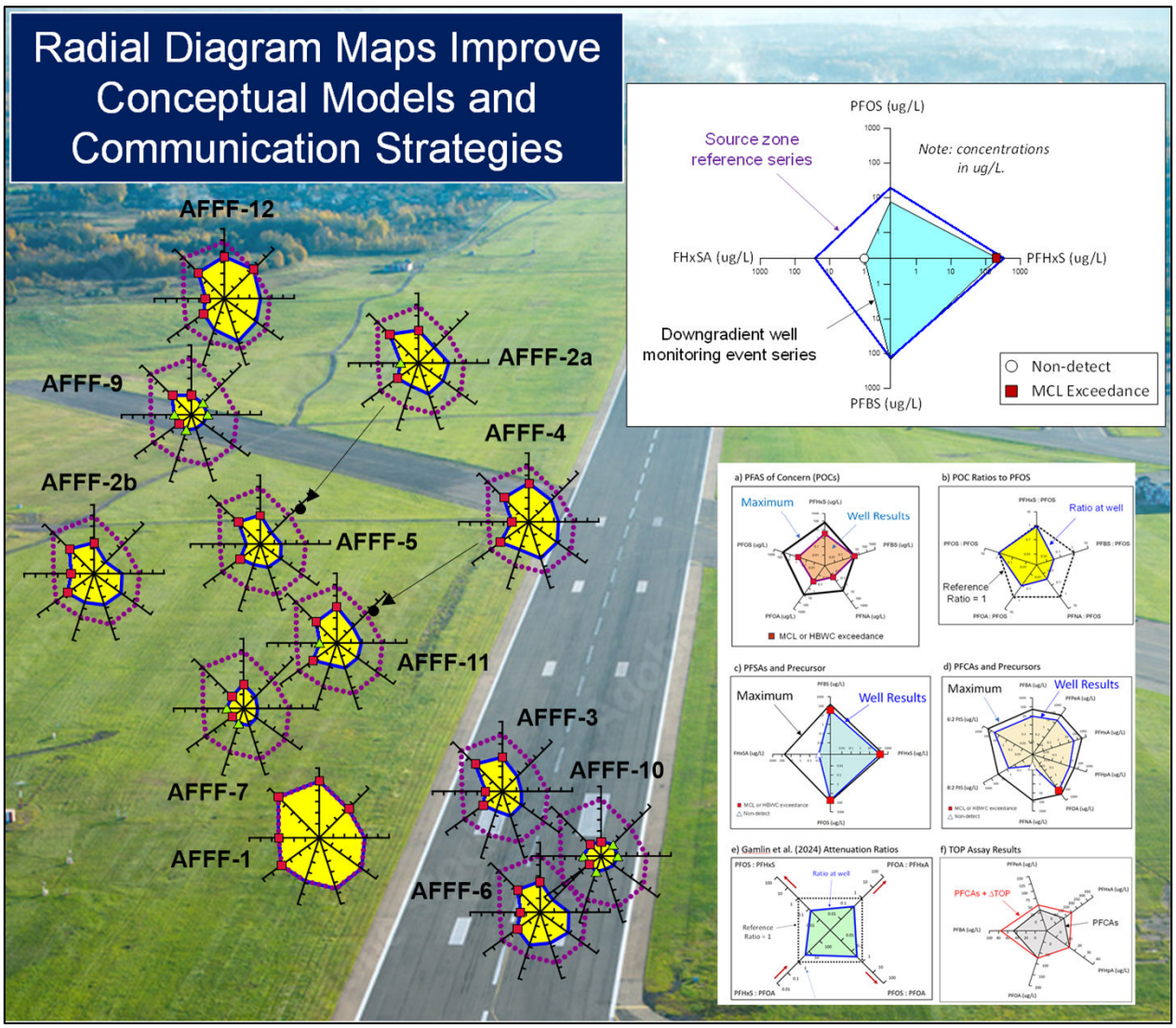
Visual PFAS™
Users Guide:

Creating Radial Diagrams

Chapter 4



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January 20, 2025

4.1 Introduction

Laboratory analysis of PFAS in groundwater and soil samples now include results for up to 40 PFAS (i.e, precursors and PFAAs) when the analysis is conducted using EPA Method 1633. The large number of analytes associated with each soil and groundwater sample poses a major challenge for data analysis, and for communicating the results of site characterization to a non-technical audience. Radial diagrams represent a simple visualization approach which is ideal for viewing trends for between 5 and 10 PFAS constituents on a single map.

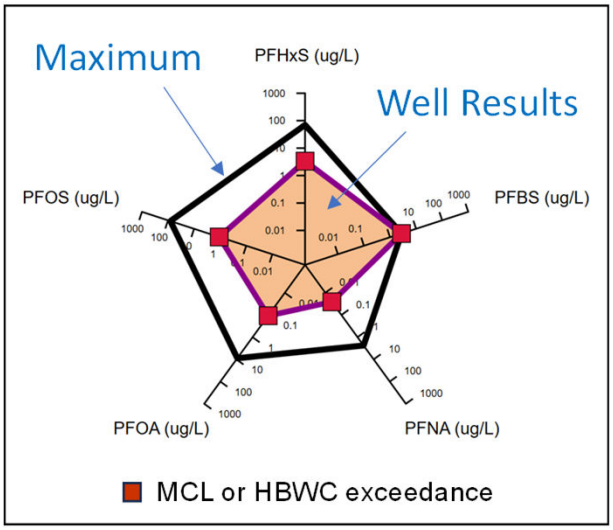
Radial diagrams may be used to support the following types PFAS site characterization, forensic, and remediation performance monitoring assessments:

- Source zone and groundwater plume delineation;
- Precursor biotransformation to corresponding PFAAs along a flow path;
- PFAS attenuation along a groundwater flow path due to precursor biodegradation, dispersion, and/or forward attenuation into silt/clay layers.
- Distribution of PFAS ratios within and downgradient of source areas;
- Redox zone delineation (e.g., aerobic, moderately anaerobic, and strongly anaerobic) to support a precursor biotransformation analysis;
- TOP assay results along a flow path to determine the maximum potential for PFAA increases due to future precursor transformations;
- Temporal changes due to remediation, or due to expanding or receding plumes;
- Source differentiation and forensic analysis of contributions from multiple sites to a commingled plume; and
- Visual comparison of background levels to PFAS at various site monitoring wells.

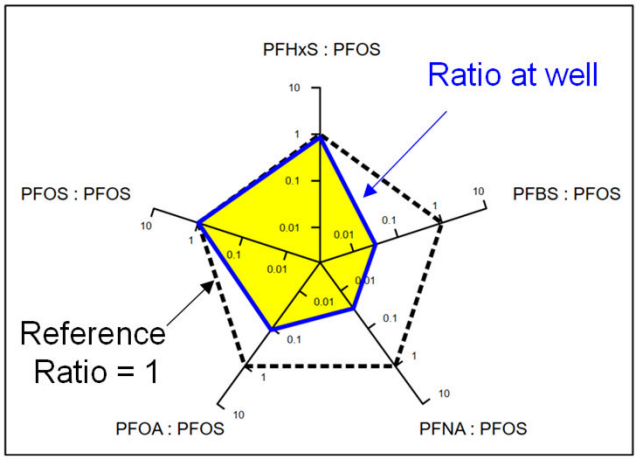
Radial diagram visual aids are capable of illustrating spatial and/or temporal distributions of multiple PFAS species on a single map, which is particularly useful given the need to assess both intra-well and inter-well trends for PFAS in the source area and within a downgradient plume. Carey et al. (2025) document a detailed case study which demonstrates how radial diagram and stacked bar maps may be used to support site characterization and source forensic assessments at an AFFF-impacted site in South Dakota. Carey et al. (1996, 1999, 2003) demonstrate several other case study examples of how radial diagrams may be used to support analogous applications for chlorinated solvents and petroleum hydrocarbons. Carey et al. (1996, 1999, 2003) also demonstrate case study examples of how specialized redox radial diagrams can be used to delineate between aerobic, moderately anaerobic, and strongly anaerobic zones in groundwater, which is important for evaluating where precursors may be biodegrading to regulated PFAAs.

Carey et al. (2025) examples of the types of radial diagrams used to characterize the South Dakota AFFF-impacted site are shown below, using both concentrations and PFAS ratios.

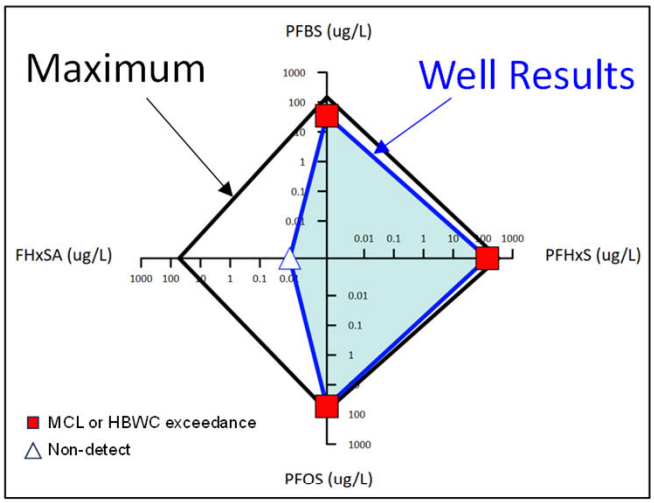
a) PFAS of Concern (POCs)



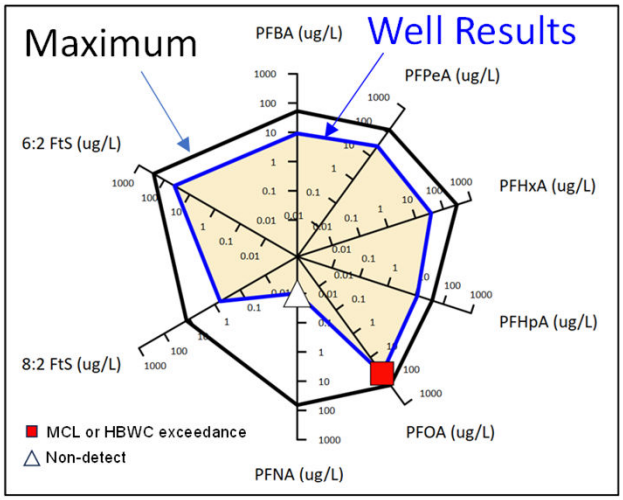
b) POC Ratios to PFOS



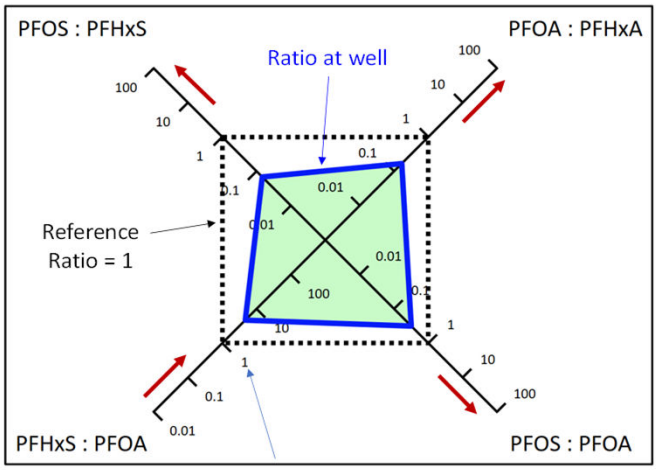
c) PFSAs and Precursor



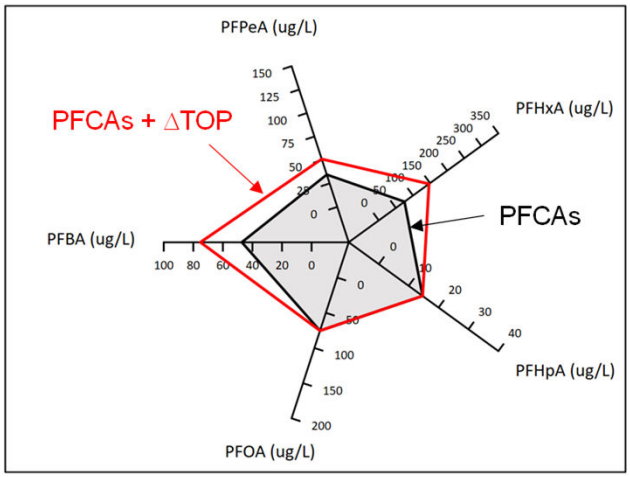
d) PFCAs and Precursors



e) Gamlin et al. (2024) Attenuation Ratios



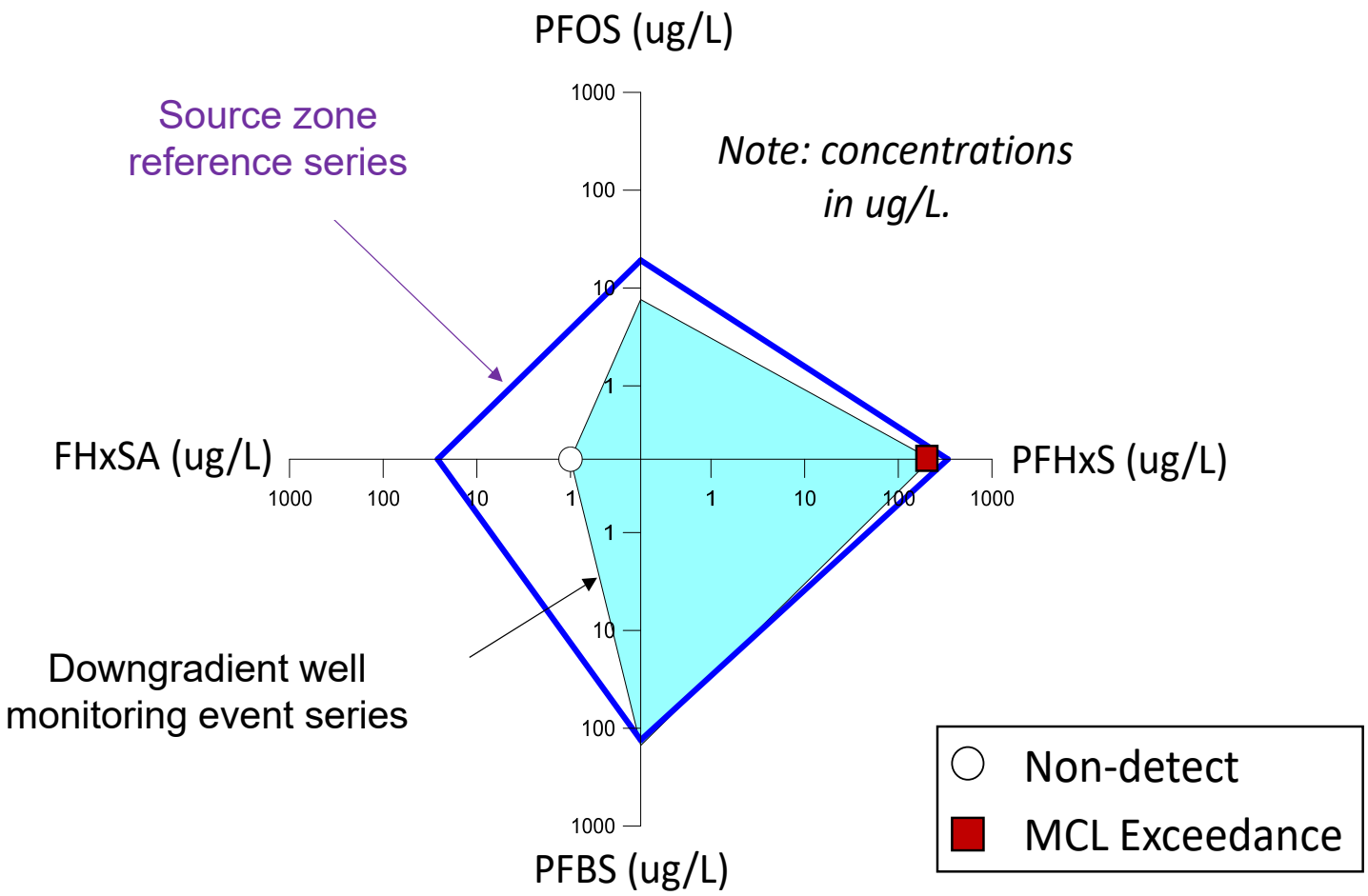
f) TOP Assay Results



Components of a Radial Diagram

The radial diagram below shows an example that includes axes to represent three sulfonates (PFOS, PFHxS, and PFBS); and FHxSA which is a precursor that may biodegrade to PFHxS under aerobic conditions. The PFAA axes are sequenced in order of chain length which facilitates a relatively quickly visual comparison of long vs. short-chain concentrations at each well location. In this example, a **reference series** is shown to represent the maximum source zone concentrations, and results for a single **monitoring event series** at a downgradient well are shown with the data series with blue fill. When these radial diagrams are plotted at individual well locations on a site map, the well-specific series will change at each well location. The reference series (e.g., maximum source zone concentrations) will be uniform across all wells.

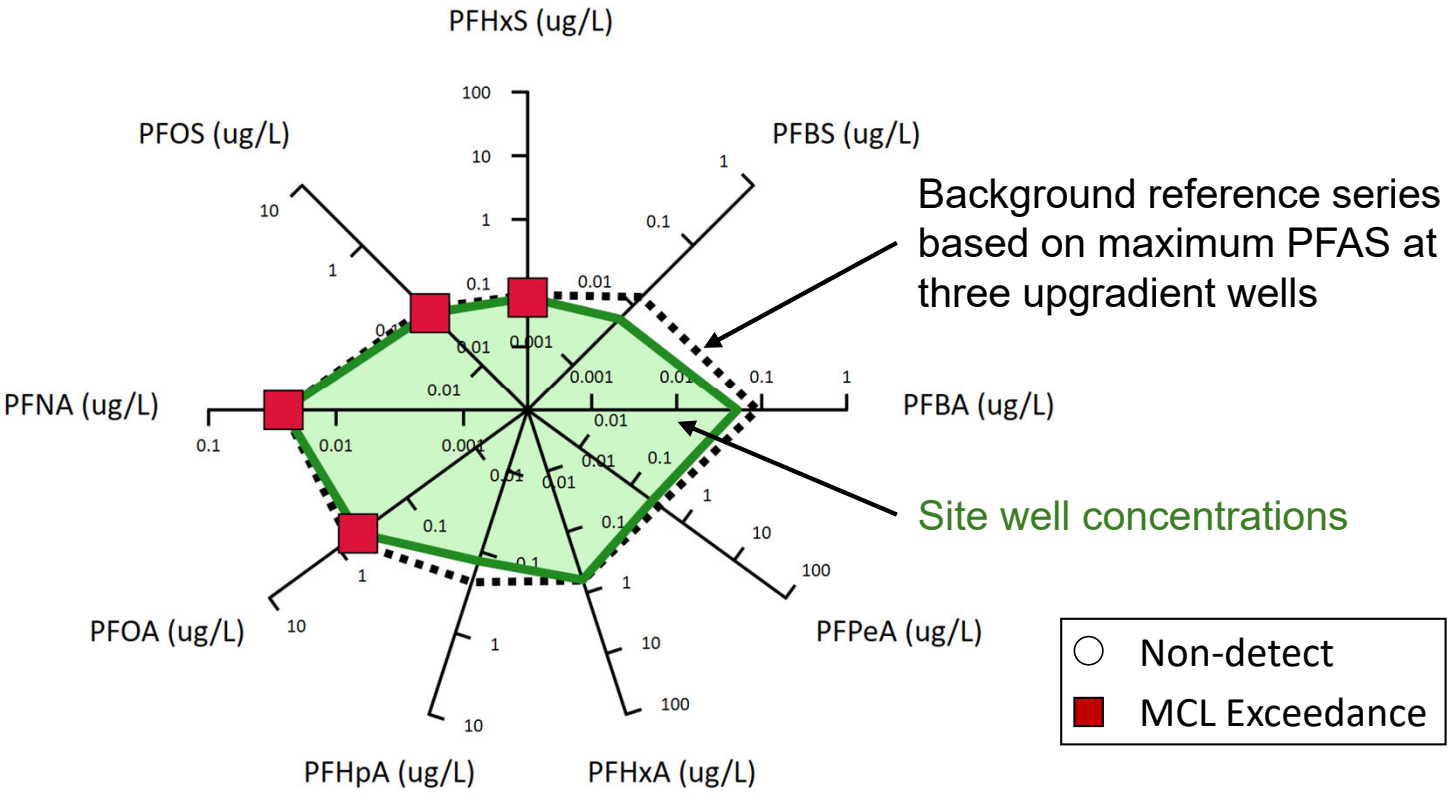
The purpose of including a reference series on the radial diagram, in addition to the well-specific concentrations for a specific monitoring event, is to allow for more effective visualization of changes in well concentrations with distance downgradient from a source zone. It is easier to visualize the size of the gap between the reference series and the well-specific monitoring event series, than trying to visually measure changes in the size of well-specific series in radial diagrams overlaid onto a site map. This will be demonstrated further in the radial diagram map discussion below.



The radial diagram example shown on the previous page indicates that the FHxSA concentration at the downgradient well has declined about 1.5 orders of magnitude relative to the maximum source zone concentration, and PFOS has declined close to half an order of magnitude. The distance between one pair of tick marks on an axis represents an order of magnitude change in concentration when the axis is plotted using a logarithmic scale. So changes in concentration with radial diagrams may be visually estimated by interpolating the number of tick marks between the reference and monitoring event series. In this example from the South Dakota AFFF-impacted site, there has been relatively little change in PFHxS and PFBS concentrations between the source zone and the downgradient well location.

The radial diagram shown on the previous page also demonstrates the use of symbols for representing MCL or other cleanup criteria exceedances, or to represent non-detects. Including symbols to identify cleanup criteria exceedances, with multiple regulated PFAS constituents shown on a site radial diagram map, facilitates delineation of the extent of exceedances and the corresponding plume boundary.

The radial diagram below shows a different example where background concentrations are used as the site-wide reference series to facilitate an evaluation of which wells at a site have similar concentrations to background.



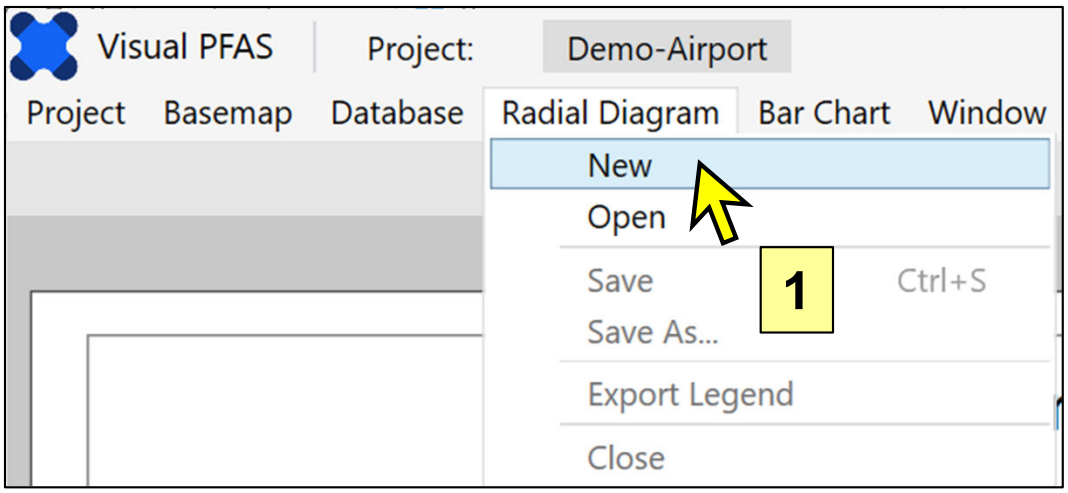
Chapter 4 in the Visual PFAS™ Users Guide provides a hands-on tutorial with step-by-step instructions for creating a radial diagram map using the example Airport Site discussed in Chapter 1. Specialized features and options available in Visual PFAS™ for creating radial diagrams are illustrated in this chapter.

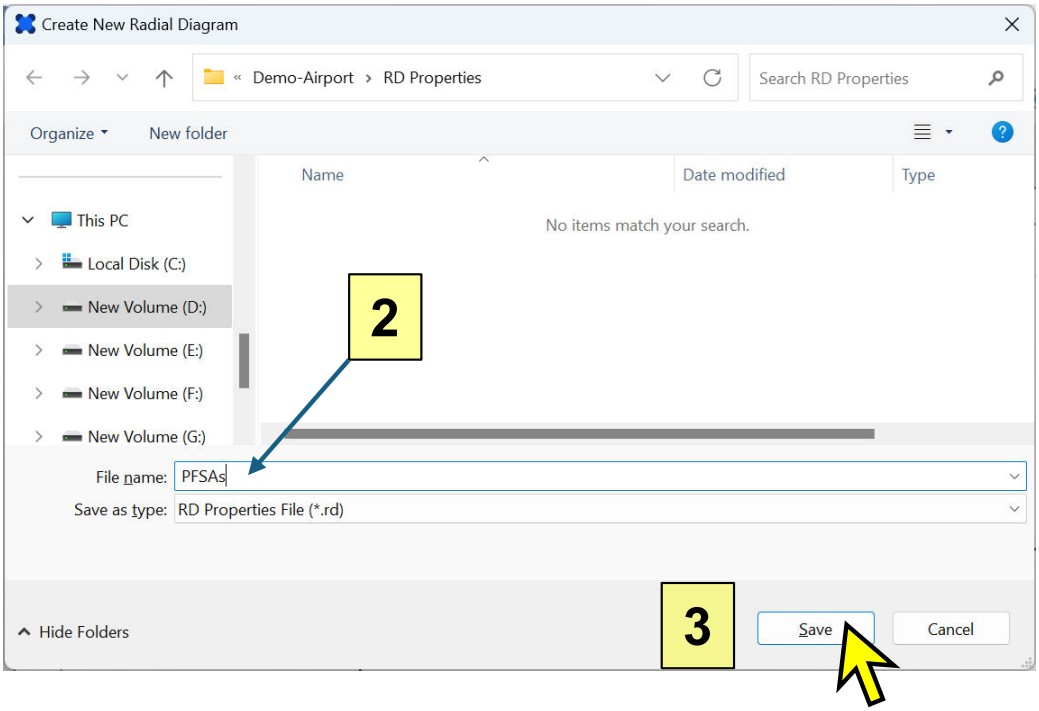
4.1.1 Creating a new radial diagram properties file

Each radial diagram map will have its own properties file that specifies the axis properties, which chemicals are to be represented on each axis, what data series and symbols to plot, and the overall look and feel of the radial diagram legend.

Once the legend has been finalized, then the radial diagrams are overlaid onto the site basemap, and additional iterations may be needed at that time to refine the length of radial diagram axes, series colors, line thicknesses, series fill, symbol sizes, etc.

To start, let's create a new radial diagram properties file. Click the **Radial Diagram** menu option, select **New** (see "1" below), and then enter the name of the radial diagram properties to create: *PFSAs* (see "2" below). The radial diagram properties file has an extension of *.rd, and by default these files are stored in the **RD Properties** sub-folder under the project folder.

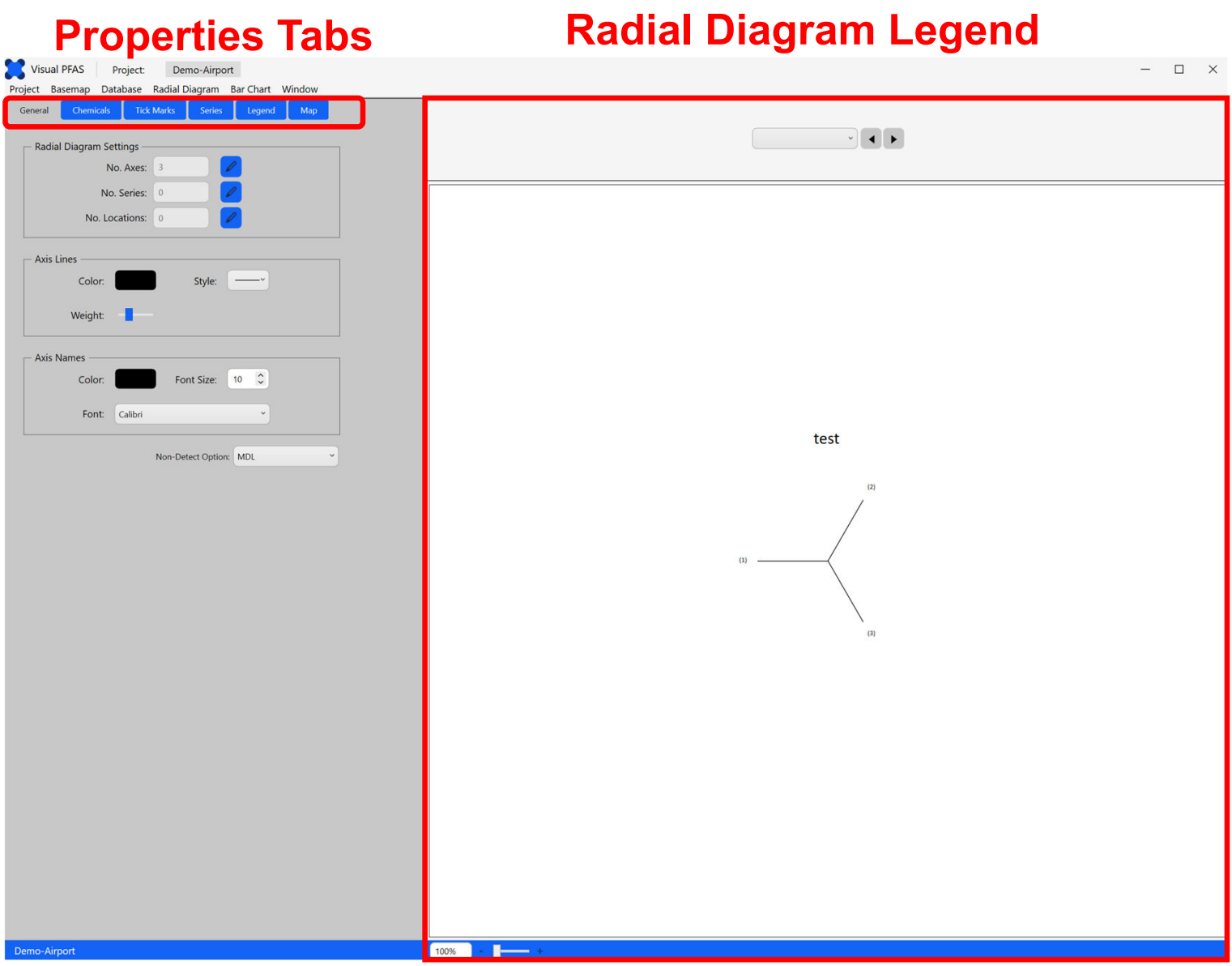




The image below shows what appears after a new radial diagram properties file has been created. The left part of the screen is where users can modify various properties of radial diagrams by clicking on the tabs at the top. The **General** tab is first selected by default when a new radial diagram file is created. This is where users can specify properties for each axis in the radial diagram, select reference and monitoring event series, the locations at which radial diagrams will be shown on the basemap, and the axis line and label properties. Other tabs facilitate user specification of properties for Chemicals, Tick Marks, Series, the legend, and the radial diagram map.

By default, radial diagrams will have three axes when the properties file is first created. The radial diagram legend is shown on the right side of the image below. The radial diagram legend can be re-sized using the scroll bar at the bottom of the legend – this allows you to re-size the legend based on the size of your window.

The top part of the legend allows you to scroll through locations once they have been selected.



4.2 General Properties

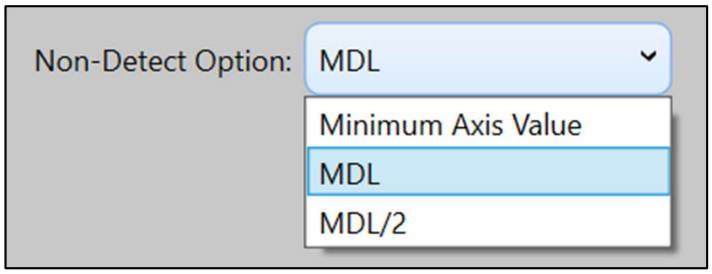
General properties for a radial diagram map include:

1. Number of axes, and which chemicals are to be represented on each axis;
2. Number and selection of reference and/or monitoring event series;
3. Number of locations at which radial diagrams will be shown on the map;
4. Axis line properties (color, style, and thickness or weight);
5. Axis name (i.e., label) properties (color, font size, and font style); and
6. Option of how to plot non-detect results on the radial diagrams. The default option is to plot non-detect results at the method detection limit (MDL) on the radial diagram axis.

The locations of these three groups of properties are identified in the image below.

> Note: Non-detect chemical concentrations are represented by negative values in the Results.csv file with the project database, where the value represents the MDL. For example, a result of -0.3 ug/L in the Results.csv file for a chemical represents a non-detect where the MDL is 0.3 ug/L.

Note: There are three **Non-Detect Options** for plotting non-detect values on radial diagrams: i) at the MDL; ii) at one-half of the MDL; or iii) at the minimum axis range. If the MDL is less than the minimum axis range, then the radial diagram series will be plotted at the minimum axis range.



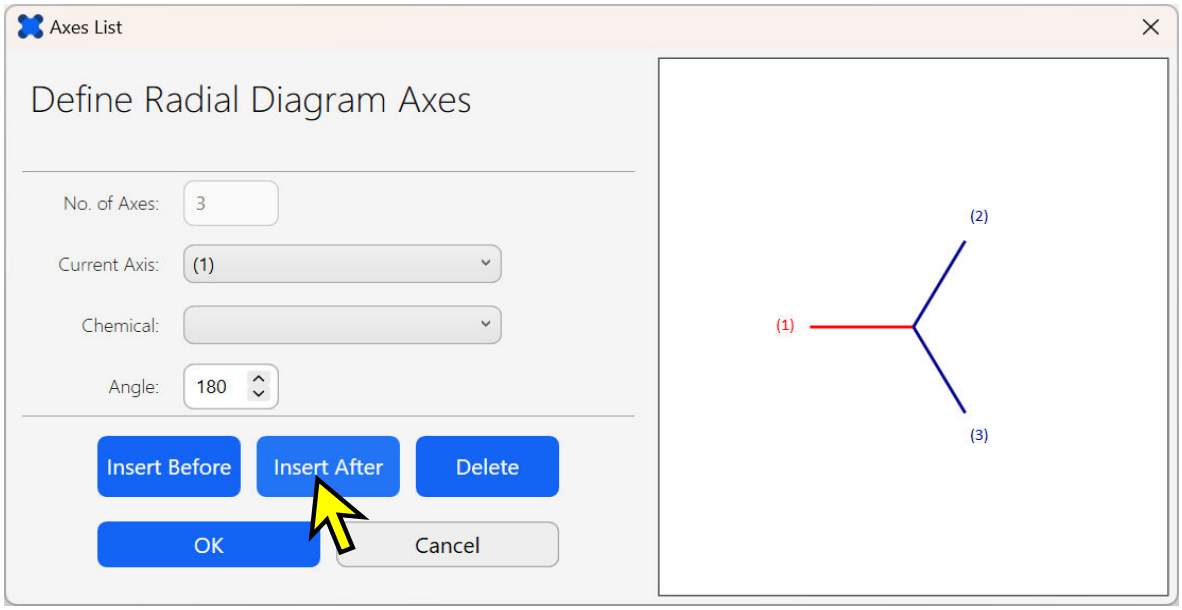
This dropdown box shows the available options for plotting non-detect results on radial diagrams.

4.2.1 Number of Axes, Chemical Selection, and Axis Angles

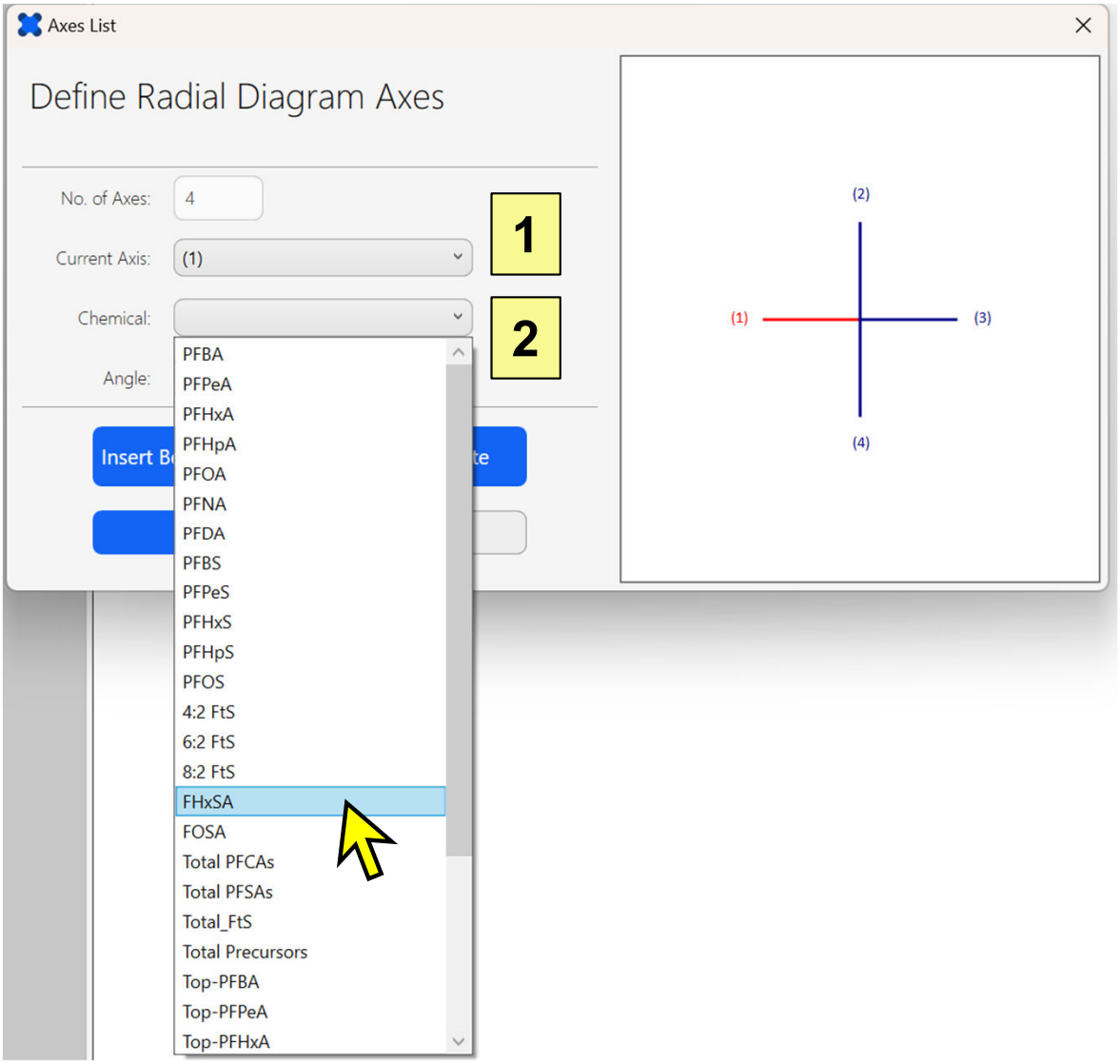
To start editing the radial diagram properties, click the pencil (i.e., **Edit**) icon next to the **No. of Axes** textbox, which currently states that there are three axes. (see "1" on previous page)

A pop-up window will then be displayed with the default 3-axis radial diagram. The current axis is shown with the red line in the legend (see image below). Any changes such as specifying the chemical, changing the axis angle, or deleting an axis will be made to the current axis selected. You can change the current axis using the corresponding dropdown box. Before a chemical is selected for an axis, the current axis is shown as the axis number. Once a chemical has been selected for an axis, then the axis label in the **Current Axis** dropdown box will be replaced with the chemical name.

For this tutorial we want to use a 4-axis radial diagram to represent: a) the precursor FHxSA which is known to degrade to PFHxS; and b) three sulfonates (PFOS, PFHxS, and PFBS). To add a fourth axis, click the **Insert After** button as shown with the yellow cursor in the image below.



1. After inserting the new axis, the current axis selected will be Axis No. 2. Click the **Current Axis** dropdown box and select (see "1" below) to make the first axis the current axis.
2. Next, click on the **Chemical** dropdown list and select *FHxSA*. The chemicals listed in the dropdown box are from the list of chemicals that were imported into the project database with the **Chemicals.csv** file. The order of chemicals in the dropdown box is based on the Sort_ID field in Chemicals.csv.



After specification of FHxSA for Axis No. 1, repeat the process for selecting chemicals for each axis as follows:

- Make Axis No. 2 the current axis and select *PFOS* from the **Chemical** dropdown box.
- Make Axis No. 3 the current axis and select *PFHxS* from the **Chemical** dropdown box.
- Make Axis No. 4 the current axis and select *PFBS* from the **Chemical** dropdown box.

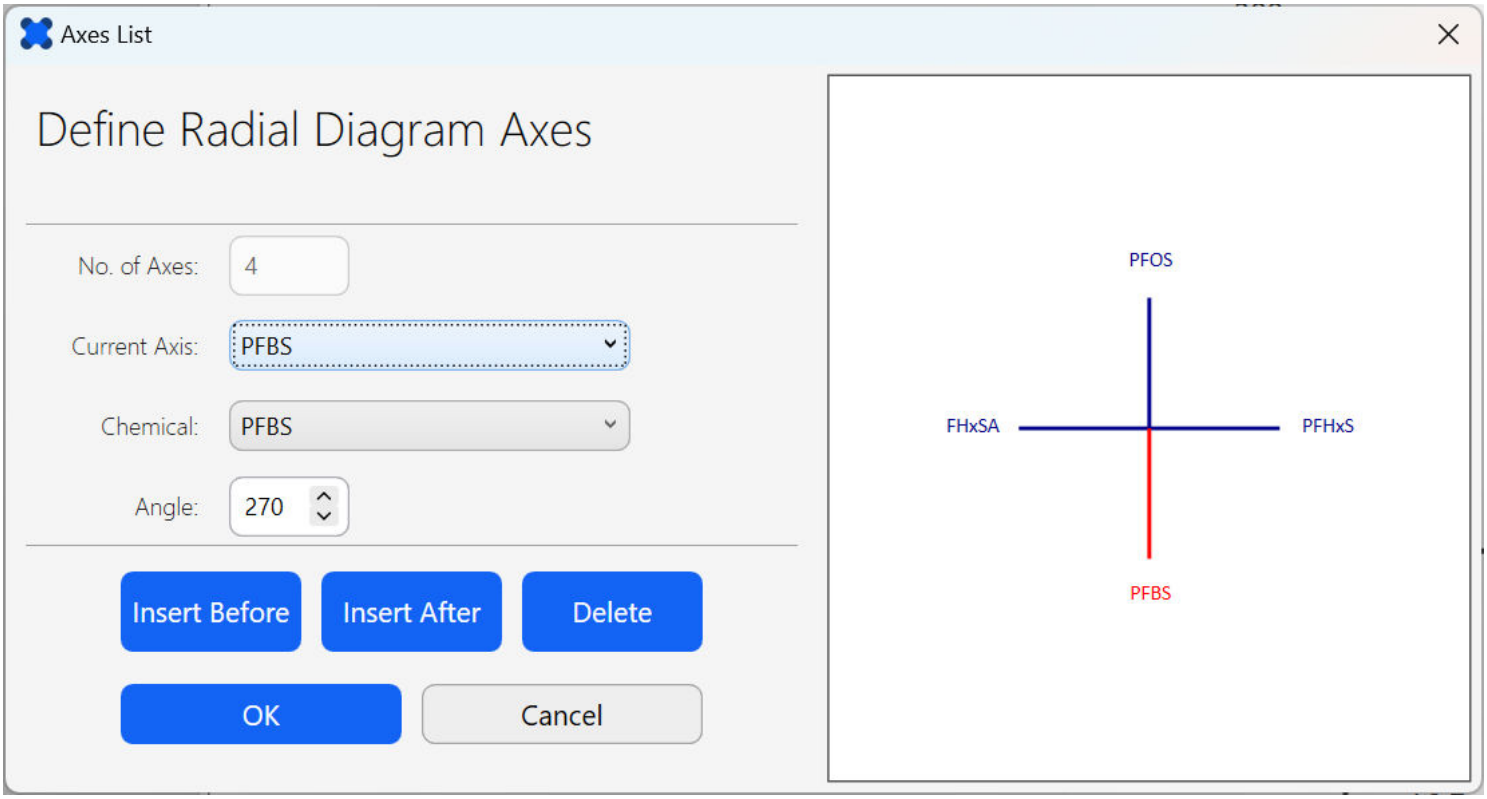
The corresponding legend for these four axes and chemicals is shown in the image below.

You have the option of modifying the angles for each axis by selecting a current axis, and then changing the value of the angle shown in the **Angle** textbox, or using the up or down arrows on the right of this textbox to make incremental changes in the angle. The legend on the right of the image below will be updated based on the new axis angle each time you make a change.

For this tutorial we will keep the default axis angles.

Click the **OK** button to save your changes and go back to the **General** tab.

> **Note:** The default angle for Axis 1 is 180 degrees. The default angle for all other axes is based on the assumption of uniform angles between all axes of the radial diagram, keeping Axis No. 1 angle at 180 degrees as the default.



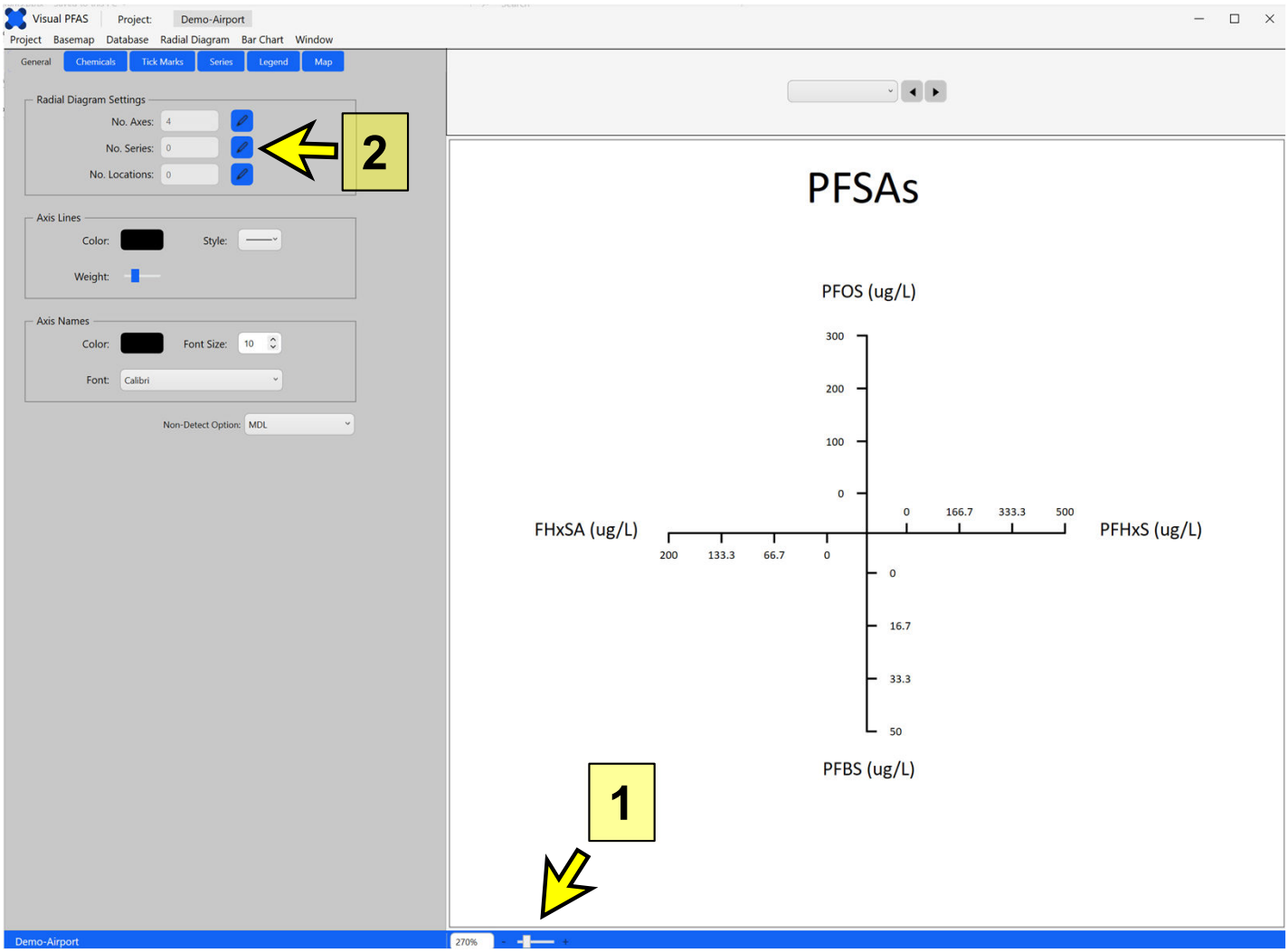
After exiting the pop-up window, you will see the window below where the radial diagram legend has now been updated to show the chemical names associated with each axis, and the default concentration units (ug/L) that are specified separately for each chemical in the **Chemicals.csv** file imported into the project database earlier.

Visual PFAS™ will search the chemical concentrations in the project database to automatically define the minimum and maximum axis ranges and major tick mark scales for each chemical, as shown in the radial diagram legend below. The default for each axis is arithmetic scale, and this is easily changed to log scale as we discuss a little later in this tutorial. Axis ranges and tick marks can also be changed as shown later.

The size of the radial diagram in the legend is dependent on each user's screen resolution and monitor size. The size of the radial diagram can be easily increased by moving the scroll bar indicated at "1" in the image below. Click and hold this scroll bar to the right to make the radial diagram a little larger in the legend.

4.2.2 Number of Reference and Monitoring Event Series

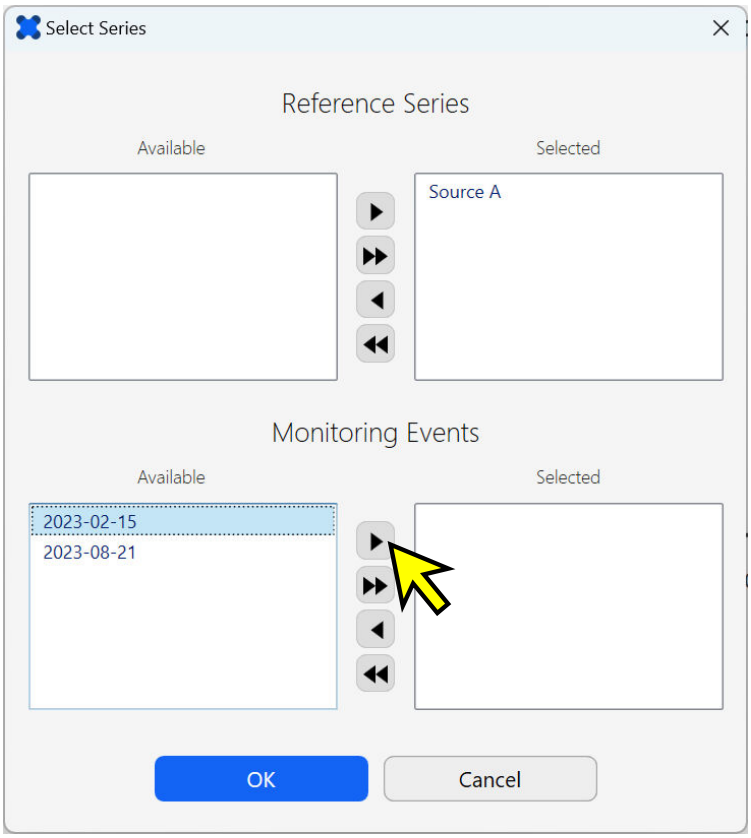
The next step in the tutorial is to click the **Edit** icon to the right of the **No. Series** textbox (see "2" below).

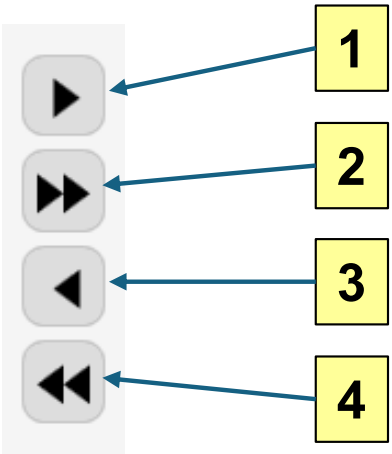


A pop-up window will appear (see below), allowing you to add reference and/or monitoring event series. The **Available** series are shown on the left side of the window based on data in the project database. To move a reference or monitoring event series from the **Available** side to the **Selected** side, you can either: a) double-click on the series in the **Available** side which will automatically move it to the **Selected** side; or click on it once in the Available side so that it is highlighted in blue, and then press the single right arrow (#1 button below) to move it to the selected side. The opposite is done to move a series from the **Selected** side back to the **Available** (i.e., unselected) side. The double arrows (#2 and #4 below) are used to move all series from one side to the other.

Note: You can highlight more than one item at a time in the Available or Selected lists by holding the SHIFT key to highlight a contiguous block of items, or by holding the CTRL key to highlight non-contiguous items in the list.

The image below shows that the *2023-02-15* monitoring event has been clicked on once (i.e., based on the blue highlighting shown below). In this case, click the single right-arrow to move this event to the **Selected** side. For this tutorial, select the *Source A* reference series and the *2023-02-15* monitoring event series to show on the radial diagrams, then press the **OK** button at the bottom of the window. All well radial diagrams will have the same Source A reference series, and each radial diagram will show the well-specific monitoring event concentrations.





Button functionality:

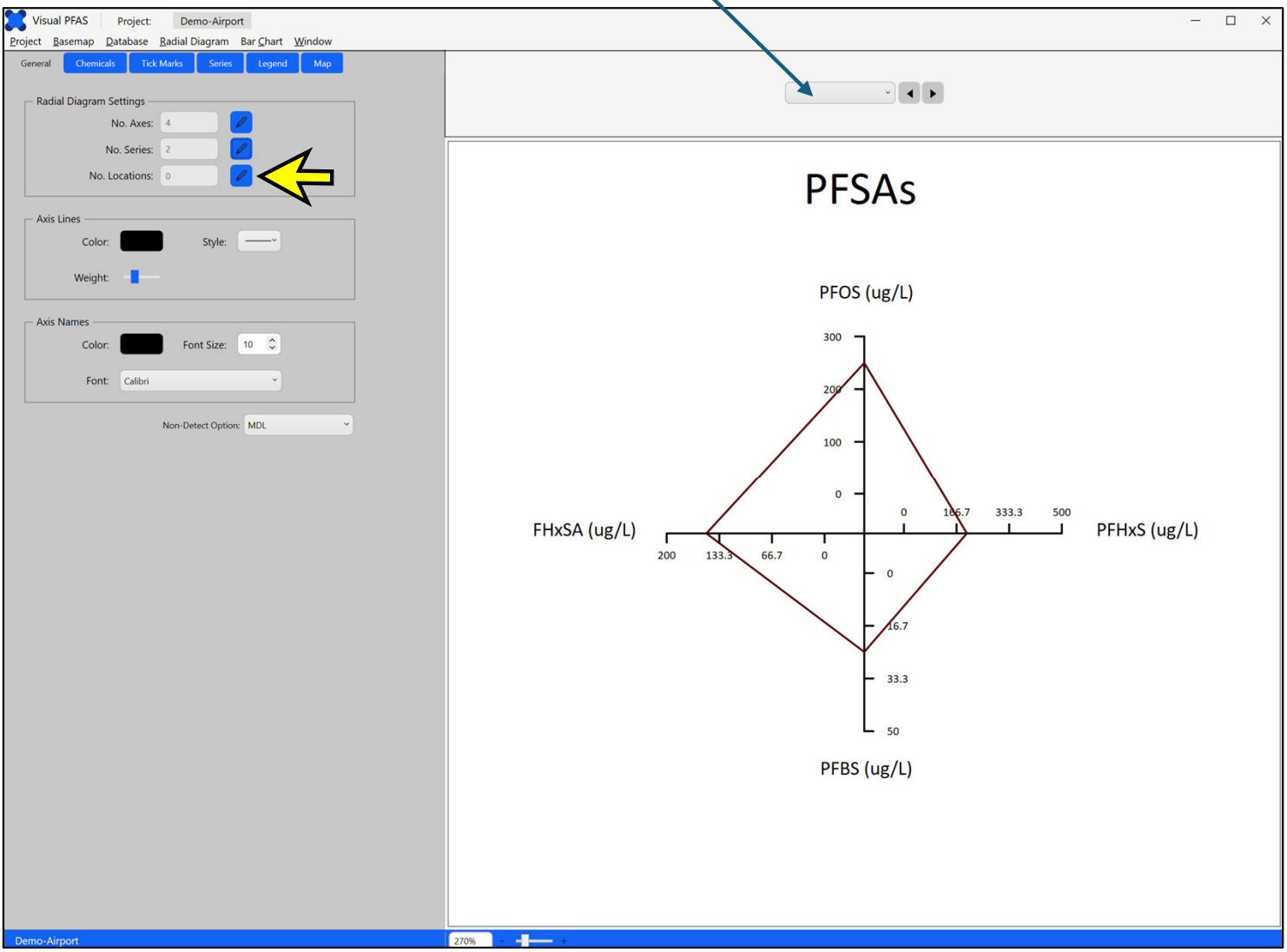
1. Move highlighted items to the **Selected** list;
2. Move all Available items to the **Selected** list;
3. Remove highlighted items from the **Selected** list back to the **Available** list;
4. Remove all items from the **Selected** list back to the **Available** list.

4.2.3 Select Locations to Plot Radial Diagrams

After selecting the two series in the previous step, the image below shows what will be displayed. Only the Source A reference series is shown because well locations for the monitoring event series haven't been selected yet. Radial diagram series have randomly assigned colors initially, which you can easily change (i.e., similar to how Excel creates random initial colors for chart series).

Click the **Edit** icon next to the **No. Locations** textbox to select monitoring well locations where radial diagrams will be plotted on the basemap.

Note: The dropdown box displayed above the radial diagram legend will include selected monitoring well locations (see next step in the tutorial). This allows you to select a specific well to review with a single radial diagram, and you can press the right and left arrows to cycle through radial diagrams for all selected monitoring wells.

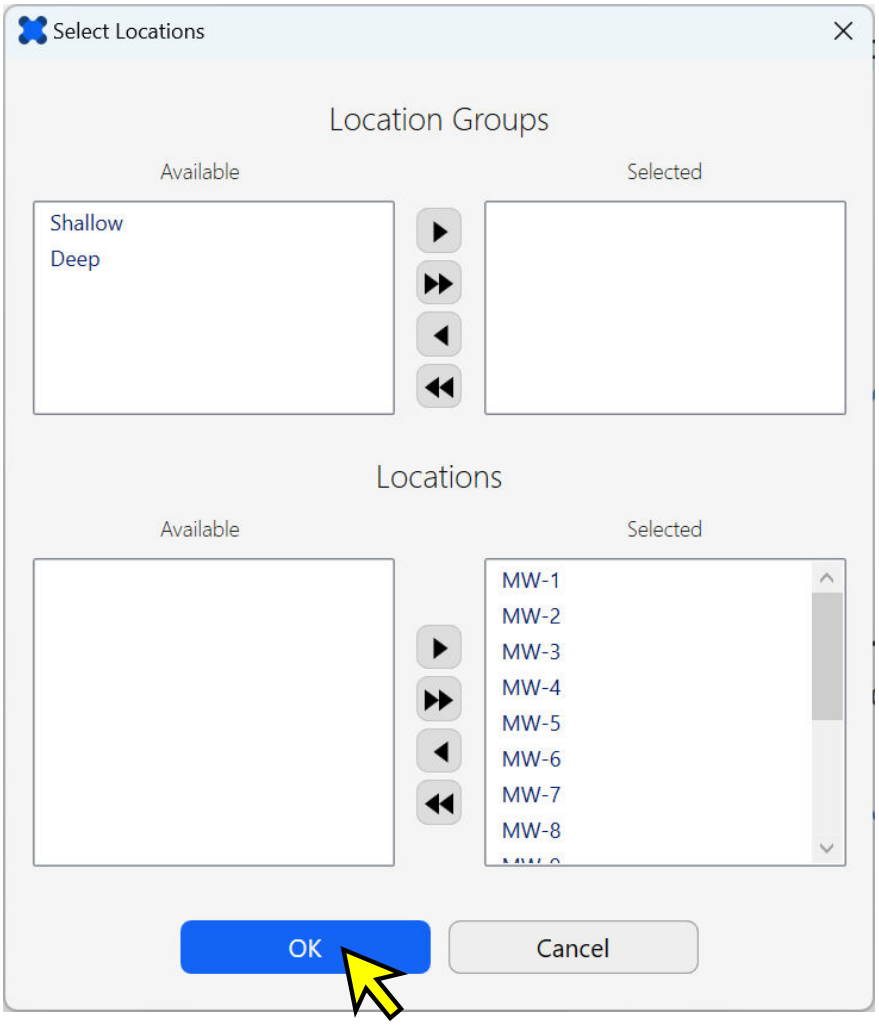


The project database for the Airport Site has two groups of locations: shallow and deep monitoring wells. Specifying groups of wells allows you to quickly filter a large list of site monitoring wells to a smaller list with only those wells that you want to select for plotting radial diagrams.

For example, if you select the *Shallow* location group by double-clicking on it to move it to the **Selected** side, then the list of **Available** locations in the lower list will be reduced to include only 11 shallow monitoring wells. Or if you selected the *Deep* location group, then only four monitoring wells would be included in the **Available** locations list.

In this tutorial, we will plot radial diagrams at all 15 monitoring well locations as a simple demonstration. (At other sites, it may be advisable to create separate radial diagram maps for shallow and deep monitoring wells.) So you will not select either of the location groups shown in the top list.

To select all 15 monitoring well locations, click the ▶▶ button and press OK to close the pop-up window.



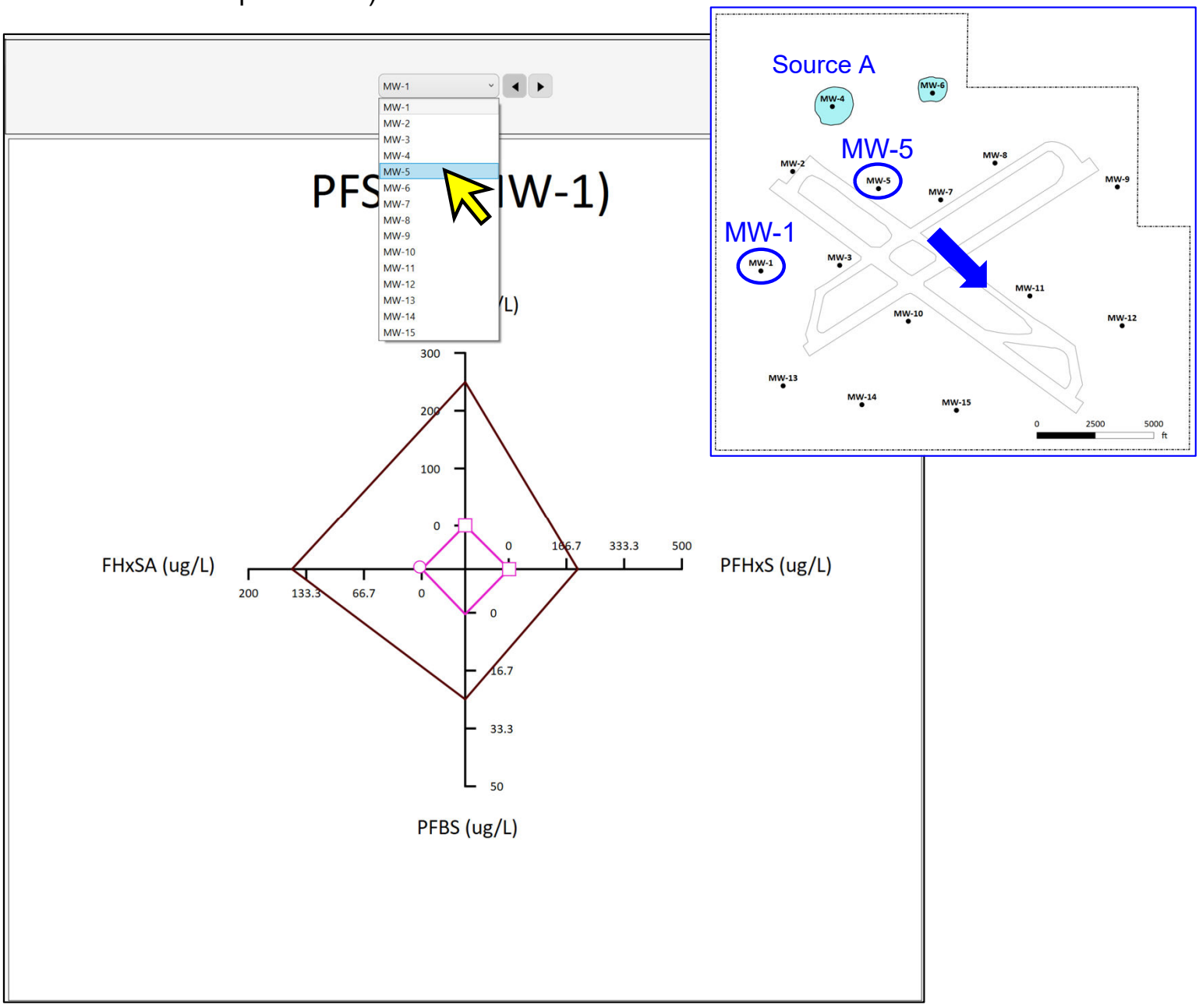
Note: The order for displaying monitoring wells in the **Available** and **Selected** lists is based on the Sort_ID field in the Locations.csv file with the project database.

This allows users to sort wells numerically (e.g., so MW-2 is shown ahead of MW-10 in the well list).

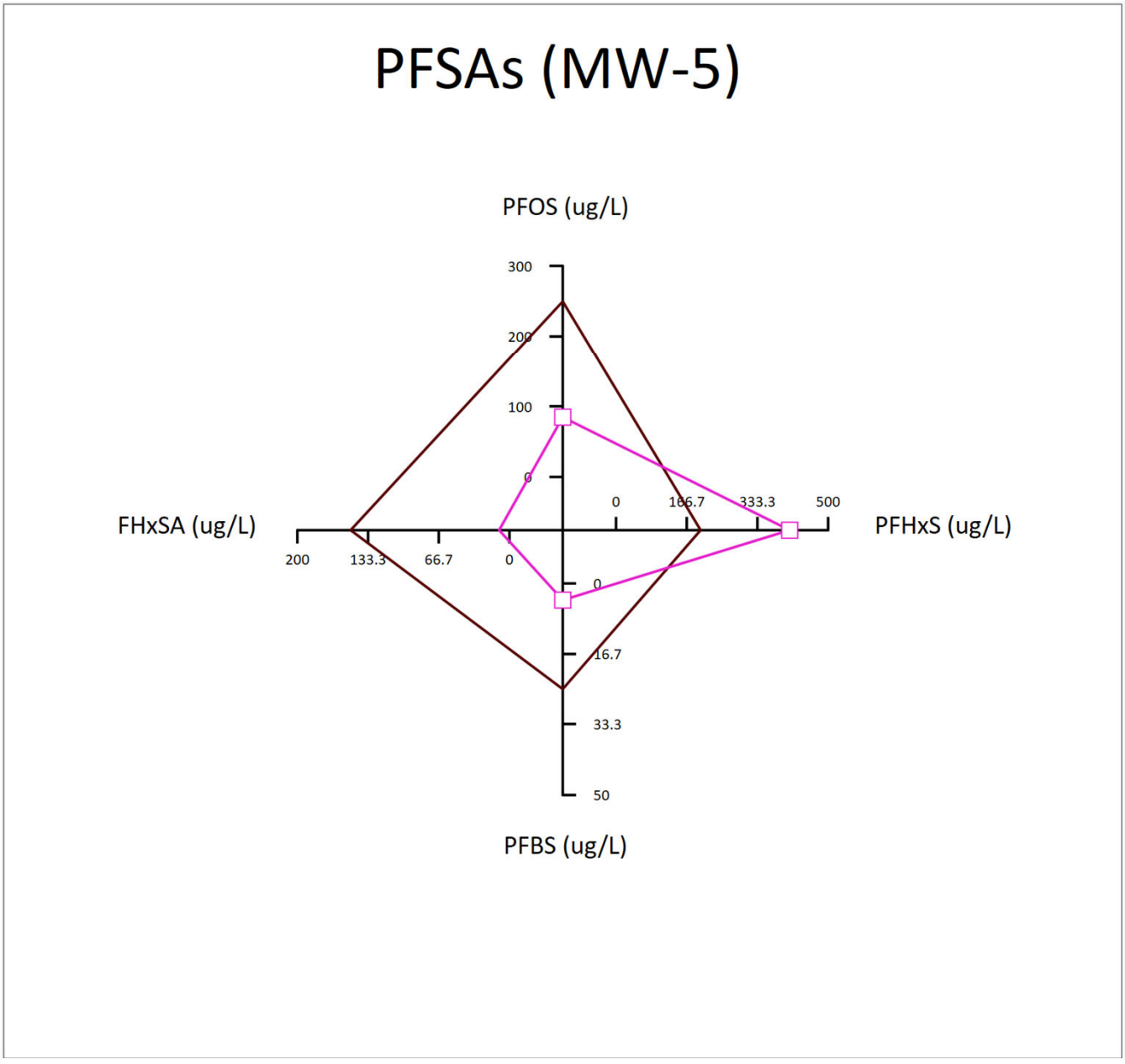
Now that monitoring well locations have been selected, both the reference and monitoring event series will be shown for the first well in the selected list (i.e., MW-1).

Recall that the reference series (red) represents the concentrations at Source A where sulfonates and FHxSA are high. The image below shows that sulfonate and FHxSA concentrations at MW-1 (pink series) are much lower than at Source A. MW-1 is cross-gradient from the source, so it is located on the fringe of the plume. This is why PFAS concentrations are much lower at MW-1 than at the source area. (see inset map below)

Monitoring well MW-5 is directly downgradient of Source A. To view the radial diagram for MW-5, click on the selected locations drop-down list above the legend, move your cursor so it is at the MW-5 location in the list, and click once. (see image below which shows the initial radial diagram for MW-1 and the subsequent selection of MW-5 in the locations dropdown list.)



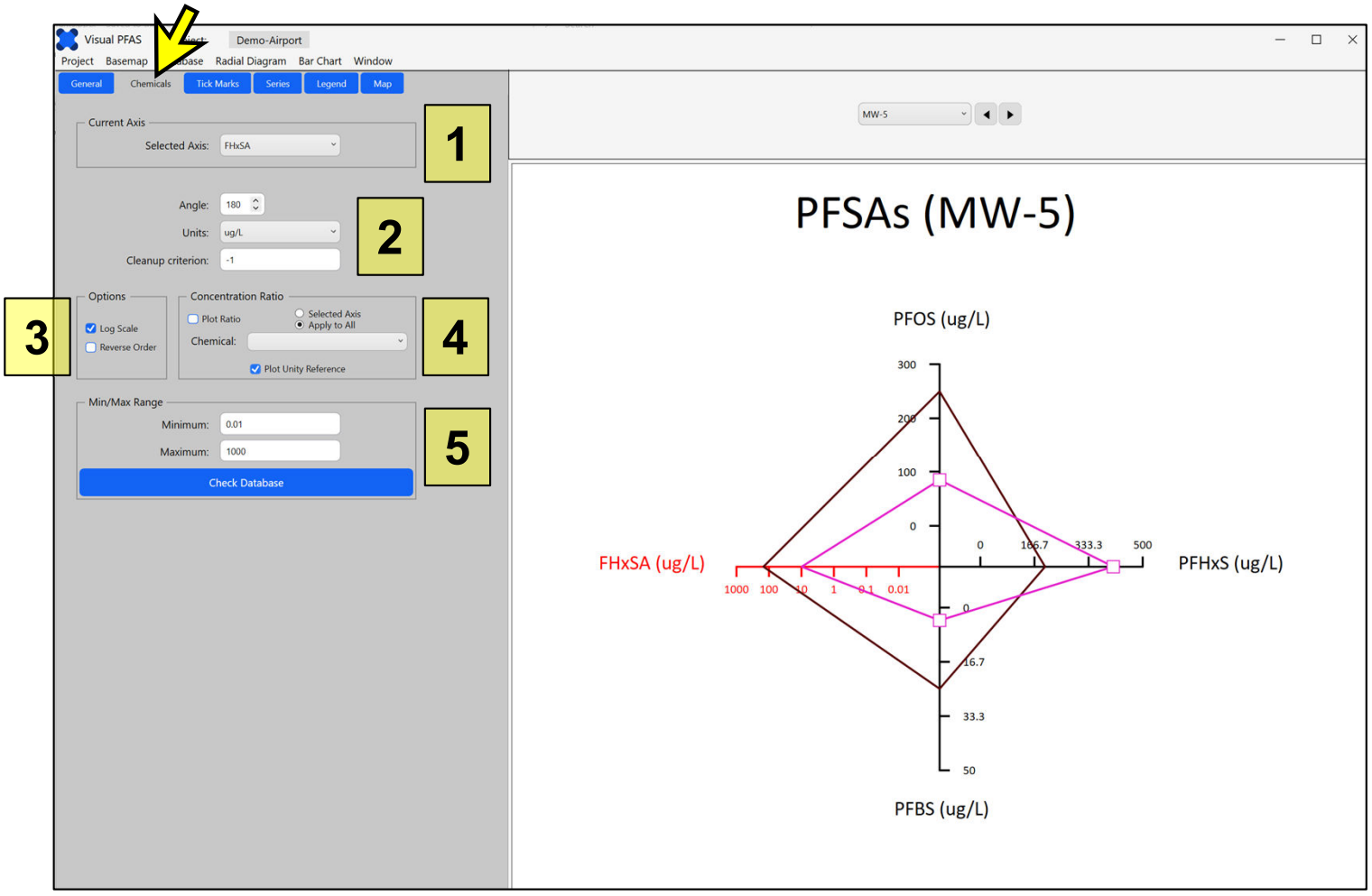
The radial diagram for monitoring well MW-5 is shown below. The red reference series represents the Source A concentrations, and the pink data series represents MW-5 concentrations downgradient from Source A. The decrease in FHxSA concentration between Source A and the downgradient monitoring well indicates that the precursor FHxSA is biodegrading, which is consistent with aerobic conditions in groundwater. PFHxS is shown to be increasing between Source A and MW-5 because PFHxS is a daughter product of FHxSA that is biodegrading. Both PFOS and PFBS are shown to be decreasing between Source A and MW-5, which indicates that neither of these two sulfonates are being produced at significant rates downgradient of the source area. Concentrations for these two species are declining along the flow path between Source A and MW-5, due to plume dispersion and/or forward diffusion into silt or clay layers in the aquifer. The increase in PFHxS indicates that the transformation of FHxSA to PFHxS is occurring at a higher rate than the attenuation caused by dispersion or diffusion.



4.3 Chemical Properties

Click on the **Chemicals** tab to change axis properties for the radial diagram. The numeric labels on the image below correspond to:

1. Selection of current axis (shown by the red line and red chemical label font in the legend) – any changes to axis properties will be made only to the current axis.
2. Axis angle, concentration units, and cleanup criterion (-1 if not applicable)
3. Toggle on/off for log scale, or to reverse the direction of increasing concentration on the axis. The minimum concentration range is by default near the origin of the radial diagram; this can be reversed to occur on the outer extent of the axis, which is useful when plotting redox indicators)
4. Change an axis from a concentration to a ratio; and
5. Checking the project database for the minimum and maximum detected concentrations and method detection limits (MDLs).



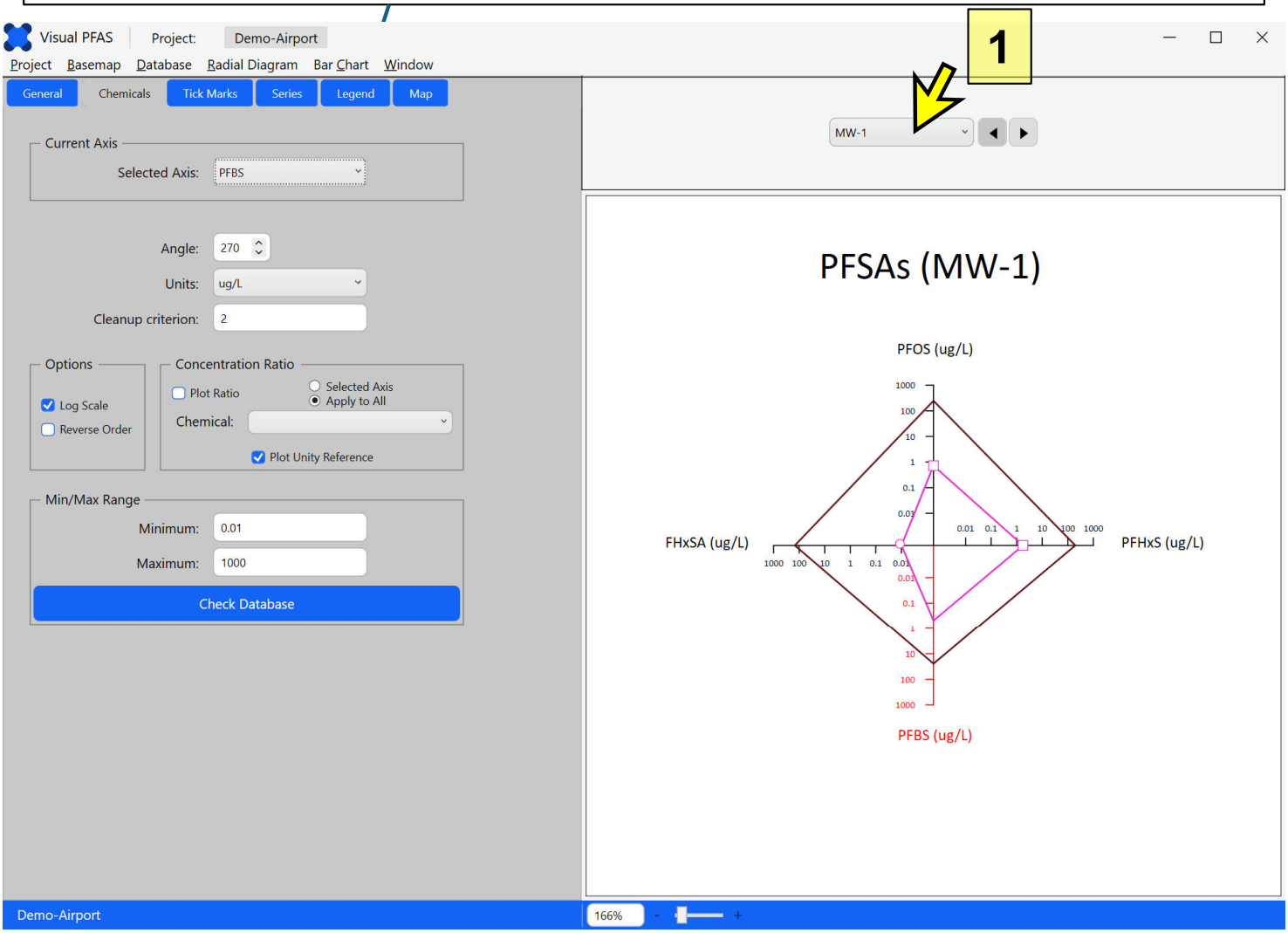
For the tutorial, switch to MW-1 (see "1") and change all four radial diagram axes to log scale which is typical for PFAS sites where concentrations vary by orders of magnitude:

i) Select FHxSA as the current axis if it's not already selected (see the dropdown box at "1" in the image on the previous page.

ii) Check the "Log Scale" option shown at the "3" label on the previous page. The axis ranges will change automatically based on the minimum and maximum project concentrations for FHxSA. You can change the minimum or maximum range for each axis by entering new values in the text boxes at the bottom of the properties section. (see "5" on previous page).

iii) Repeat steps i) and ii) for each of the remaining three axes (PFOS, PFHxS, and PFBS). The image below shows the updated radial diagram legend with all four axes now using log scale.

Note: The default units selected for each chemical axis (ug/L in this example) are based on the default units specified in the Chemicals.csv file which was imported into the project database. Database results and axis ranges are automatically updated to reflect the selected units for each axis.

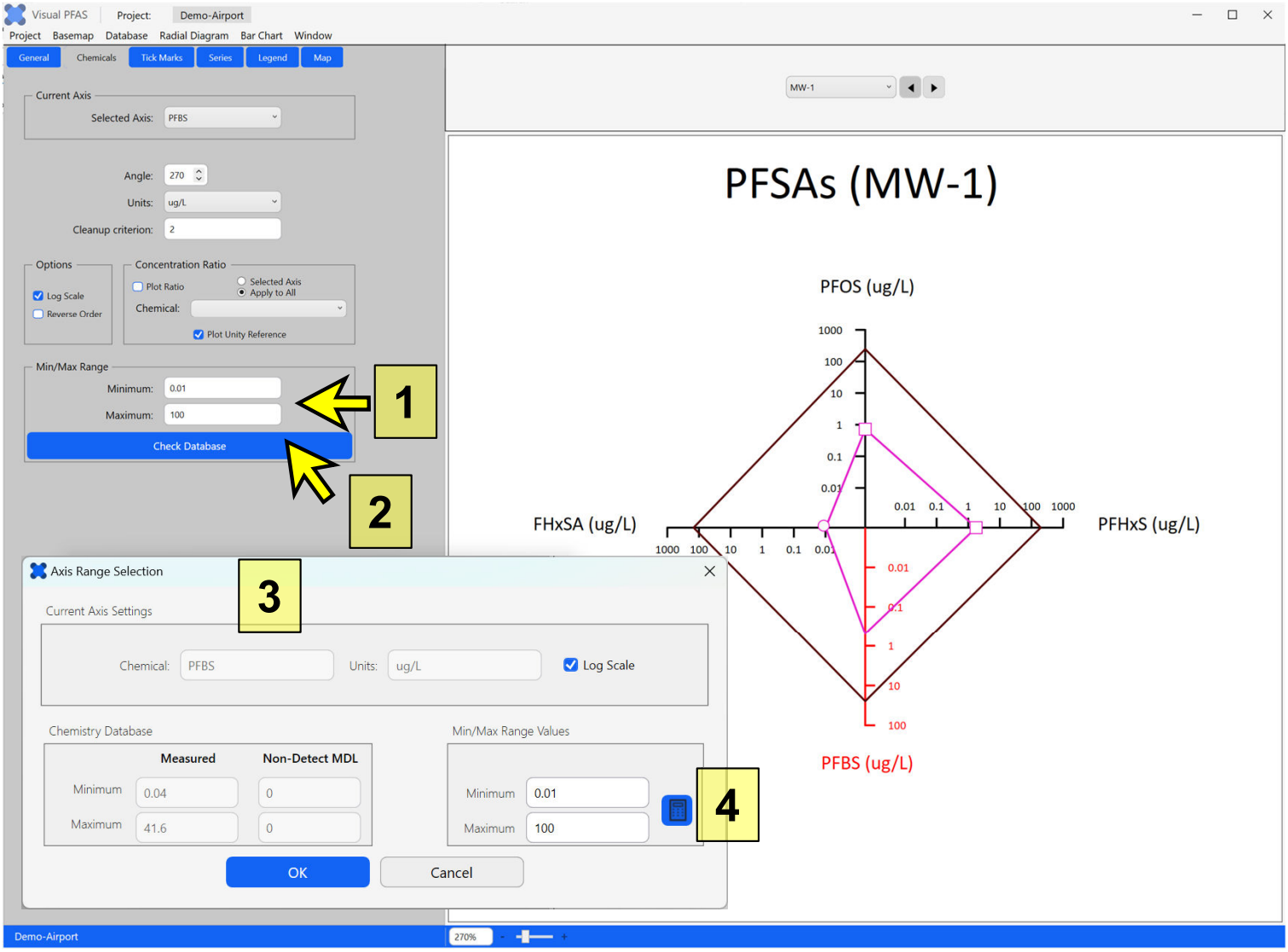


As discussed above, you can change the axis minimum or maximum ranges by entering new values in the textboxes at "1" below.

You can also check the range of project concentrations for the chemical at the current axis by pressing "Check Database" at "2" below. The **Axis Range Selection** pop-up window will appear (see "3" below), which lists the minimum and maximum concentrations for detected (i.e., measured) and non-detect (MDL) results.

You can update the minimum and maximum axis ranges with the textboxes on the right of this pop-up window, or you can re-calculate the axis default ranges (based on database min/max values for this chemical) by pressing the calculator icon at "4" below.

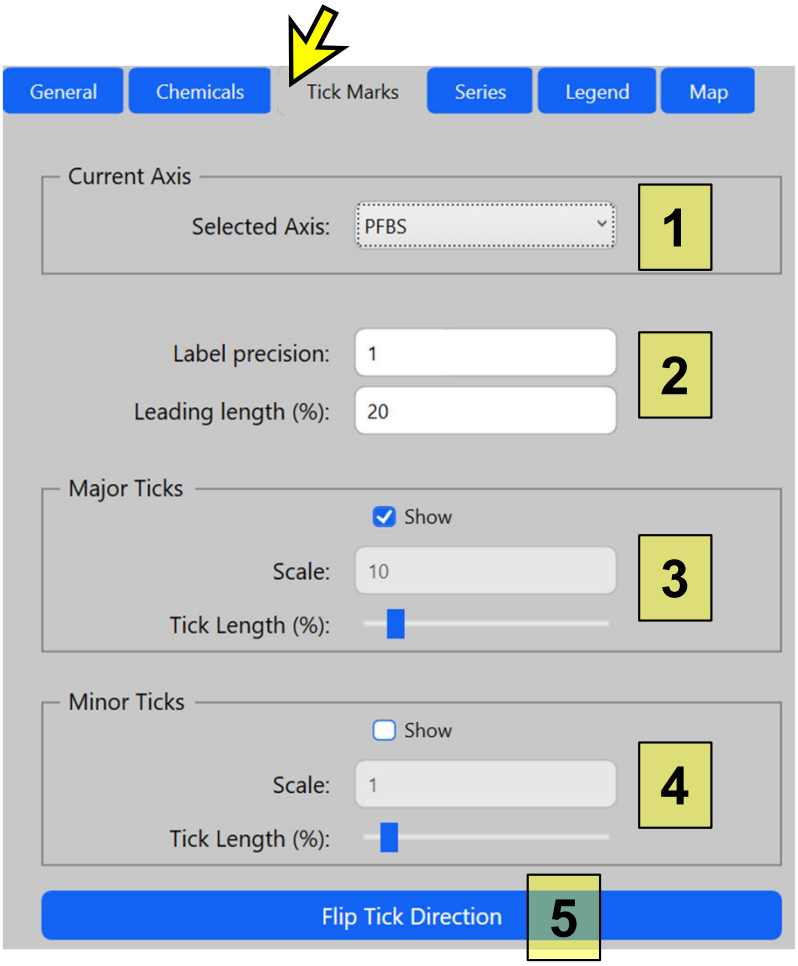
Note that Visual PFAS™ automatically converts project concentrations to the selected concentration units when the database stores values in different concentration units.



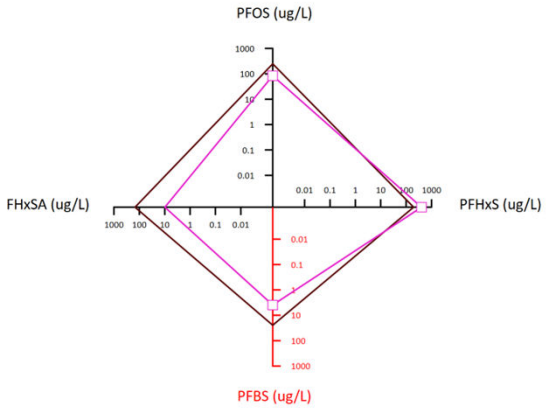
4.4 Tick Mark Properties

Click on the **Tick Marks** tab to view tick mark properties. There are several options for changing tick marks corresponding to "1" through "4" in the image below.

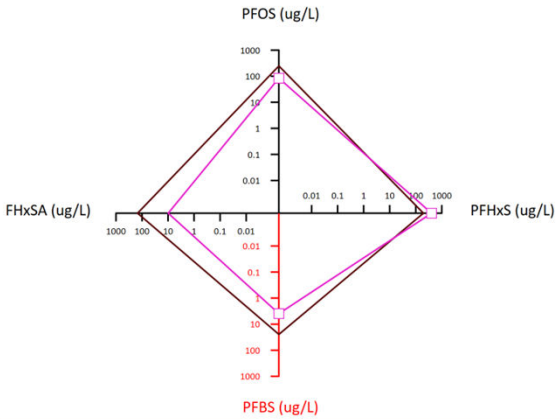
1. Select Current Axis (as shown by the red line and red chemical label in the legend).
2. Update the axis tick mark label precision (i.e., number of decimal places). This only applies for axes that are based on arithmetic scale, not for log scale). The leading length can also be modified – this is the distance on the current axis between the centroid of the radial diagram, and the first tick mark on the axis next to the centroid. By default, this leading length is specified to be 20% of the total axis length.
3. Major tick marks – can toggle on/off by clicking the *Show* checkbox. If the axis is based on arithmetic scale, you can change the scale of the major ticks which is the interval (in concentration units) at which the major tick marks are plotted. You can also change the length of the major tick marks by clicking on the scroll bar, holding it while moving to the left or right to change the tick mark length.
4. Minor tick marks – same options as major tick marks.
5. Clicking the **Flip Tick Direction** button will plot the tick marks on the opposite side of the axis. See the different tick locations on the PFBS axis below.



1. Default tick directions



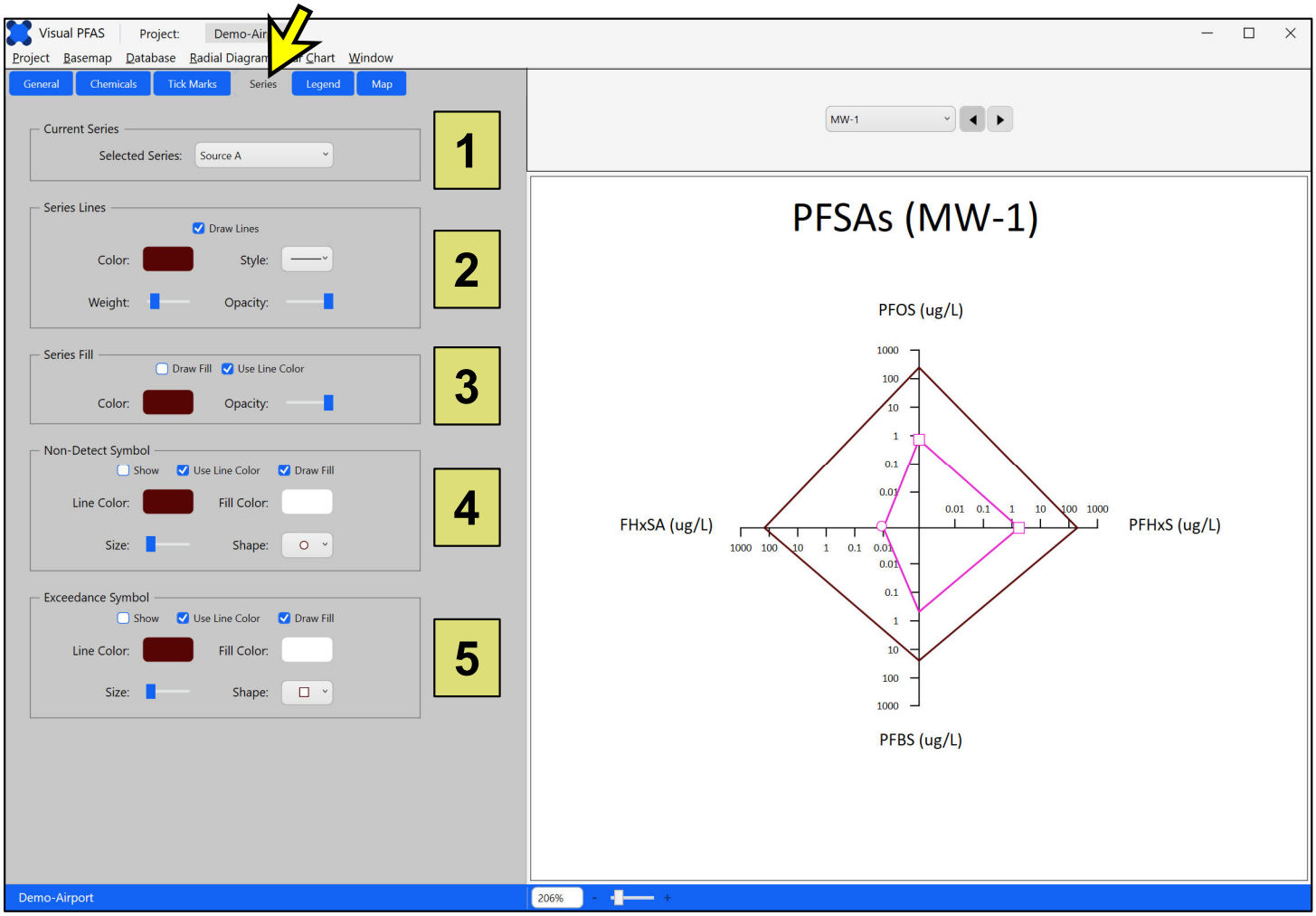
2. Flipped tick direction for PFBS axis



4.5 Series Properties

Click on the **Series** tab to view the series properties. There are several options for changing series properties corresponding to "1" through "5" in the image below.

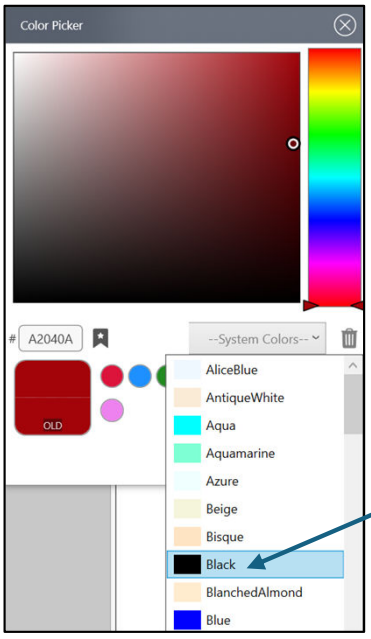
1. Select the current series. (Note – ignore "Unity Reference" series in the dropdown list unless ratios are being plotted, in which case a unity reference series is optionally plotted at Ratio=1)
2. Revise series lines: Draw checkbox, color, style, weight, and opacity (which is the opposite of transparency).
3. Revise series fill: Draw checkbox, use same color as series lines checkbox, color, and opacity.
4. Non-detect symbols: show checkbox, and various options for line and fill color, symbol size, and symbol shape.
5. Exceedance symbols (plotted on an axis when the result exceeds the applicable cleanup criterion): show checkbox, and various options for line and fill color, symbol size, and symbol shape.



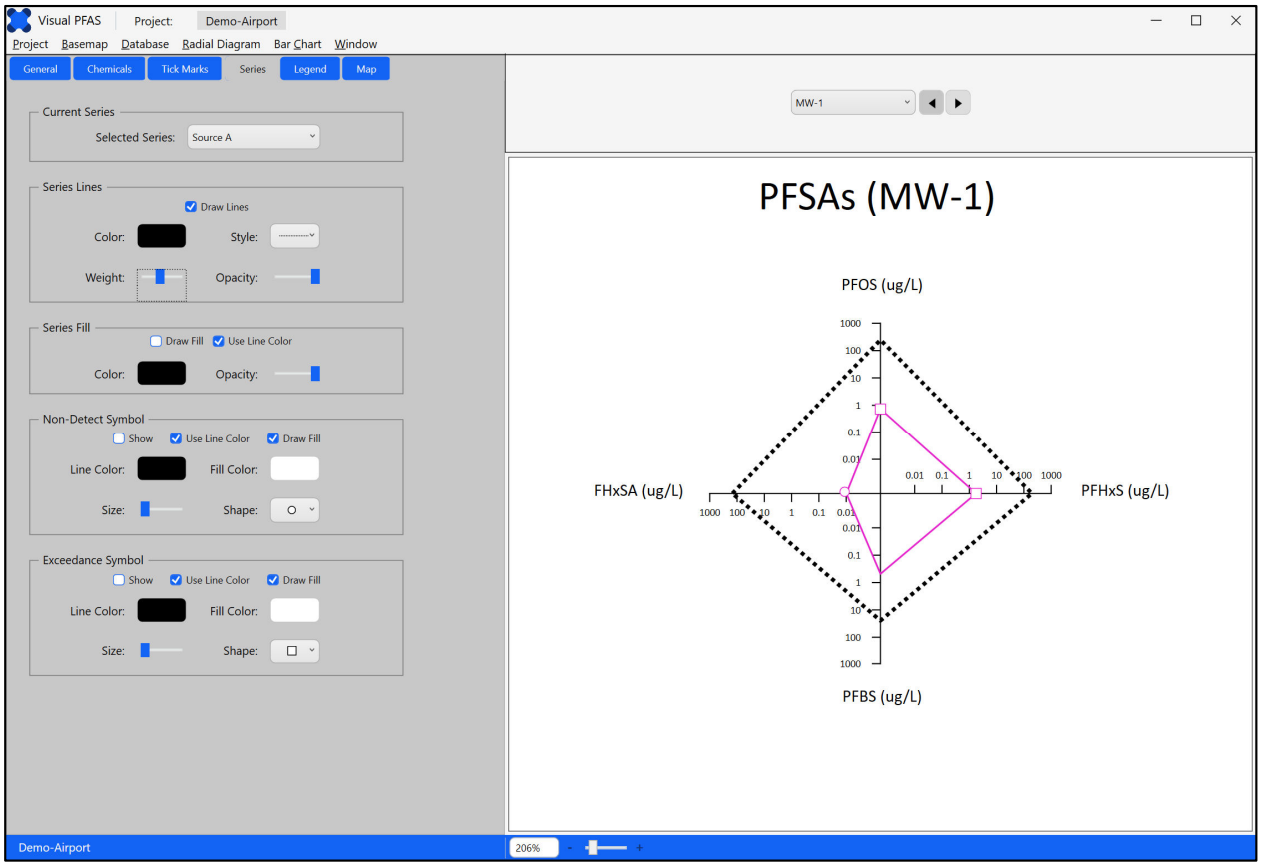
For the tutorial, first select the Source A reference series if it's not already selected.

Then change the series line color to black, change the style to a dotted line, and increase the thickness (i.e., weight) of the series line as shown below.

Note: Non-detect or exceedance symbols are typically not plotted with a reference series.



Select black from the system colors dropdown menu



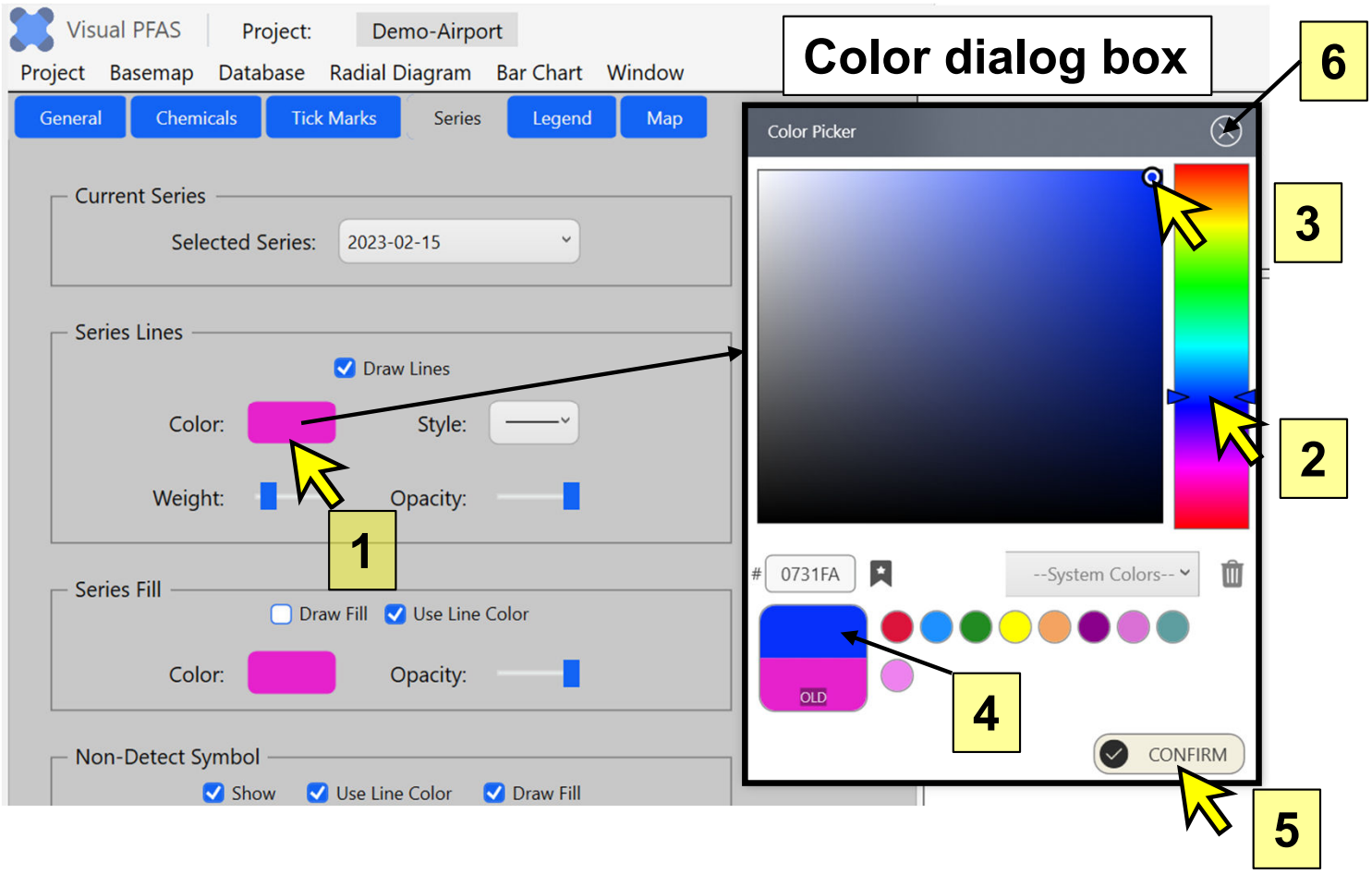
The next step in the tutorial is to change the monitoring event series as follows:

i) Select the **2023-02-15** monitoring event series from the dropdown list.

ii) Change the line color to blue:

1. Click the line color box (see “1” below) to pop-up the color dialog box.
2. Click on blue in the scale bar at the right of the color dialog box (see “2”).
3. Click in the top right corner of the color palette (see “3”).
4. Now that a new line color has been selected, this color will be shown as the new selection (see “4”).
5. To save the line color change, click the Confirm button at the bottom-right of the color dialog box (see “5”). The line color box will automatically be updated with the new selected color for the series line.

Note: To cancel the selection of a new color and retain the original color selection, click the “x” icon at the top-right of the color dialog box (see “6”). This will close the color dialog box without changing the color.



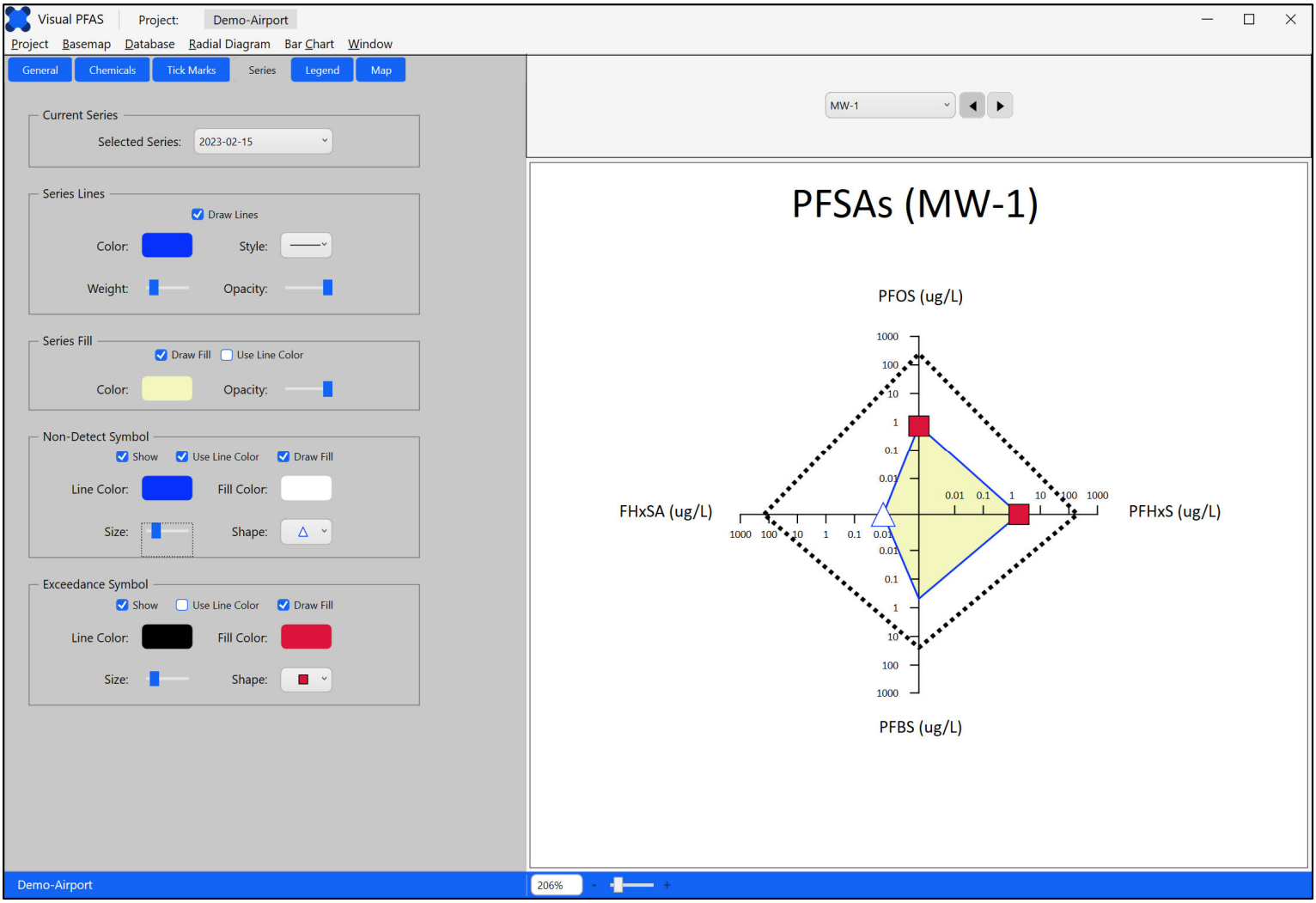
After updating the series line color, you will see that the series fill and symbol line colors will automatically change to the series line color. That's because the default is to have these colors be the same as the series line color – see the **Use Line Color** checkbox for each of these properties.

For the tutorial, change the series fill and symbol properties as follows:

i) Change the series fill to a light yellow color. Once the series fill color has been changed, the **Draw Fill** checkbox will automatically be toggled on. You can turn off the series fill by toggling **Draw Fill** off.

ii) Change the non-detect symbol to a triangle, and increase the size as shown below.

iii) Change the exceedance line color to black, change the fill color to red, and increase the size as shown below.

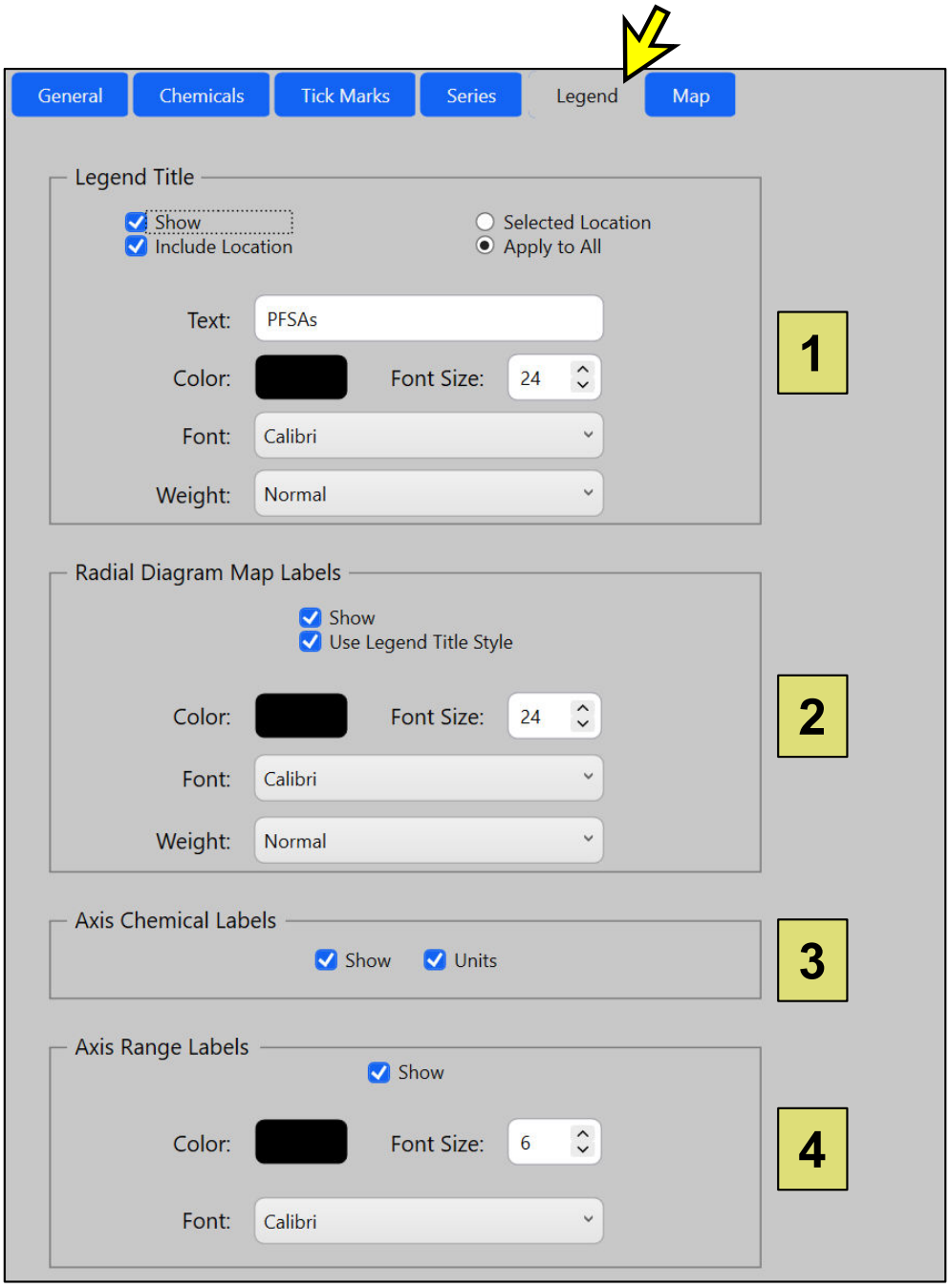


4.6 Legend Properties

Click on the **Legend** tab to view legend properties related to:

1. Legend title shown above the radial diagram;
2. Radial diagram map labels (i.e., location names) that are optionally shown above each well radial diagram when radial diagrams are overlaid on the project basemap;
3. Axis chemical labels on the legend; and
4. Axis range labels.

Try changing various legend properties to see how the plot is updated.

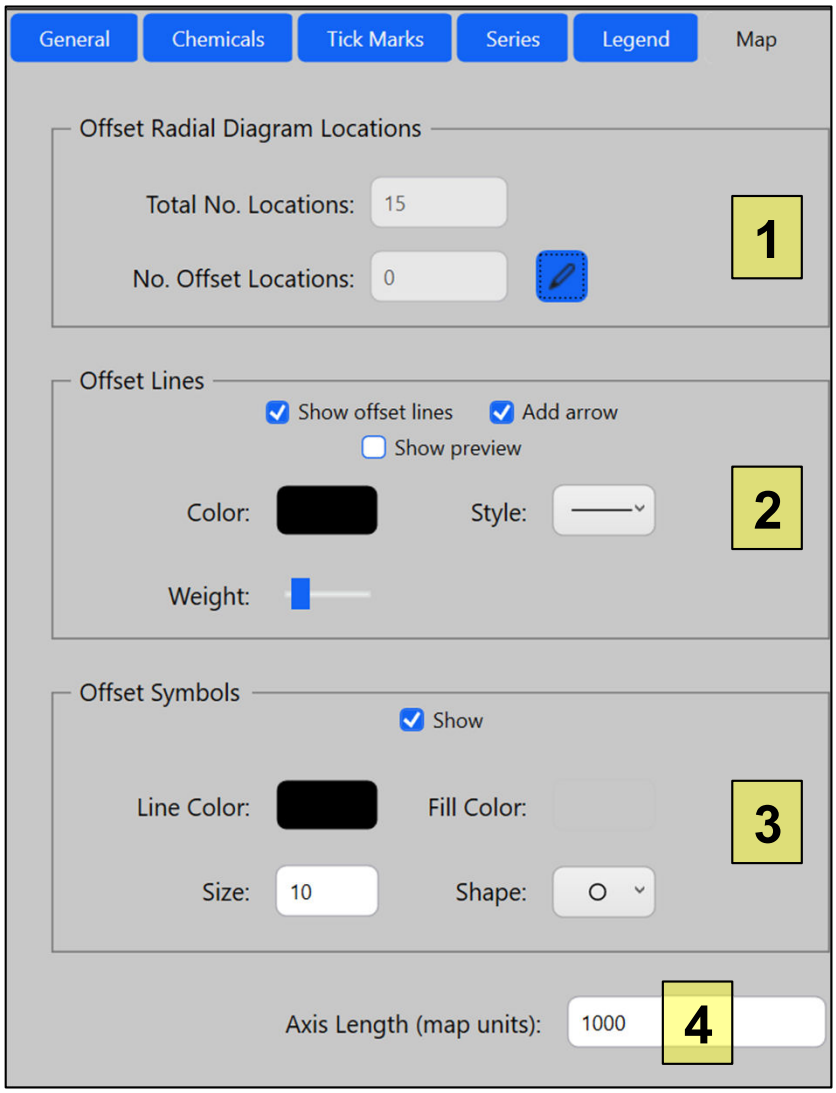


4.7 Map Properties

Click on the **Map** tab to view map properties related to:

1. Offset radial diagrams from the original locations, to avoid overlapping of radial diagrams at locations that are adjacent to each other. (An example of this process is provided later in this tutorial.)
2. Offset lines (or arrows) that are optionally shown between the offset radial diagram, and the original location.
3. Offset symbols which are plotted to show the original location(s) that have been offset to avoid overlap with adjacent locations.
    - The symbol size is in map units. If offset symbols do not appear to be shown on the basemap, it may be that this size is too small. The size should reflect the symbol size in map units (e.g., feet or meters).

4. Axis length in map units (e.g., feet or meters). This will govern the size of the radial diagram axes on the map. **Change the length to 1000 in the textbox at "4" below.**



Note: Determining the final axis lengths will depend on the distance between locations where radial diagrams are plotted. For example, if two locations are situated 100 ft apart, then axis lengths of 50 ft or less will ensure that these radial diagrams will not overlap.

It will typically take a few iterations to get the sizes adjusted to a preferred level for axis lengths and offset symbol sizes.

The series symbols are proportional to the axis length, so increasing the axis length in a radial diagram will increase the series symbol sizeson the map automatically.

All radial diagram axes have a uniform length.

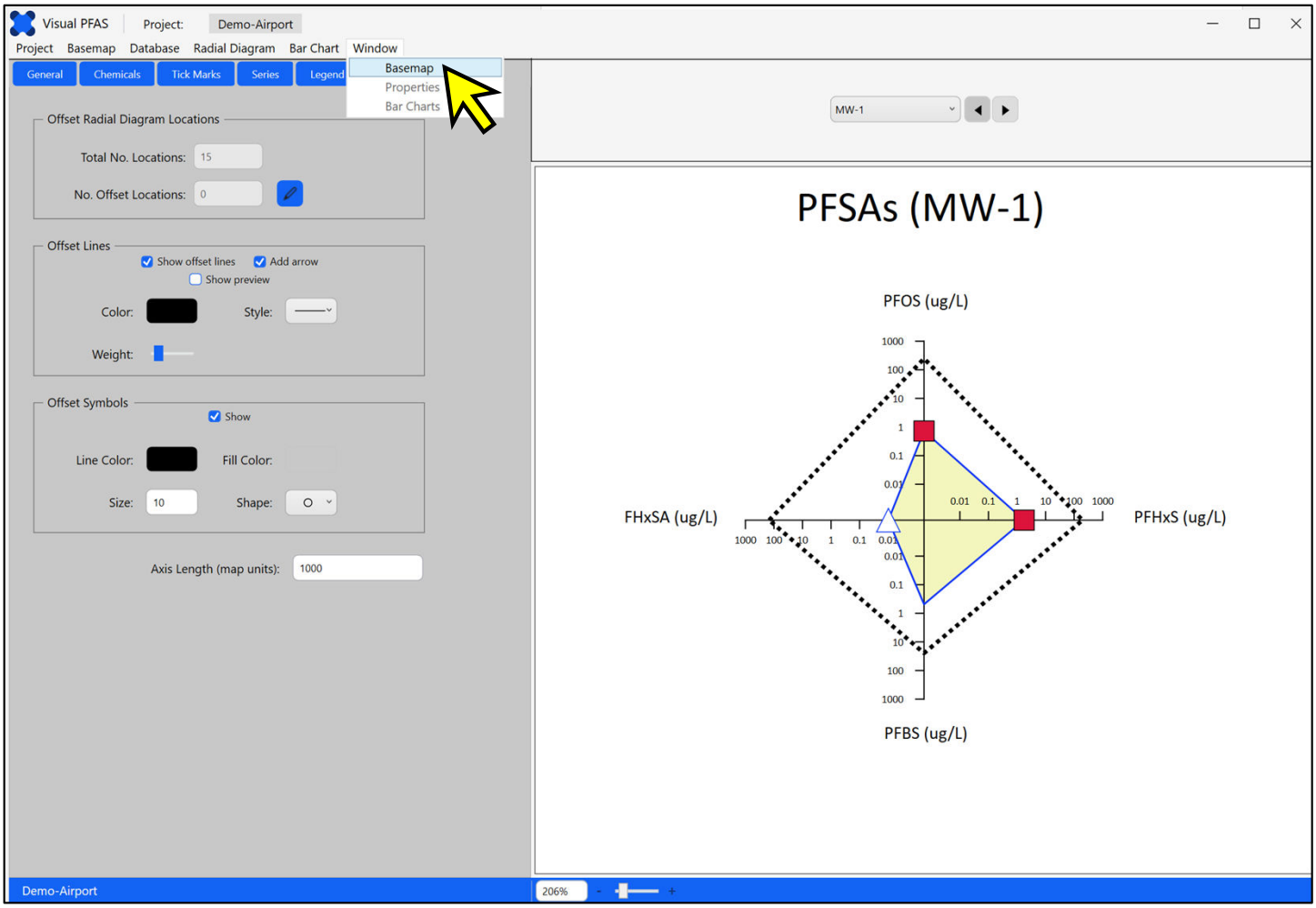
4.8 Iterating Between the Basemap and Radial Diagram Properties

The next step is to overlay the radial diagrams on the site basemap. The typical process is to move back-and-forth between viewing the radial diagrams on the basemap, and then adjusting various radial diagram properties (e.g., series line weights, fill colors, axis lengths, radial diagram location label font size, etc.)

First save the radial diagram properties by selecting **Radial Diagram** from the top menu bar and clicking on **Save**.

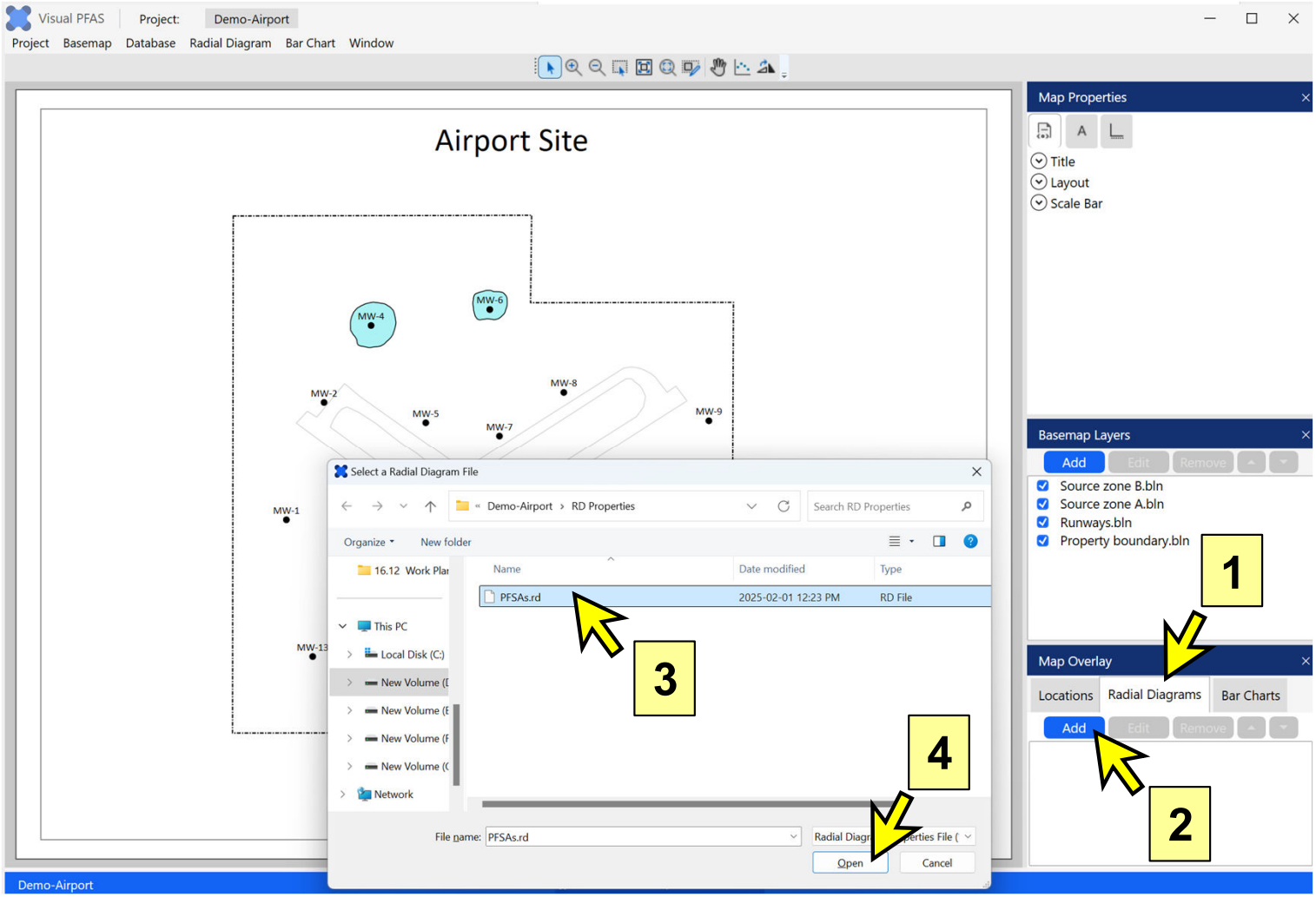
To switch between the **Basemap** and radial diagram **Properties** options, use the **Window** option in the top menu bar send click on **Basemap** to return to the site basemap window (see arrow in image below). This is where you can overlay the radial diagrams on the basemap.

Note: Auto-save is used to save radial diagram properties on a regular basis. Still, it's good practice to use the menu Save option periodically to ensure that your changes are saved. When Visual PFAS™ is closed and then opened again, the software will remember which radial diagram properties file was open last, and will automatically open that properties file again, as well as the site basemap.

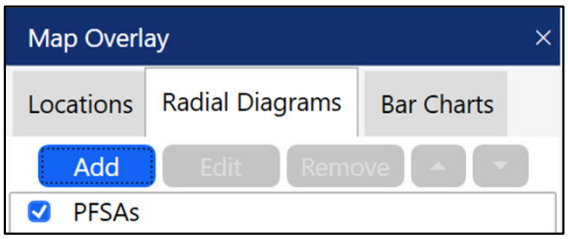


The map overlay options at the bottom right is where you can add radial diagrams as an overlay layer on the basemap. Follow these steps which correspond to the numeric labels below, to plot the radial diagrams:

1. Click on the **Radial Diagrams** tab in **Map Overlay**. At first no radial diagram maps have been added as layers so none will be shown.
2. Click the **Add** button to add a layer with radial diagrams.
3. A pop-up window will appear where you can select the *PFSAs.rd* radial diagram properties file to add as a layer. Select the *PFSAs.rd* file that you just finished saving (see "3"). Visual PFAS™ uses the "RD Properties" sub-folder under the project folder as the default for where these radial diagram properties files are saved.
4. Click the **Open** button to add this radial diagram map as another layer in the basemap.

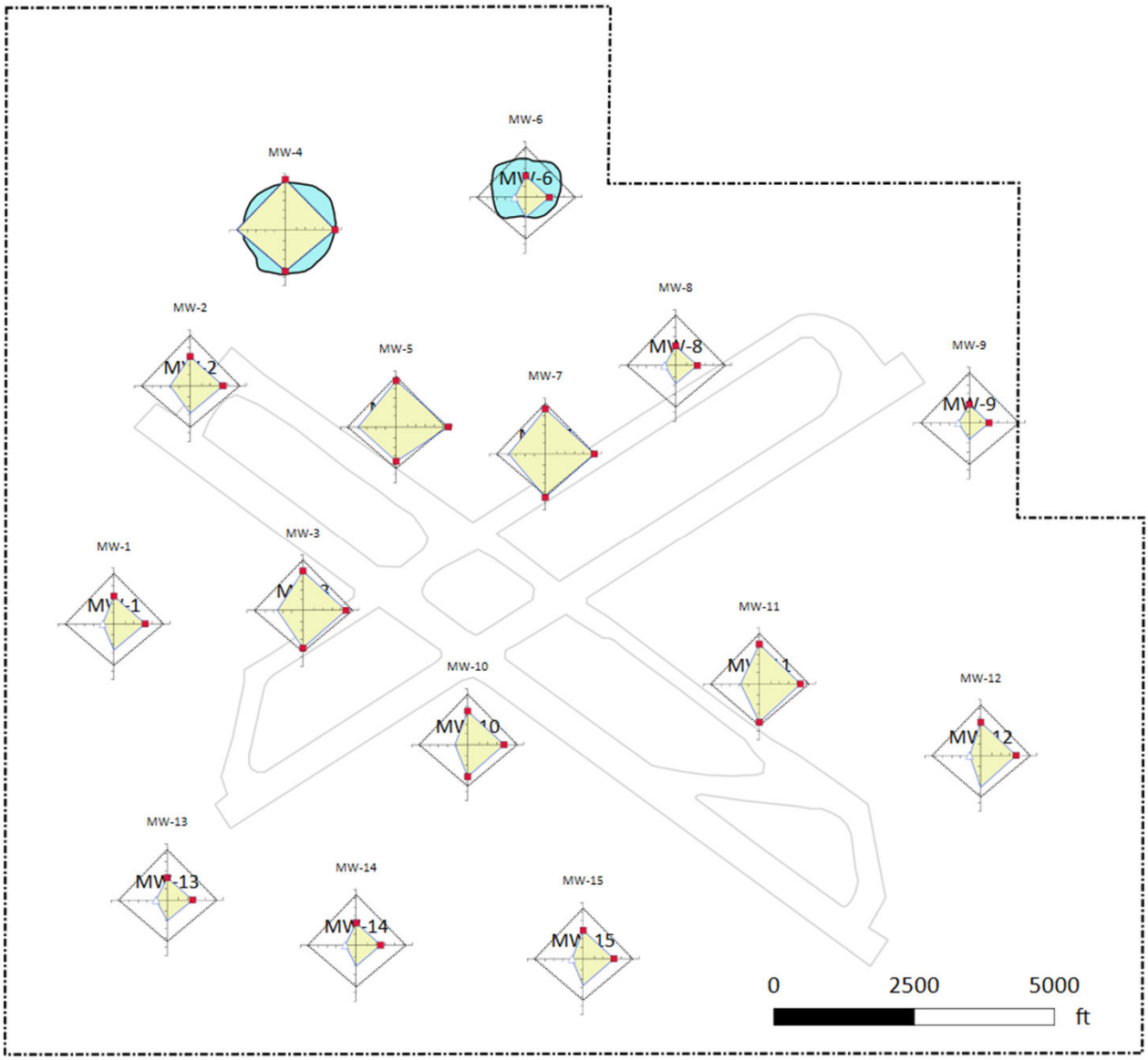


After adding the PFSAs radial diagrams, your Map Overlay window should look like the one on the right. The checkbox is used to show or hide a radial diagram overlay or layer.



You can add multiple radial diagram layers, and either show all at the same time or view one at a time. This allows you to prepare different types of radial diagrams for different well locations if that helps with a site evaluation.

Your radial diagram map should look like the one below after adding this layer to the basemap. You can see that there's a lot of space between radial diagrams, so we can increase the axis length to make the radial diagrams larger. This will help you to better visualize trends at and between wells.



Fortunately, it's a simple matter to edit the axis length without having to go back to the radial diagram properties window. There is an edit feature that allows you to change the axis length while in this basemap window. (All radial diagram axes have a uniform length which is based on map units like feet or meters.)

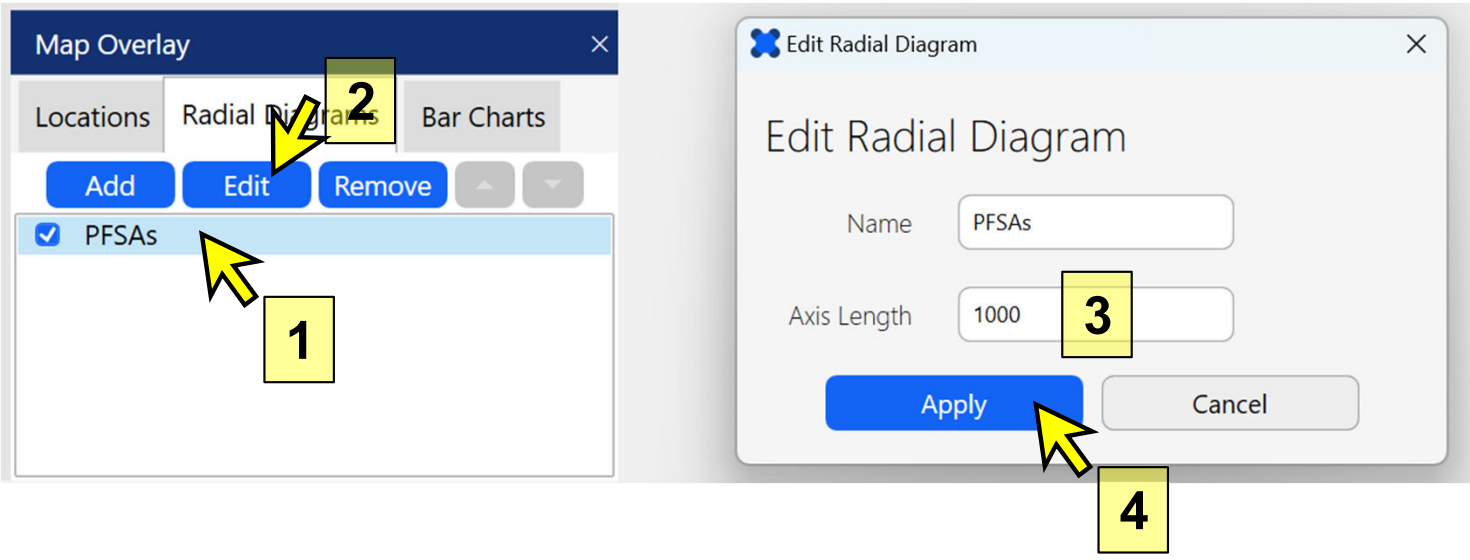
First, click on the line where the *PFSAs* layer is shown (see "1" below) in the **Map Overlay** section. Clicking on this row will cause the row to be highlighted in light blue, meaning you have selected this layer to be the current layer.

Now that a radial diagram layer has been selected, the **Edit** button will change to blue meaning that it is now enabled so you can make changes to the highlighted layer.

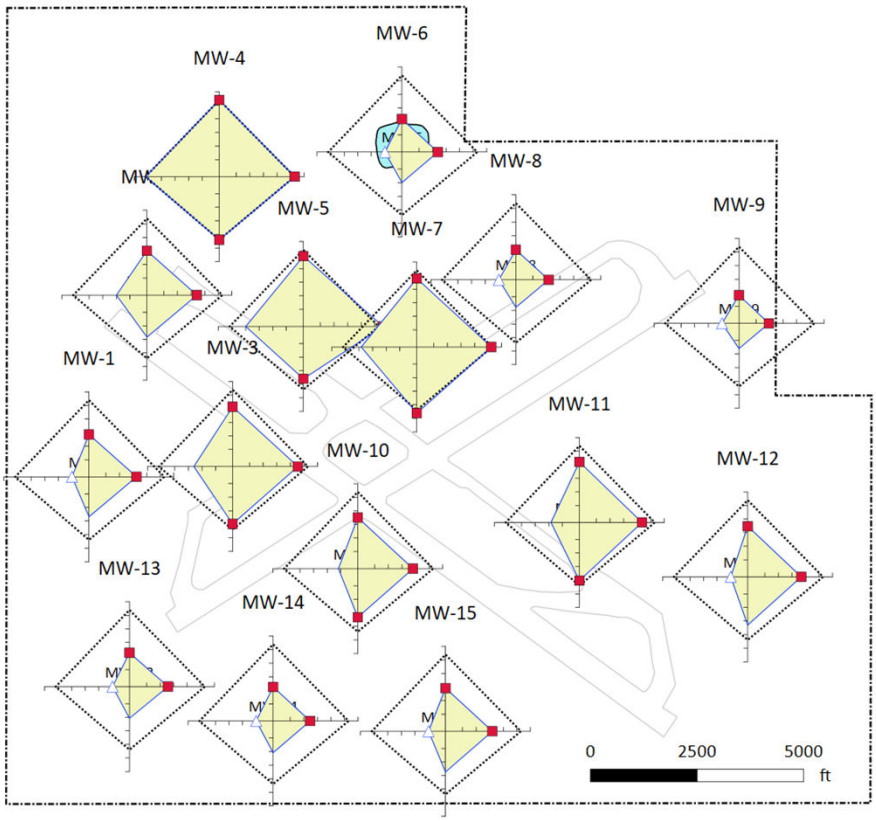
Click the edit button (see "2" below). An **Edit Radial Diagram** dialog box will pop-up. You have the option of changing the name of the layer that's shown. (The radial diagram layer name does not need to be the same as the radial diagram properties filename.)

You can also change the axis length. For this tutorial, change the Axis Length from 1000 to 2000 (see "3" below), and then click the Apply button to register this change (see "4" below).

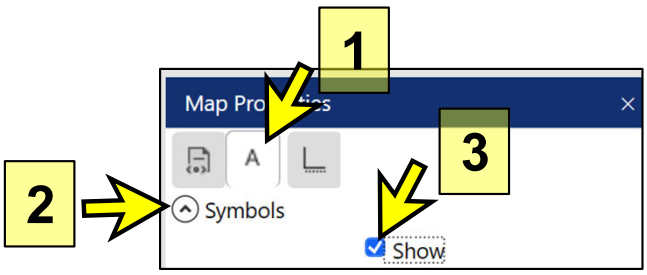
The radial diagram map will now be redrawn using this longer axis length of 2000 ft.



The radial diagrams are now easier to interpret because each diagram is twice the size of the original version (see image below). This makes it easier to count the number of tick marks (i.e., number of orders of magnitude) between the reference series and the monitoring event series at different well locations. This process allows you to identify order of magnitude changes between the source areas and downgradient wells along the flowpath, or cross-gradient from the main flow paths.



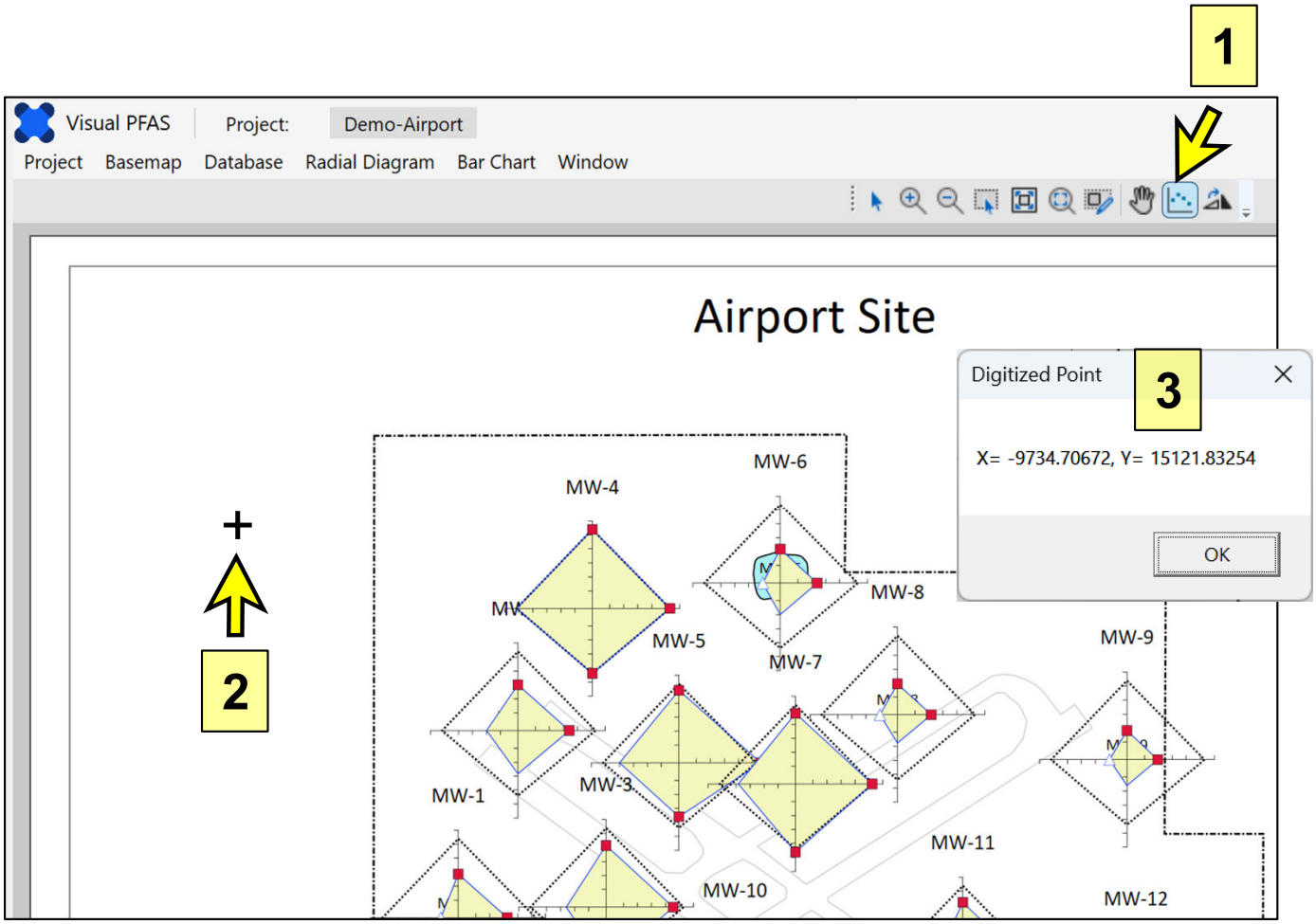
If you look closely at the image above, you'll see that the original basemap location symbols and labels are still shown as a layer below the radial diagrams. (see p. 4.26 for the basemap location symbols and labels.) Since we don't need this underlying locations layer when the radial diagrams are shown, you can turn off the location symbols in the Map Properties section (top-right of the basemap window) by following the steps shown in the image below.



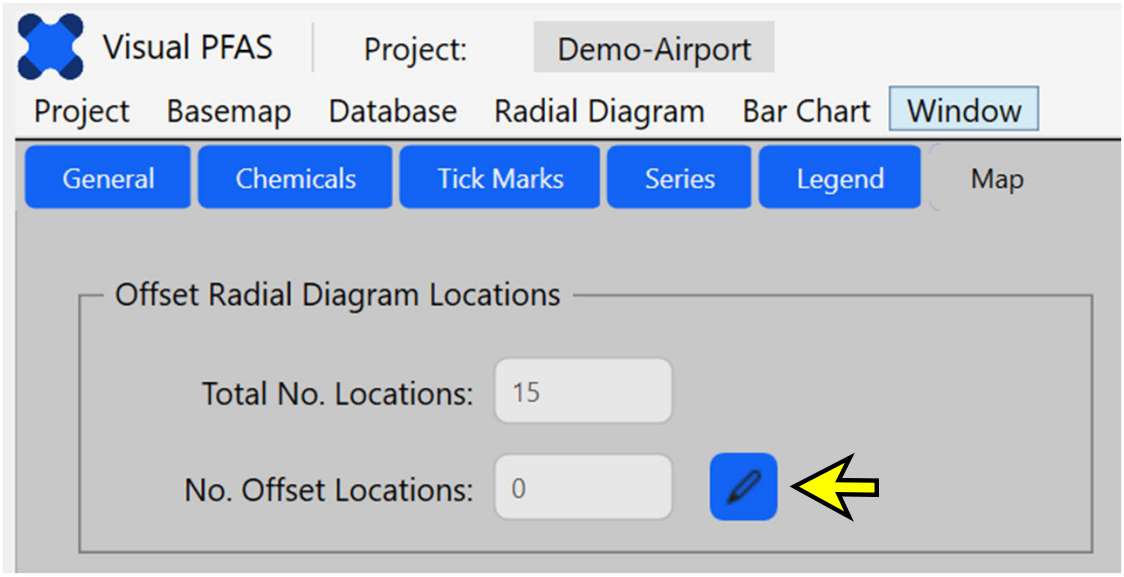
1. Click the A tab for location symbols.
2. Click the Symbols arrow to show related options.
3. Click the Show checkbox to toggle off symbols. This will hide the location symbols and labels.

Inspection of the radial diagram map on the previous page indicates that there is a small amount of overlap between radial diagrams for monitoring wells MW-5 and MW-7. To offset the MW-5 radial diagram to mitigate this overlap:

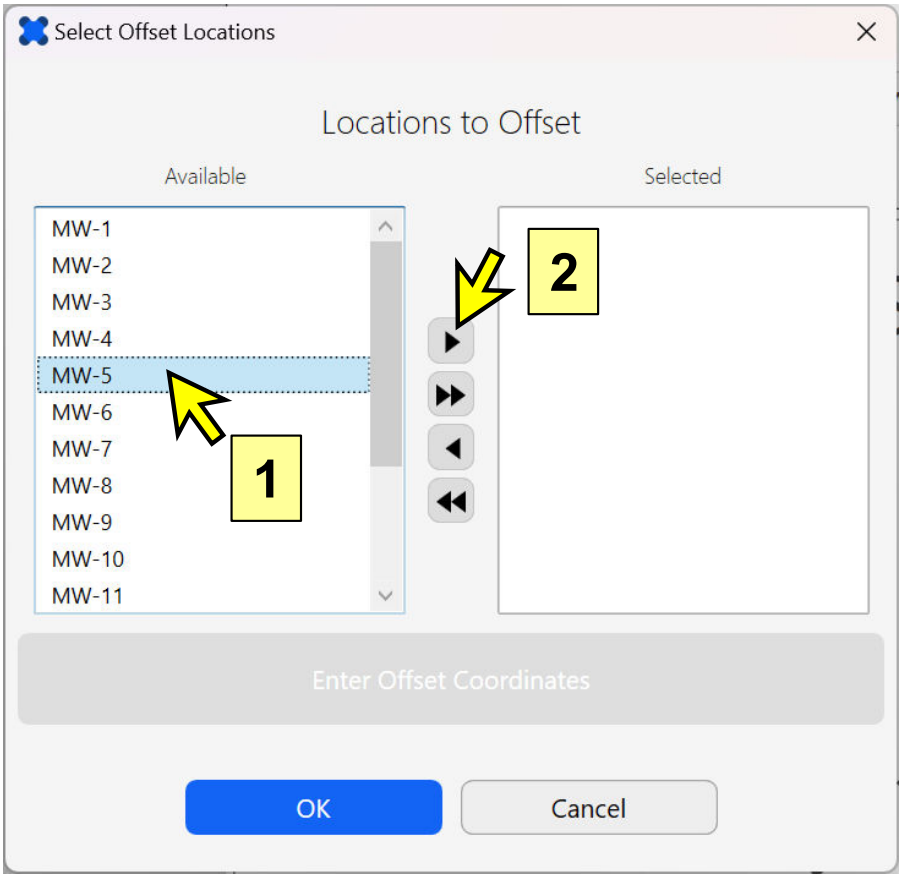
1. Click the **Digitize icon** in the top basemap menu bar (see "1" below). The cursor will change to a "+" symbol.
2. Move the cursor to the location shown northwest of MW-5 and click once to register the location – this will digitize the easting, northing (x,y) coordinates (see "2" below).
3. After clicking at the digitized location, the **Digitized Point** dialog box will pop-up to show the digitized coordinates for that point (see "3" below). Click the **OK** button which will save these coordinates to the clipboard.
4. To offset the MW-5 radial diagram from the original well location, select the **Window → Properties** menu to return to the radial diagram properties, and click the **Map** tab in the radial diagram properties window.



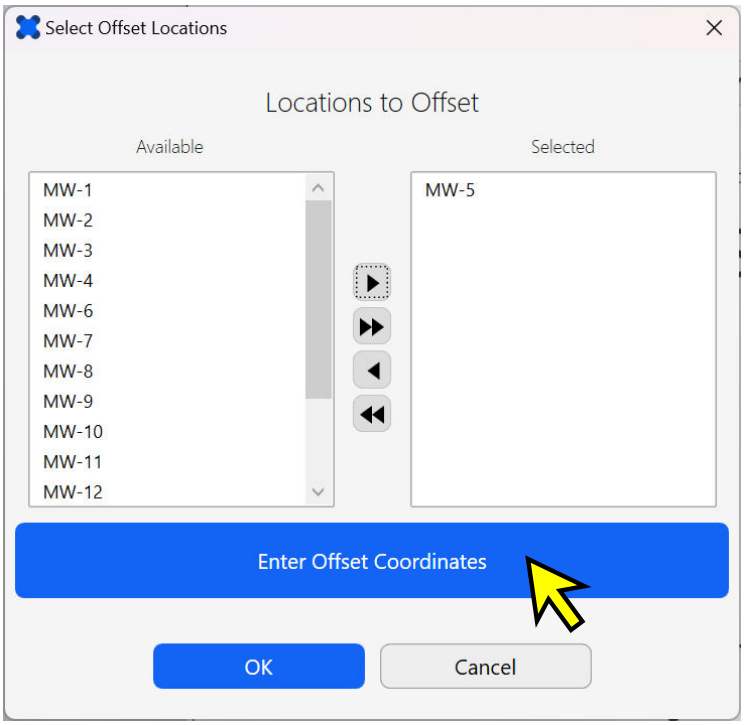
To specify which well(s) should have offset radial diagrams, click on the **Edit** icon shown for **No. Offset Locations** (see arrow below). This will open-up the **Select Offset Locations** dialog box shown at the bottom of the page.



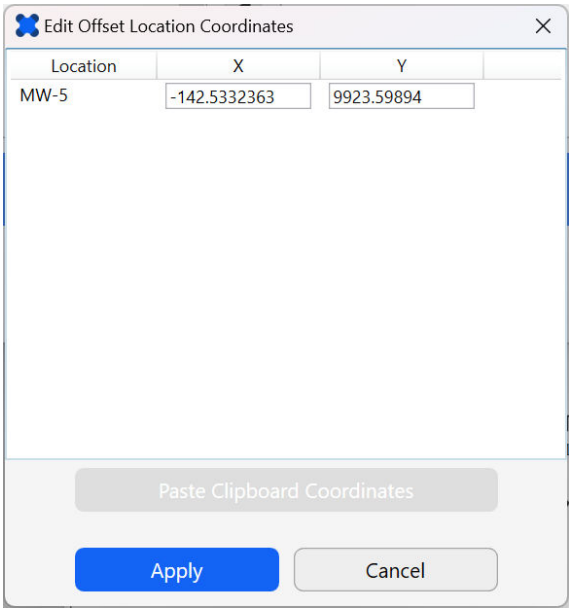
Click on MW-5 in the Available list so that it is highlighted in blue (see "1" below). Then click on the single right-arrow (see "2" below) to move this well from the Available to the Selected List.



Once MW-5 has been moved to the Selected list, the **Enter Offset Coordinates** button will change to blue meaning that it is now enabled because at least one offset location has been selected. Click the **Enter Offset Coordinates** button to open-up the dialog box where offset coordinates can be pasted or entered manually.



The Edit Offset Location Coordinates dialog box will pop-up (see image below) with at least one (or multiple) locations to have offset radial diagrams (see image below).

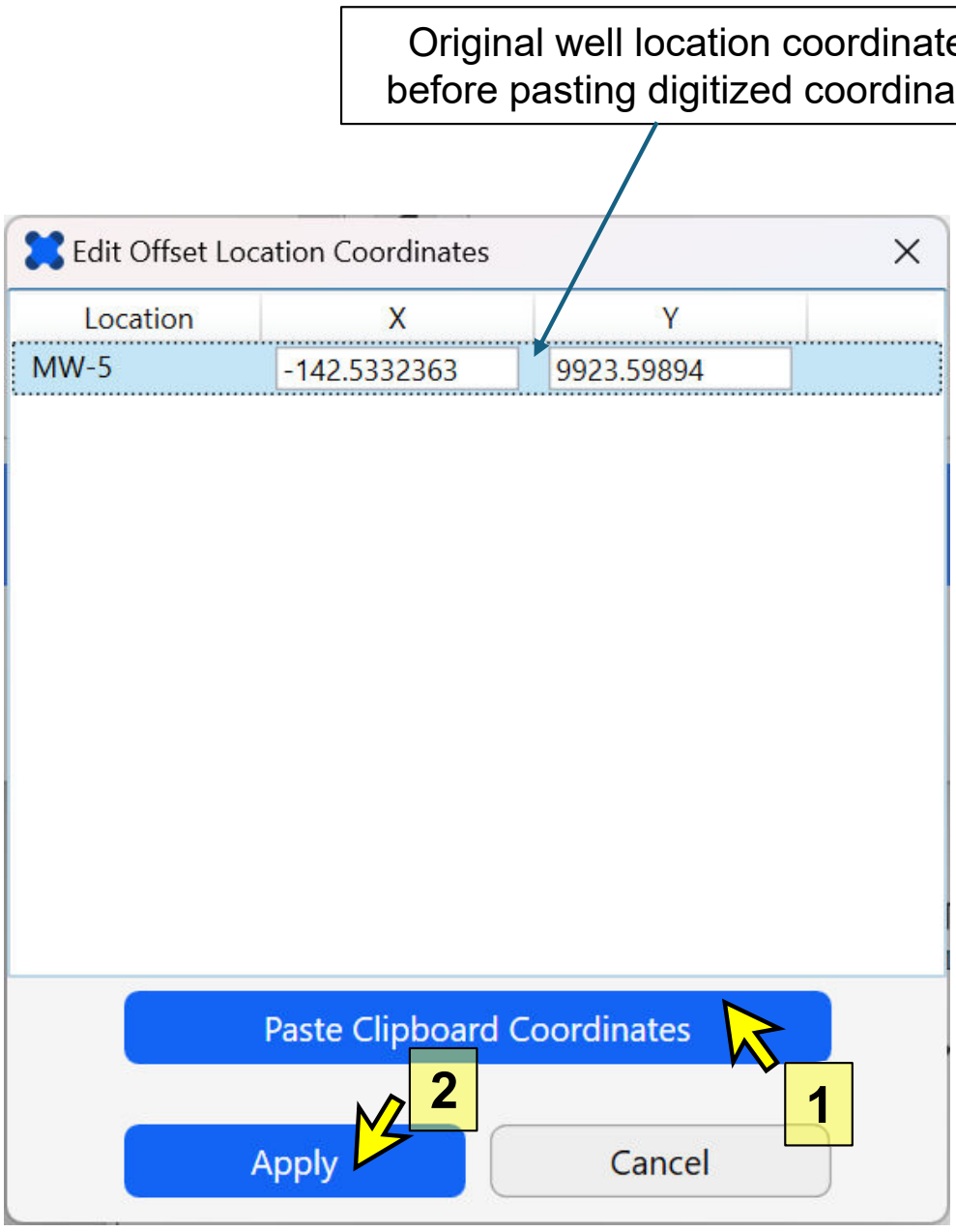


Click on the row in the table with the MW-5 location so that this row becomes highlighted in blue. Now that a row has been highlighted, the **Paste Clipboard Coordinates** button will change to blue meaning that it is now enabled.

The image below shows the original well location coordinates for MW-5 (x=-142.5 ft and y=9923.6 ft). After pressing the **Paste Clipboard Coordinates** button (see "1" below), the x and y coordinates will automatically be changed to the digitized point coordinates from the basemap. (Our digitized point coordinates are shown in the image on page 4.30 – see "3" label in this image.)

After the coordinates have been pasted, click the Apply button to register this new offset location for the MW-5 radial diagram (see "2" below).

The click the OK button on the Select Offset Locations window to save your changes.

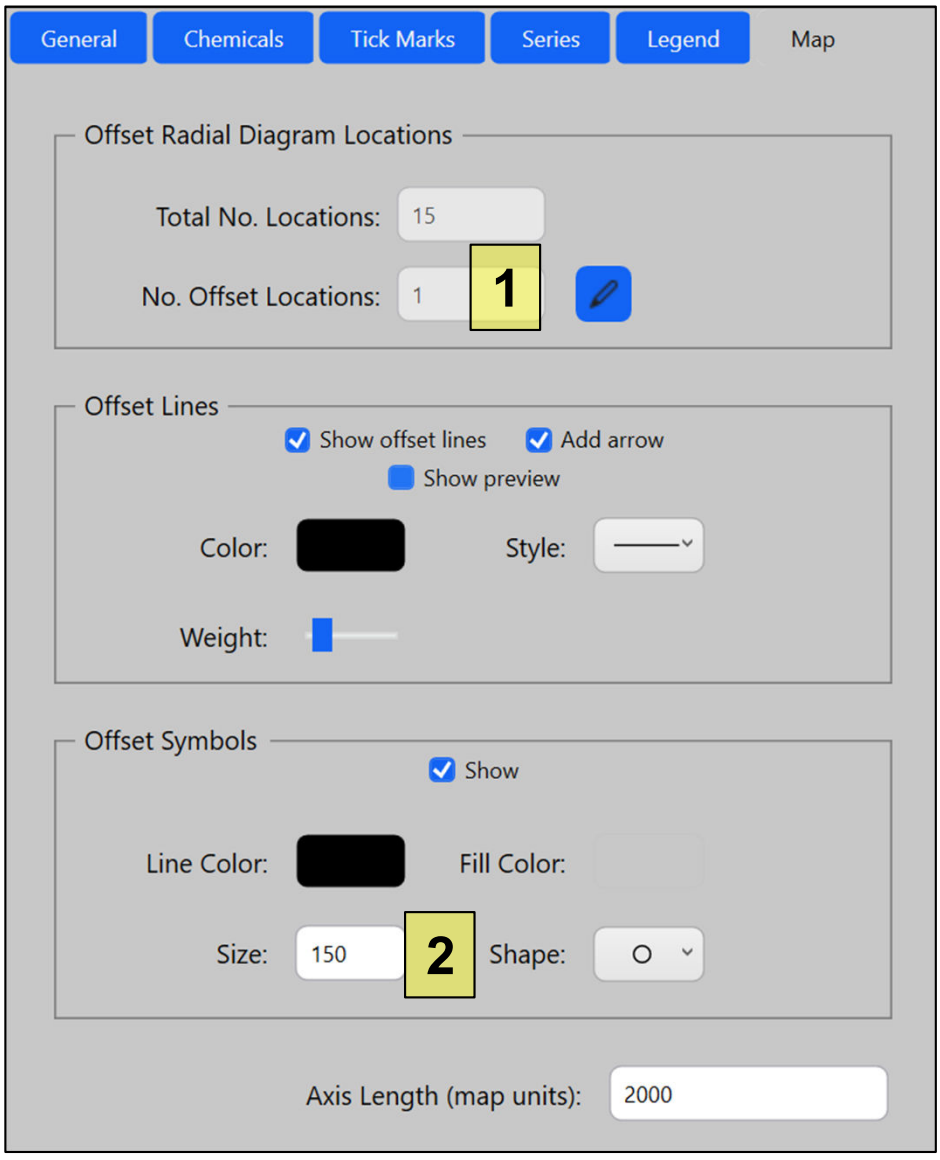


Note: An alternative to using the copy-paste method for entering offset location coordinates, is to simply write down the x,y coordinates after digitizing, and then to enter these coordinates manually using the dialog box shown to the left.

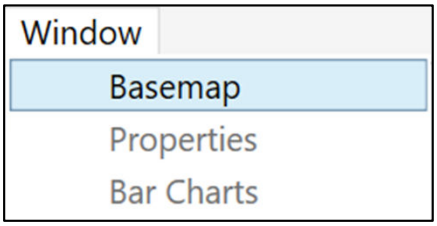
After closing the **Select Offset Locations** window, the **No. Offset Locations** will change to 1 to reflect the new offset saved for monitoring well MW-5 (see "1" below).

An optional offset symbol will be shown at the original MW-5 location (i.e., the location before the offset), and an optional line or arrow will be shown between the offset radial diagram and this original location. The respective checkboxes can turn these on/off.

The default symbol size is 10 map units, which will be too small to see for the basemap in this example tutorial. Change the symbol size to 150 map units (i.e., ft) as shown in "2" below.

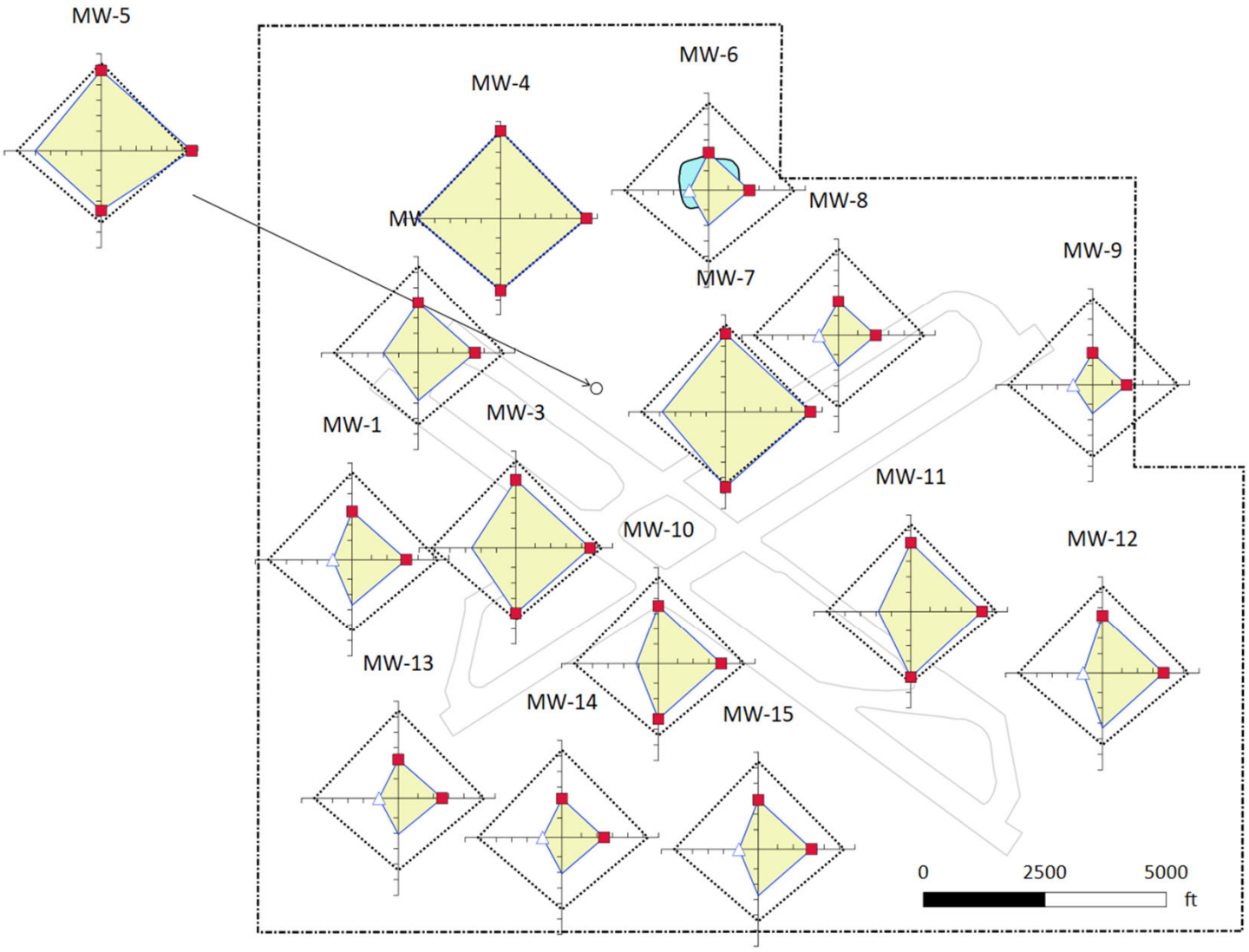


Then using the **Window** option in the top menu bar, select **Basemap** to return to the basemap to view the updated radial diagram map.



The updated radial diagram map, with the MW-5 offset radial diagram, is shown below. You can easily re-digitize the MW-5 location if you want to move it to a different location and then re-paste the digitized offset coordinates using the same steps discussed previously.

> **Note:** The offset line arrowhead size is proportional to the offset symbol size.

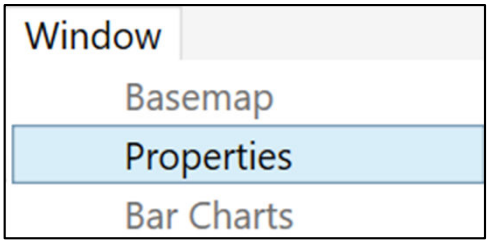


Let's make one more change to illustrate another option for visualizing these radial diagrams as a layer on the site basemap.

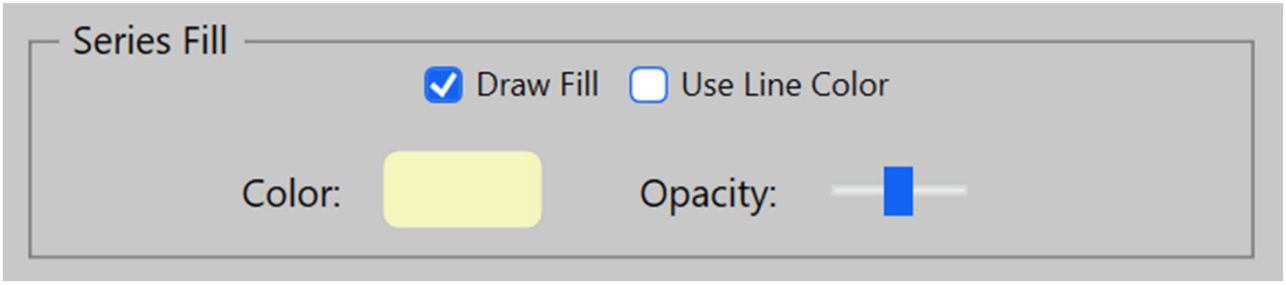
Using a solid color (i.e., 100% opacity or 0% transparency), the radial diagram for monitoring well MW-4 overlies the Source A basemap layer which isn't visible. And Source B is just shown around the edges of the filled monitoring even series for MW-6.

The next step will be to assign a 50% opacity/transparency to the event series fill so that underlying basemap ayers can be seen.

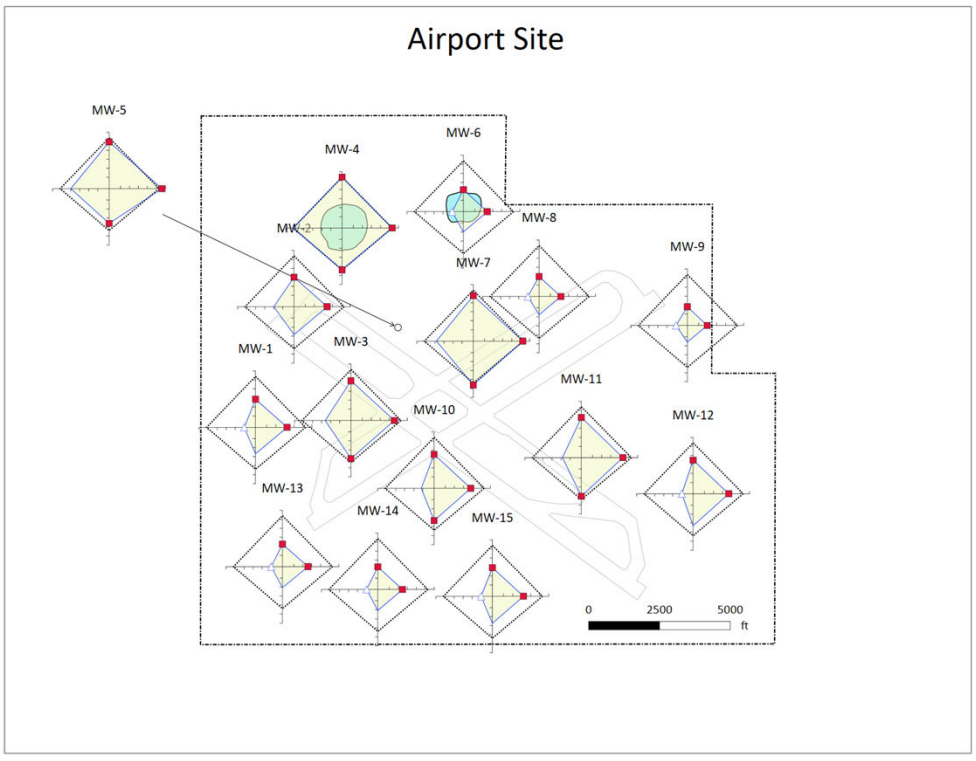
Using the **Window** option in the top menu bar, select **Properties** to return to the radial diagram properties, and click on the **Series** tab.



Make sure that the *2023-02-15* monitoring event series is selected as the current series in the top dropdown list. Then change the **Opacity** for the series fill to be at about a 50% level as shown in the image below. This will increase the transparency of the series fill, so that basemap layers under the radial diagram layer can be seen.



Then use the **Window → Basemap** option to return to the basemap window and the updated radial diagrams (see below). You can now see the full outlines for Sources A and B below the radial diagrams for monitoring wells MW-4 and MW-6, respectively.



Note: Using exceedance symbols allows you to clearly identify where PFAS of Concern are exceeding cleanup criteria across a site.

This tutorial demonstrates that it is a relatively simple process to create a radial diagram map. Some iteration will probably be needed to update properties like series line and fill colors, symbol properties, location labels, opacity, and basemap layer properties.

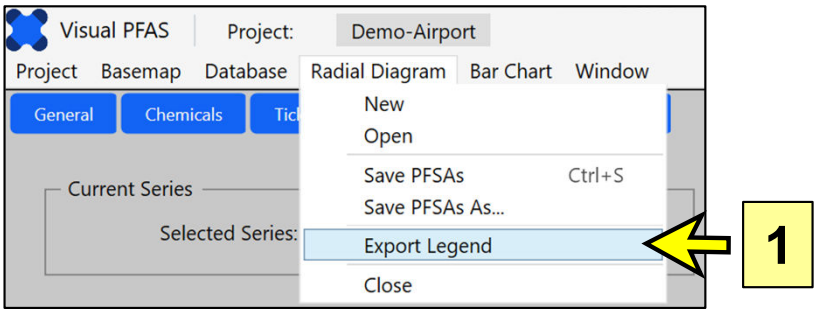
4.9 Exporting Radial Diagram Legends and Maps

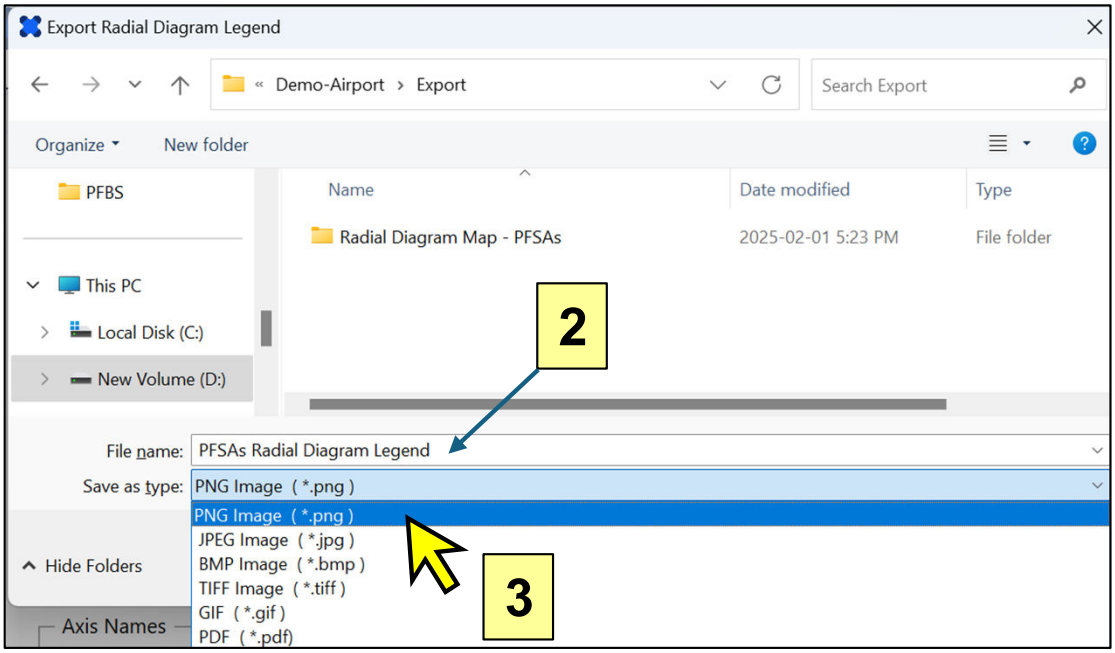
Once the radial diagram map has been completed, the final product may be exported in several types of formats:

1. The radial diagram legend may be exported as a pdf file, or as one of five possible image files: png, jpeg, bmp, tiff, or gif format.
2. A radial diagram map may also be exported as a pdf file or the same five types of image files. Alternatively, a radial diagram map including symbols may be exported in native format so that these files may be opened in GIS or CAD (dxf format), or Surfer (bln format). Exceedance, non-detect, offset symbols are saved as x,y text (dat) files which may be posted in GIS, CAD, or Surfer.

This allows you to create final report figures or presentations using Visual PFAS™ figures directly, or to quickly re-create these figures in GIS, CAD, or Surfer using the exported polyline, polygon, and symbol posting files. This allows you to easily iterate through different figure versions using Visual PFAS™, and then to use more sophisticated software for making final report figures in your company template.

To export the radial diagram legend as a pdf or image format, go to the radial diagram **Properties** window and select the **Export Legend** menu option (see "1") as shown below. Then, then identify the folder, filename (see "2"), and file type for the export (see "3" below).

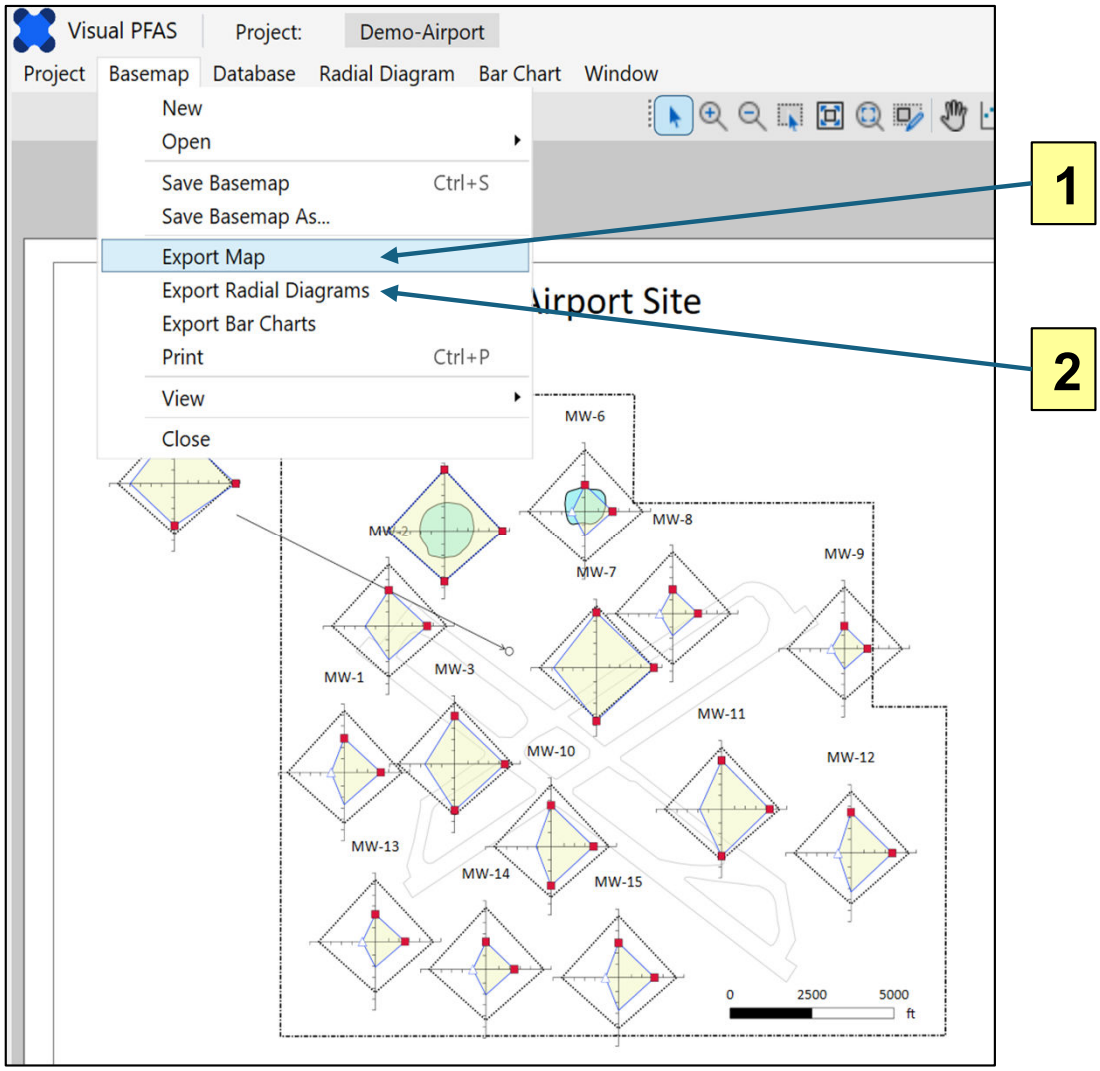




There are two options for exporting the basemap: i) as a pdf or image file that includes both the underlying basemap and the radial diagrams; or ii) as separate polyline/polygon (dxf or bln) files, and symbol x,y coordinate (dat) files so that these figures can be re-created in software typically used to make final report figures (e.g., GIS, CAD, or Surfer).

To export the combined basemap and radial diagrams as a pdf or image file, select the **Export Map** option under the **Basemap** menu (see "1" below). The five image file type options are the same as those shown for the radial diagram legend on the previous page. Exporting the map as a pdf or image file will present the radial diagram map (including all basemap layers, the basemap title, and scale bar or axes) as the map is shown on the page in the basemap window. Image files can be loaded directly into reports, or additional customization can be done using PowerPoint to create final images for inserting into a report or presentation.

Alternatively, you may export the radial diagram layer as separate files for polylines, polygons and symbols (bln/dxf for lines and polygons, and dat for symbol coordinates) which can then be imported into GIS, CAD, or Surfer for further processing as final figures. In this case, select the **Export Radial Diagrams** option in the **Basemap** menu (see "2" below).

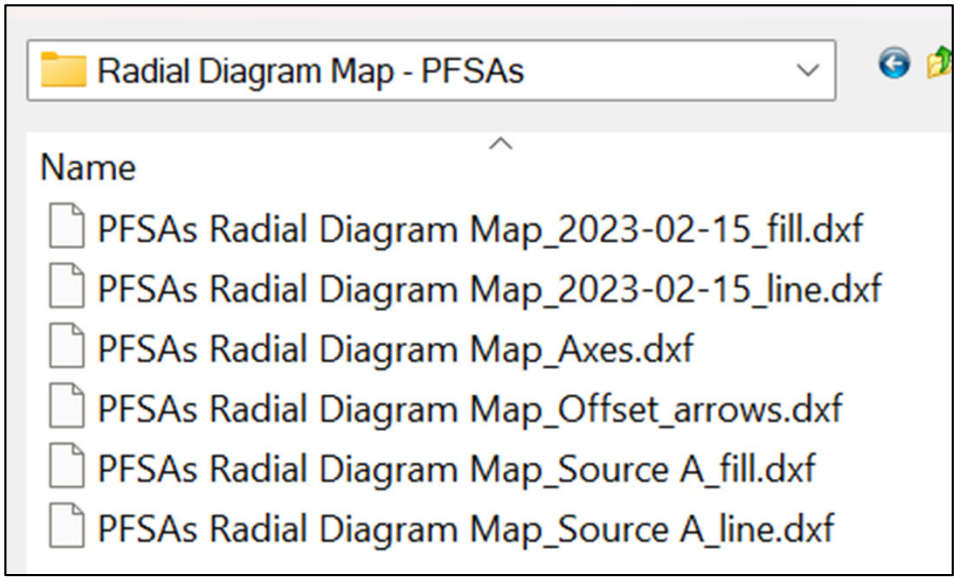


When exporting only the radial diagram layer (i.e., without the underlying basemap layers), separate files are created for: a) axis lines with tick marks; b) series lines and polygons (one set of files for each series); c) offset arrow lines that point from the offset radial diagram(s) to the original location; d) exceedance symbol coordinates; e) non-detect symbol coordinates; and offset symbol coordinates at the original location(s).

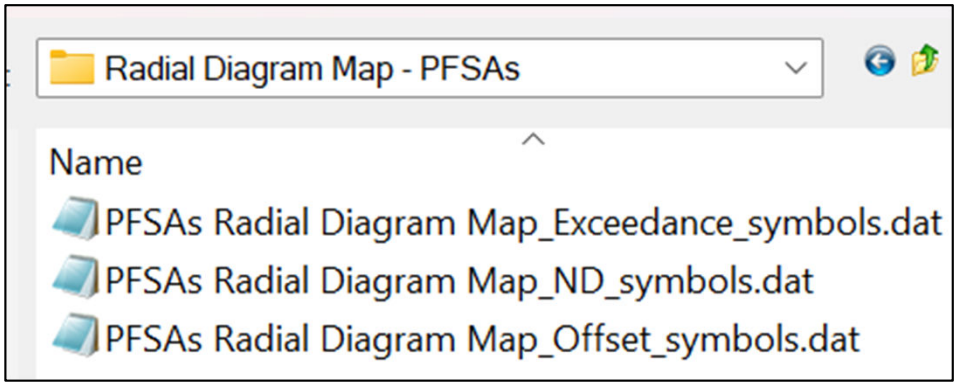
Each of these polyline/polygon (dxf or bln) and symbol dat files can then be imported into GIS, CAD, or Surfer as separate layers. Each polyline/polygon layer may be assigned distinct properties for line color, weight, and fill. The symbols may be posted at the assigned coordinates using symbol properties such as shapes, sizes, and colors that are assigned or changed in the software that is being used to process the final report figures.

Examples of polyline/polygon and symbol files created for the PFSAs radial diagram layer that was prepared as part of this tutorial are shown below. Users have the option of selecting either dxf or bln format for the polyline/polygon files.

Examples of two radial diagram figures from the Carey et al. (2025) journal paper, which documents a case study for a South Dakota Air Force Base, are shown on the next few pages. These examples demonstrate how legends may be added to radial diagram maps and how custom labels can be added using common third party graphics software.

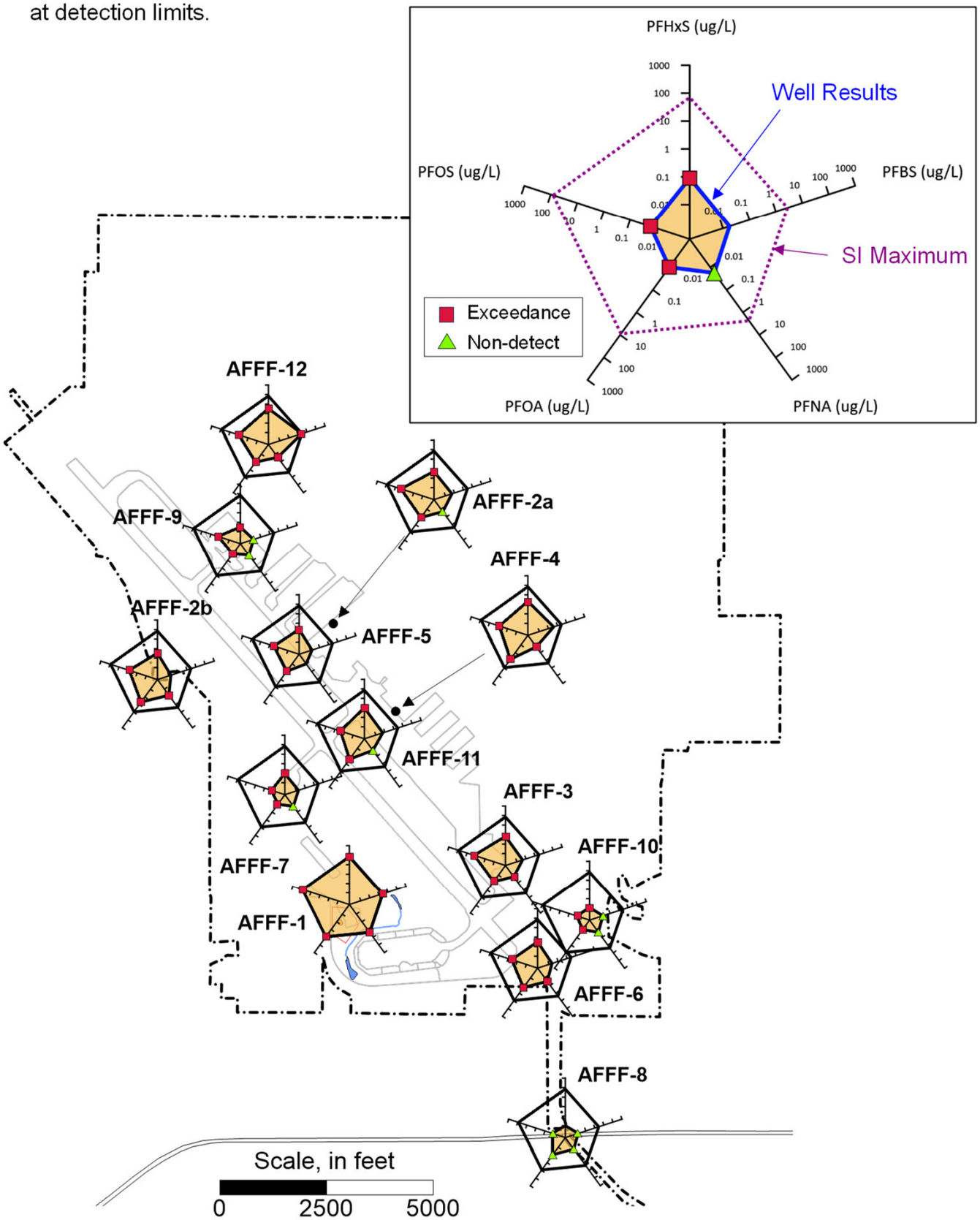


Radial diagram polyline / polygon layer files

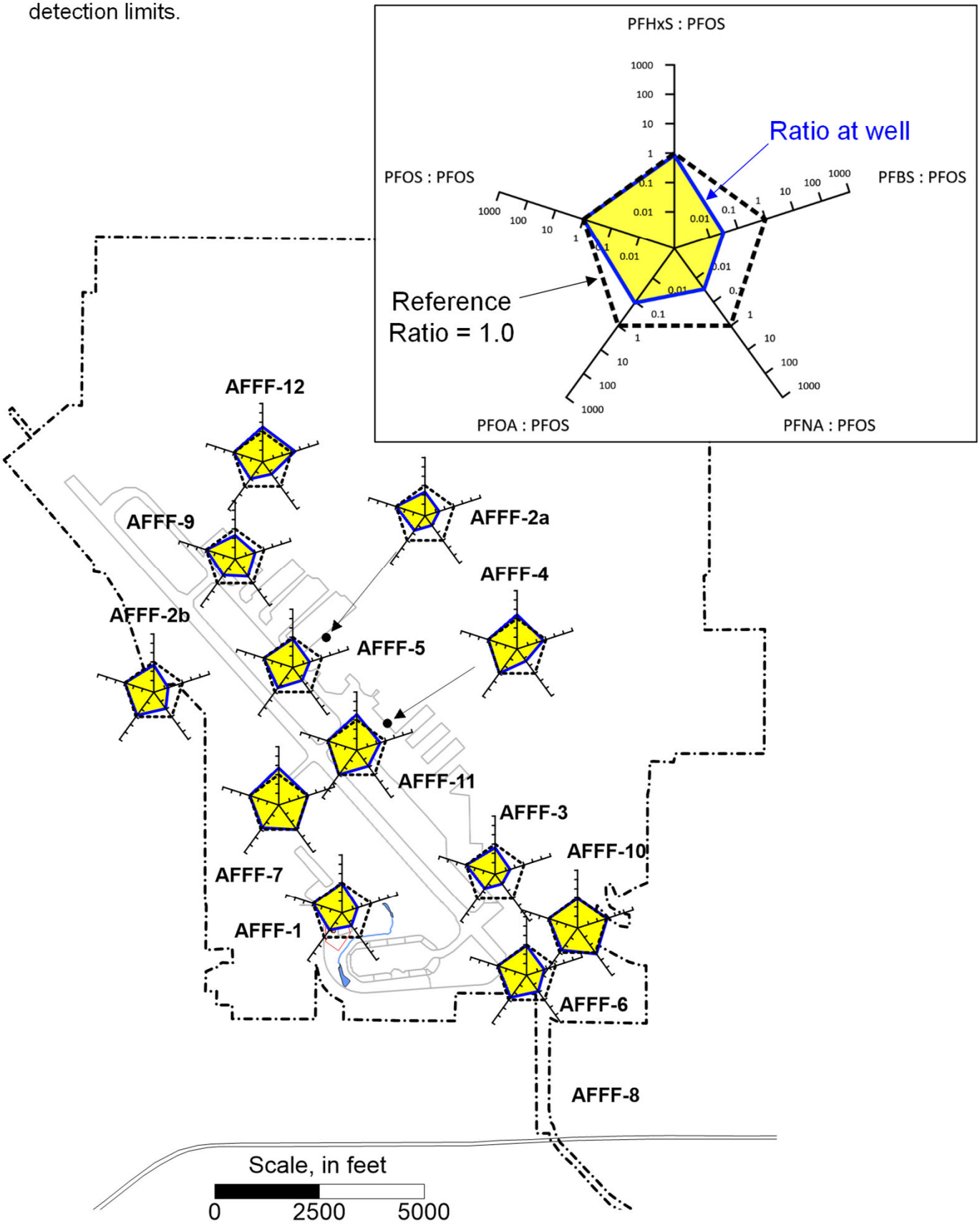


Radial diagram symbol coordinate files

Carey et al. (2025) Figure 2. PFAS of Concern (POCs) radial diagrams at AFFF source areas with PFSAs in the upper portion (PFOS, PFHxS, and PFBS) and PFCAs in the lower portion (PFNA and PFOA). Exceedance symbols are based on EPA maximum contaminant levels (MCLs), or EPA health-based water concentrations for PFBS. Non-detects are plotted at detection limits.



Carey et al. (2025) Figure 3 . PFAS of Concern (POC) radial diagrams at AFFF source areas with ratios to PFOS. PFSAs are in the upper portion (PFOS, PFHxS, and PFBS) and PFCAs are in the lower portion (PFNA and PFOA). Non-detect POC ratios are based on detection limits.



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