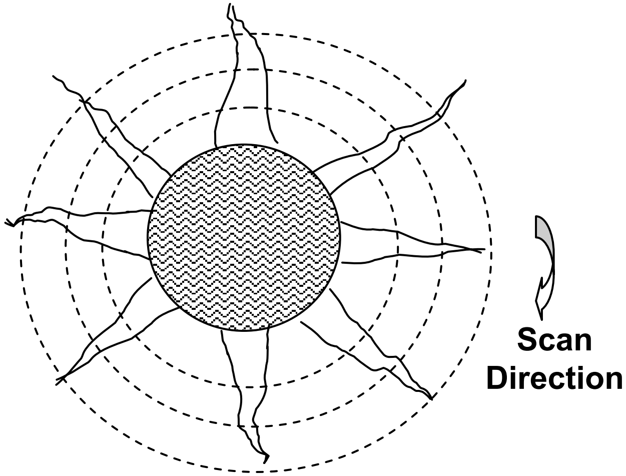


Predicted Root Locations & Depth



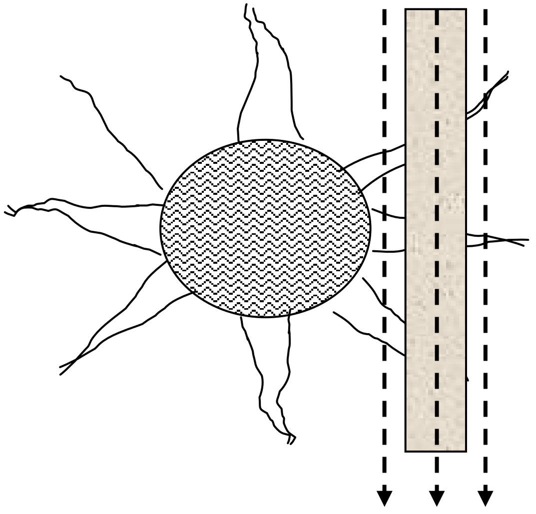
Root Scanning Protocol

Case I – Open Access – No Ground Cover → Line or Circular Scans



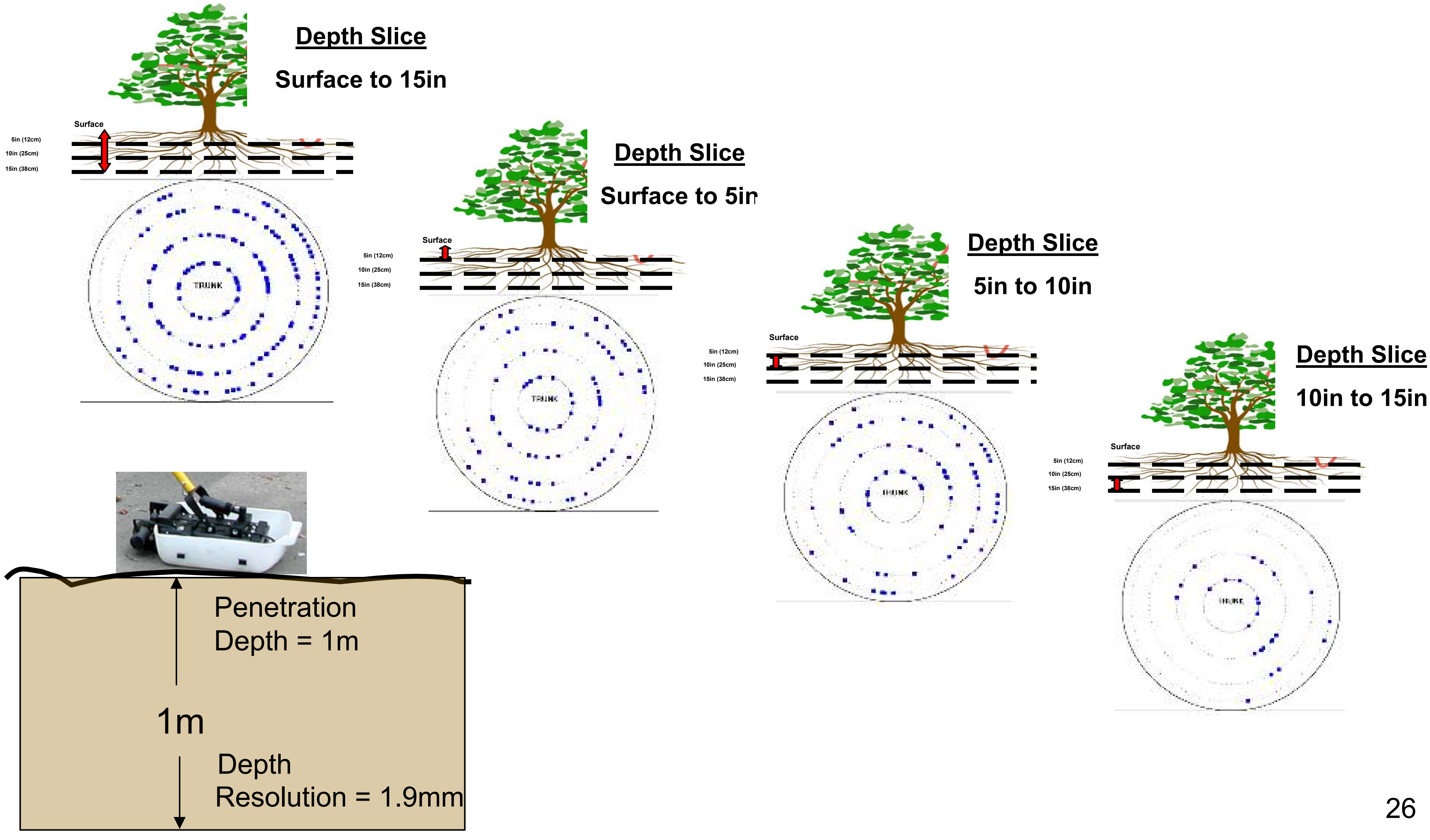
Detect & Map Roots at Different Depths

Case II – No Open Access – Ground Cover → Line Scans



Detect & Map Roots on Either Side + Underneath Ground Cover

Top-Down 3D Image of Subsurface Structural Roots at Four Depth Slices



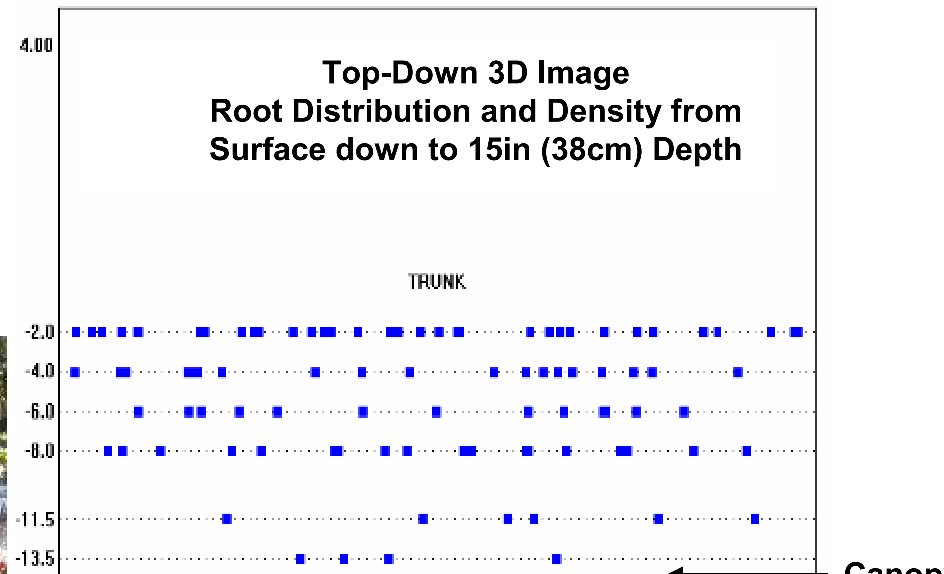
Inspection of a Magnolia with Suspected Stem Girdling Root

<u>**Government House – Magnolia – Suspected Stem Girdling Root**</u>

3D Top-Down View Showing Root Distribution and Density

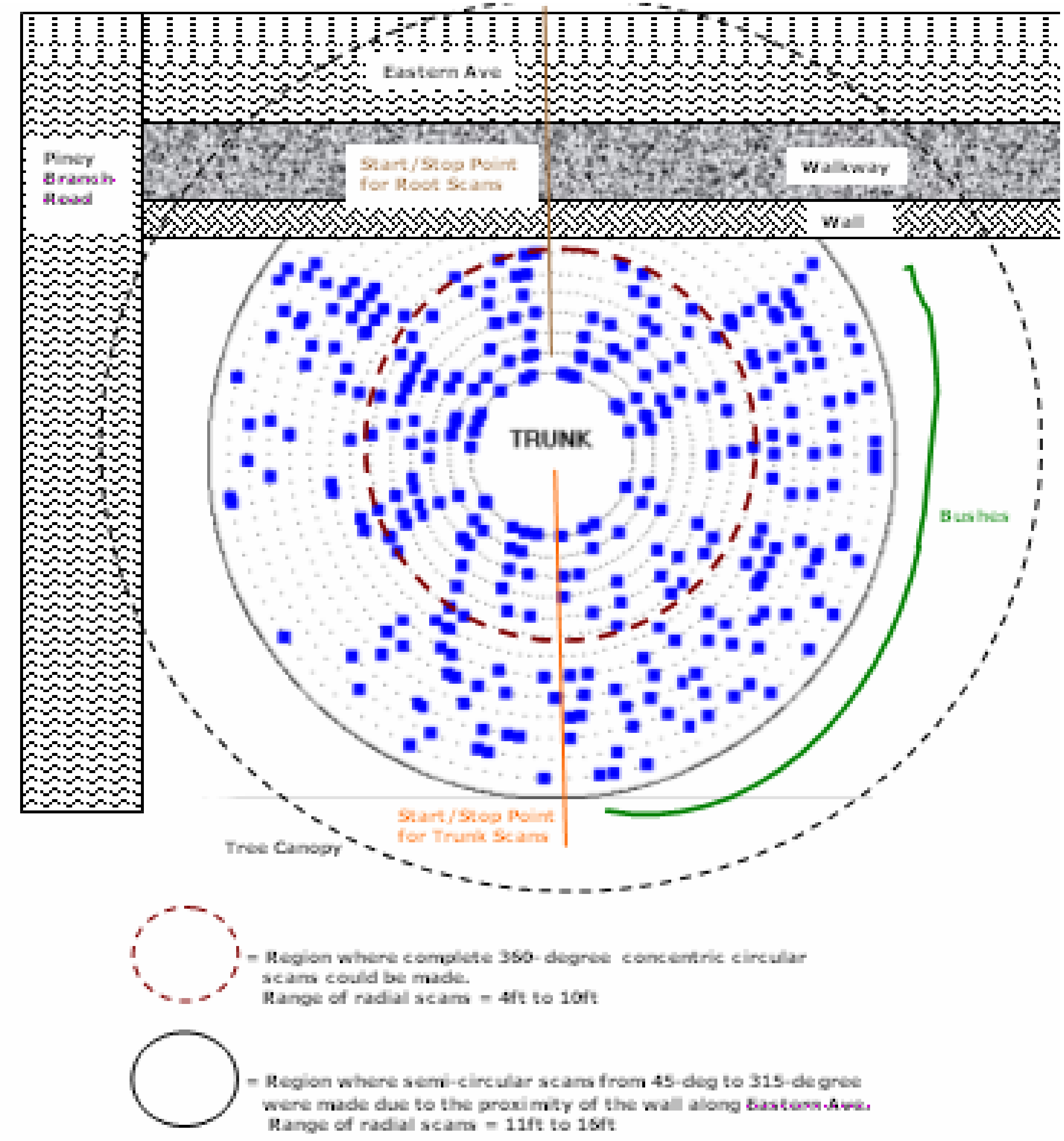
Data Recorded in Line Scans Parallel to the Brick Walkway

Distance Scanned from 2ft (0.6m) from trunk to Canopy Edge (4m)

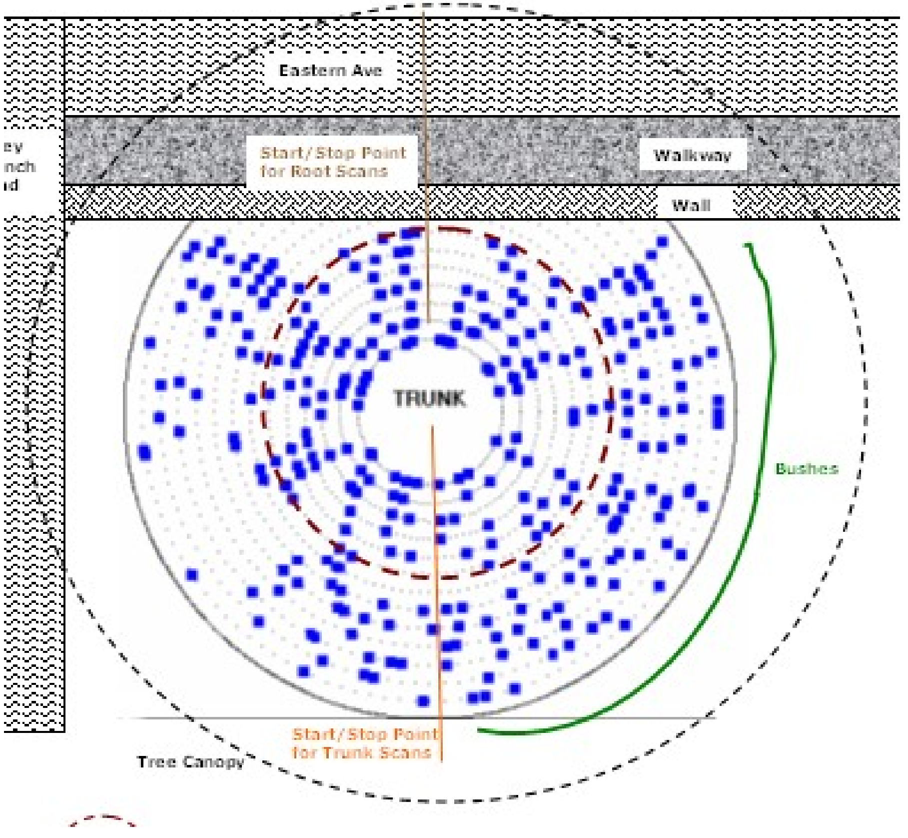


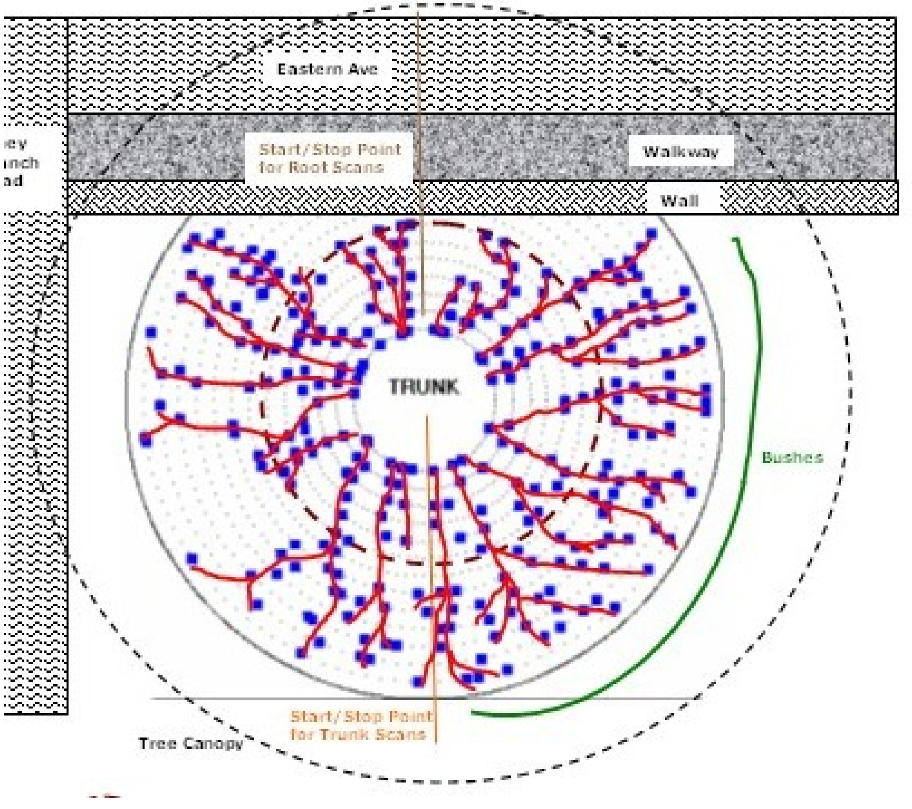
Top-Down 3D Plan View of Root Layout and Density

Blue Dots indicate detected Roots along a given Circular Scan Line



Connect-the-Dots Algorithm





Subsurface Structural Roots Inspection

- **Detection & Mapping**

- **Sizing (diameter)**

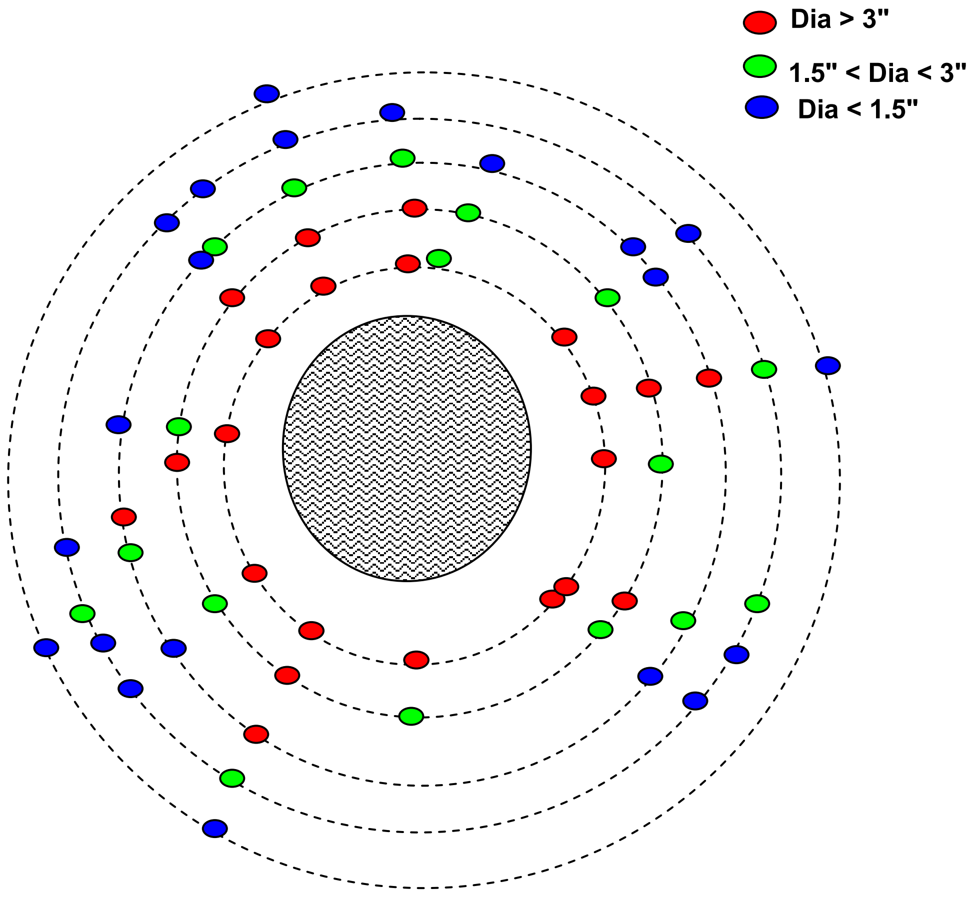
Dia > 3"

1.5" < Dia < 3"

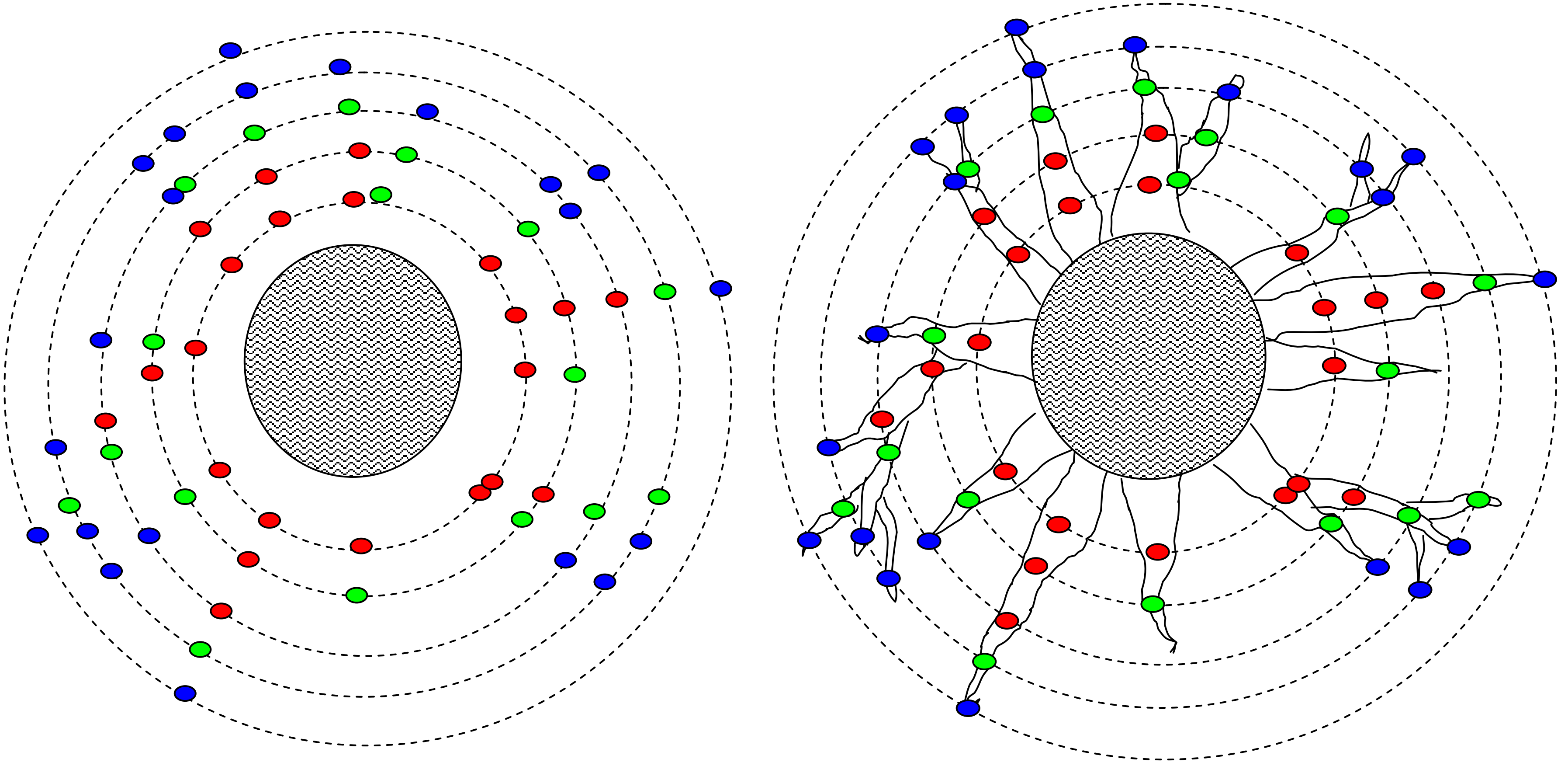
Dia < 1.5"

- **Decay Inference**

Schematic of 3D Top-Down Root Map



Schematic of 3D Top-Down Root Map



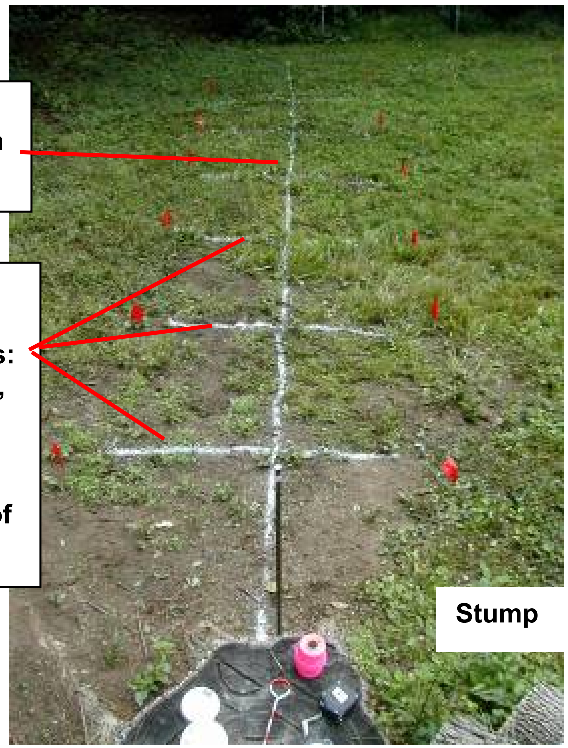
Root Sizing Calibration

Pope Farm – Montgomery County – TRU Scan of Subsurface Roots of a recently-cut 28" diameter Ash stump (9-15-04)

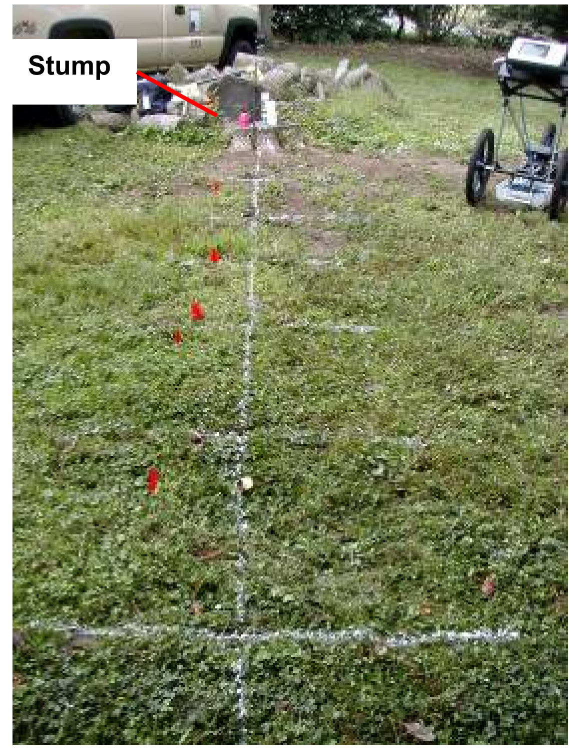
18-ft line drawn radially out from the stump

4-ft cross hatch lines drawn every 3-feet, at locations: 3-ft, 6-ft, 9-ft, 12-ft, 15-ft, 18-ft

Ground was scanned at each of the six 4-ft cross hatch locations



View standing on stump looking to the end of the 18-ft line



View standing towards stump from end of the 18-ft line

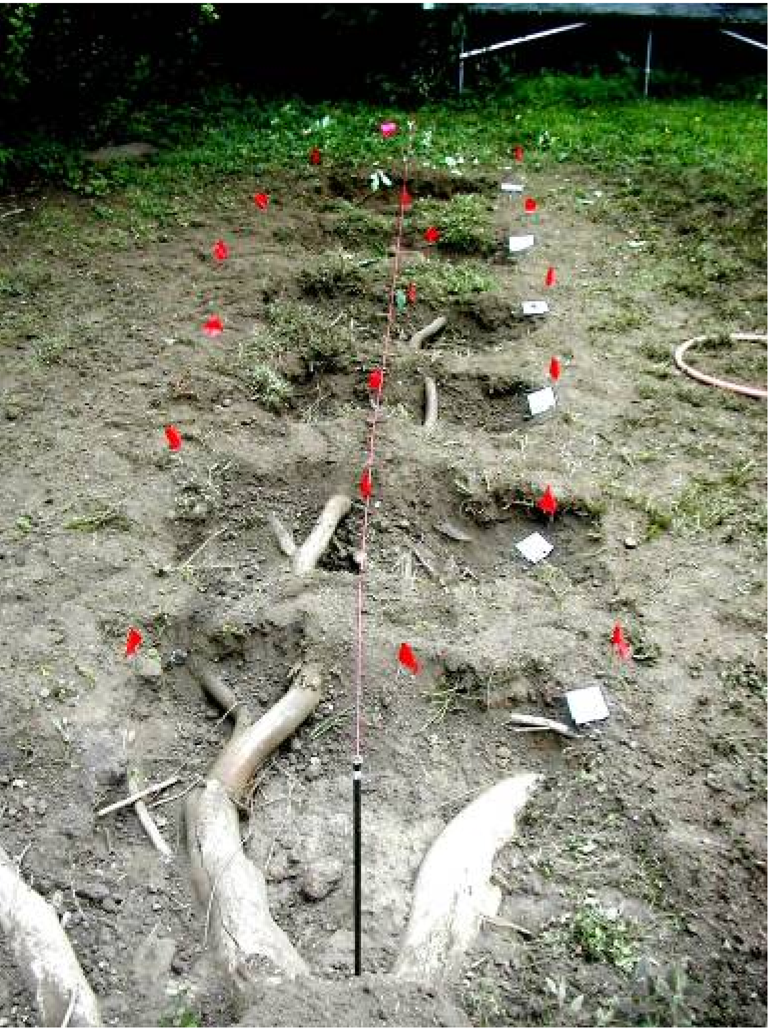
Root Sizing Calibration

Excavating the Soil using the Air-Spade high-velocity Air Gun

Root Sizing Calibration

Six excavated "windows" into the ground

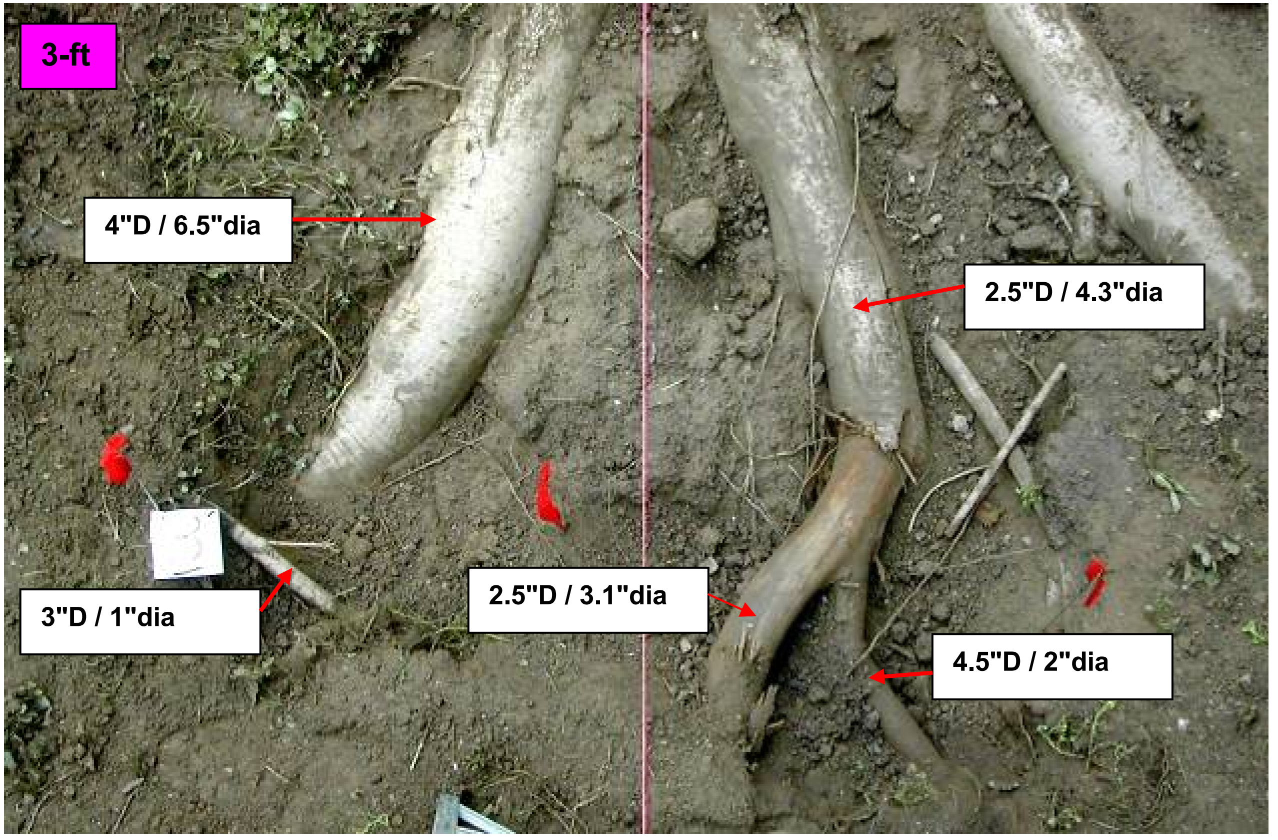
View – looking from the farthest, 18-ft, window towards the stump



Six excavated "windows" into the ground

View – looking from stump towards the farthest, 18-ft, window

Root Sizing Calibration



Subsurface Structural Roots Inspection

- Detection & Mapping
- Sizing (diameter)
- Decay Inference

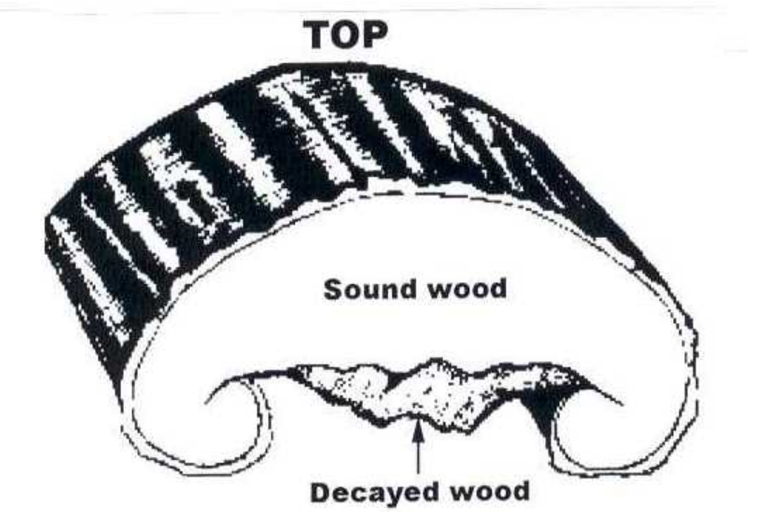


Figure 1. Root decay typically progresses from root tips toward the stem and from the bottom of the root upward.

Subsurface Structural Roots Inspection

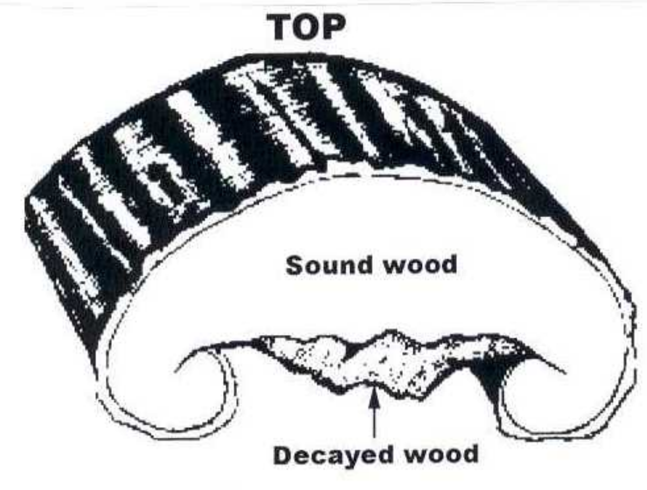


Figure 1. Root decay typically progresses from root tips toward the stem and from the bottom of the root upward.

- **Algorithm Efforts Currently in Progress**
- **Key Parameter is interior Moisture Content since this produces a large Dielectric Contrast with Surrounding Soil Matrix**
- **Decreased Moisture => Lower Signal Amplitudes**
- **Likely Multi-Level Decision Algorithm:**
  - **Level 1 – Detect Root (as currently done) and note (a) Distance from Stem & (b) Depth**
  - **Level 2 – Find (relative) Peak Amplitude**
  - **Level 3 – Lower Amplitudes in “wrong” Locations & Depth may indicate Root Decay**
  - **Assign a Probability of Decay via a Color Palette**

Current Research Effort with UC / Davis to Create Root Test Beds, using Natural Roots, to Develop Root Sizing & Decay Algorithms

Case Studies

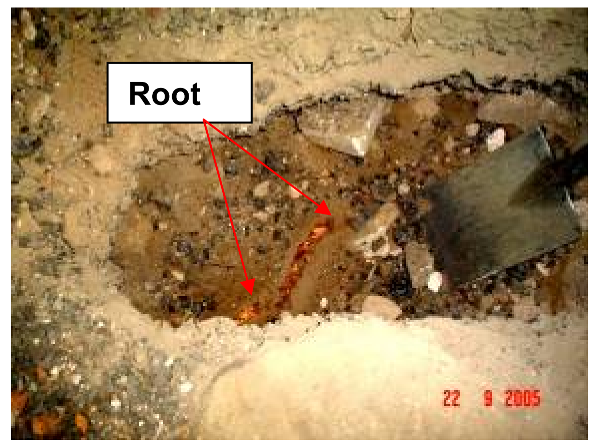
Case Study

Seven Oaks, UK (Sep. 2005)

Homeowner believes tree roots are causing upheaval in garage floor due to encroachment of roots from large trees outside the garage wall, while local Council Authorities believe it is due to settling and are unwilling to take responsibility without “scientific evidence”

Root Scans were conducted on asphalt walkway outside the garage wall and inside on the concrete garage floor

Scans showed the existence of three large roots under the concrete floor at a depth of 12”



Excavation verified one of the large roots (4” dia) at a 12” depth that was causing major upheaval

Resolution: Local Council Authorities have agreed to stop root encroachment and to compensate homeowner for all garage subsidence damage caused by roots

Case Study

Trunk & Root Scans on a Historic Oak Tree in Washington, DC (Nov. 2005)

Results of Trunk Scans at 4 Elevations:

"These results suggest that the decay becomes progressively more extensive near the base of the tree. The hollow sounding area, between 4:00 and 9:00 o'clock for all elevations, appears to be near-surface decay with the RSW between 0 to 3 inches."

Results of Root Scans around the Trunk:

"The root density is fairly sparse in the back of the tree facing the wall. This is a down-hill slope and represents the compression side of the tree. This is also where trunk decay was found to be the most extensive and where the trunk vertical crack exists."

Conclusions:

"This tree represents a potential risk hazard and should now be examined by a certified arborist to make a final assessment."

Based on examination by 3 Independent Consulting Arborists + TreeRadar report, tree was felled on December 1, 2005

Cady-Lee Mansion Washington, DC 200+ year old Oak
Felled on December 1, 2005

Prior to TreeRadar Scans

String Grid Lines to mark Elevations to be Scanned

Tree Felling Progress all branches removed

Cady-Lee Mansion Washington, DC 200+ year old Oak
Felled on December 1, 2005

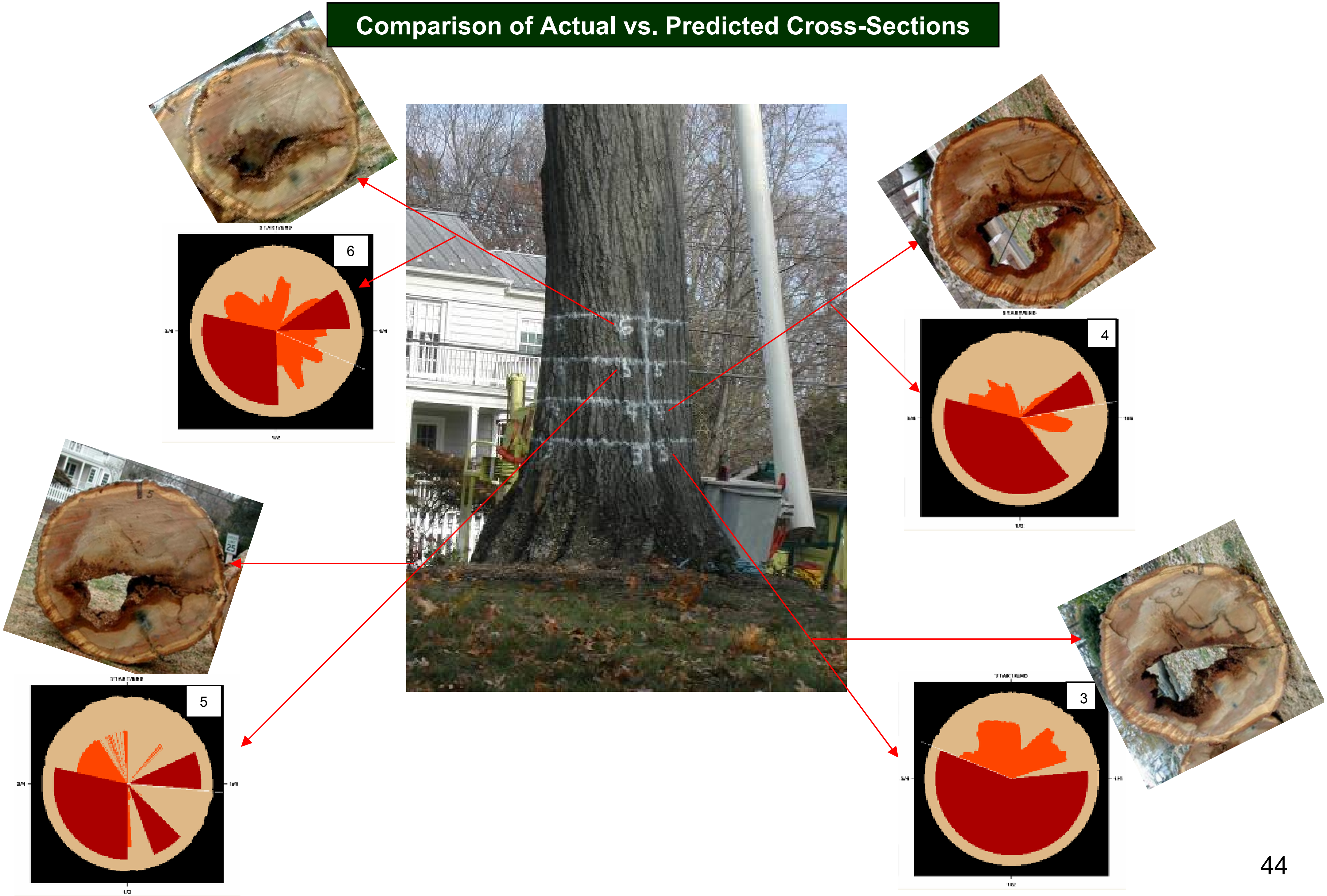
Cross-Sections of each Elevation Scanned showing Progressively Increased Decay as Base is Approached
Base was completely rotted as were the Roots

2-ft elevation

Base

Top Section 6 tons weight

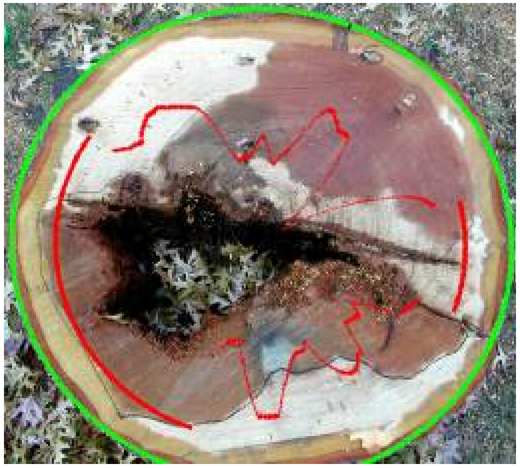
Comparison of Actual vs. Predicted Cross-Sections



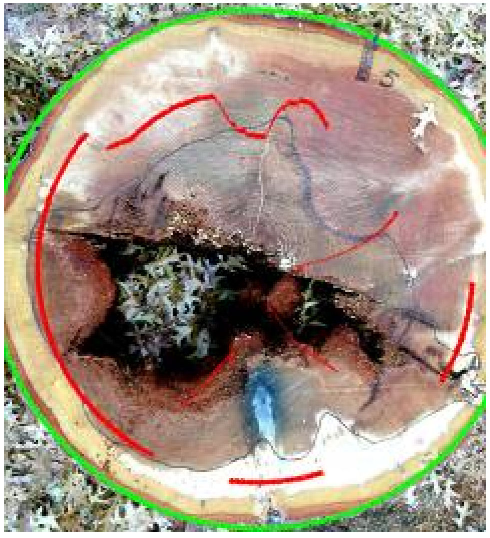
Comparison of Actual vs. Predicted Cross-Sections

Red Line shows where the Radar Wave detected an interface – a transition between solid and compromised wood

Overlay of Predicted Cross-Section onto Actual Cross-Section



6ft (1.8m) Elevation

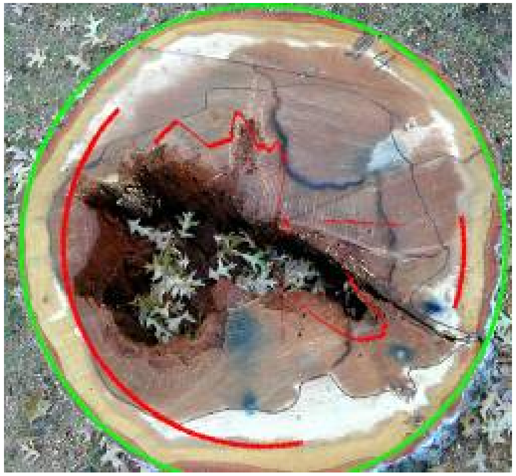


5ft (1.5m) Elevation

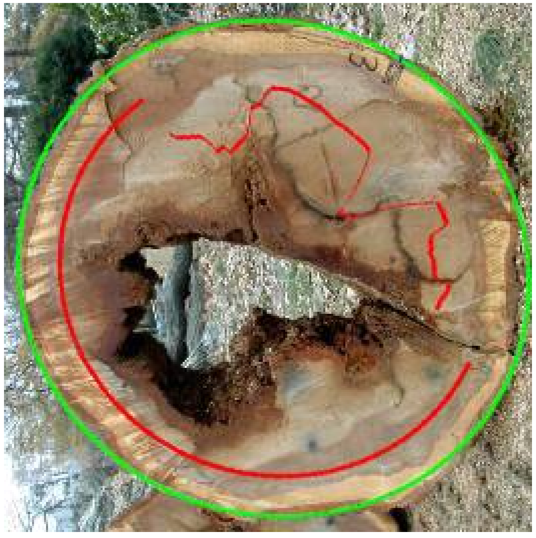
Comparison of Actual vs. Predicted Cross-Sections

Red Line shows where the Radar Wave detected an interface – a transition between solid and compromised wood

Overlay of Predicted Cross-Section onto Actual Cross-Section



4ft (1.2m) Elevation



3ft (0.9m) Elevation

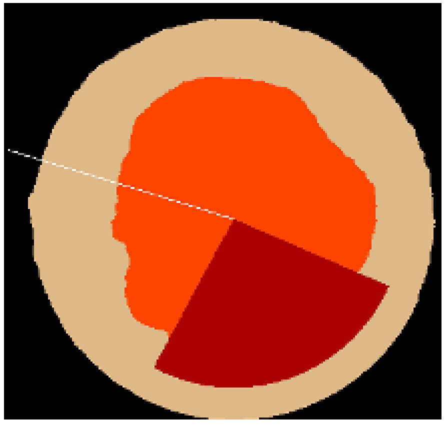
Case Study

Sycamore (6ft dbh) with Two Large Cavities at High Elevations next to Playground
Rock Creek Park   Bethesda, Maryland   (May 2006)

Actual vs. Predicted for the 7ft Elevation Trunk Scan; other six scans had comparable results

Actual:

- **Avg 3in RSW bet 4:00 & 7:00**
- **6in to 10in RSW elsewhere**



Predicted:

- **2in to 4in RSW bet 4:00 & 7:00**
- **6in to 10in RSW elsewhere**

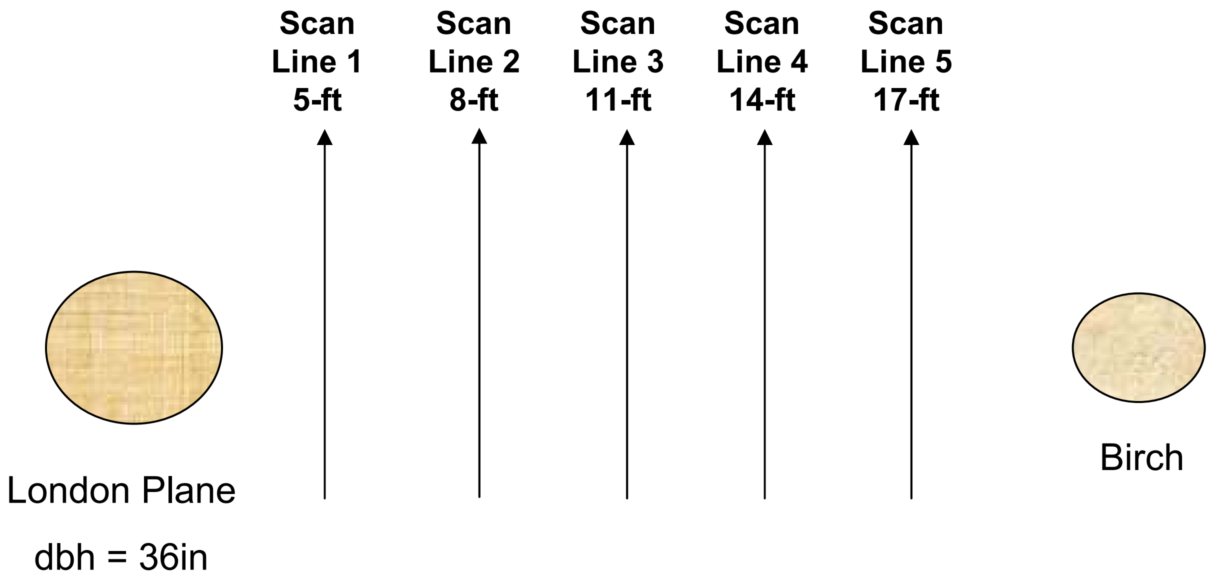
Case Study

Comparison of Predicted Root Location and Depth with Excavated Data

Donner Way Road – Sacramento, California (September 2005)

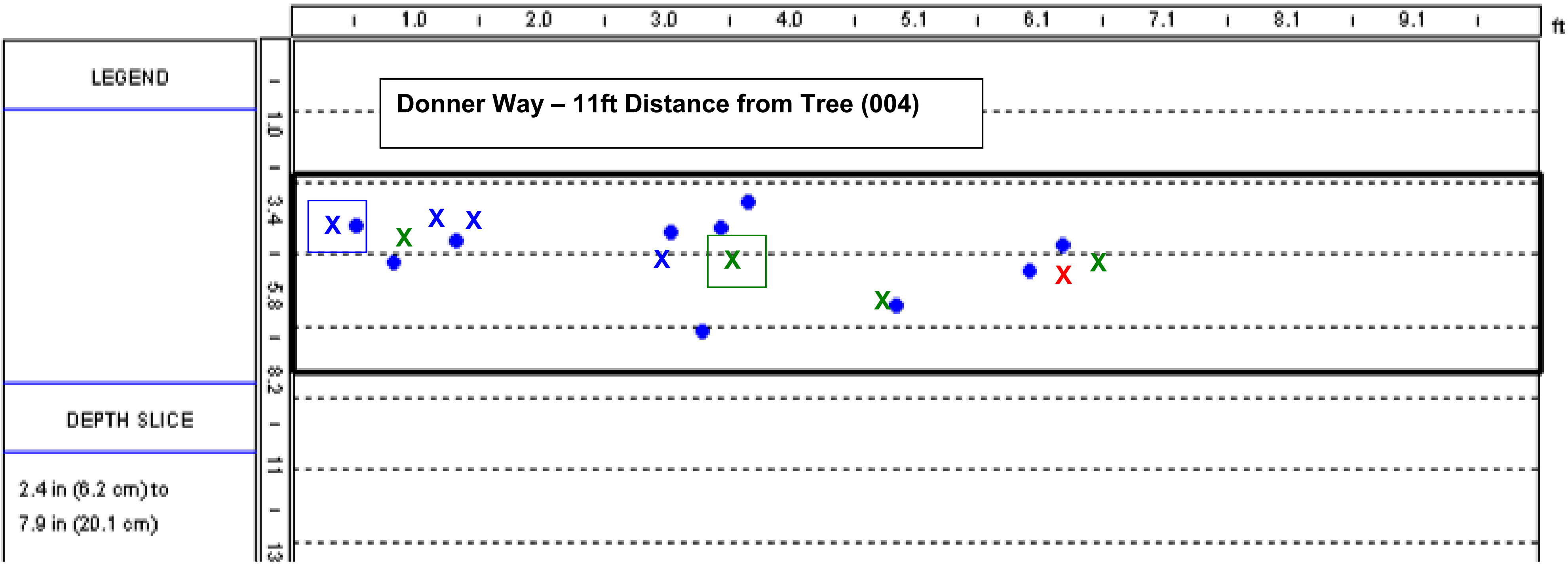
Five Line Scans conducted, each 10ft (3m) long

2D Planar “Virtual Trenches”



● = Predicted

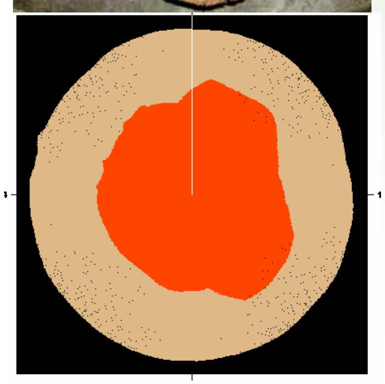
X = Actual



Red ≥ 2"
1" ≤ Green < 2"
Blue < 1"
X Oblique

Advantages of TRU System



- **Non-Invasive**
- **Portable, via Battery Supply**
- **Minimal Set-Up, Easy to Use**
- **Same System can Scan both Trunk and Roots**
- **Rapid Scan – Less than 1 minute per Horizontal Circumferential Section**
- **Multi-Elevations Scanned to Track Decay**
- **High-Resolution 360° Cross-Sectional Image – "Virtual Drill"**
- **Quantitative Table of Remaining Solid Wood**
- **Subsurface Images of Structural Roots – Location and Depth – "Virtual Excavator"**