Transmission & Distribution Line Vegetation Management in PLS-CADD

Introduction

Vegetation management of overhead transmission and distribution line corridors has been a major topic in our industry for many years. More recently this has come more to the forefront as the impact and scale of seasonal storms and wildfires appears to be increasing.

Tree contact with overhead lines is a leading cause of electric power outages, which puts vegetation management practices under ever increasing regulatory scrutiny. Most common requirements involve preventing vegetation encroachments:

- Into the Minimum Vegetation Clearance Distance (MVCD)
- Due to fall-in from inside and outside the ROW
- Due to the movement of applicable lines and vegetation located inside the ROW caused by wind forces.

Some regulatory requirements are now requiring lateral checks to vegetation points to consider the displacement of conductor with movement of suspension insulators and deflection of flexible structures.
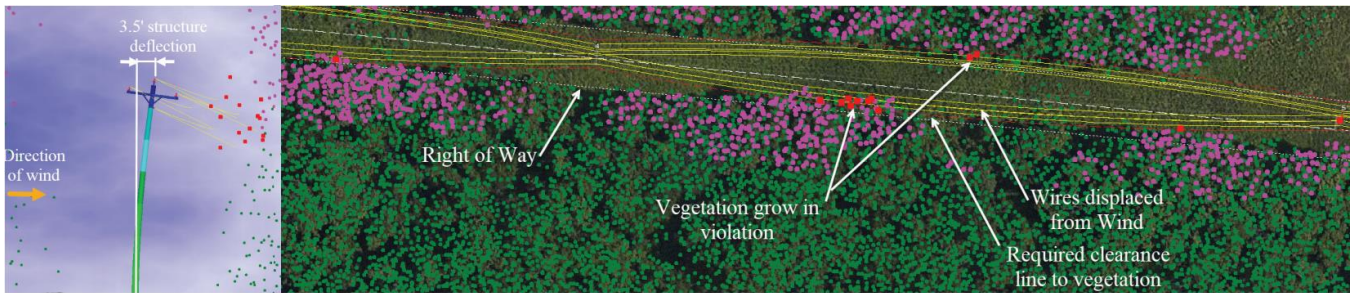
Figure 1: Grid integrity and vegetation management

More than ever the value of having an overhead line modeled in **PLS-CADD** is a necessity for grid operators who care about the integrity their grid. The ability to leverage the unsurpassed engineering features including state-of-the-art sag-tension, structural analysis and clearance evaluations has revolutionized the management of vegetation along overhead line ROW's.

Danger Tree Locator Background Information

The Danger Tree Locator (DTL) feature in **PLS-CADD** was originally developed in 2002 in cooperation with British Columbia Hydro (BCH). British Columbia Transmission Corporation (BCTC) took over responsibility for management of the BC transmission system after this project was started and many of the people involved are now at BCTC. BCH was looking for a safer, more reliable and less costly alternative to existing vegetation management procedures. They were interested in identifying danger trees that were too close to their wires and trees that could contact the wires if they were to fall. Existing procedures relied on field personnel predictions or "guesswork" for wire positions under maximum operating temperature and high wind. Inaccuracies in these guesstimates resulted in failure to cut danger trees and/or excessive cutting of non-danger trees. Their goal was to perform a LiDAR survey to collect points along wires and trees, and then import this into **PLS-CADD** for accurate danger tree classification. **PLS-CADD** would be responsible for predicting wire positions under different combinations of wind, ice and operating temperature. Wire positions were then compared against the surveyed vegetation points to identify those that encroached on the wires. The project was a success with BCH personnel declaring "the LiDAR/**PLS-CADD** system is the best thing to hit transmission vegetation management since the chain saw". For more background on BCH's experiences please see the following articles:

- ["Airborne Surveying Aids in Vegetation Management" (isoclearance lines)](#), by Thomas Wells, British Columbia Transmission Corp., November 2005
- ["Aerial Surveys Calculate Vegetation Growth" (danger tree locator)](#), by Bryan Hooper and Tom Bailey, British Columbia Hydro, October 2004
- ["Vegetation Management Takes to the Air"](#), by Bryan Hooper, British Columbia Hydro, September 2003

The images below show two cross section views of a line where the ground surface is rendered in the form of a TIN model and two vegetation points (A and B) have been located.

PLS-CADD can perform Grow-In and Falling Tree vegetation clearance checks accessible through **Lines/ Reports/ Danger Tree Locator**. Both checks are performed for the weather cases described in the **Criteria/ Survey Point Clearances and Danger Tree Locator** dialog box.

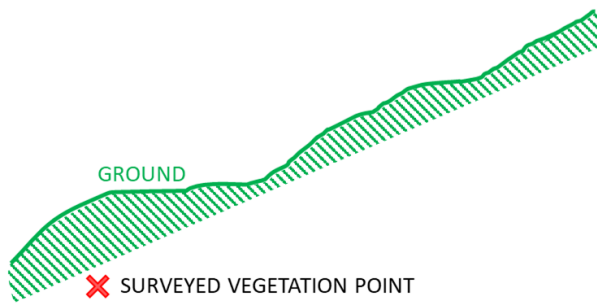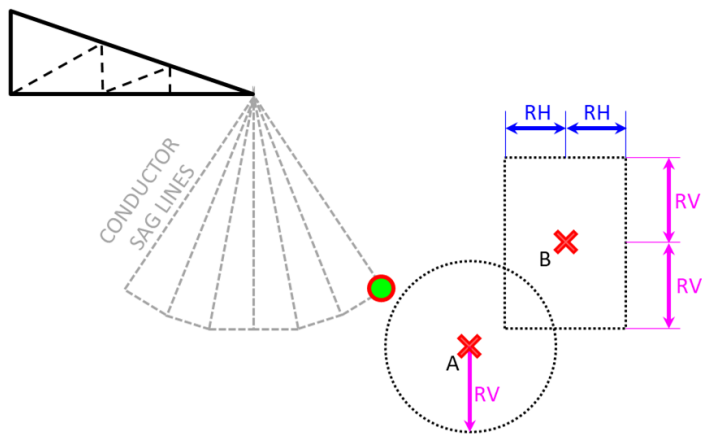Problems are shown in the clearance reports as well as reflected graphically.

Figure 2: Grow-in check

A grow-in vegetation clearance check is indicated to the left (Figure 2). To run this check, you need to assign the feature codes (that represent vegetation points) with values for the required vertical and horizontal clearances, RH and RV. It is recommended that these clearance values are equal to the required electrical clearances *plus* an allowance for vegetation growth *plus* any additional safety margin.

For a radial grow-in vegetation clearance check, if the wire falls within the circle, of radius RV and centered on the vegetation point, it will be flagged as a Grow-in violation. This is indicated for point A

For a rectangular grow-in vegetation clearance check, if the wire falls within the rectangular box, of width 2RH x height 2RV and centered on the vegetation point, it will be flagged as a Grow-in violation. This is indicated for point B.
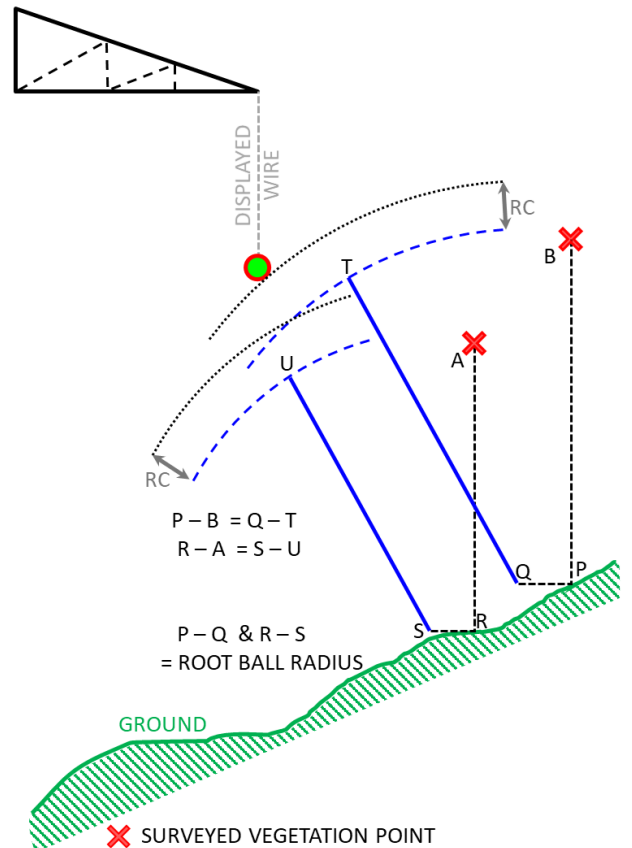
The clearance of a wire to a falling tree is checked as indicated to the right (Figure 3). The assumption made for each vegetation point is that it is potentially the top of a tree. **PLS-CADD** automatically locates the base of the assumed tree on the TIN surface (P for point B and R for point A). It further assumes that a falling tree rotates as a rigid body about the edge of its root ball (Q for Tree P-B and S for Tree R-A). The user enters both the radius of the root ball (as a percentage of the tree height above ground) and the required clearance (RC) between the position of the wire and the circular trajectory of the top of the falling tree.

The clearance circle center (Q for Tree P-B and S for Tree R-A) is located at a horizontal distance equal to the root ball radius from the base of the tree. Points for which the wire is closer to its associated circle than the required clearance will be flagged.

Figure 3: Falling tree check

Running the Danger Tree Locator Report

The Danger Tree Locator (DTL) feature can check up to 200 weather cases (combination of wind, ice and wire temperature). These weather cases are shown with our Survey Point Clearance Criteria dialog and are defined under **Criteria/ Survey Point Clearance and Danger Tree Locator** (Figure 4). DTL automatically checks clearances to wires in the wind from left and wind from right blowout positions and can also check the arc through which the wire swings between these positions also known as the conductor movement envelope.

DTL can even consider unbalanced ice scenarios where a span is subjected to more ice than neighboring spans ("*Add optional concentrated load or ice to the span under consideration*" option Figure 5). This results in additional sag as suspension insulators swing into the more heavily iced span.

Figure 4: Criteria for the Danger Tree Locator

The clearance requirements for the grow-in check are entered in **Terrain/ Feature Code Data/ Edit** table and may include components for flashover or minimum approach distance, buffers for LiDAR accuracy and growth allowances. When checking for falling tree violations the program assumes trees will pivot about a root ball. The size of the root ball is calculated automatically as a user entered percentage of tree height. A violation is indicated if the top of the tree can swing within the specified Clearance Allowance of a wire. The clearance allowance should include flashover clearance, growth allowances and any extra buffers desired.

The Danger Tree Locator dialog box is available when you go to **Lines/ Reports/ Danger Tree Locator**. This dialog box has four tabs that define the parameters of the danger tree report.

The **Vegetation Check** tab defines the parameters used for the Grow-In and Falling Tree vegetation clearance checks:
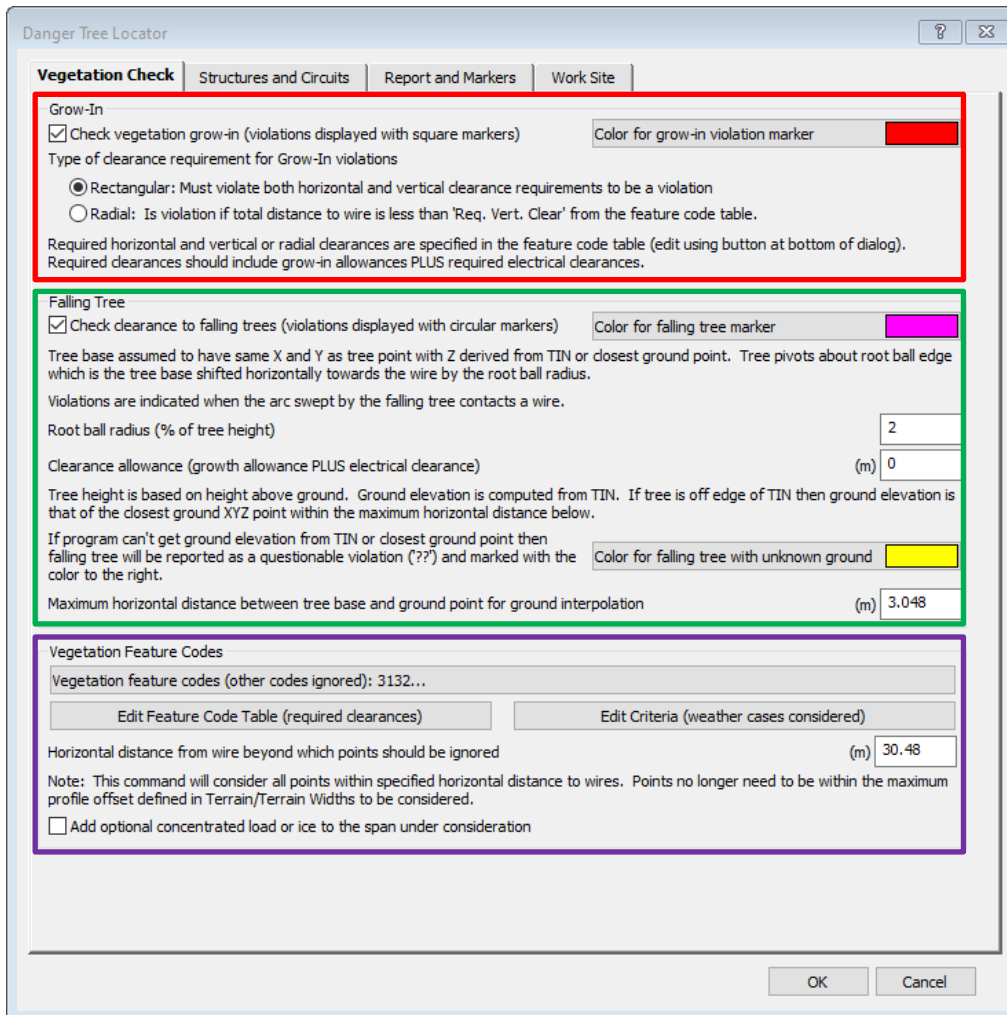

Figure 5: Danger Tree Locator - Vegetation Check tab

Grow-In:

- Option to select grow-in clearance check. If the option is not selected, then a grow-in clearance check will not be performed.
- Option to select either a radial or rectangular clearance check.
- Option to define the color of Grow-In clearance markers to be displayed.

Falling Tree:

- Option to select falling tree clearance check. If the option is not selected, then a falling tree clearance check will not be performed.
- Input for the root ball radius. This parameter is defined as a percentage of the tree height. The root ball radius defines the rotation point of the base of the tree as shown in Figure 3.
- Clearance allowance input is the value used for falling tree clearance check. The falling tree clearance check uses this value and does not use the clearance requirement from the feature code table.
- Option to define color of Falling Tree clearance markers to be displayed. Two colors may be selected one for violations determined when the TIN model is underneath the vegetation point and the other when the ground position is unable to be determined.
- Input for the Maximum horizontal distance between the tree base and a ground point for ground interpolation. This parameter is used to estimate the ground beneath a vegetation point when the project does not have a TIN available.

Vegetation Feature Codes:

- The Vegetation Feature Codes button allows the user to select the vegetation feature codes used for the clearance check
- Shortcuts to the **Terrain/ Feature Code Data/ Edit** and **Criteria/ Survey Point Clearances and Danger Tree Locator** tables so user can check or change any of these inputs.
- Input for the horizontal distance from the wire beyond which points should be ignored.
- Election to include an optional concentrated load or ice to the spans under consideration. If this option is selected, then you will be prompted to choose a concentrated load file and location of the concentrated load in the spans.

The **Structures and Circuits** tab allows the user to define the structures or circuits used to determine on which spans the Grow-In and Falling Tree vegetation clearance checks will be performed:

Select structures:

- This dialog allows the user to define specific structures or a range of structures, or multiple discontinuous ranges of structures to run the danger tree report on.

Select the circuits:

- This dialog allows the user to define specific circuits to run the danger tree report on.

Selection Summary:

- Displays a summary of the structures and circuits selected from the above 2 options for the analysis.

For more information on circuits and their definition please see the video on the subject at "Defining and Labeling Circuits and Electrical Phasing in PLS-CADD".
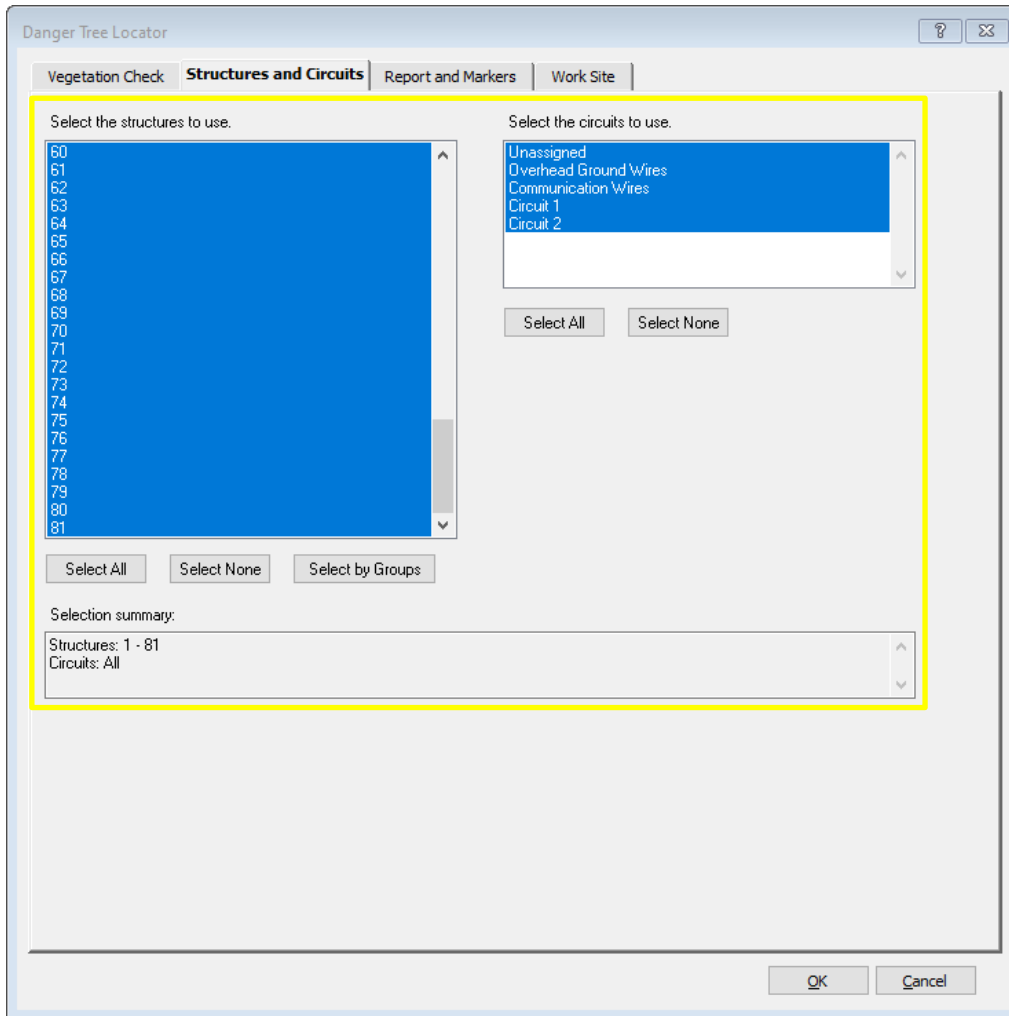

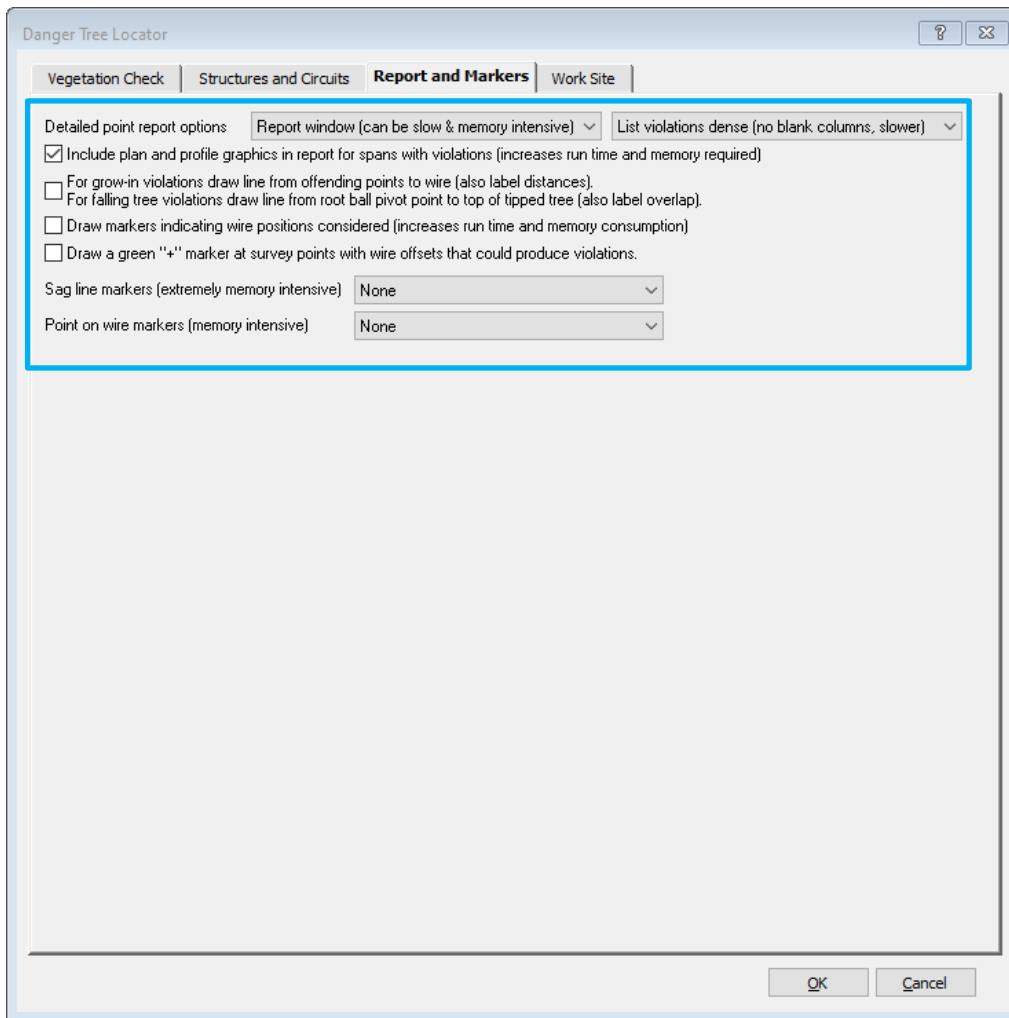**Figure 6: Danger Tree Locator - Structures and Circuits tab**

The **Report and Markers** tab controls the output of the report and graphical markers shown in model views.

Figure 7: Danger Tree Locator - Report and Markers tab

Detailed point report options:

- Select the type of report for output of the danger tree locator. Options include No Report, Report window, text file, XML or CSV.
- The report can list all points checked (very slow to produce) or only report on violations. There are 2 options to report on violations:
  - **Sparse:** (faster to produce) some empty columns appear in the report. If a vegetation point violates only the grow-in requirements or only the falling tree requirement, only the details for check that failed will be shown.
  - **Dense:** (slower to produce) here the results for Grow-in and Falling Tree are printed for all points considered. Irrespective of whether a vegetation point violates only the grow-in requirements or only the falling tree requirements, the details for both checks will be shown.
- *Option to include plan and profile graphics in the report for spans with violations:* This adds the plan and profile graphics for each selected span to the end of the report. All parts of the model are grayed out except for the violation markers. See Figure 10.

Options to turn on/off markers:

- *For grow-in violations draw line from offending points to wire.*
- *For falling tree violations draw line from root ball pivot point to top of tipped tree*. These are the blue lines visible in Figure 17.
- *Draw markers indicating wire positions considered.* Gray dashed lines indicating the position of each wire position considered in running the analysis.
- *Draw a green "+" marker at survey points with wire offsets that could produce violations.* This marker is placed at all points, within the Horizontal offset from wire positions considered (bottom of the **Vegetation Check** tab - Figure 5), provides a view of all the points considered during the analysis.
- *Sag line markers:* Includes markers to more clearly indicate the wire sag and swing for all the weather conditions selected in **Criteria/ Survey Point Clearances and Danger Tree Locator** table. Represented as gray conductor movement envelope indicated on Figure 16 & Figure 17.
- *Point on wire markers:* Will add bright green points on the wire positions that are checked. Can be done for violations only, or for all points checked. See Figure 16 & Figure 17.
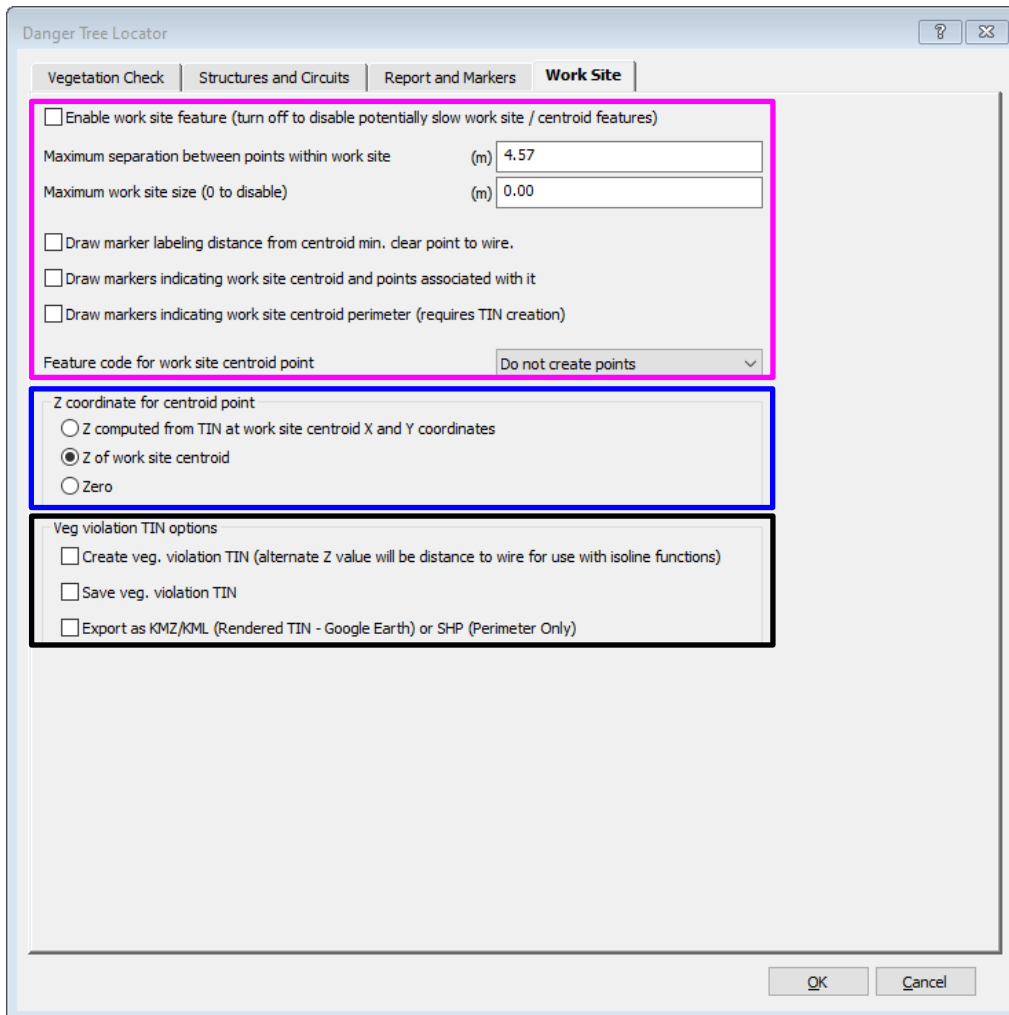
Figure 8: Danger Tree Locator - Work Site tab

You can also choose to enable the work site feature which groups clusters of xyz points that are identified as clearance issues into one worksite based on the information input in **Work Site** tab.

Enable work site feature:
- If the option is not selected, then the work site feature will not be enabled.

Maximum separation between points within work site:
- Input allows the user to define the maximum separation between points in a work site.

Maximum work site size:
- Input allows the user to define the maximum work site size.

Option to turn on/off markers:
- Draw marker labeling distance from centroid min. clear point to wire.
- Draw markers indicating work site centroid & points associated with it.
- Draw markers indicating work site centroid perimeter.

Feature code for work site centroid point:
- Drop down menu to select the feature code used to create a xyz point at the centroid location of each worksite.

Z coordinate for centroid point:
- Options to assign Z value for the work site centroid. It may be useful to create an independent worksite feature code for this option.

Veg violation TIN options:
- Three options that allow you to create, save and export a veg. violation TIN. This tool takes all of the vegetation clearance violations and makes a surface that can be loaded or saved in the model using the **Terrain/ TIN/ Veg. Violation/ Load or Save Veg. Violation TIN** File command. You can also use the **Terrain/ TIN/ Display Options** command to render the Veg. Violation TIN similar to a Ground TIN for viewing in the model. Creating a Veg. Violation TIN is necessary if you want the work site centroid report to include the area of the work site. The last option allows you to create a KMZ/KML or SHP file of the work site areas. The KMZ/KML will be the actual rendered TIN while the SHP file will only show the perimeter.

For more information on the vegetation work sites feature please see the video on the subject at "PLS-CADD Vegetation Work Sites".

The report, created once the analysis is complete, contains the following information:

- Basis of the Report
  - Criteria Notes (if entered for the project under **Criteria/ Notes**)
  - A list of the Weather Cases relevant for Vegetation Analysis and those indicated for the Danger Tree Locator criteria (**Criteria/Survey Point Clearances and Danger Tree Locator**)
  - The required clearances for the Feature code selected for Vegetation Feature Code (extracted from the Feature Code table).
  - A list of the Sections evaluated.
- Output:
  - *Vegetation Analysis by Span Report*: a summary of the number of points checked and the number and type of violations calculated
  - *Work Site / Centroid Report*: Provides insight into the calculated work sites. The number of points and triangles in each site, the centroid coordinate of the site and the Area of the TIN surface and the land area of each Work Site. Only included if the Work site feature was enabled on the **Work Site** tab of the **Danger Tree Locator** dialog box (Figure 8).
  - *Vegetation Analysis Report:* the full detailed report for each point considered in the checks. Only included if *Report Window (can be slow and memory intensive)* is selected from the drop down list for Detailed point report options, selected on the **Report and Markers** tab of the **Danger Tree Locator** dialog box (Figure 7).
  - *Graphical Views*: Span by Span plan and profile drawings for spans with violations. Only visible if *Option to include plan and profile graphics in the report for spans with violations* is selected on the **Report and Markers** tab of the **Danger Tree Locator** dialog box (Figure 7). The line and ground models appear in grayscale with violation markers appearing in color to emphasize the location of the points.
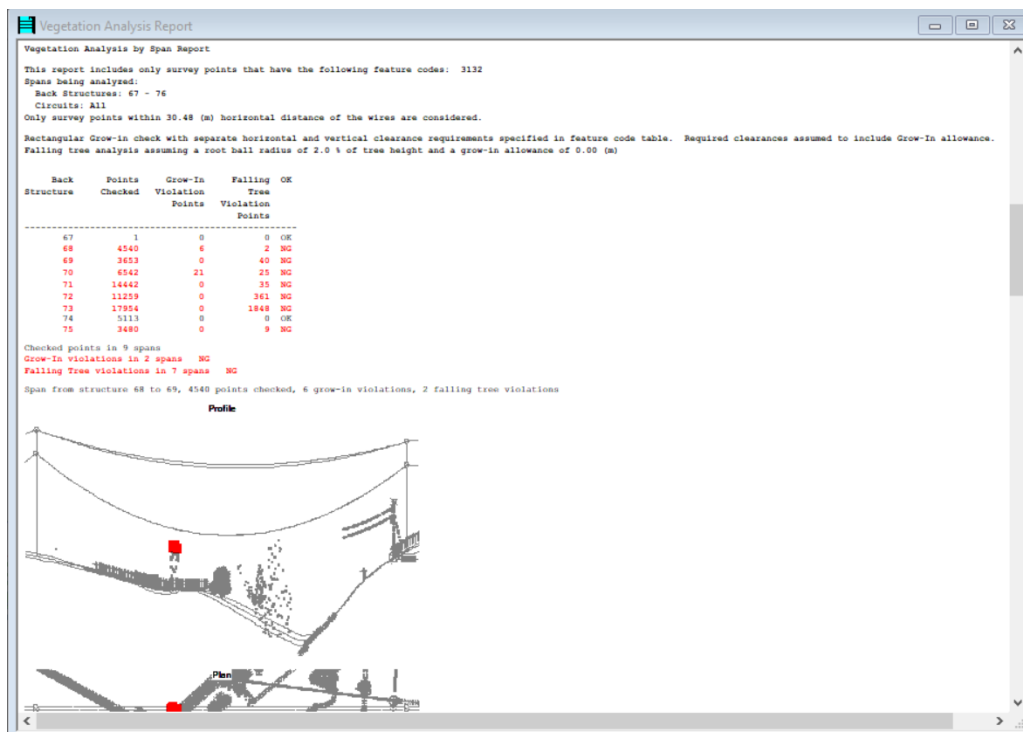

Figure 9: Vegetation Analysis Report

Danger Tree Locator output examples

Sample PLS-CADD plan & profile sheets with danger tree graphics (courtesy of BC Hydro)

- [Sheet showing grow-in violations.](#) Different colors are used for violations under hot conductor, swung conductor and maintenance conditions.
- [Sheet showing falling tree violations.](#)

Since there are so many variables in the **Danger Tree Locator** dialog box, the following section of this tech note indicates the type of outputs and graphics that can be created by using this tool.

Span from structure 70 to 71, 6542 points checked, 21 grow-in violations, 25 falling tree violations
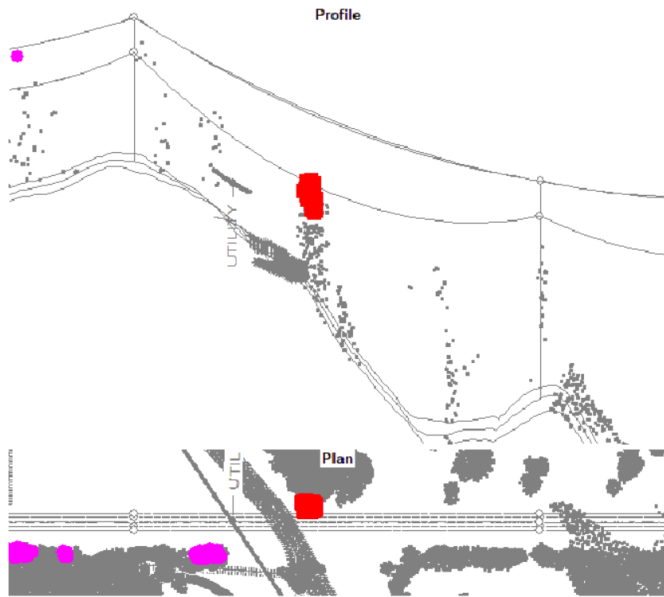
Figure 10: Plan and Profile views of violations from Report

Figure 11: Grow-In and Falling Tree violations displayed in 3D view with rendered TIN

Violations in report form with listing of number of grow-in and falling tree violations in each span along with inset plan and profile graphic for each span
- Magenta circles are falling tree violations
- Red squares are grow-in violations
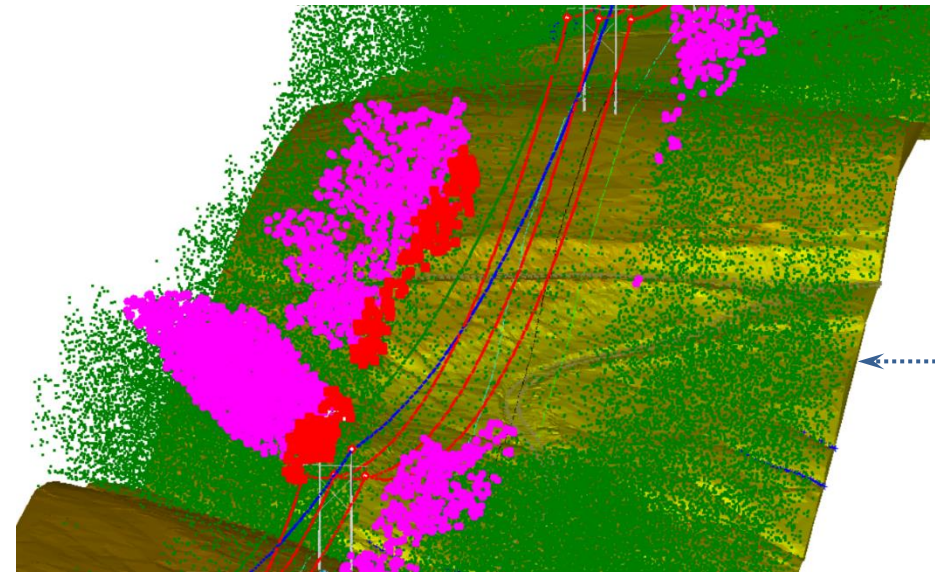- Wires displayed in Maximum Operating Temperature position (100°C)

Grow-in and falling tree violations in **3D view**
- Green dots are vegetation survey points
- Magenta circles are falling tree violations
- Red squares are grow-in violations
- Red lines are wires displayed in Maximum Operating Temperature position (100°C)
- Blue line is OHGW displayed at EDT (15.6°C)

To obtain the view in Figure 10:
Select the option to *Include plan and profile graphics in the report for spans with violations* as indicated in the **Report and Markers** tab of the **Danger Tree Locator** dialog box (Figure 7) before running the analysis.

All parts of the model are grayed out (ground, wires, structures, and survey points), except for the violation markers for grow-in and falling tree points.

To obtain the view in Figure 11:
Make sure that you have selected to include both a Grow-In and a Falling Tree check in the **Vegetation Check** tab of the **Danger Tree Locator** dialog box (Figure 5) before running the analysis.

The created markers are displayed in all views.

Grow-in and falling tree violations in **plan & profile sheet view.**
This is a handy way to document the required extent of the clearing activities needed.

- Green dots are vegetation survey points
- Magenta circles are falling tree violations
- Red squares are grow-in violations
- Red lines are wires displayed in MOT position (100°C)
- Blue line is OHGW displayed at EDT (15.6°C)

To obtain the view in Figure 12:
Make sure that you have selected to include both a Grow-In and a Falling Tree check in the **Vegetation Check** tab of the **Danger Tree Locator** dialog box (Figure 5) before running the analysis.

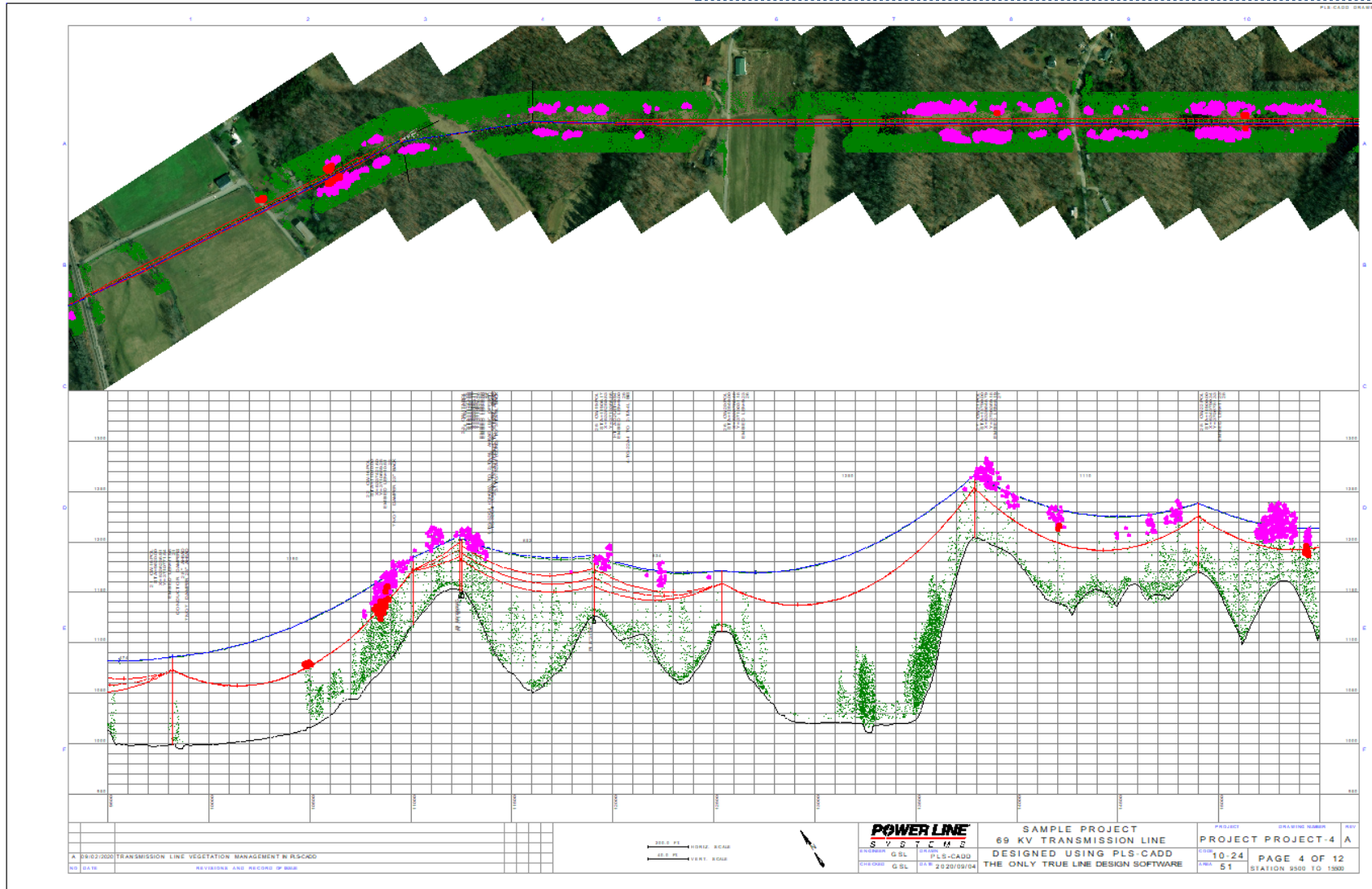The created markers are displayed in all views.

Figure 12: Plan and Profile Sheets showing violation locations

Grow-in and falling tree violations in **plan** portion of the **Sheets view** with wire displayed in still air (Figure 13) and blown-out (Figure 14 & Figure 15) positions:

- Magenta circles are falling tree violations
- Red squares are grow-in violations
- Red lines are wires displayed in MOT position (100°C)
- Blue and Green lines are the OHGW's displayed at EDT (15.6°C)
- Yellow lines are all wires displayed in the blown-out position more clearly indicating how the grow-in violations are calculated considering the conductor displacement (NESC Blowout 6 psf)

Figure 13: Plan view of violations - wires in still air

To obtain the views in Figure 13, Figure 14 & Figure 15:

These views have the optional plan grid displayed, which can make measuring violation offset from centerline easier off of the P&P Sheets.

To see this grid in the plan portion is a two-step process:

1. Select **Terrain/ TIN/ Isoclearance Lines/ Sheet plan view offset and station grid** and enter the offset or width of the grid to be placed on the plan view (example to the left has an offset of 150 ft).
2. To display the grid and control the grid spacing, navigate to **Drafting/ Plan & Profile Sheet Configuration/ Scales** and select the Station Tick Mark Interval (the example uses 25 ft). This will display the grid.

The wires can be displayed in the blown-out positions and alternative colors by using the options entered in **Sections/ Display Options**.
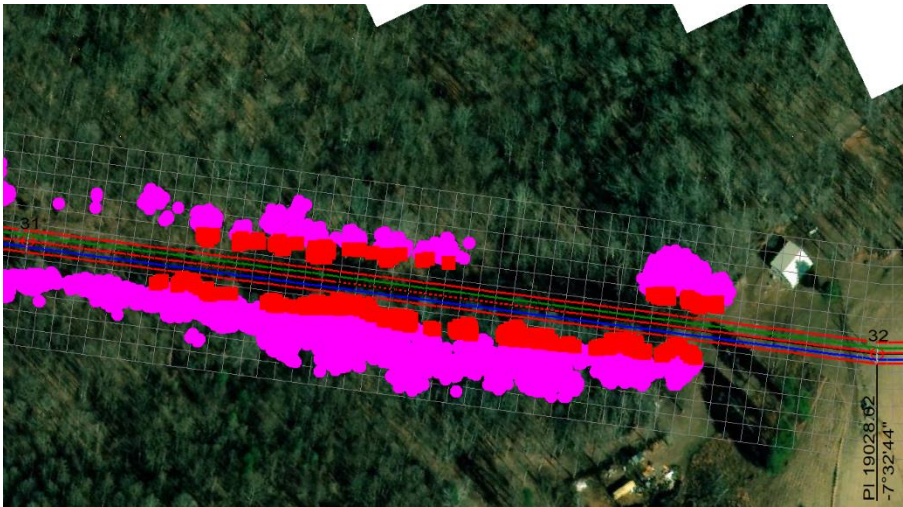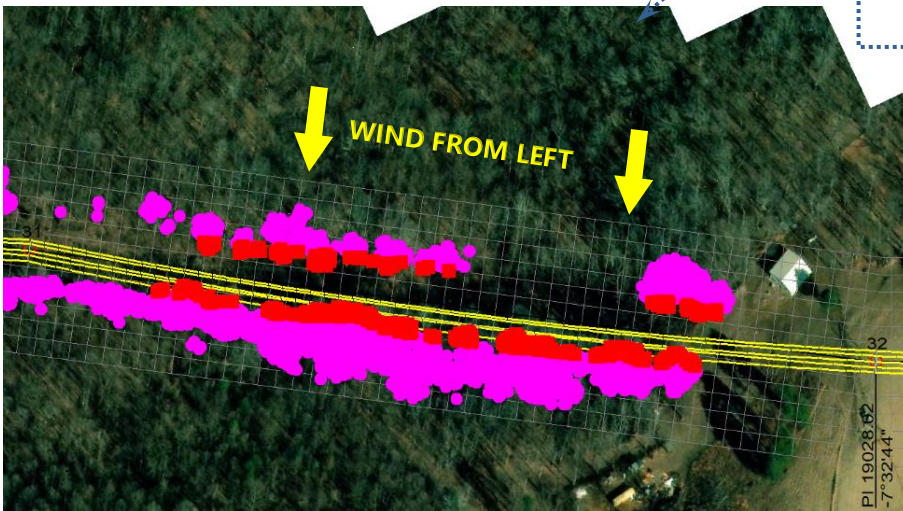

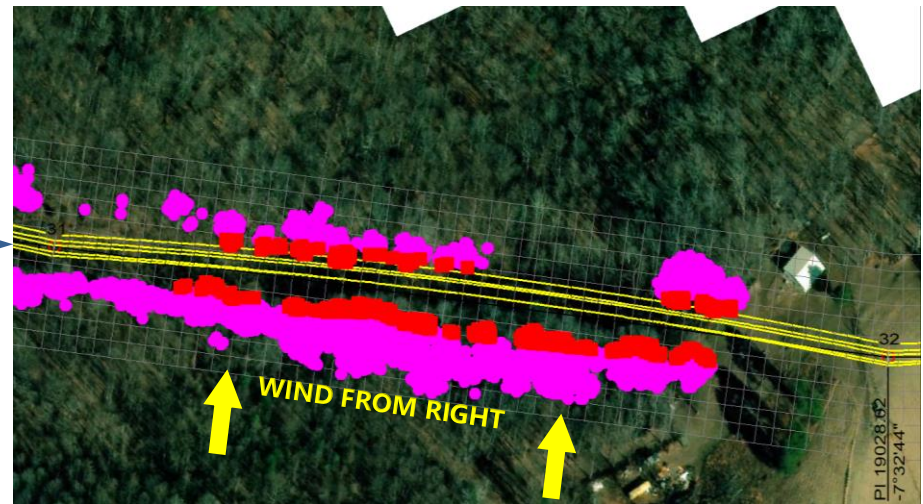**Figure 14: Plan view of violations - wire blown out (Wind from Left)**

Figure 15: Plan view of violations - wire blown out (Wind from Right)
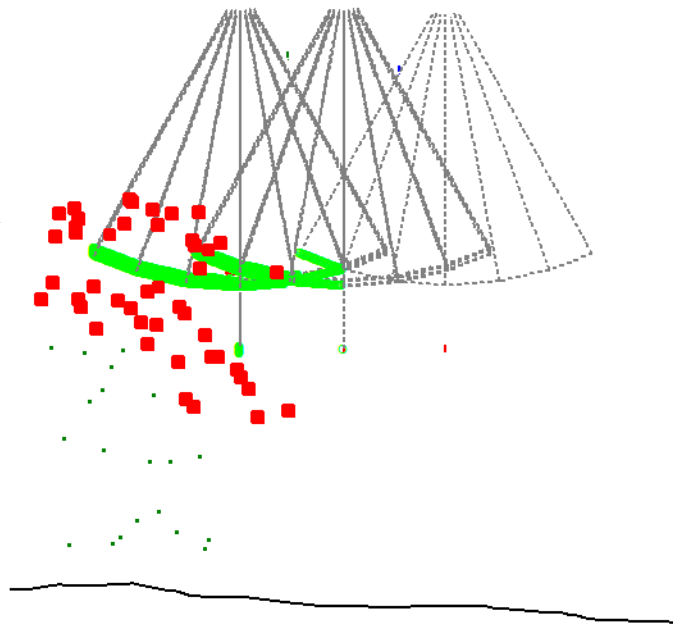
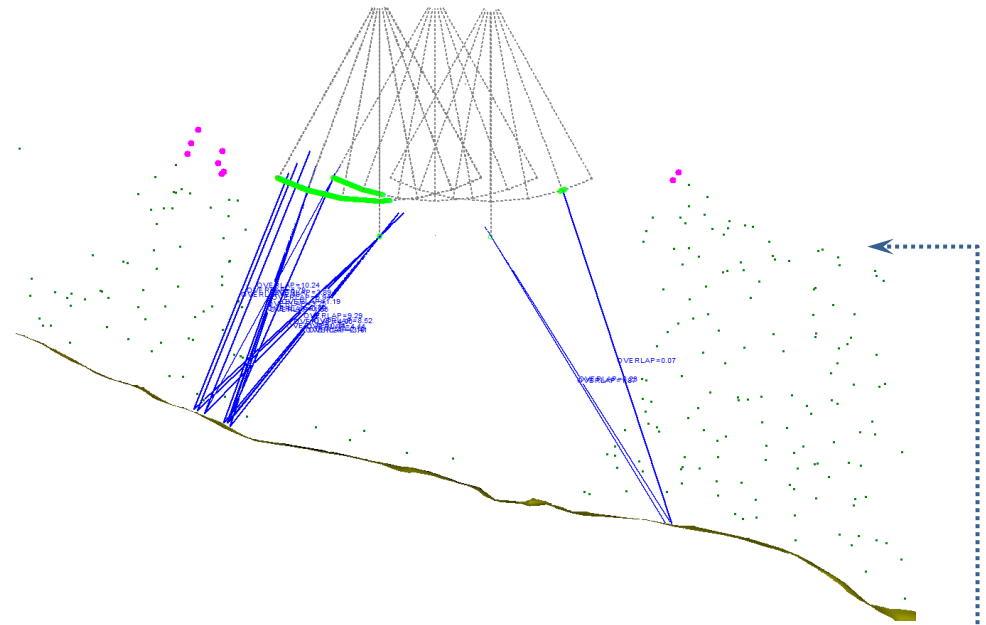**Figure 16: Grow-in violations in cross section view**

Figure 17: Falling Tree violations in cross section

Grow-in violations (Figure 16) and Falling tree violations (Figure 17) in **cross section view** with wire displayed for the full conductor movement envelope

- Dark green dots are vegetation survey points
- Gray lines represent the range of wire positions possible as wire swings from left blowout position to right blowout position (NESC Blowout 6 psf) and the sag at MOT (100°C)
- Red squares are grow-in violations
- Magenta circles are falling tree violations
- Blue lines show where falling tree contacts wire
- Bright green points represent wire positions that are too close to vegetation

To obtain the view in Figure 16:
Make sure that you have selected to create *Sag line markers* for violations found and the *Point on wire markers* for violations found on the **Report and Markers** tab of the **Danger Tree Locator** dialog box (Figure 5) before running the analysis.

You can then obtain a cross-section view by either pressing the "**C**" key at the desired location or by selecting **View/ Pan, Zoom & Rotate/ Cross Section**.

To obtain the view in Figure 17:
Make sure that you have selected to display markers *For falling tree violations draw line from root ball pivot point to top of tipped tree* and the *Point on wire markers* for violations found on the **Report and Markers** tab of the **Danger Tree Locator** dialog box (Figure 5) before running the analysis.

You can then obtain a cross-section view by either pressing the "**C**" key at the desired location or by selecting **View/ Pan, Zoom & Rotate/ Cross Section**.
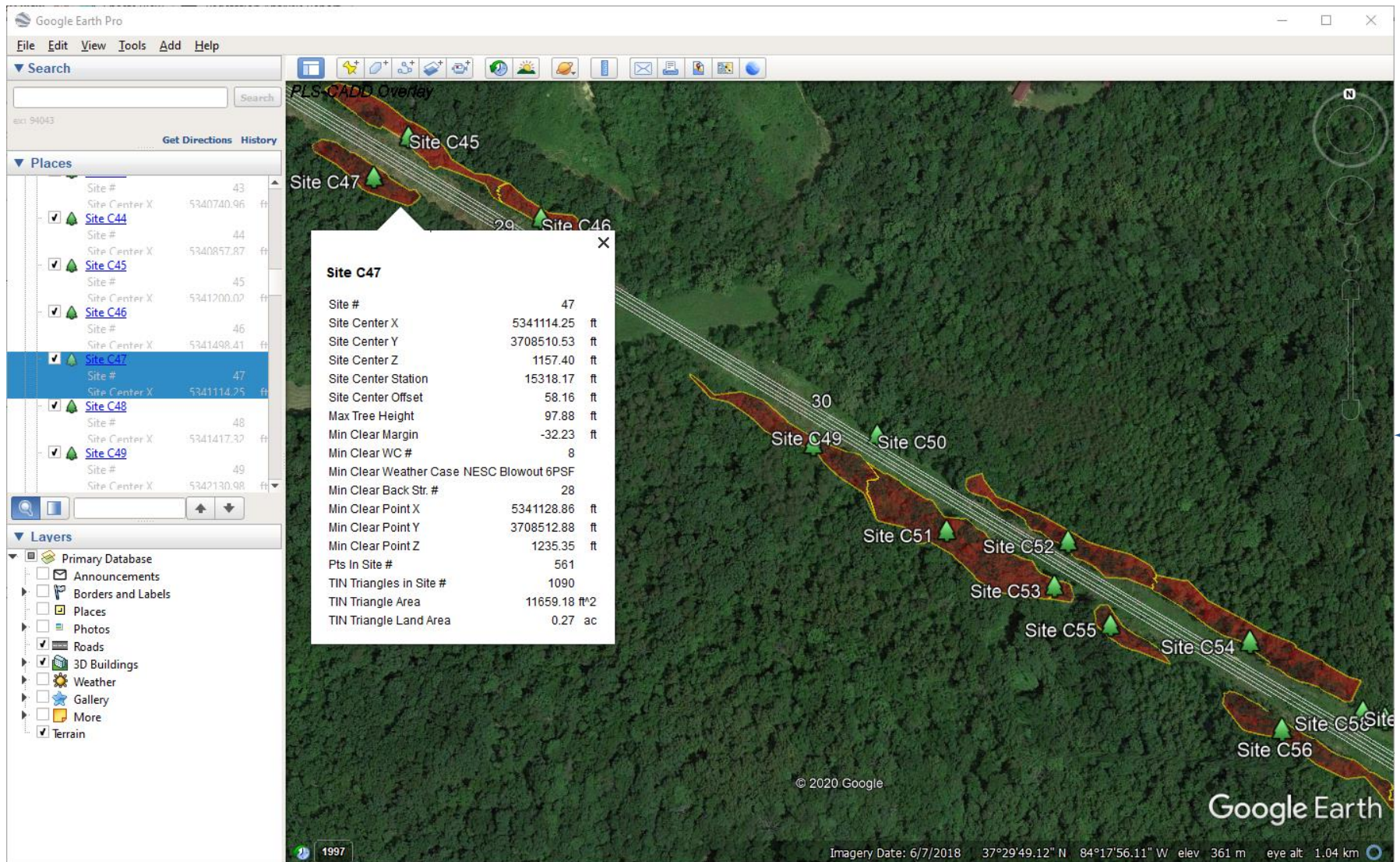
Figure 18: Work Sites exported to KMZ and viewed in Google Earth

Work Site of the vegetation violations exported as a KMZ file and viewed in Google Earth.

- is the centroid of the work site
- Red surfaces are work sites
- Yellow lines are the perimeters of the work sites

To obtain the view in Figure 18:

Make sure that you have selected to *Enable the work site feature*; and *Draw markers indicating work site centroid perimeter* and select the option to *Export as a KMZ/KML or SHP* on the **Work Site** tab of the **Danger Tree Locator** dialog box (Figure 8) before running the analysis.

The KMZ file created will then open in Google Earth,

Isoclearance Line Feature

Isolines are polylines that connect points of equal value. Ground elevation contours are isolines where the points along the lines have the same ground elevation. Isoclearance lines are similar, but the points all have the same distance to the closest wire rather than the same elevation.

Wire position varies with wind, ice and temperature. PLS-CADD can generate isoclearance lines for any given combination of wind, ice and temperature. A composite isoclearance line can also be generated to represent the worst case clearance to a range of up to 200 different wind, ice and temperature combinations (same assumptions as in Danger Tree Locator shown above).

We developed the isoclearance line feature in 2004 after discussions with Bryan Hooper of British Columbia Transmission Corporation. Bryan introduced us to the concept of the isoclearance line and explained how to use them to identify different areas of interest. The areas include:

- areas of inadequate ground clearance- some can be resolved by re-grading the ground.
- areas with different ranges of clearances that may require different vegetation management protocols.
- areas where falling trees of certain heights could hit wires- 40' trees inside the 40' isoclearance contour can hit your wires when they fall.

To activate the isoclearance line feature in PLS-CADD navigate to **Terrain/TIN/Isoclearance Lines/Create Clearance TIN**... This feature will evaluate the clearances to the ground surface from wires and establish a ground TIN model surface storing the values gotten from the clearance calculations. After you create the clearance TIN you can then navigate to **Terrain/TIN/Isoclearance Lines/Clearance TIN Display Options...** to adjust the display settings and contour line displays to generate views like those shown below.

For more information on isoclearance lines please see the November 2005 T & Distribution ["Airborne Surveying Aids in Vegetation Management"](#) article by Thomas Wells, the vegetation program manager of British Columbia Transmission Corp.

Figure 19 on the next page shows the isoclearance lines, for a 500 kV wire where the required clearance is 40'. Can you spot the clearance violation?
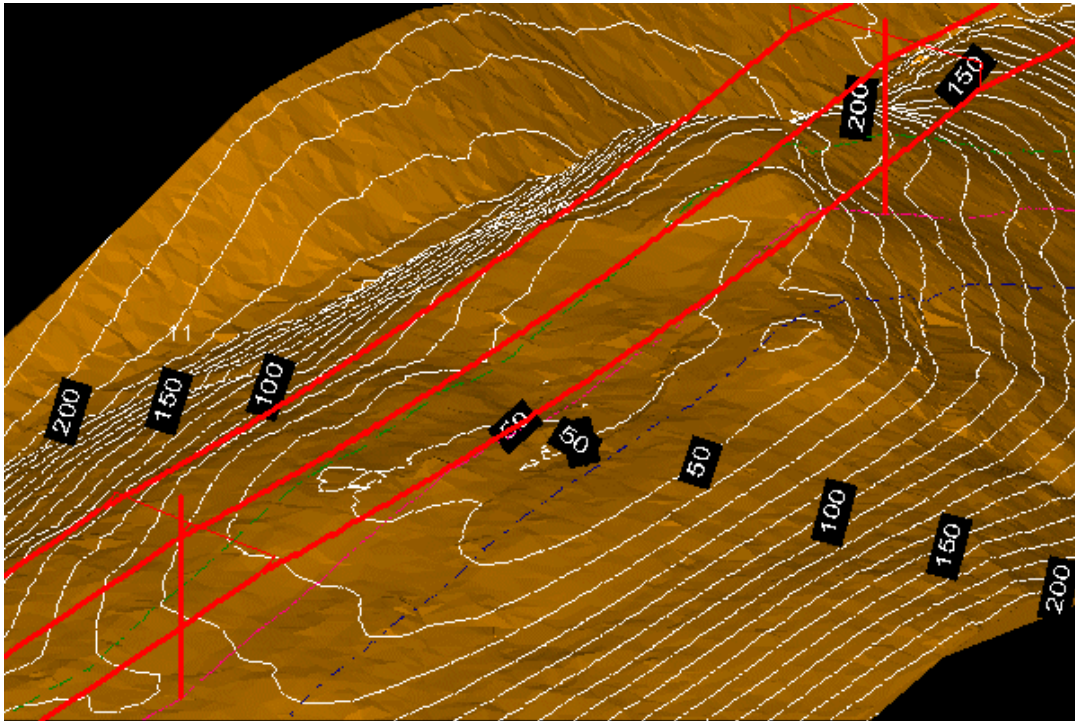
Figure 19: 10' interval isoclearance lines in 3D view

Figure 20 indicates more clearly the clearance violation, and, since we see only 2 lines, we know the violation is less than 2' in magnitude. With only a 2' violation contained to a relatively small area it is a good candidate for remediation by re-grading of ground.
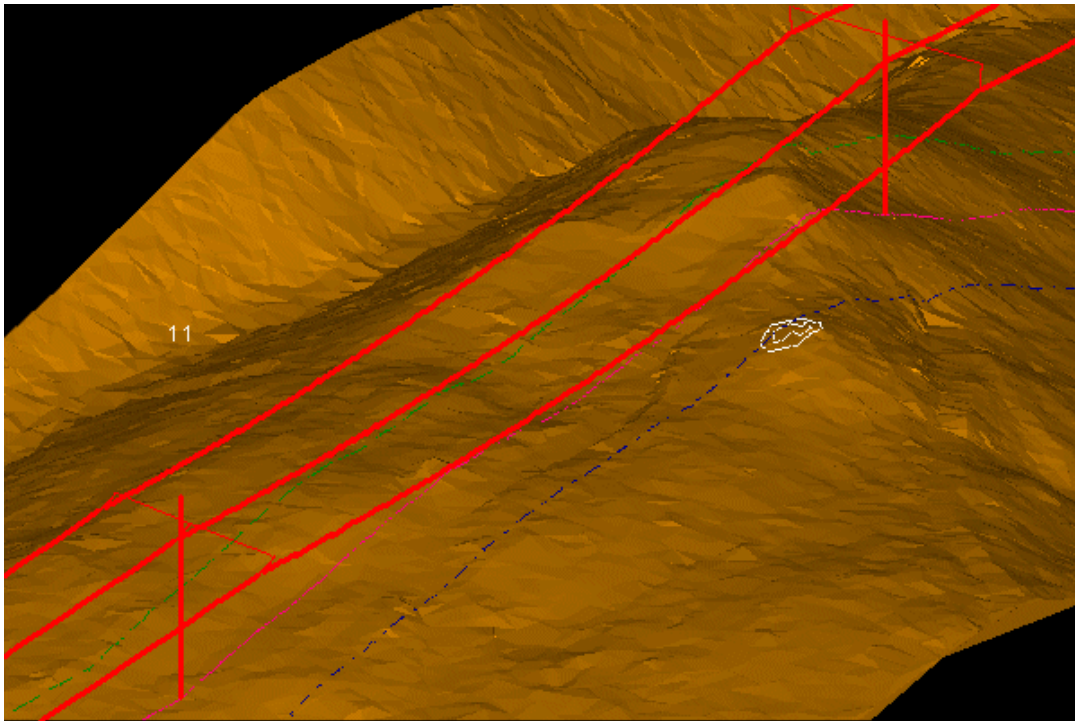

Figure 20: 1' interval isoclearance with program hiding lines with clearance in excess of 40'