Rayonier Mill Off-Property Soil Dioxin Study

Technical Workshop
Port Angeles, Washington

August 3, 2011

Presentation

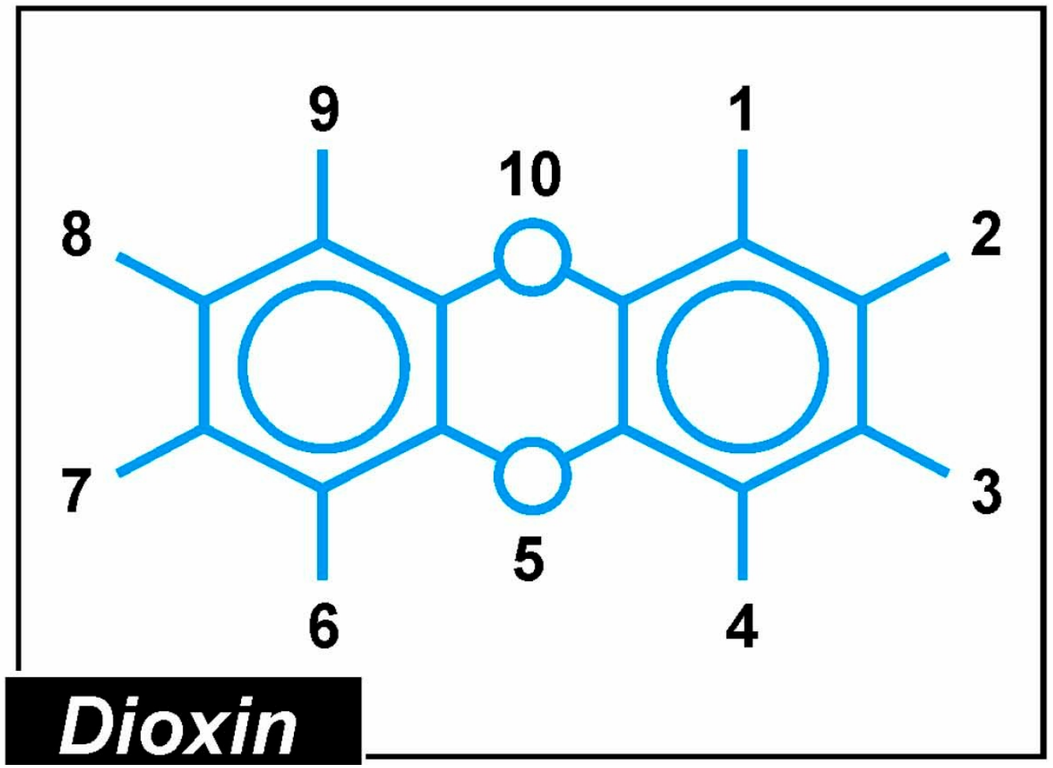
- Dioxins and Furans
- Potential Rayonier Mill Impacts: Approaches
- Study Design: Sampling
- Chemical Analyses
- Soil Dioxin/Furan Results

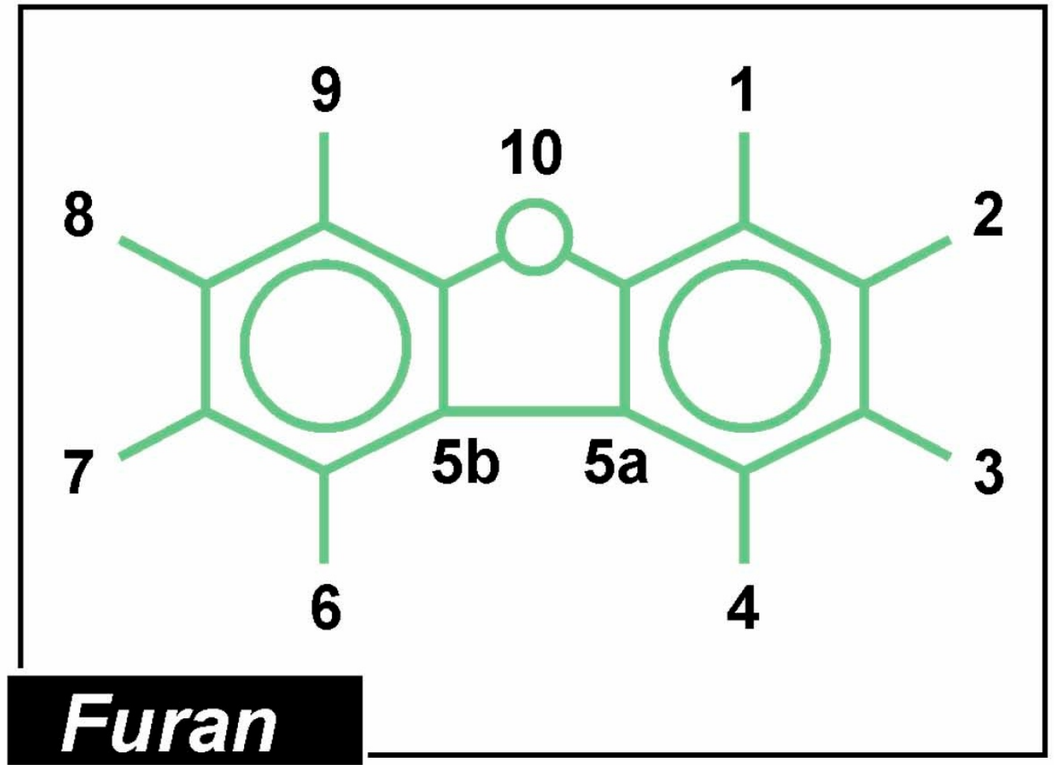
Presentation (continued)

- Interpretation of Soil Results
  - Magnitude
  - Spatial Pattern
  - Chemical Pattern
  - Mass Balance
- Chemometrics = “Unmixing”
  - Methods
  - Results and Interpretation
- Conclusions

Dioxins and Furans: Chemistry

- Double ring chemical structures
- 1 to 8 chlorines attached
- 210 forms depending on number and position of chlorines: congeners
  - 17 congeners with 2,3,7,8 chlorines of primary toxicity concern (7 dioxin, 10 furan)
- 16 homolog groups: dioxins, furans with same number of chlorines (1 to 8), different positions


9
1
10
8
2
7
3
5
6
4
Dioxin


9
1
10
8
2
7
5b
5a
3
6
4
Furan

Dioxins and Furans: TEQs

- Lab analyses = bulk congeners = ng/kg = ppt
- TEFs: scaling for relative toxicity
  - > 3,000-fold range of TEFs (1 to 0.0003)
  - Changes to set of TEF values over time
- TEQ
  - Scaling of bulk concentrations: x TEFs
  - Sum over 17 2,3,7,8 congeners = TEQ
  - Example: 86 ng/kg bulk x TEF of 0.01 = 0.86 ng TEQ/kg contribution to sample TEQ

Dioxins and Furans: TEQs (continued)

- Health risks, cleanup regulations based on TEQs not bulk concentrations
- Dioxin/furan profiles or patterns (17 congeners) can be based on bulk or TEF-scaled values
  - “TEQ profiles”

Dioxins and Furans: Sources

- Natural
  - Forest fires
  - Ball clay
- Anthropogenic
  - Spatial Scale:
    - Point sources
    - Diffuse area sources
    - Property-specific sources

Dioxins and Furans: Sources (cont.)

- Processes
  - Combustion sources
  - Effluent sources
  - Solids disposal sources
  - Chemical manufacturing sources
    - Herbicides
    - PCBs
    - PCP
- Rayonier Mill HFB emissions a known source, origin of this study

Dioxins and Furans in Soils

- Typically reflect multiple sources (mixtures)
- Urban to rural gradients in TEQs; measurable even at remote locations
  - Long range transport
  - Limited local deposition of air emissions
  - Studies of point sources show limited spatial impacts
- Congener profiles can vary with source(s)

Emissions and Impacts: Approaches

- "Forward" approach
  - Monitoring
    - Multiple stack emissions tests over operating history, conditions
    - Air quality sampling, long-term and multiple locations
    - Deposition monitoring, long-term and multiple locations
    - Soil sampling
  - Modeling: air transport and deposition, soil impacts

Emissions and Impacts: Approaches (continued)

- "Receptor-oriented" approach [this study]
  - Monitoring: soil sampling
  - Modeling
    - Multivariate mathematical "unmixing" model
    - Model interpretation
      - Site-specific information
      - Comparison source profiles and soils data sets

Study Design

- Study area
  - 4.2 sq miles, up to 3 miles from HFB stack
  - Additional upslope transect areas
- Sampling zones
- Sampling grids (variable density) in zones
- Property selection in grids
- Sample locations within properties
- Surface soils defined

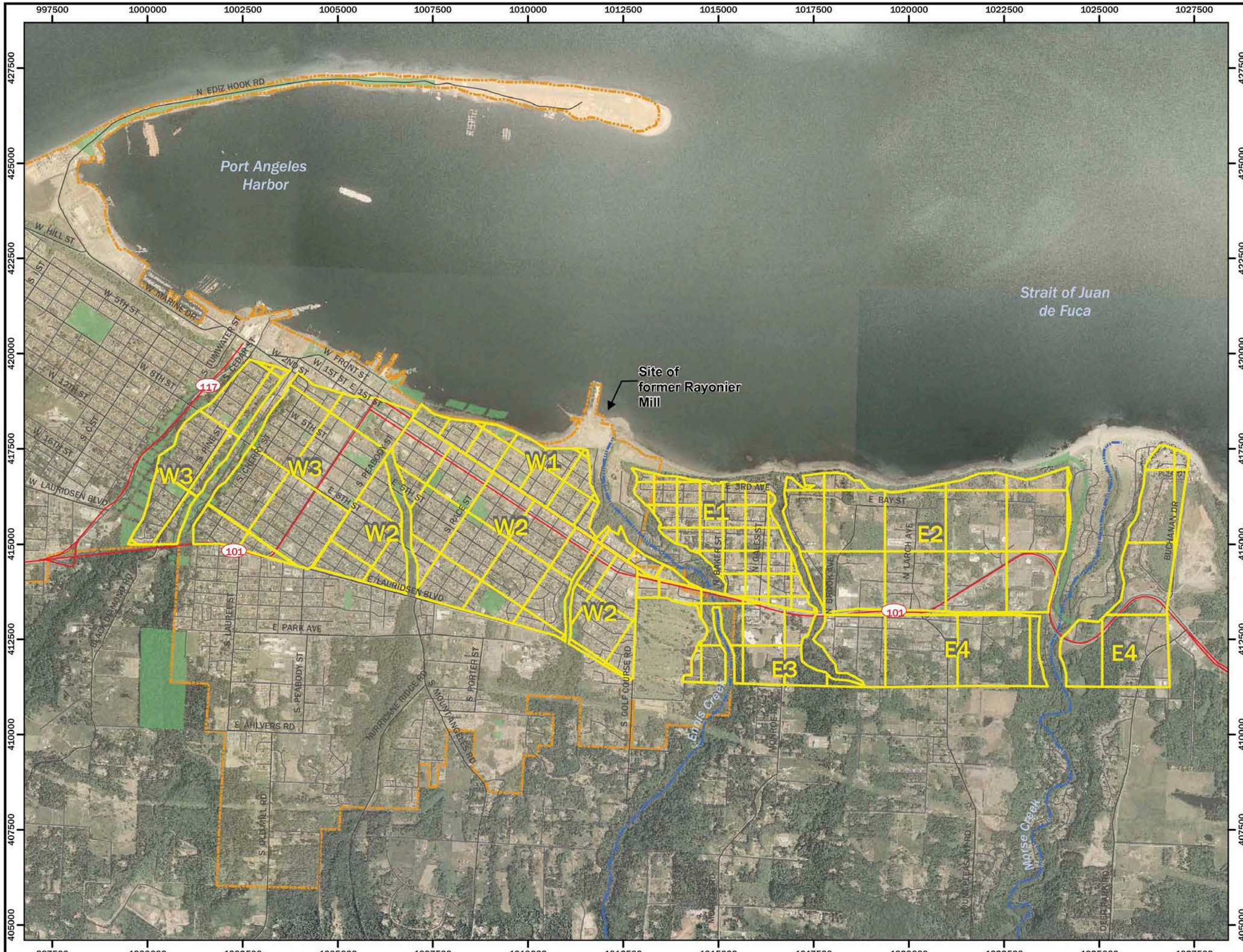


Figure 3-4
Sample Grid Spacing
Rayonier Mill Off-Property
Soil Dioxin Study
Port Angeles, WA

Legend

- Grid Cell Boundary
- River
- Highway
- Arterial or Collector Road
- Road
- Port Angeles City Limits
- Park

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HERRERA ENVIRONMENTAL CONSULTANTS

0 1,250 2,500 5,000 feet

Coordinates: Washington State Plane South
NAD 83 (feet)
Aerial: USDA, 2006

N

Produced By: GIS (JAS)
Project:
K:/Projects/06-03386-006/Projects/Study Area Grids.mxd (09/09/2008)

Figure 3-5
Generalized Upslope Transect Sampling Areas
Rayonier Mill Off-Property Soil Dioxin Study
Port Angeles, WA

Legend

- Upslope Transect Sampling Area
- Study Area Boundary
- River
- Highway
- Arterial or Collector Road
- Road

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0 2,250 4,500 9,000 feet

Coordinates: Washington State Plane South
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Aerial: USDA, 2006

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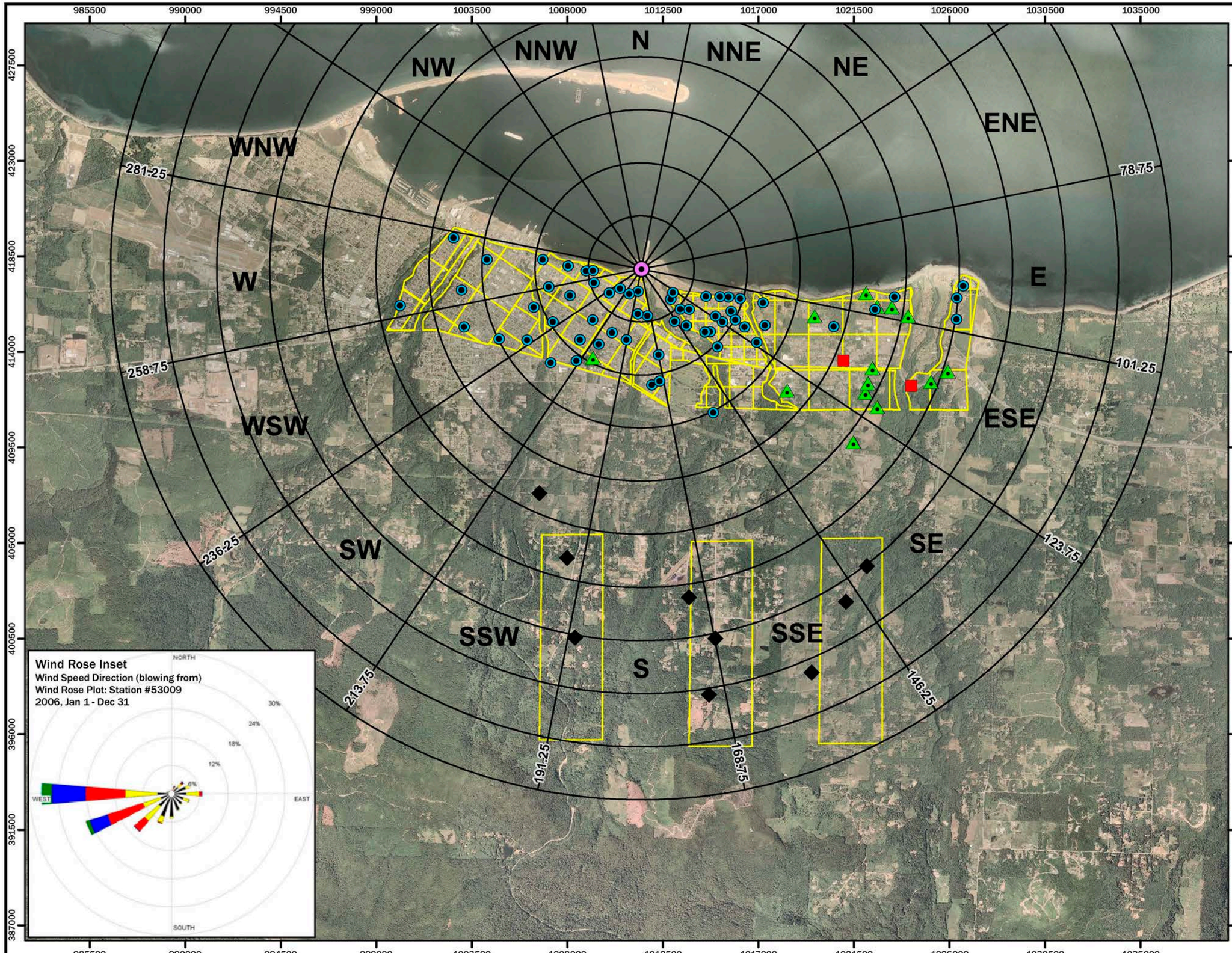

Figure 6-7.
Study area showing sample locations and wind and compass roses with former Rayonier Mill hog fuel boiler as point of origin
Rayonier Mill Off-Property
Soil Dioxin Study
Port Angeles, WA

Legend

Grid cell and/or upslope transect boundary

Collected sample

- Forested
- Grid
- Highway
- Transect
- Former hog fuel boiler

Wind Rose Inset

Wind speed (knots)

- >=22
- 17 to 21
- 11 to 17
- 7 to 11
- 4 to 7
- 1 to 4

Calms: 0.55%

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0 2,250 4,500 9,000 Feet

Coordinates: Washington State Plane South
NAD 83 (feet)
Aerial: USDA, 2006

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Produced By: GIS (RDR)
Project:
K:/Projects/06-03386-006/Projects/Compass Rose Report.mxd

Soil Sampling (Sept and Nov 2008)

- 0 to 3 inch depth, below vegetation or forest duff layer
- Small composites (5:1), typical 10 x10 foot area
- Exclusion and preference criteria applied
- Presence of char
  - 23 of 85 locations, mostly E zones
  - Analysis screening out char locations did not change results

Soil Sampling (continued)

- Sample types:

  Grid [n=60] Forest [n=14]
  Road [n=2] Upslope [n=9]

- 85 of targeted 100 samples collected
- Forest sample locations available only in limited part of study area
- Grid samples mostly residential lawns
- Sample locations: distance and direction from HFB stack

Chemical Analyses

- Dioxins and Furans
  - 17 2,3,7,8-substituted congeners
  - 10 homolog groups (4 to 8 chlorines)
  - High resolution analytical methods, low detection limits
  - Infrequent ND results (< 2% of 1,445 congener results), little impact on sample pattern analyses or TEQs
- TOC
  - Demonstrated correlation to forest sample results, not to overall study results – spatial scale issue
- Independent data validation

Data Evaluations: Lines of Evidence

- Magnitude (TEQs)
- Spatial Pattern
- Chemical Pattern
- Mass Balance

Soil Dioxin/Furan Results: Total TEQs

- Magnitude
  - 0.80 to 76.3 ng TEQ/kg for 85 samples
  - 40 of 85 samples, and 33 of 60 grid samples, > MTCA Method B value (direct contact, standard exposure model, 1 in million cancer risk) of 11.1 ng TEQ/kg
    - MTCA cleanup level not yet determined for site

Soil Dioxin/Furan Results: Total TEQs

- Magnitude (continued)
  - Upslope samples had lower TEQs than urban locations
  - One high outlier value of 76.3 ng TEQ/kg; only 15 of 85 samples had value above 20 ng TEQ/kg
  - Comparisons to other soil dioxin studies indicate somewhat higher TEQs in Port Angeles

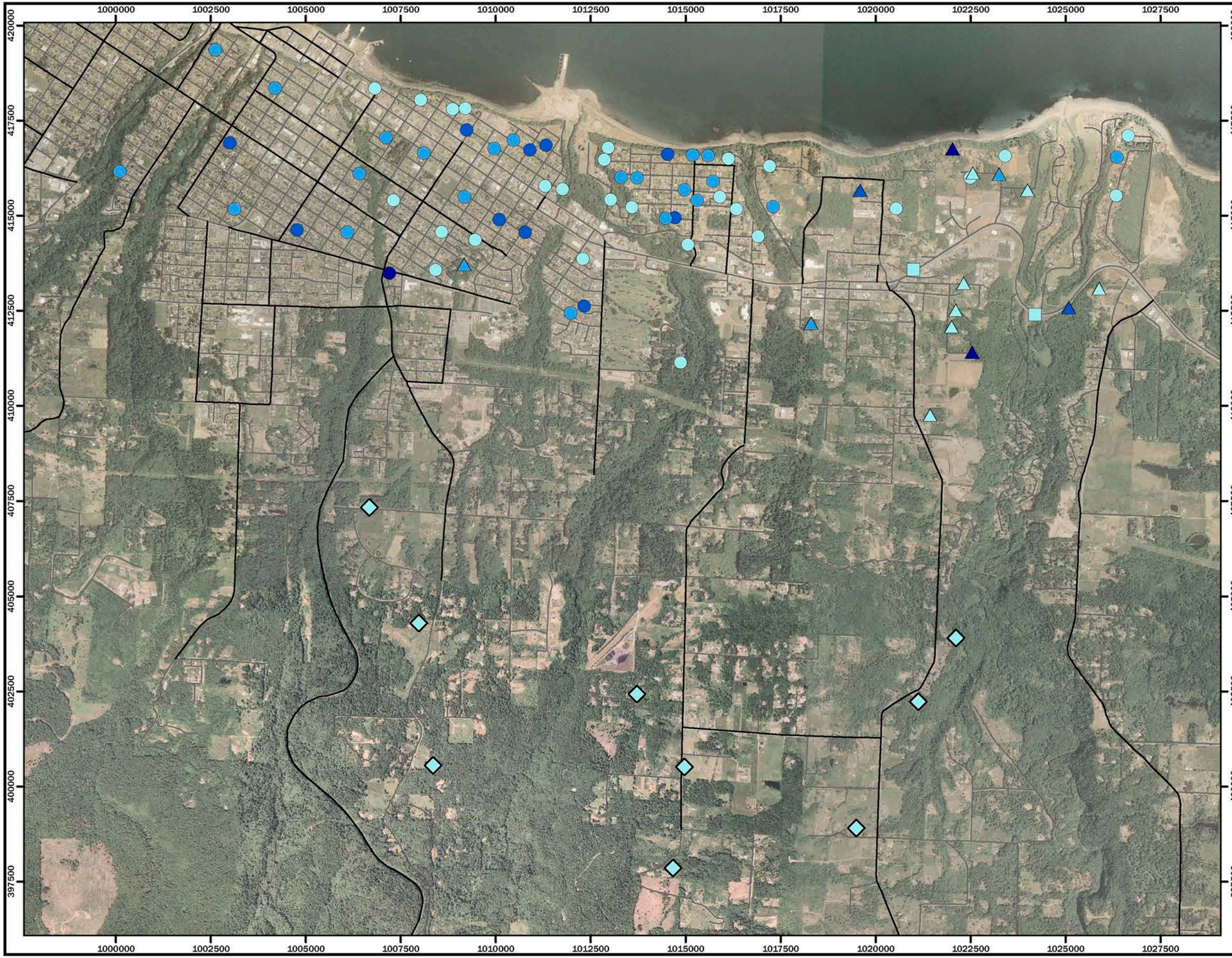

Figure 6-2.
Overview of TEQ concentrations across study area
Rayonier Mill Off-Property
Soil Dioxin Study
Port Angeles, WA

Legend

TEQ (ND=1/2 DL) concentrations shown in ng/kg
TEQ (ND=1/2 DL) range = 0.8 to 76.3 ng/kg

- 0 to 11
- 11 to 20
- 20 to 30
- > 30

Soil sample type

- Forested
- Grid
- Highway
- Transect
- Arterial or Collector Road
- Road

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0 1,250 2,500 5,000 feet

Coordinates: Washington State Plane South
NAD 83 (feet)
Aerial: USDA, 2006

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Produced By: GIS (RDR)
Project:
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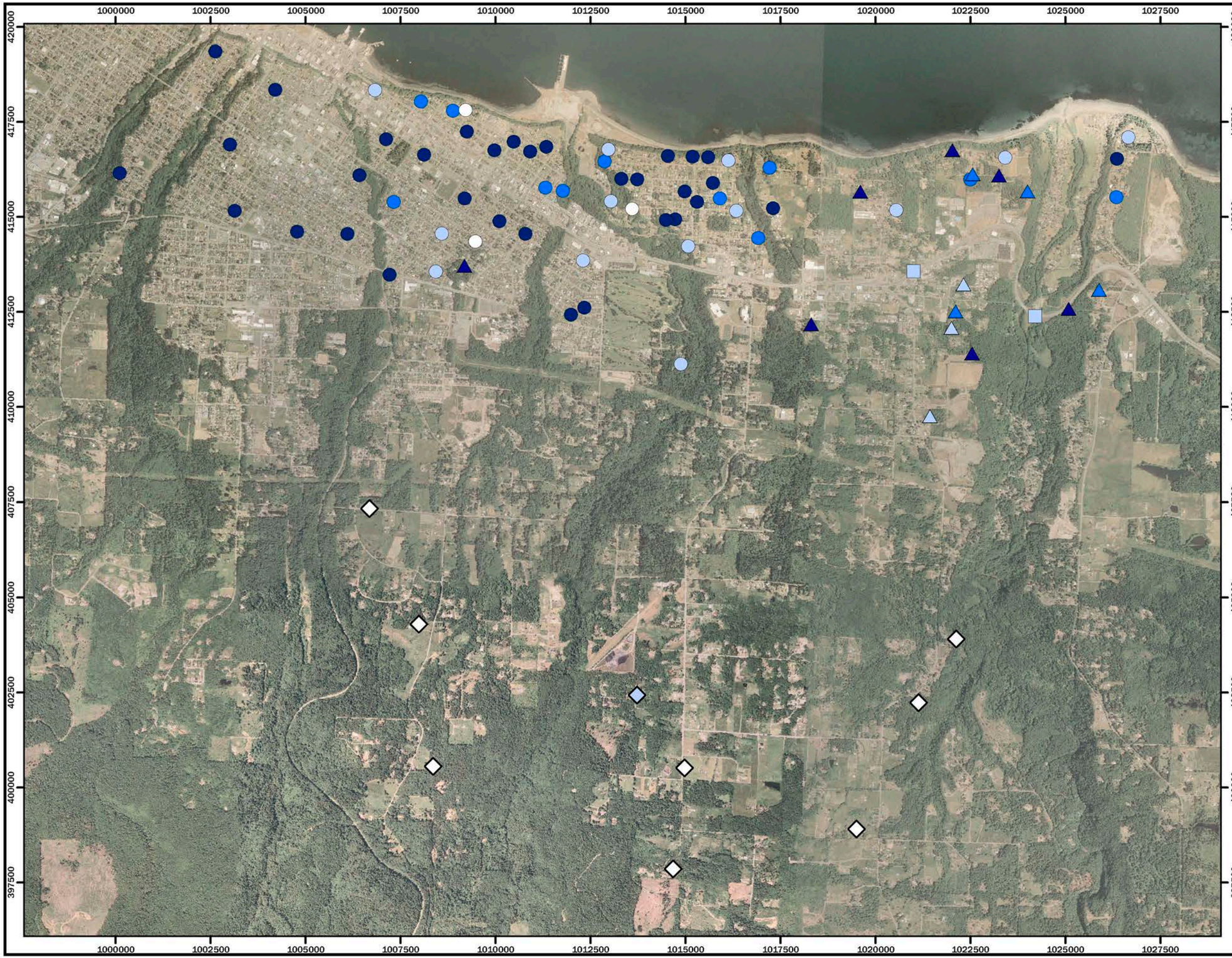

Figure 8-5.
Total TEQs
Rayonier Mill Off-Property
Soil Dioxin Study
Port Angeles, WA

Legend

TEQ (ND = 1/2 DL) concentrations shown in ng/kg

- 0 to 3
- 3 to 7
- 7 to 11
- > 11

Soil sample type

- Forested
- Grid
- Highway
- Transect

Note: Contour plots used in these data evaluations cannot predict values at unsampled locations. Rather, they help visualize the large-scale distribution of the Port Angeles soils data. Local variability in dioxin/furan concentrations may be high and is likely to reflect individual property histories.

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HERRERA ENVIRONMENTAL CONSULTANTS

0 1,250 2,500 5,000 feet

Coordinates: Washington State Plane South
NAD 83 (feet)
Aerial: USDA, 2006

N

Produced By: GIS (RDR)
Project:
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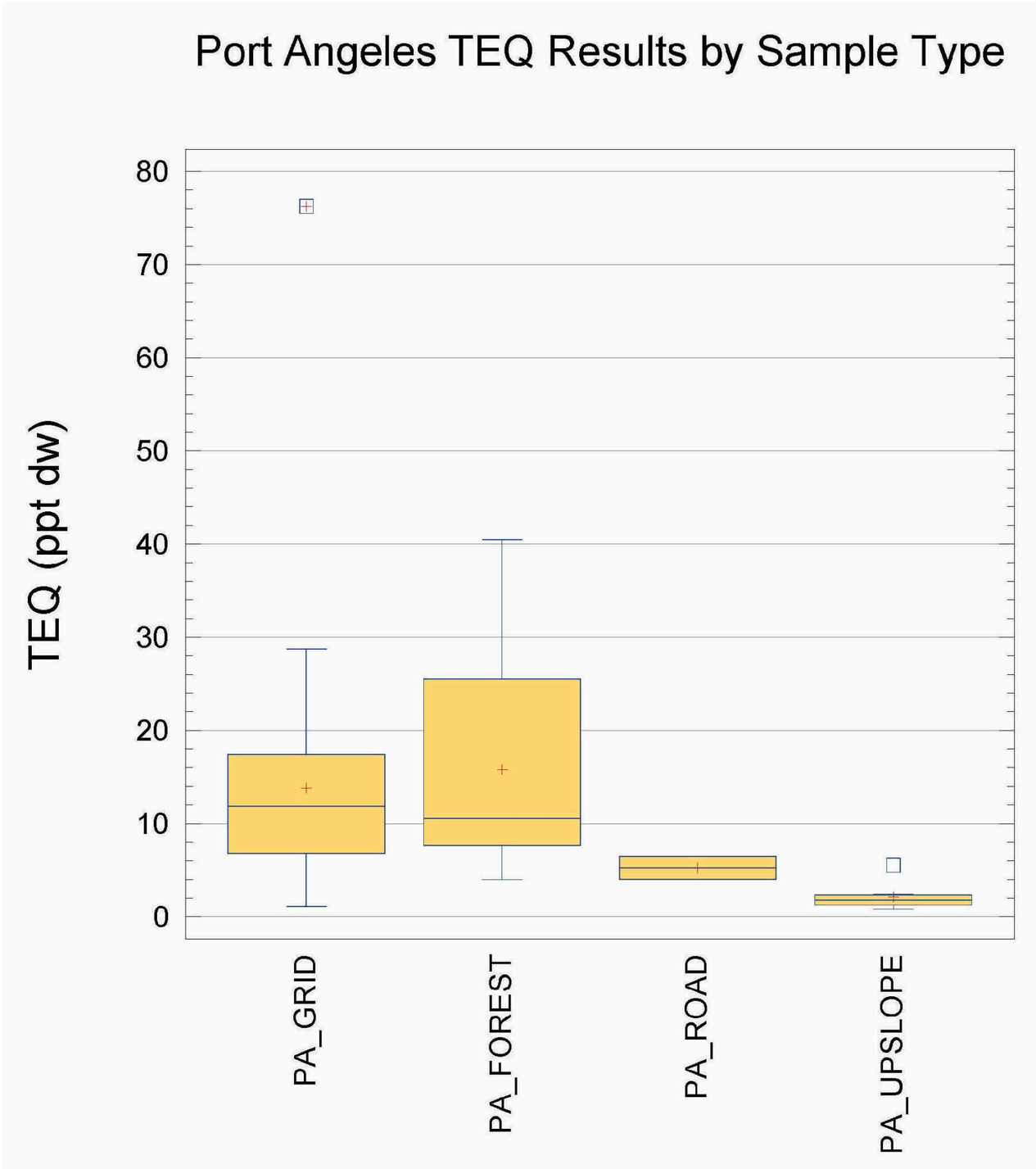
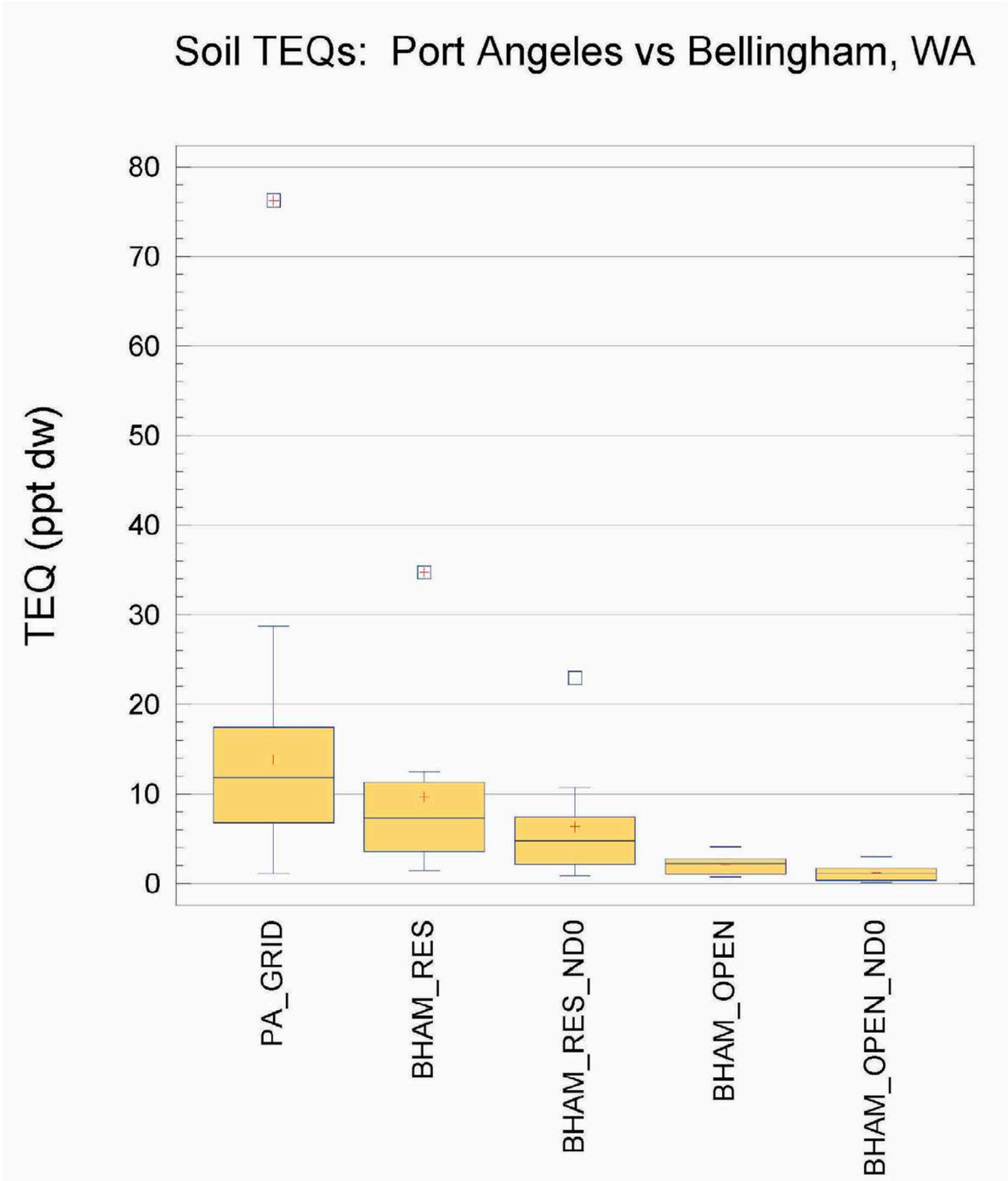

Port Angeles TEQ Results by Sample Type
TEQ (ppt dw)
80
70
60
50
40
30
20
10
0
PA_GRID
PA_FOREST
PA_ROAD
PA_UPSLOPE


Soil TEQs: Port Angeles vs Bellingham, WA
TEQ (ppt dw)
80
70
60
50
40
30
20
10
0
PA_GRID
BHAM_RES
BHAM_RES_ND0
BHAM_OPEN
BHAM_OPEN_ND0

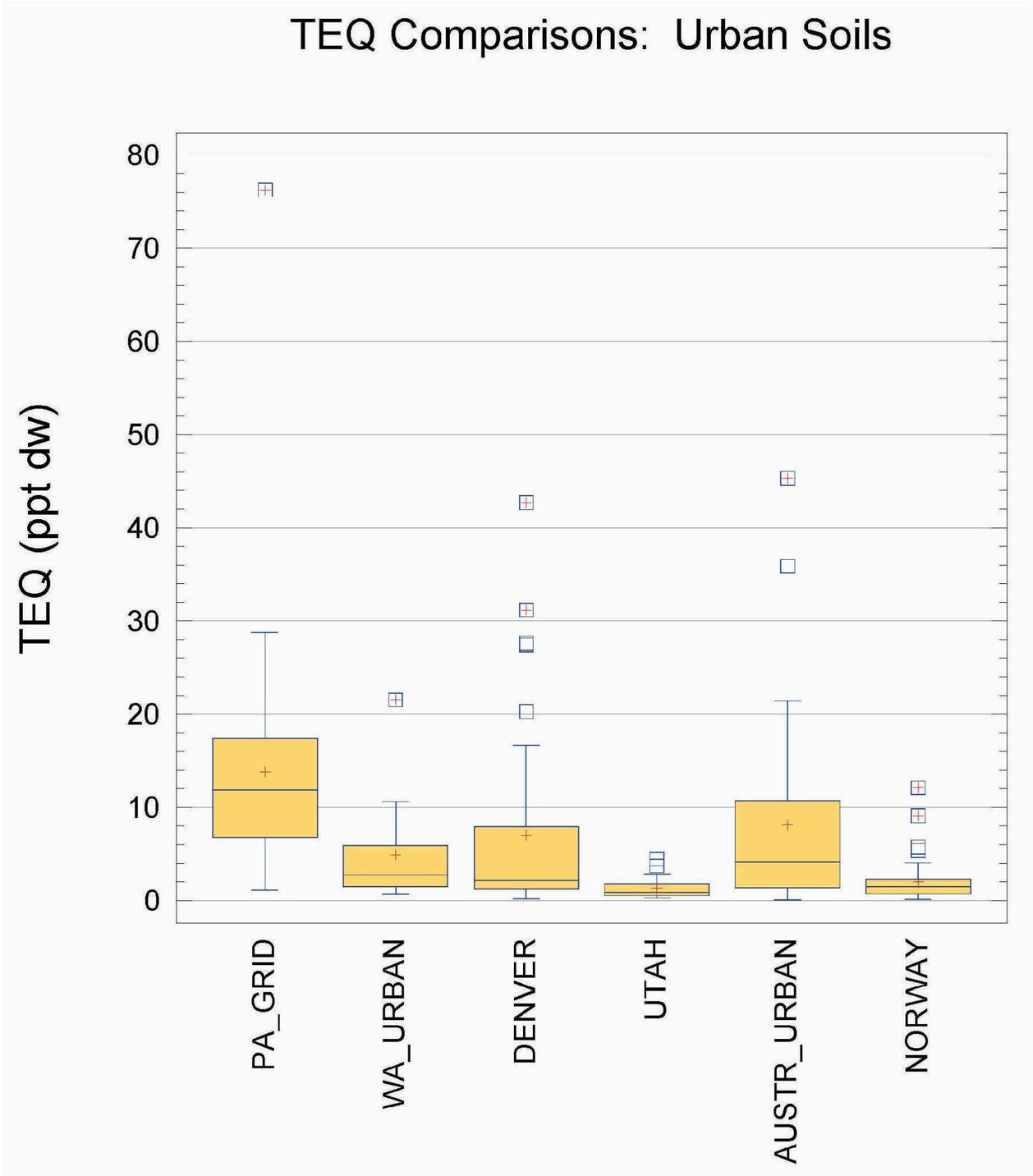
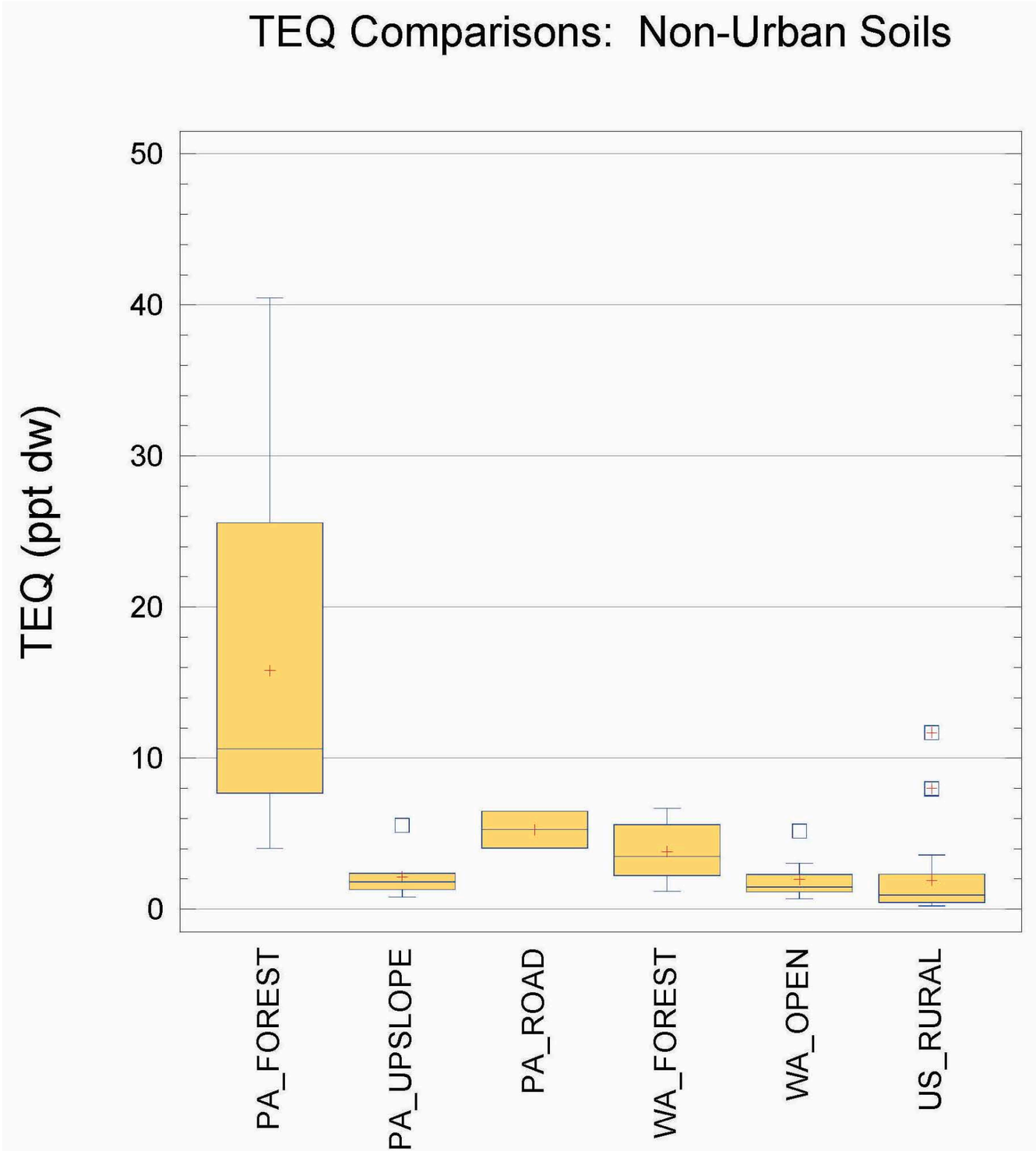
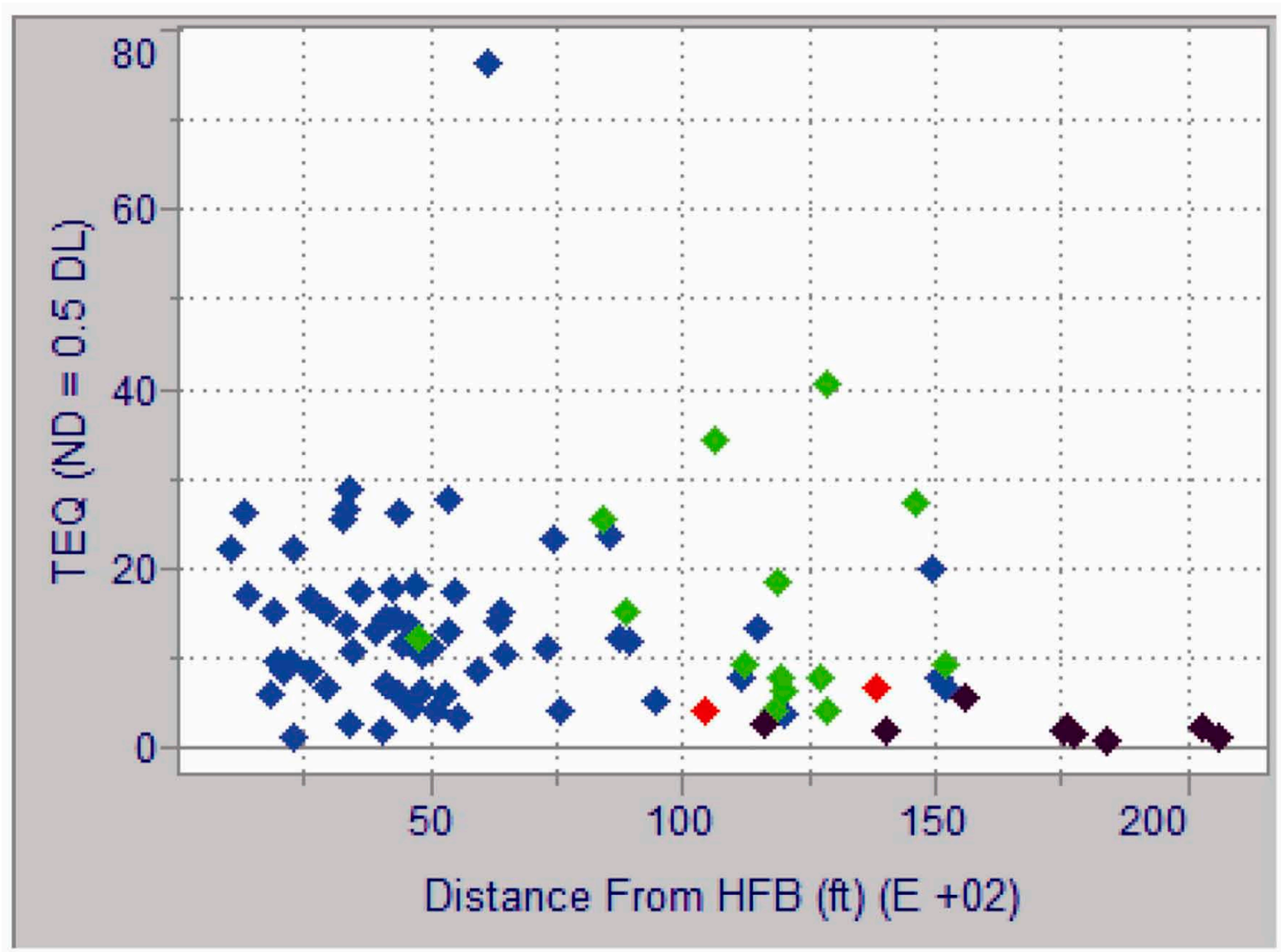


Figure 8-3 Comparison of soil TEQs: Port Angeles versus urban soils


TEQ Comparisons: Non-Urban Soils
TEQ (ppt dw)
50
40
30
20
10
0
PA_FOREST
PA_UPSLOPE
PA_ROAD
WA_FOREST
WA_OPEN
US_RURAL

Soil Dioxin/Furan Results: Total TEQs

- Spatial Pattern
  - Other than lower upslope TEQs and general urban to rural gradient, little evidence of spatial pattern
  - Examples of large variability in closely-spaced sample locations
  - Widespread spatial occurrence of > MTCA Method B value of 11.1 ng TEQ/kg
  - Likely reflection of contributions from multiple sources



Key:

- = Grid sample
- = Upslope transect sample
- = Roadside sample
- = Forested sample

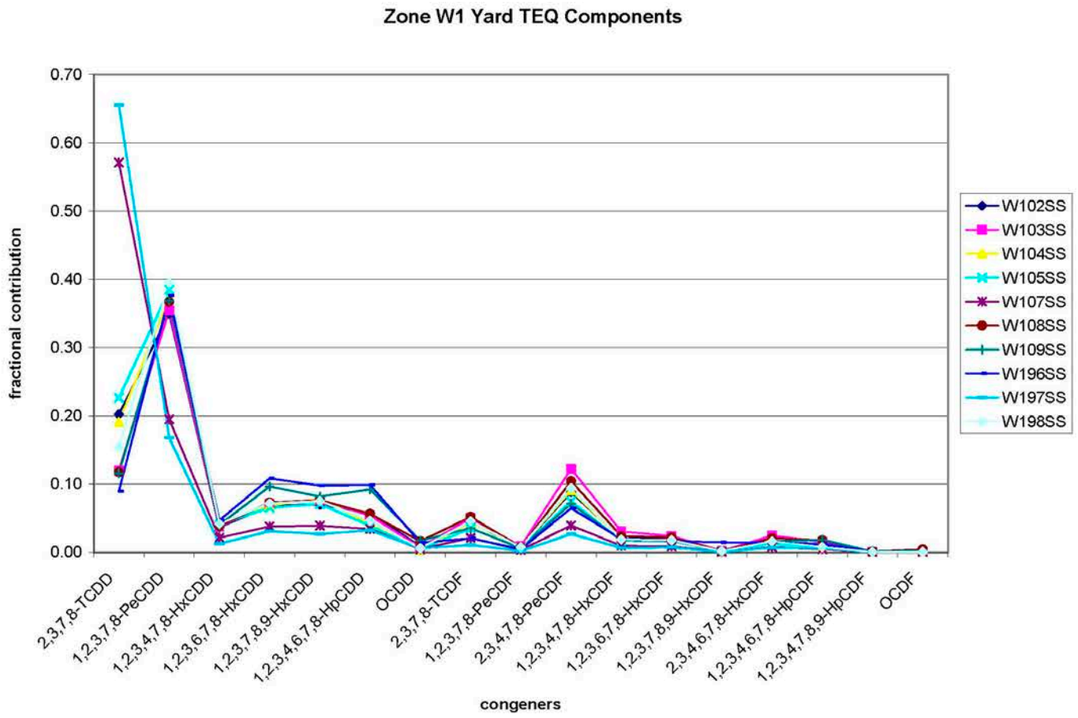
Figure 6-8 Scatter plot showing TEQ concentrations and distance of samples from the former Rayonier Mill hog fuel boiler

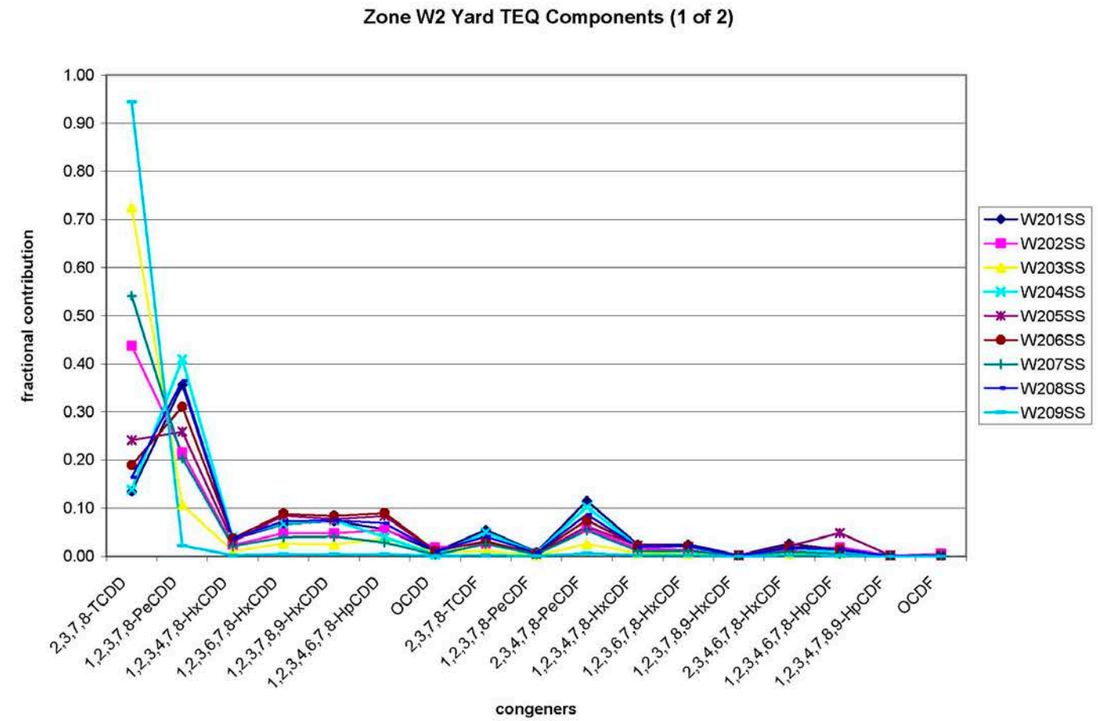
Soil Dioxin/Furan Results: Total TEQs

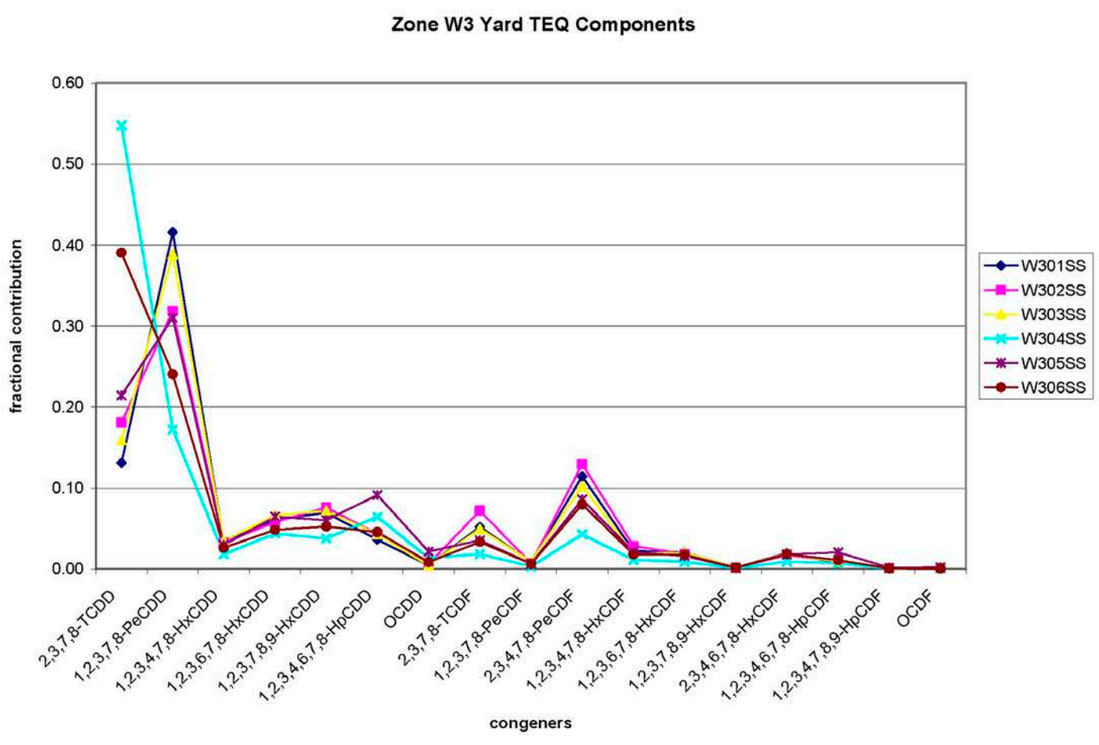
- Chemical Patterns
  - Normalized TEQ profiles for 85 samples
    - By sampling zone, by sample type
    - Normalization focuses on pattern, not magnitude; examine similarity in profiles
  - Input to chemometric analyses; not yet “unmixed”
  - Apparent subset of samples with high 2,3,7,8-TCDD fractional contribution

Soil Dioxin/Furan Results: Total TEQs

- Chemical patterns (continued)
  - First-order similarity of many sample profiles
  - Variations of patterns on close examination
  - Primary Question for further evaluations: what sources and source contributions would produce these sample profiles?
    - Receptor-Oriented Modeling Approach







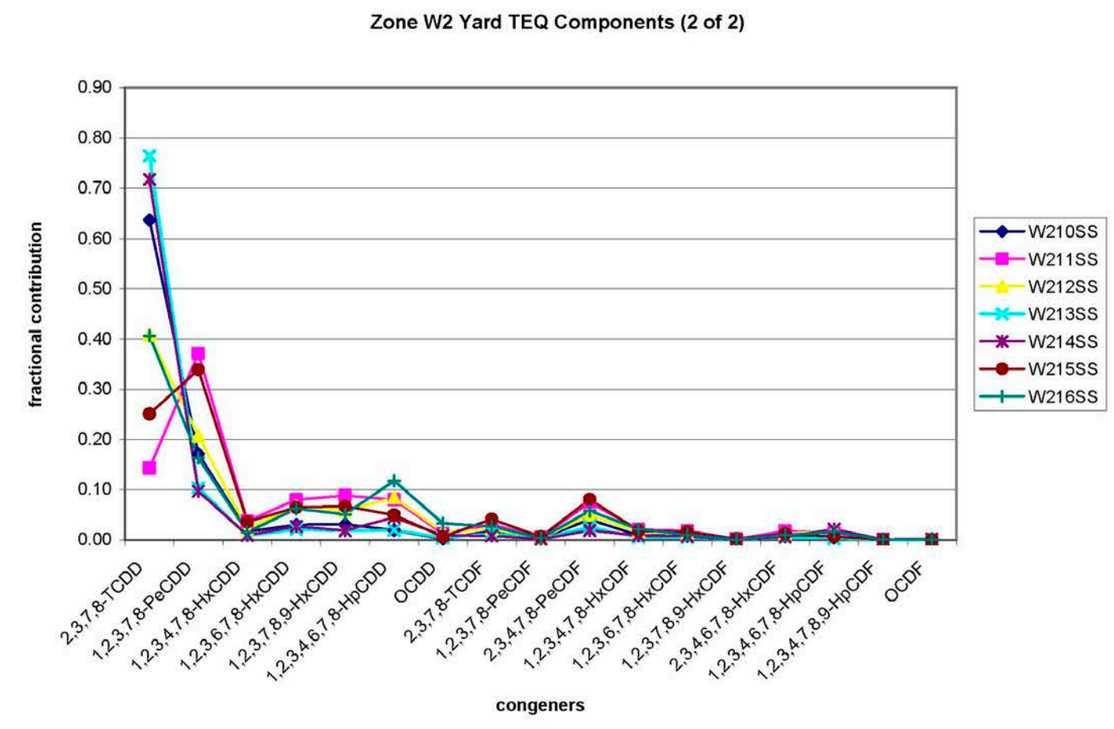
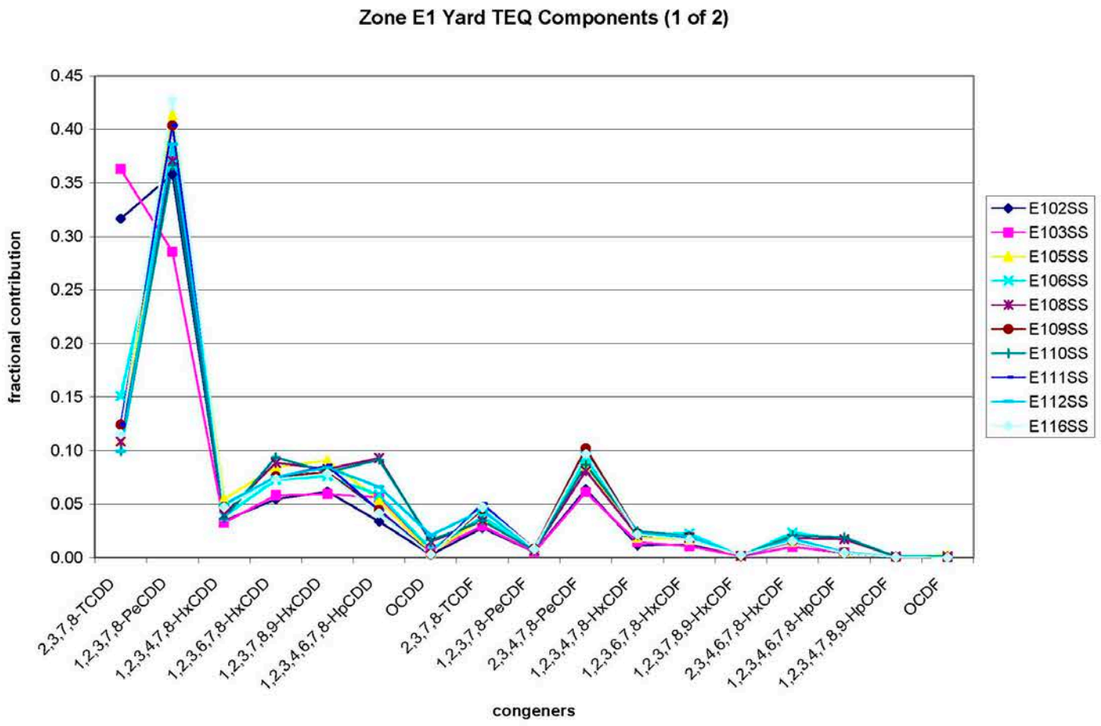
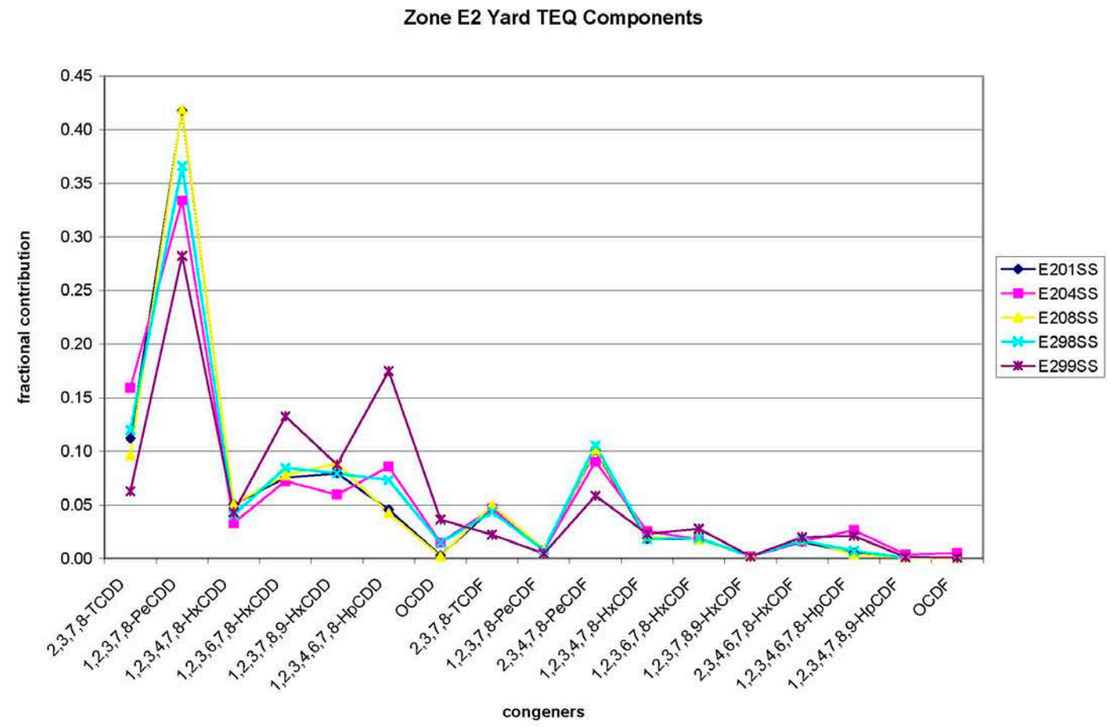
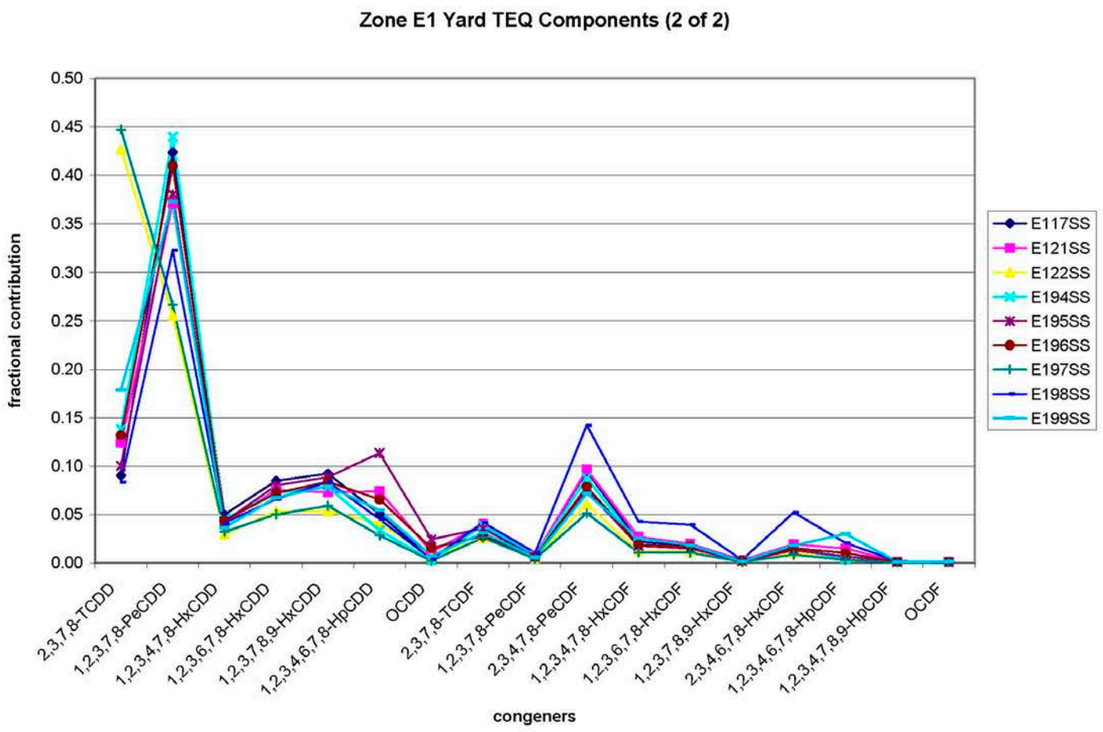


Figure 6-10 Line plots showing fractional contributions of congeners to TEQ results







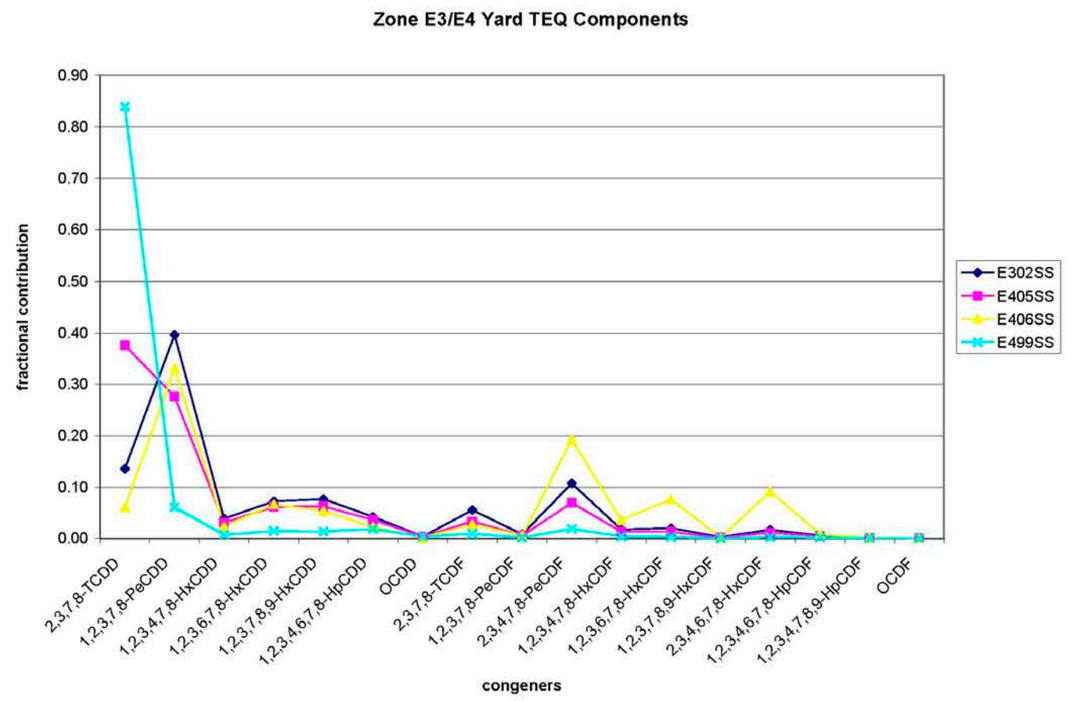
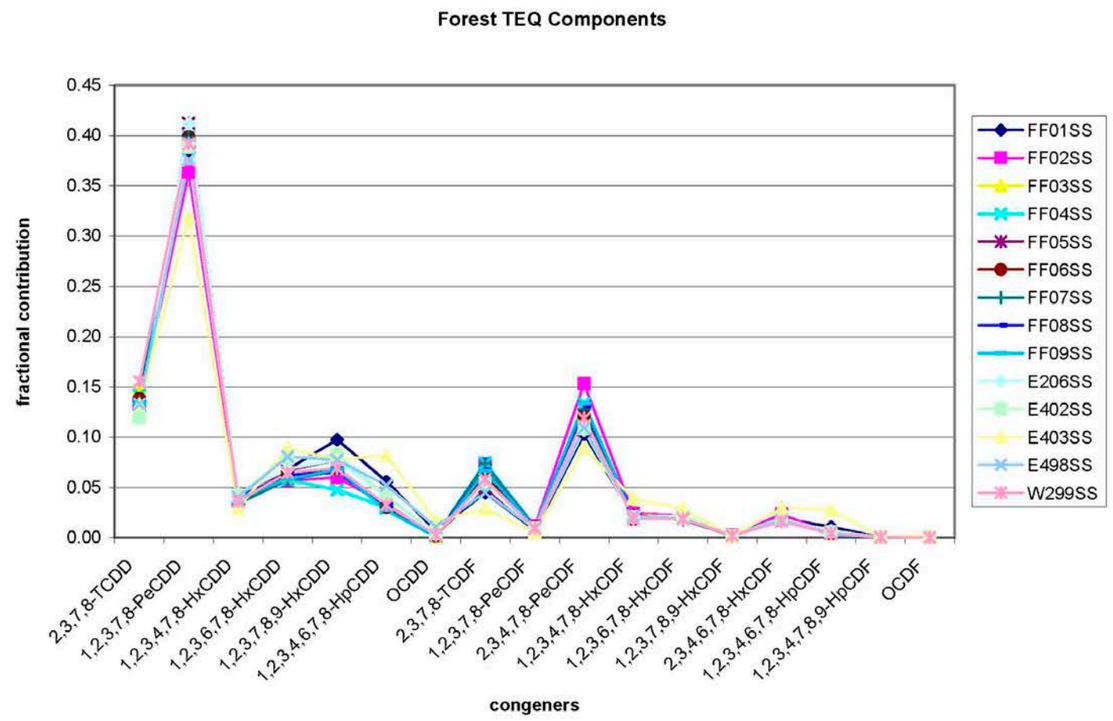
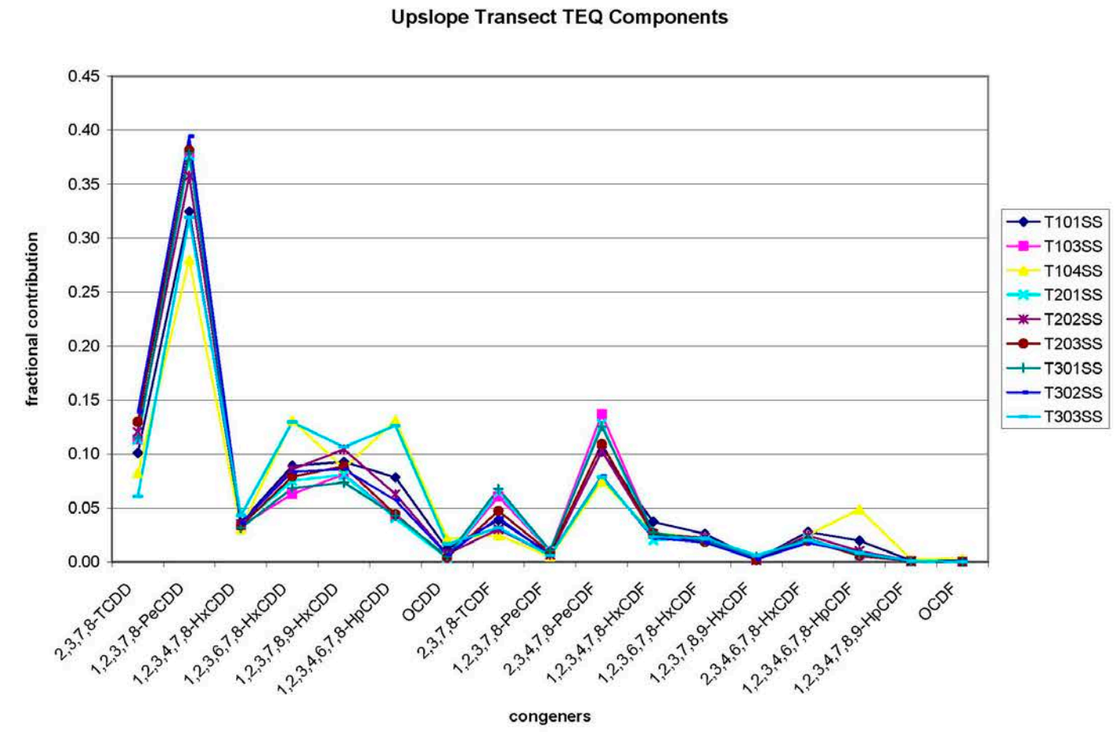


Figure 6-10 (continued) Line plots showing fractional contributions of congeners to TEQ results





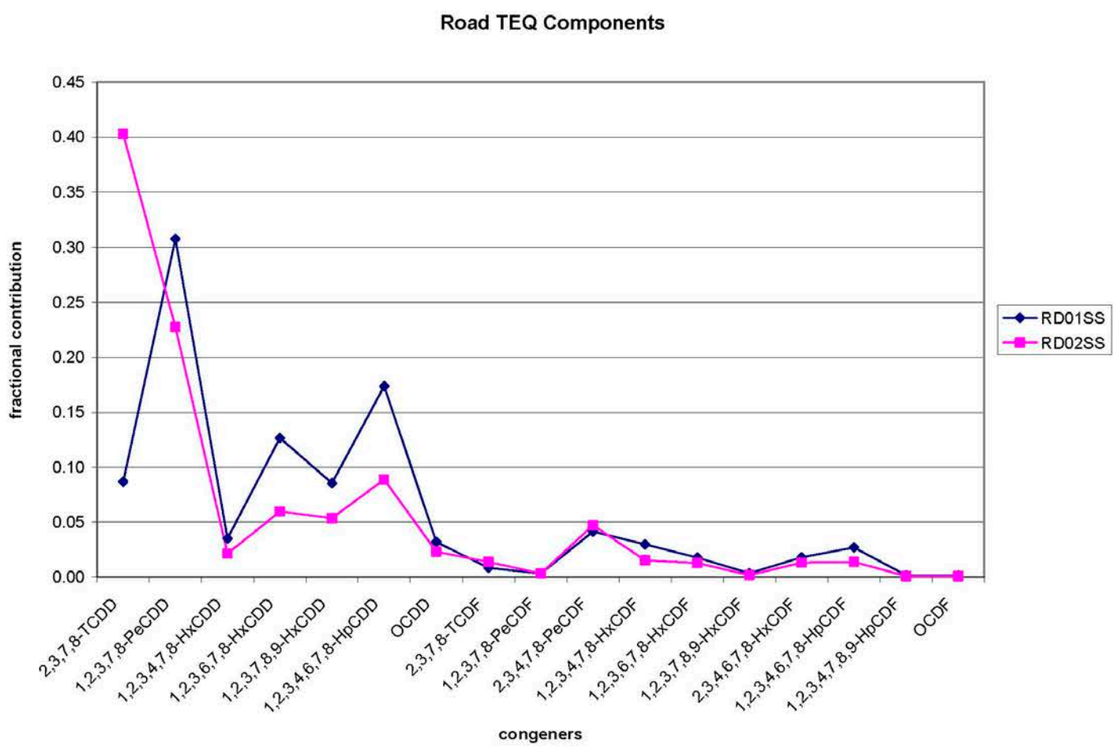


Figure 6-10 (continued) Line plots showing fractional contributions of congeners to TEQ results

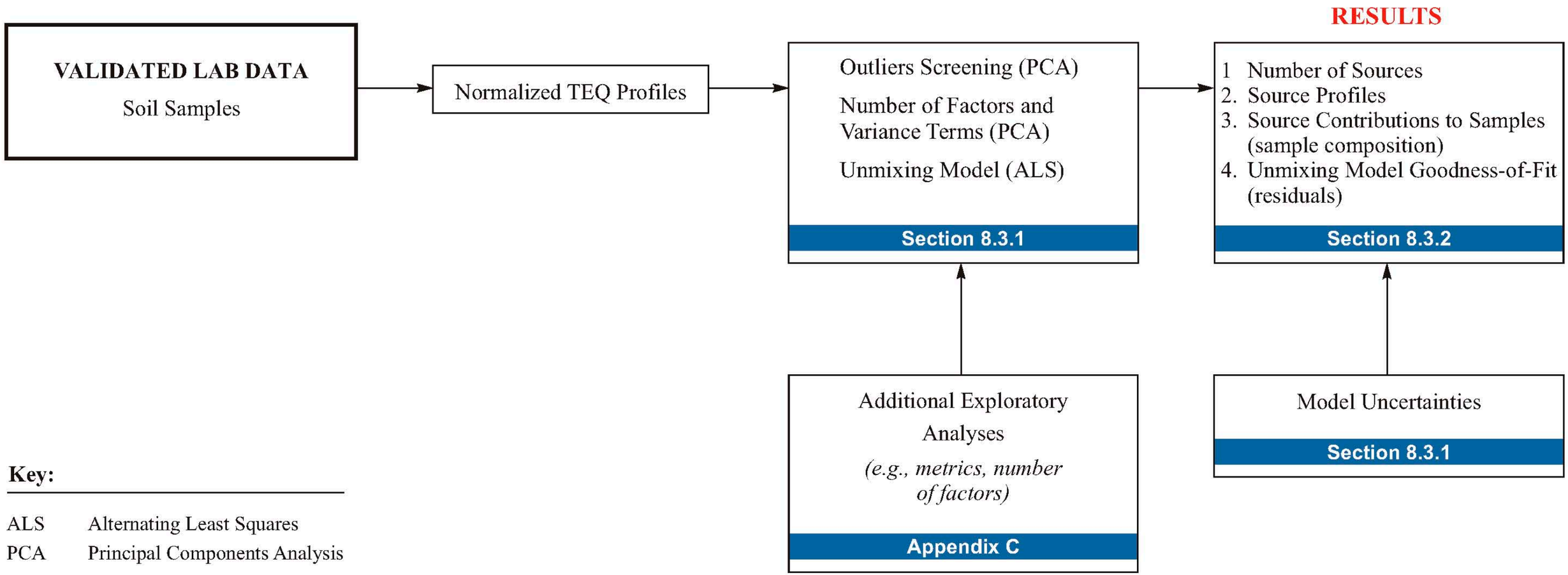


Figure 7-1 Chemometric analysis schematic

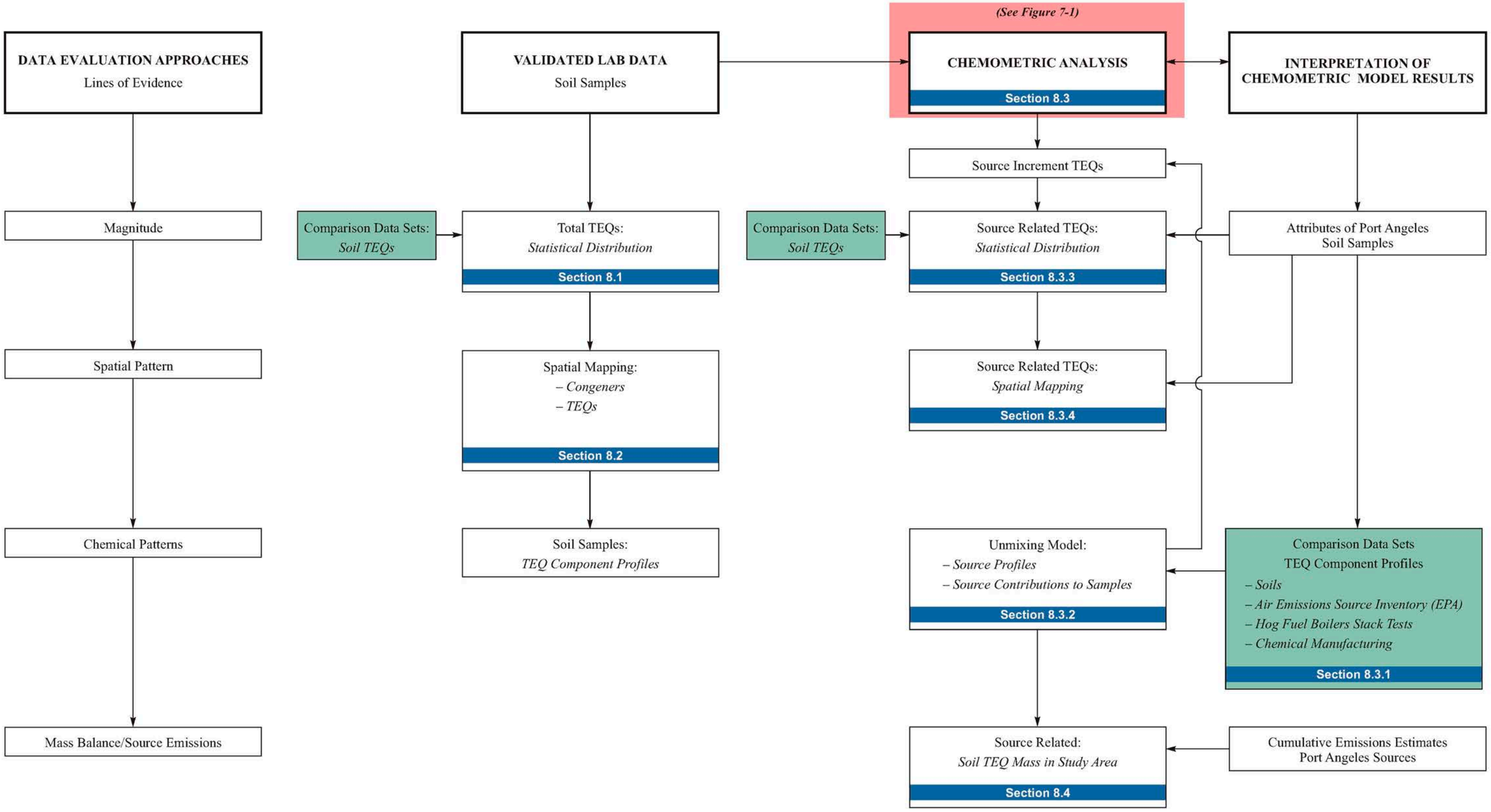


Figure 7-2 Data evaluations: overview

Chemometrics (Unmixing): Methods

- Input Data
  - Matrix of 17 normalized congener values for 85 samples (ND = ½ DL)
  - No additional information about samples is considered yet (location, sample type, distance from HFB, etc.); mathematical analysis only!
  - Outliers screening (anomalous/atypical profiles) [n=83 sample profiles used]

Unmixing: Methods (continued)

- Iterative calculations
  - Number of sources from PCA
  - Product of source profiles and source amounts in samples compared to sample results
  - Constraints applied between iterations (e.g., no negative source amounts)
  - Convergence, with small residuals in congener profiles

Unmixing: Methods (continued)

- Model output
  - Number of sources
  - Source profiles
    - Source types, not physical sources
  - Source amounts in each sample
  - Residuals (difference in modeled versus measured profiles)
  - Source TEQ increments (sample TEQ composition; sum of TEQ increments is total TEQ)

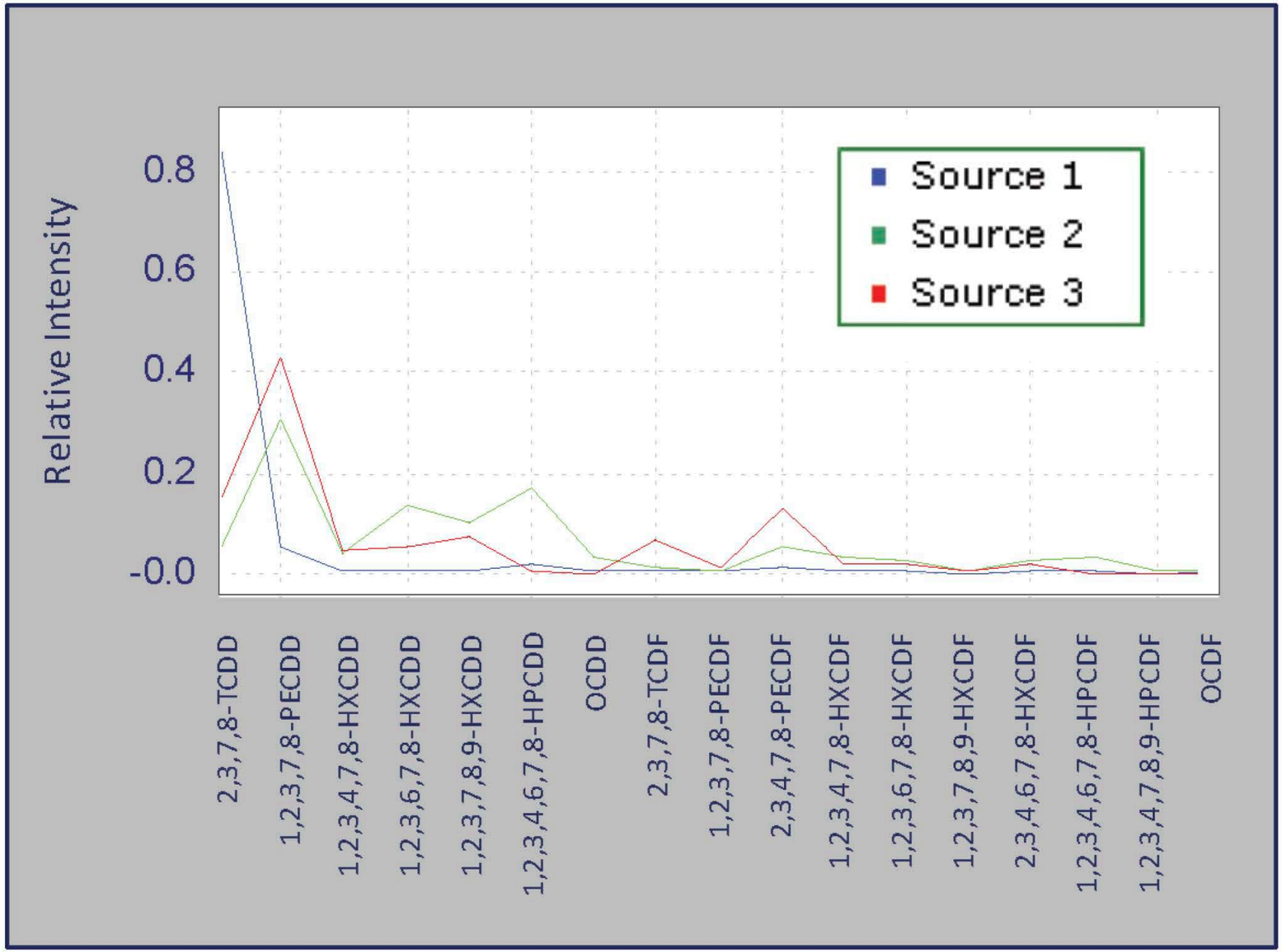
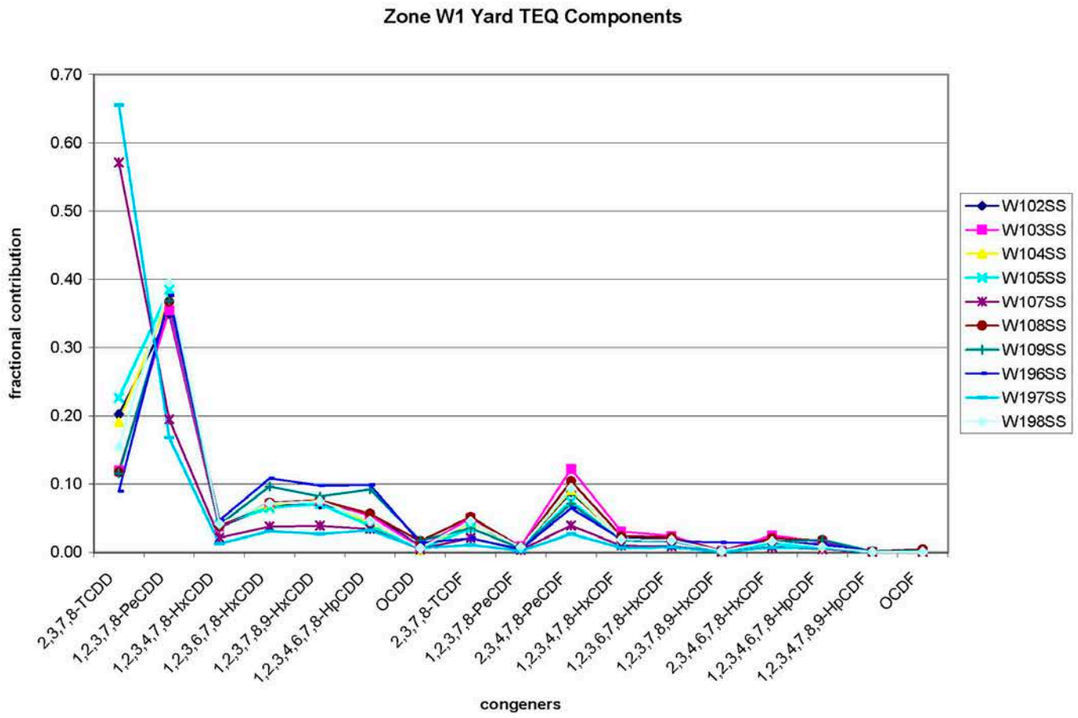
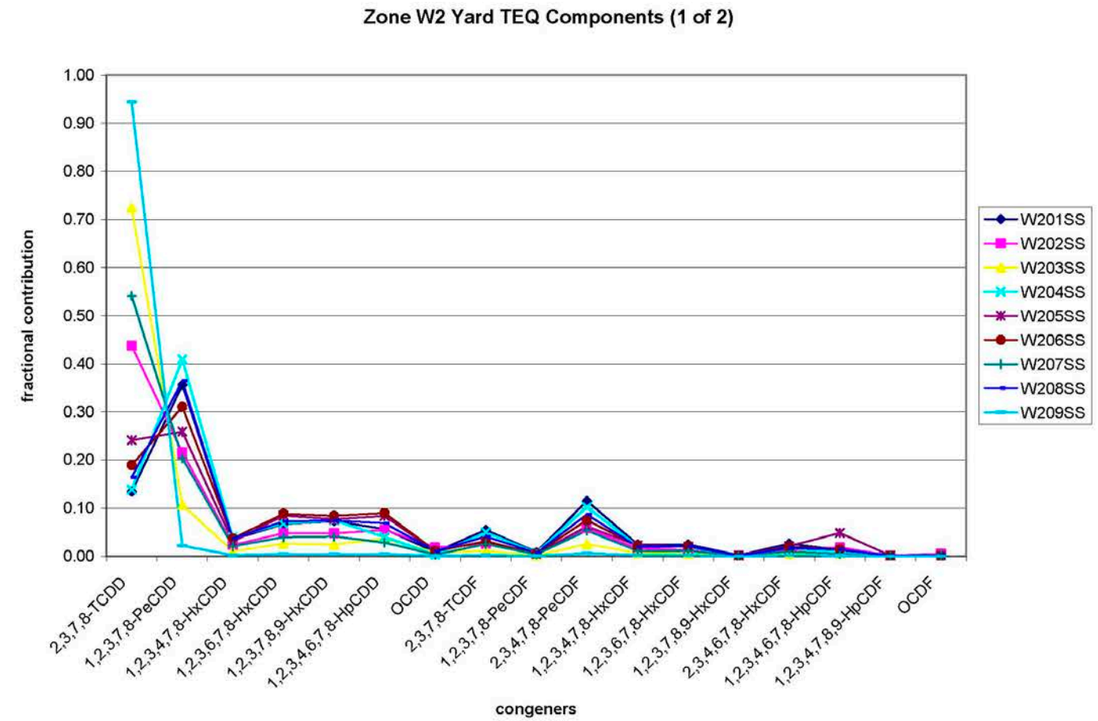
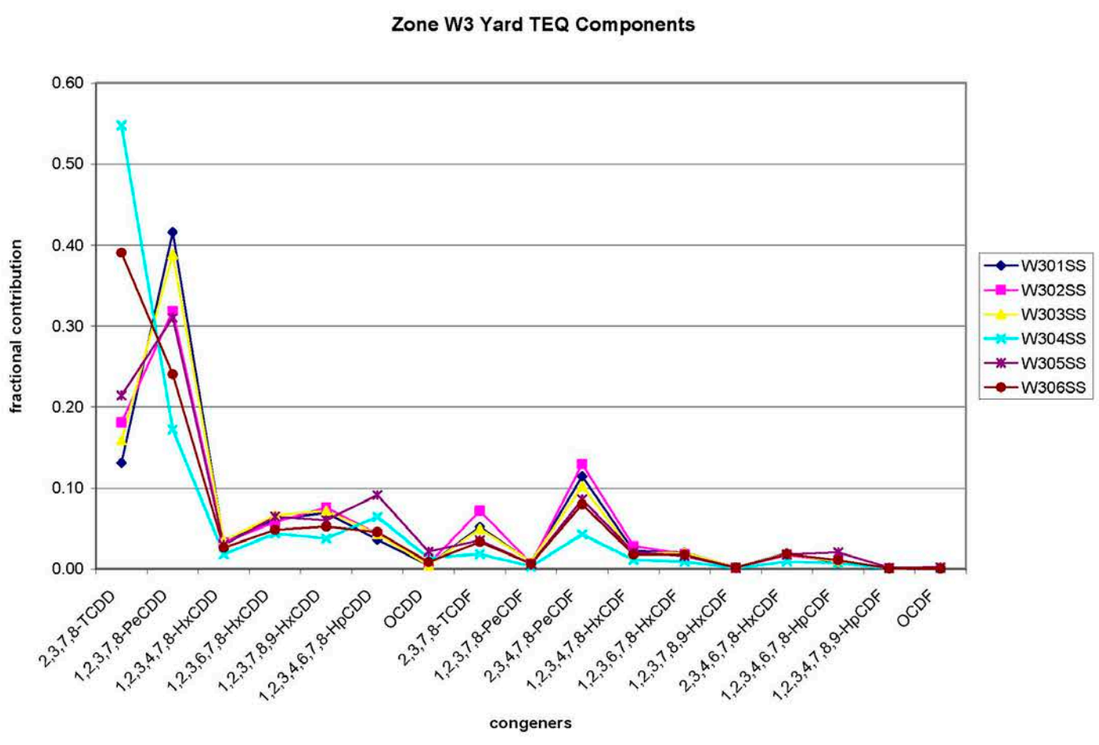


Figure 8-10 Unmixing model source profiles







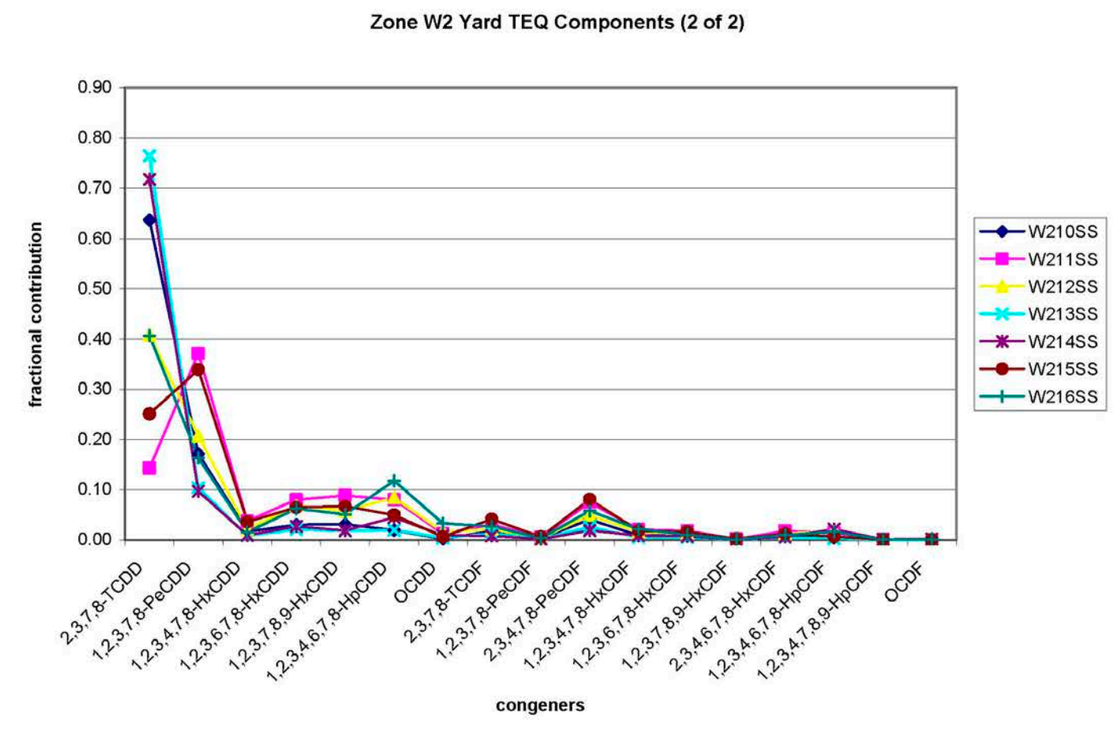


Figure 6-10 Line plots showing fractional contributions of congeners to TEQ results

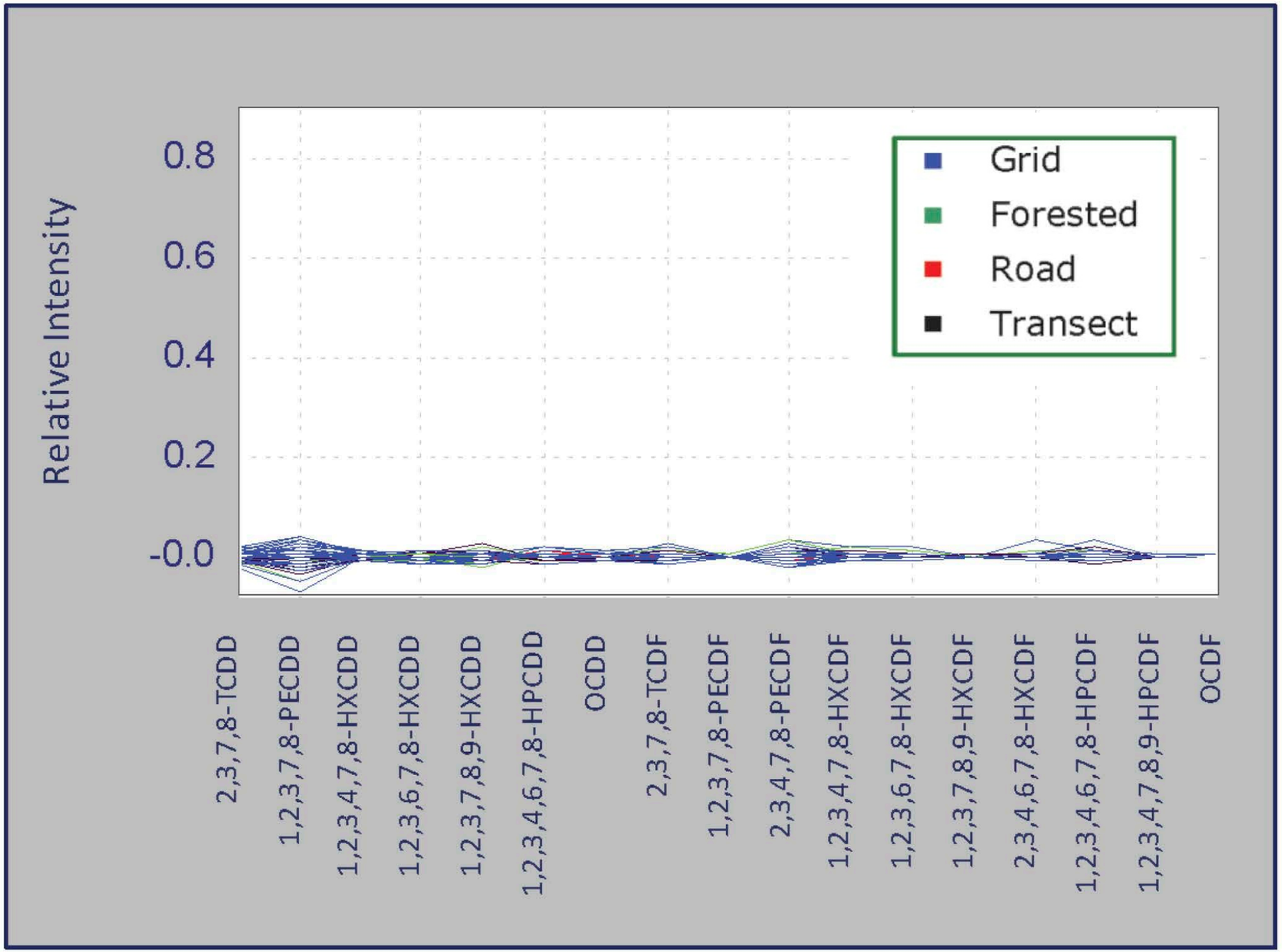


Figure 8-13 Unmixing model residuals

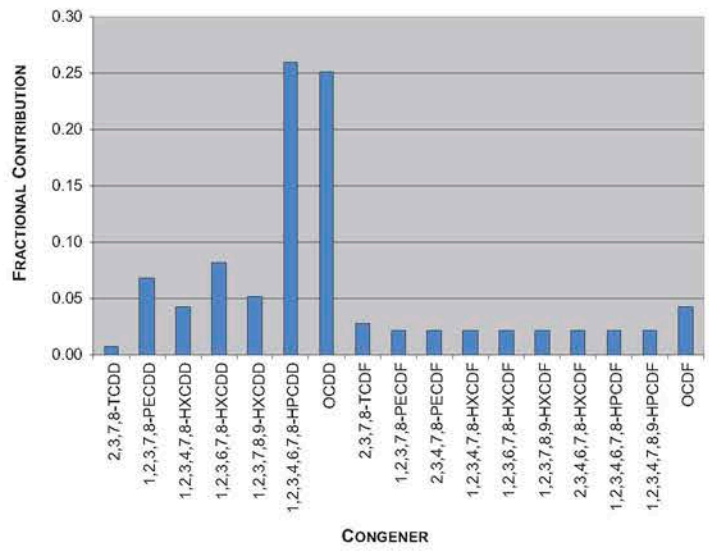
Unmixing: Chemical Patterns

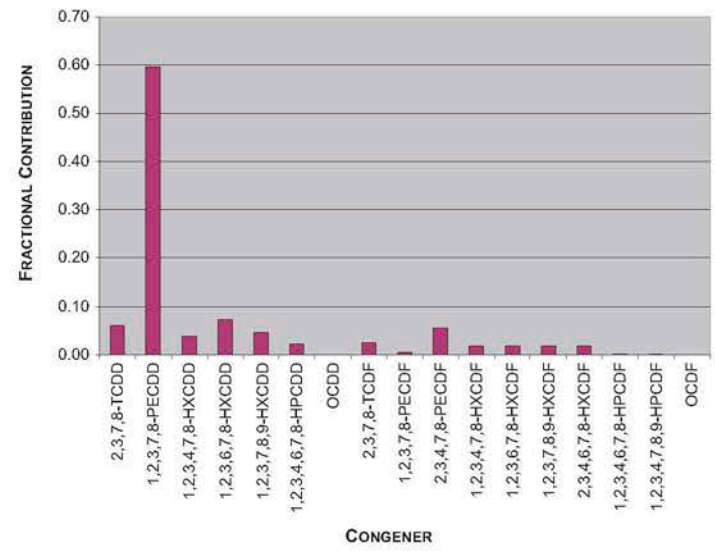
- Source Profiles
  - Model with 3 sources has small residuals
  - 3 model sources have distinct TEQ profiles
  - Comparison data sets
    - Inventory of source profiles, including > 60 stack tests at HFBs burning salt-laden wood
    - Other soils data sets

BULK PROFILE | **TEQ PROFILE**

Rayonier Hog Fuel Boiler - 1995(a)

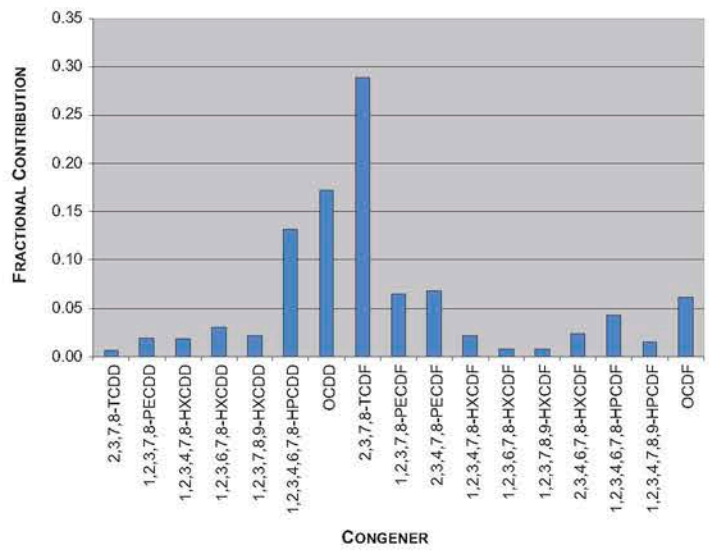
Reference No. 1

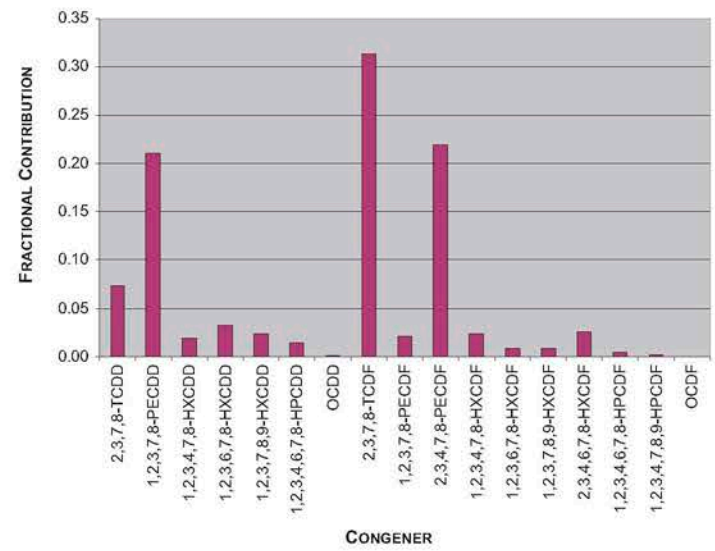




Rayonier Hog Fuel Boiler - 1995(b)

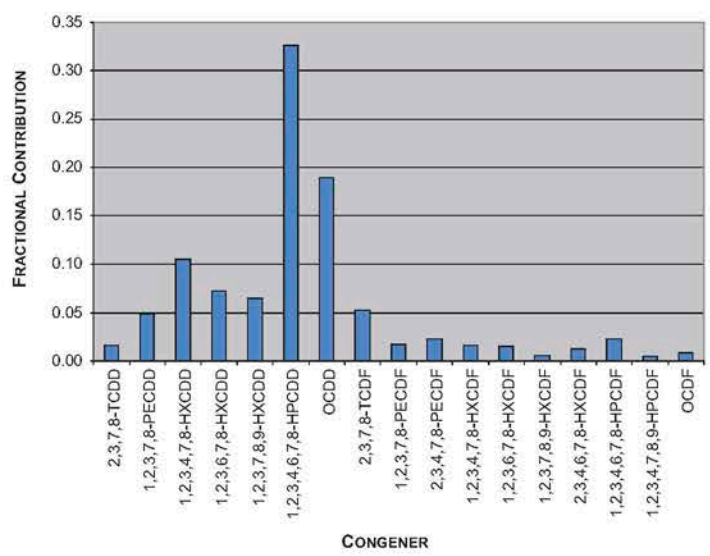
Reference No. 1

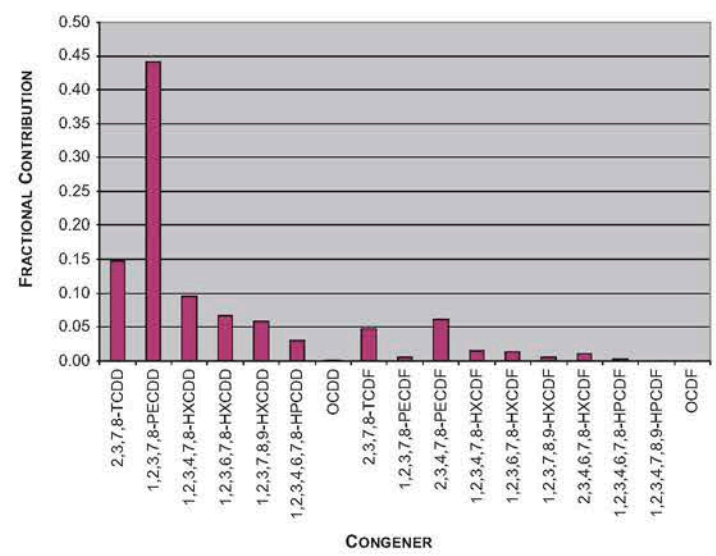




Rayonier Hog Fuel Boiler Ash - 1989

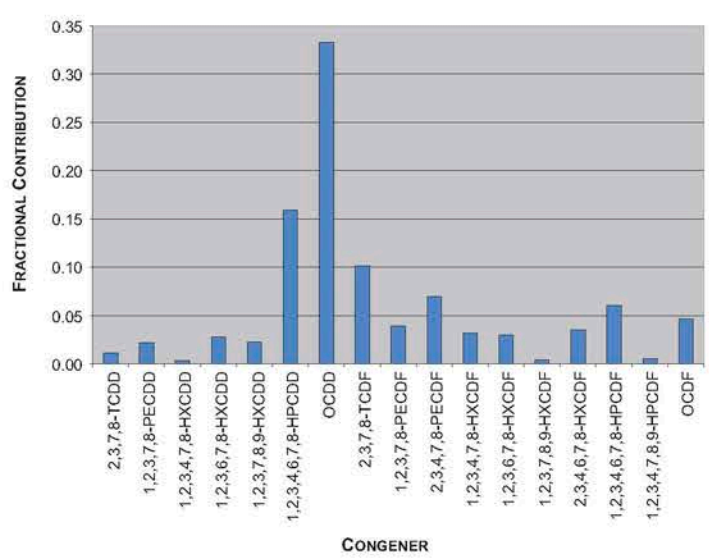
Reference No. 5

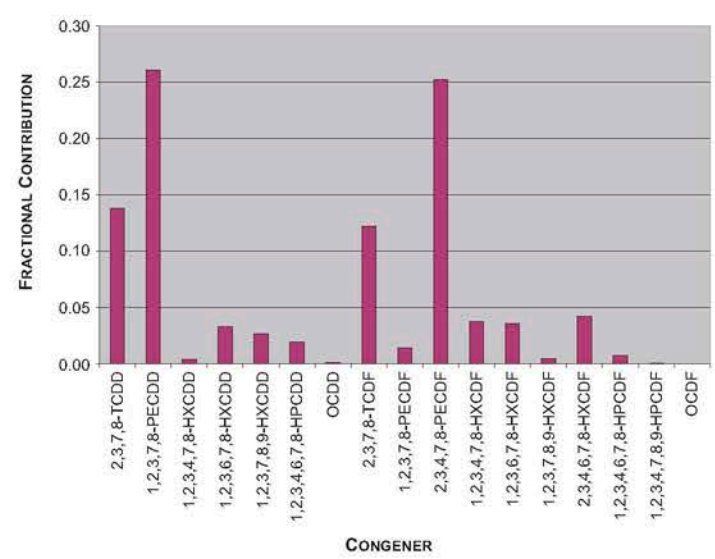




Nippon Hog Fuel Boiler - 2009

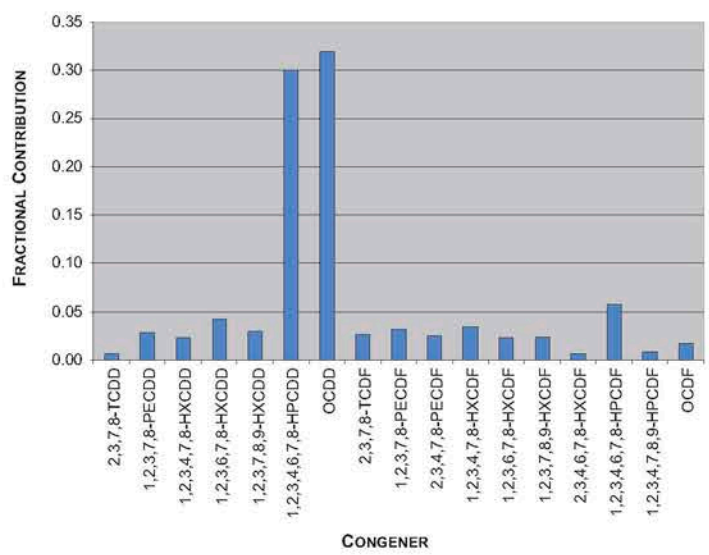
Reference No. 2

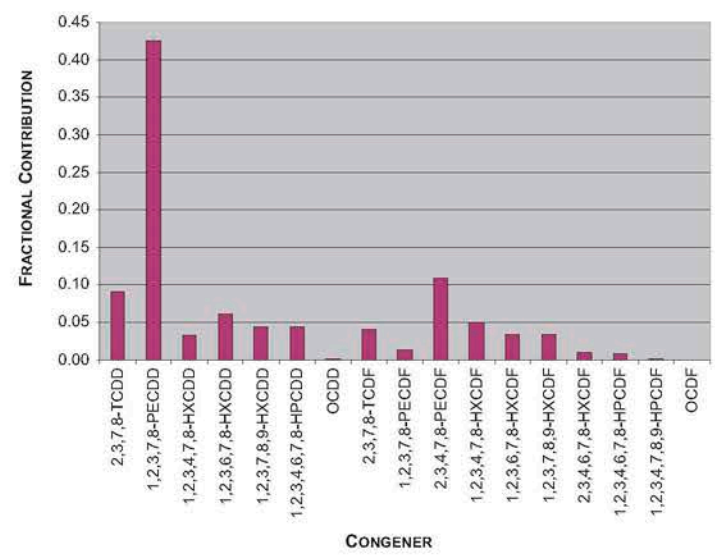




Canadian Hog Fuel Boiler 1 - 2007

Reference No. 4





Unmixing: Chemical Patterns (cont.)

- Source 1: 2,4,5-T (Silvex)
  - High contribution only at developed sample locations
  - Occurrence of 2,3,7,8-TCDD well established
  - New Zealand soils study near 2,4,5-T manufacturing site
  - Established history of use (lawn care recommendations, USDA/Beltsville, 1965)
  - Pattern observed in small number of samples across multiple studies
  - Also similar to tire burning profile

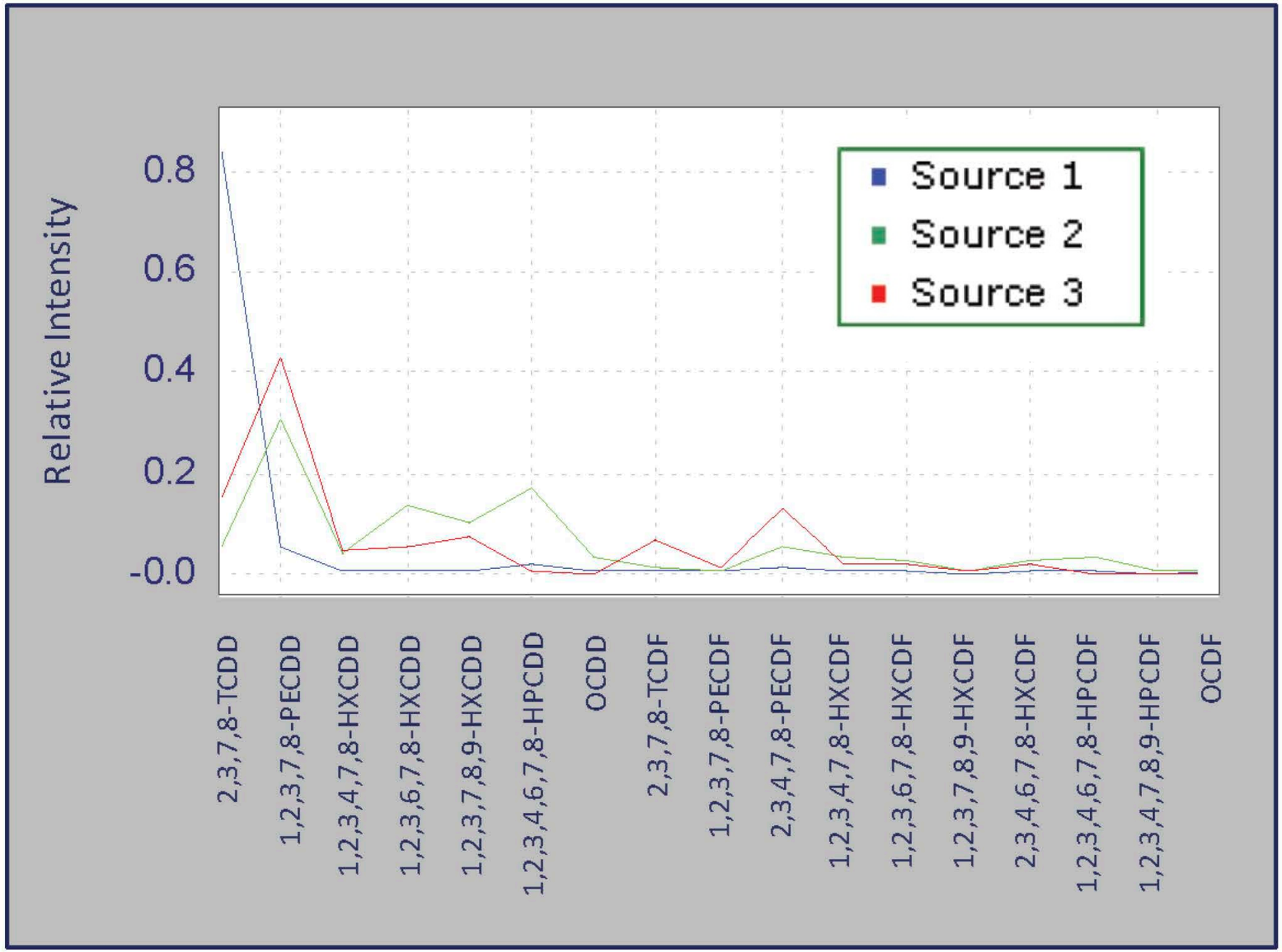


Figure 8-10 Unmixing model source profiles

Unmixing: Chemical Patterns (cont.)

- Source 2: urban soils
  - Similar to other urban soil and storm drain samples
  - Similar to some Canadian HFB stack test profiles
  - Relatively high contributions to a number of roadside samples
  - Likely reflects typical mixed urban soil sources, including vehicle emissions
  - May include some HFB emissions component (composite profile)

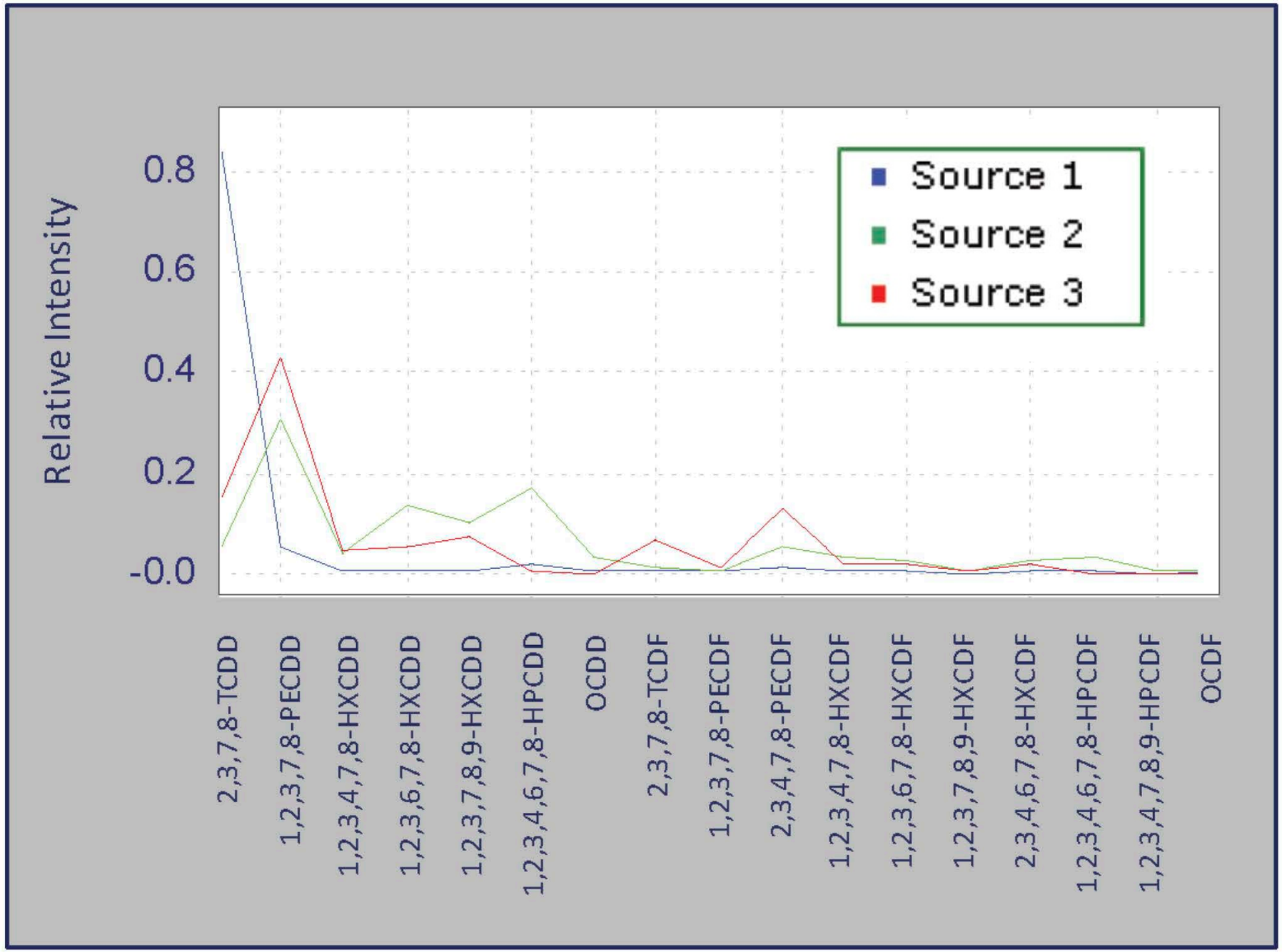


Figure 8-10 Unmixing model source profiles

Unmixing: Chemical Patterns (cont.)

- Source 3: HFB emissions
  - Similar to Rayonier HFB stack test and cluster of Canadian HFB profiles (burning salt-laden wood)
  - No other profile in the inventory has this pattern to the same degree
  - Also similar to HFB ash samples from Rayonier

Unmixing: Magnitude

- Source TEQ increments for 85 samples and 3 modeled sources
- Source 3 has large contribution to TEQ for many samples
  - For grid + forest samples, Source 3 TEQ increments largest for 34 of 41 E locations, 16 of 33 W locations
  - Without Source 3 TEQ increments, median grid sample TEQ reduced by almost 60%
  - Of 40 samples with total TEQ > MTCA Method B value of 11.1 ng TEQ/kg, without S1/S2/S3 TEQ increments 25/27/12 remain

Unmixing: Magnitude (continued)

- Source 3 fractional contributions are particularly high for forest samples
- If Source 3 TEQ increments are removed, remaining sample TEQs are similar to other soil dioxin data sets
- Source 1 has the largest TEQ increments for a subset of high total TEQ samples at developed properties; otherwise Source 1 TEQ increments are small
- Source 2 TEQ increments are moderate, relatively uniform across urban parts of study area, and similar to results for other urban soils

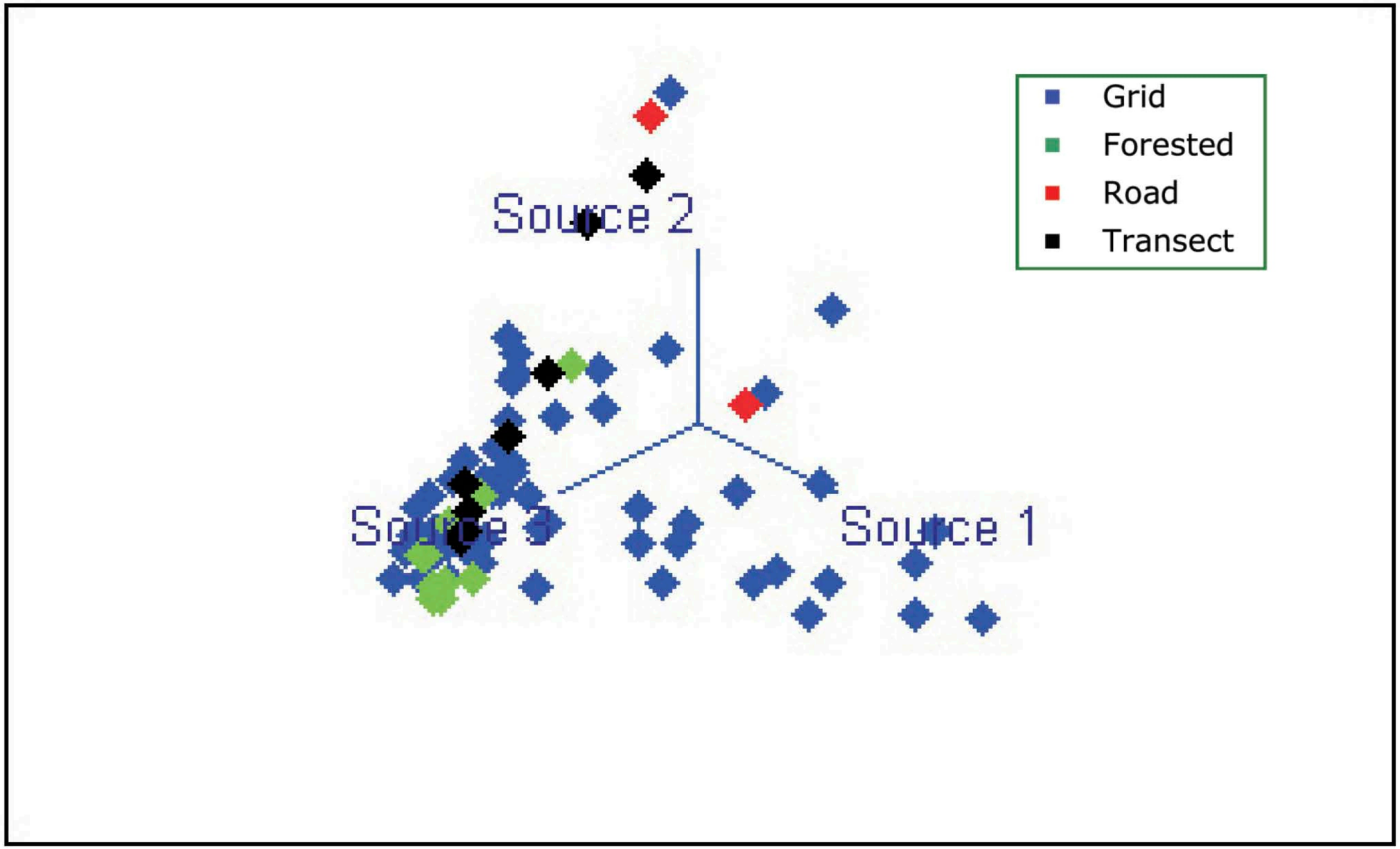
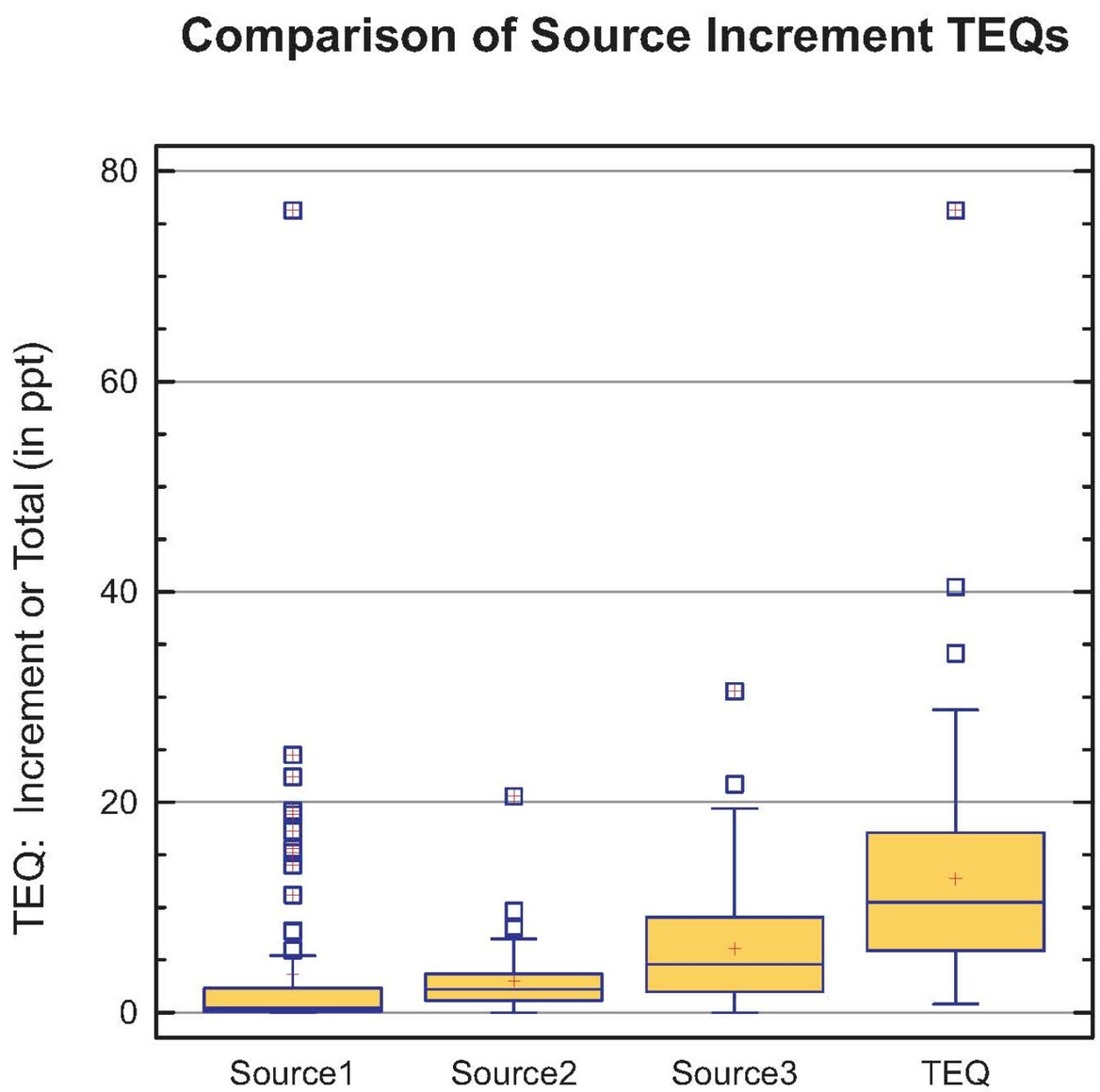
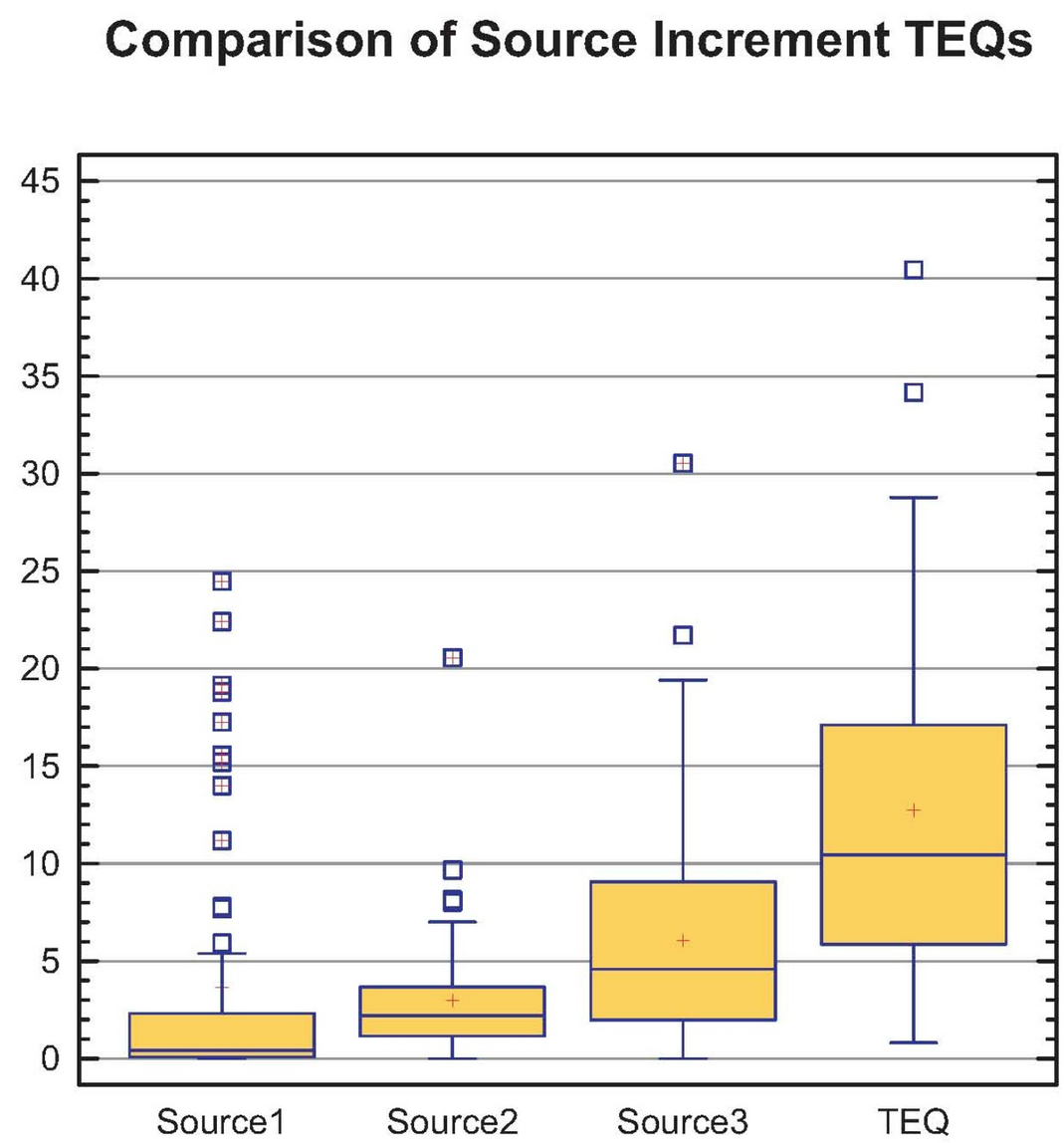
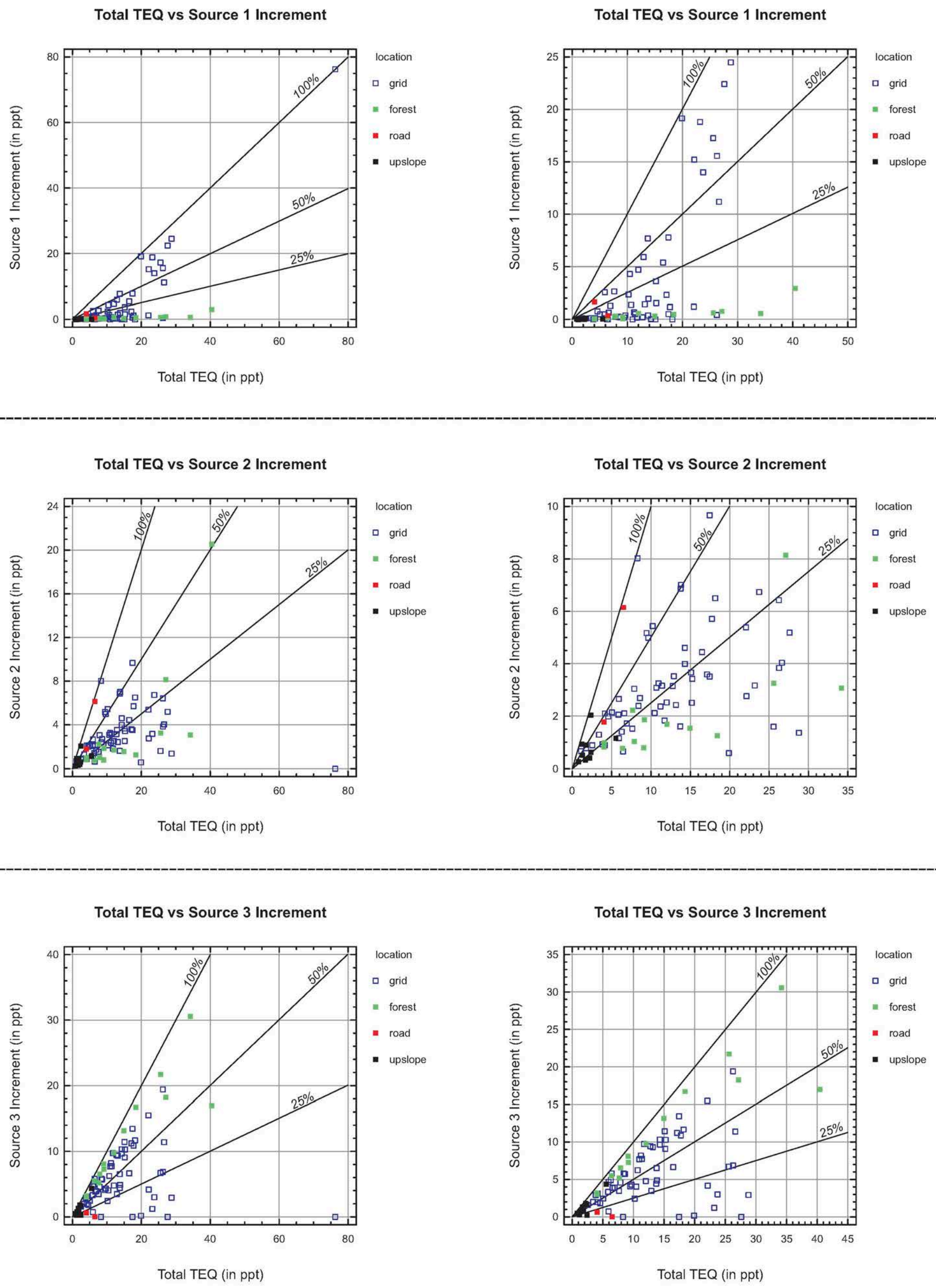


Figure 8-12 Ternary plot of sample compositions


Comparison of Source Increment TEQs
TEQ: Increment or Total (in ppt)
80
60
40
20
0
Source1
Source2
Source3
TEQ


Comparison of Source Increment TEQs
45
40
35
30
25
20
15
10
5
0
Source1
Source2
Source3
TEQ



Note: Scatter plots in right hand column omit one or two high outlier values and rescale the axes to better show patterns for the bulk of the data points.

Figure 8-15 Scatter plots showing source increment contributions to total TEQ

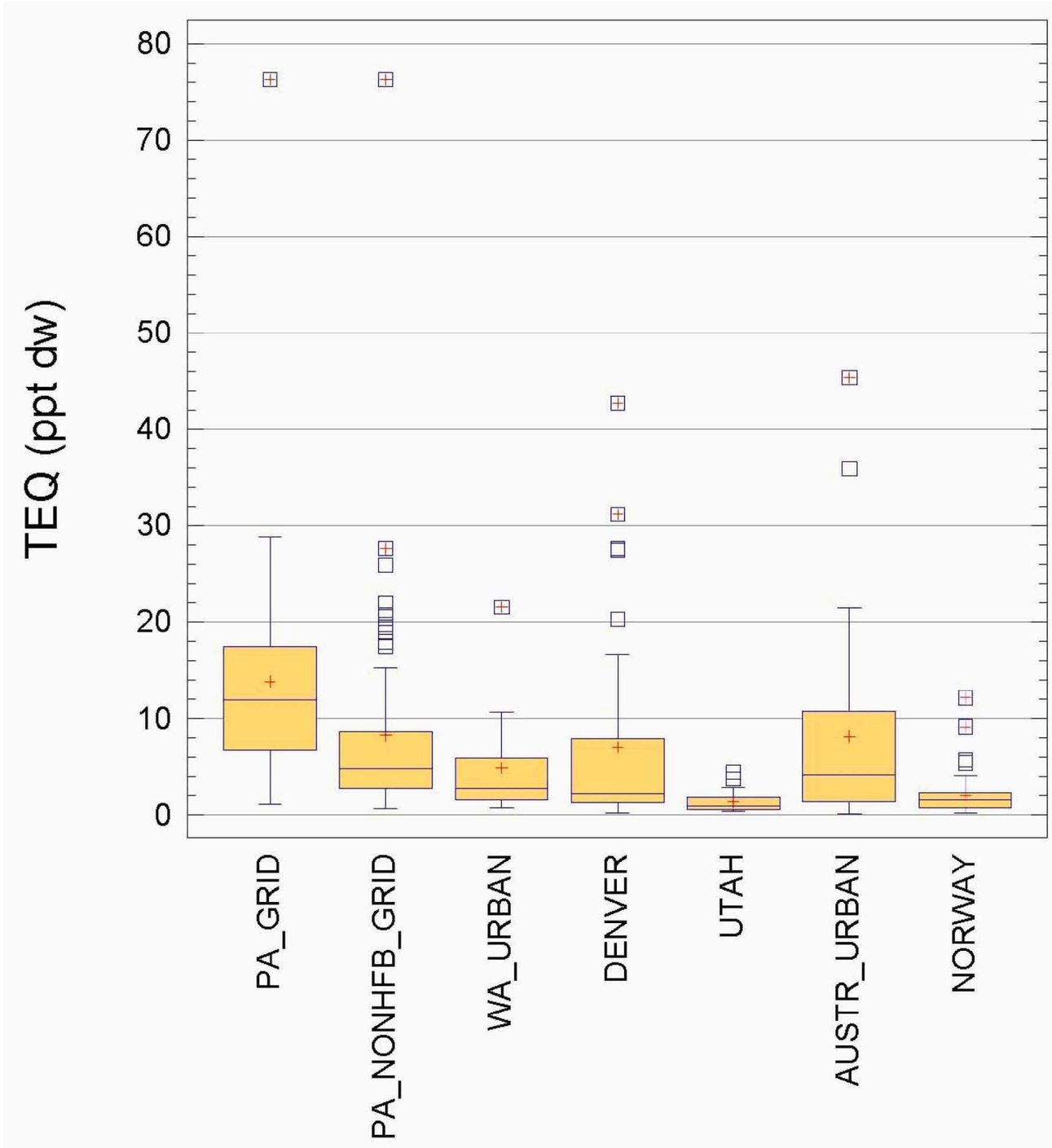


Figure 8-16 Comparison of soil TEQs: Port Angeles minus Source 3 versus urban soils

Unmixing: Spatial Pattern

- Source 1 TEQ increments show generally low values, with a few scattered higher values, and no overall spatial pattern
- Source 2 TEQ increments show relatively even spatial distribution at moderate values, with a few higher results
- Source 3 TEQ increments at grid locations show strong spatial pattern with higher values near Rayonier Mill and a few higher values near the W study area boundary

Unmixing: Spatial Pattern (continued)

- Source 2 and Source 3, but not Source 1, TEQ increments show a general urban to rural gradient
- For nearly co-located grid and forest samples, forest samples have higher total TEQs and higher Source 3 contributions

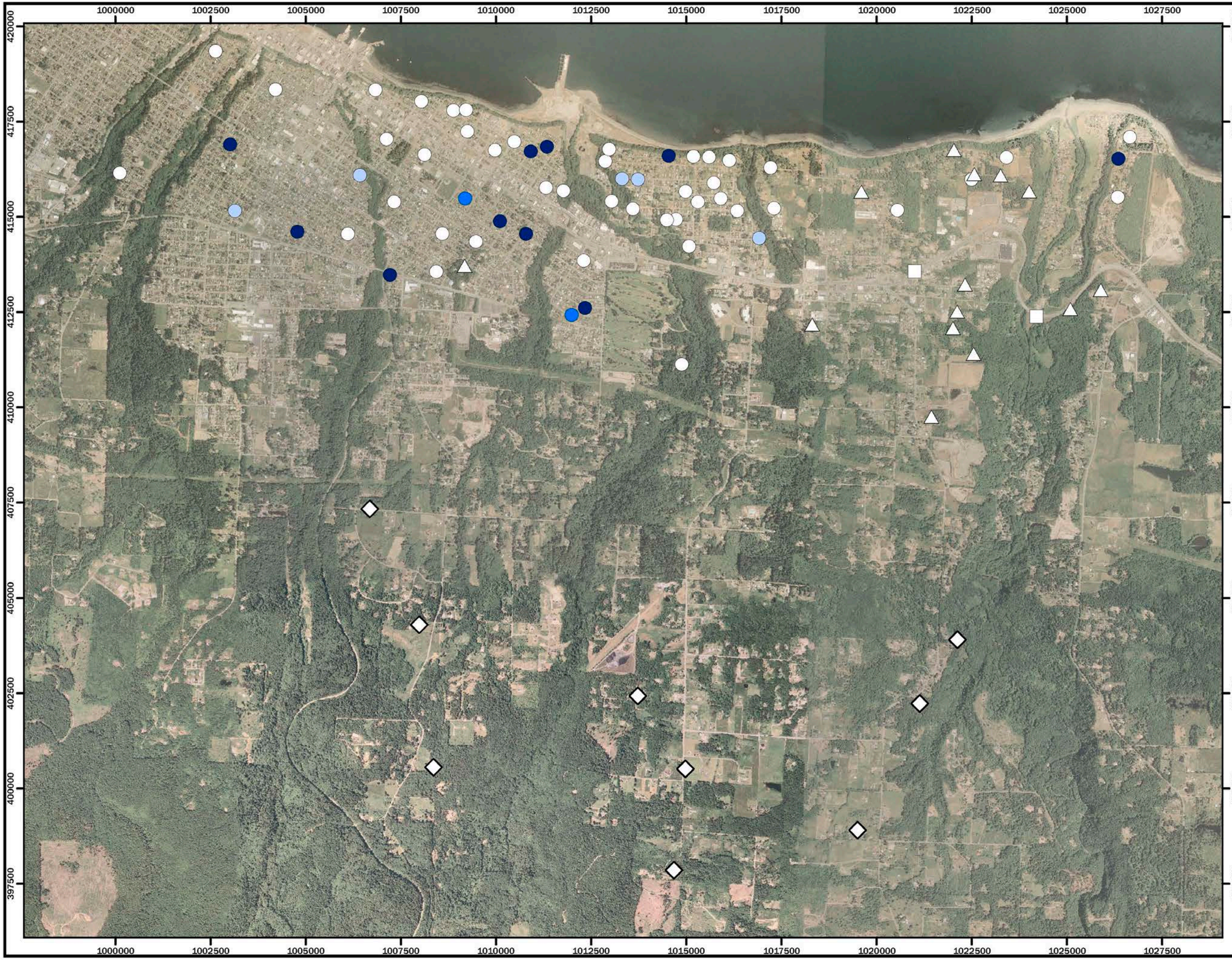


Figure 8-18.
Unmixing model Souce 1 TEQ increments
Rayonier Mill Off-Property
Soil Dioxin Study
Port Angeles, WA.

Legend

TEQ (ND = 1/2 DL) concentrations shown in ng/kg

- 0 to 3
- 3 to 7
- 7 to 11
- > 11

Soil sample type

- Forested
- Grid
- Highway
- Transect

Note: Contour plots used in these data evaluations cannot predict values at unsampled locations. Rather, they help visualize the large-scale distribution of the Port Angeles soils data. Local variability in dioxin/furan concentrations may be high and is likely to reflect individual property histories.

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HERRERA ENVIRONMENTAL CONSULTANTS

0 1,250 2,500 5,000 feet

Coordinates: Washington State Plane South
NAD 83 (feet)
Aerial: USDA, 2006

N

Produced By: GIS (RDR)
Project:
K:\Projects\06-03386-006\Collected_Samples\TEQ_Calc\TEQ Increment Grid Dots and Contours.mxd

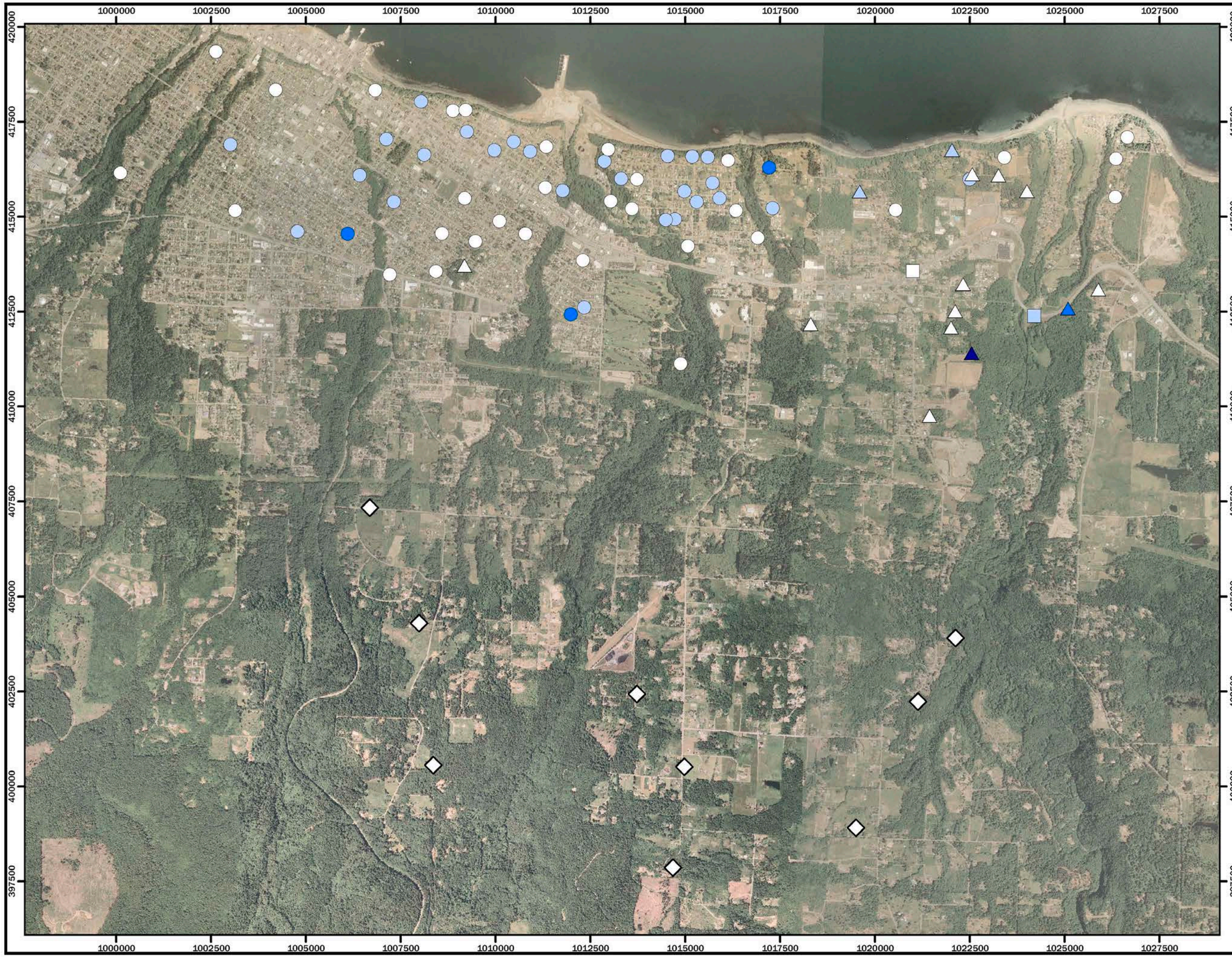

Figure 8-19.
Unmixing model Souce 2 TEQ increments
Rayonier Mill Off-Property
Soil Dioxin Study
Port Angeles, WA

Legend

TEQ (ND = 1/2 DL) concentrations shown in ng/kg

- 0 to 3
- 3 to 7
- 7 to 11
- > 11

Soil sample type

- Forested
- Grid
- Highway
- Transect

Note: Contour plots used in these data evaluations cannot predict values at unsampled locations. Rather, they help visualize the large-scale distribution of the Port Angeles soils data. Local variability in dioxin/furan concentrations may be high and is likely to reflect individual property histories.

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HERRERA ENVIRONMENTAL CONSULTANTS

0 1,250 2,500 5,000 feet

Coordinates: Washington State Plane South
NAD 83 (feet)
Aerial: USDA, 2006

N

Produced By: GIS (RDR)
Project:
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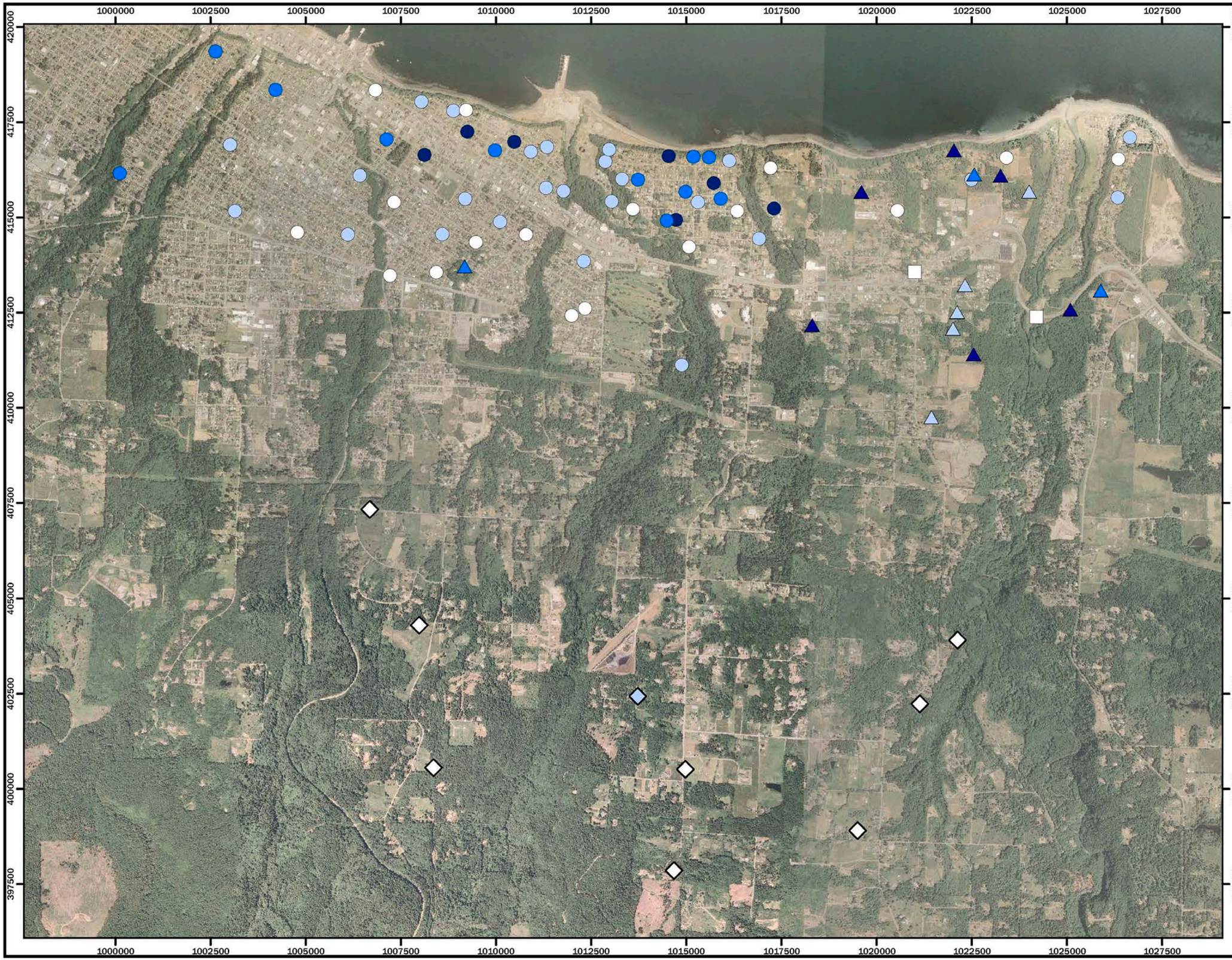

Figure 8-20.
Unmixing model Souce 3 TEQ increments
Rayonier Mill Off-Property
Soil Dioxin Study
Port Angeles, WA

Legend

TEQ (ND = 1/2 DL) concentrations shown in ng/kg

- 0 to 3
- 3 to 7
- 7 to 11
- > 11

Soil sample type

- Forested
- Grid
- Highway
- Transect

Note: Contour plots used in these data evaluations cannot predict values at unsampled locations. Rather, they help visualize the large-scale distribution of the Port Angeles soils data. Local variability in dioxin/furan concentrations may be high and is likely to reflect individual property histories.

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HERRERA ENVIRONMENTAL CONSULTANTS

0 1,250 2,500 5,000 feet

Coordinates: Washington State Plane South
NAD 83 (feet)
Aerial: USDA, 2006

N

Produced By: GIS (RDR)
Project:
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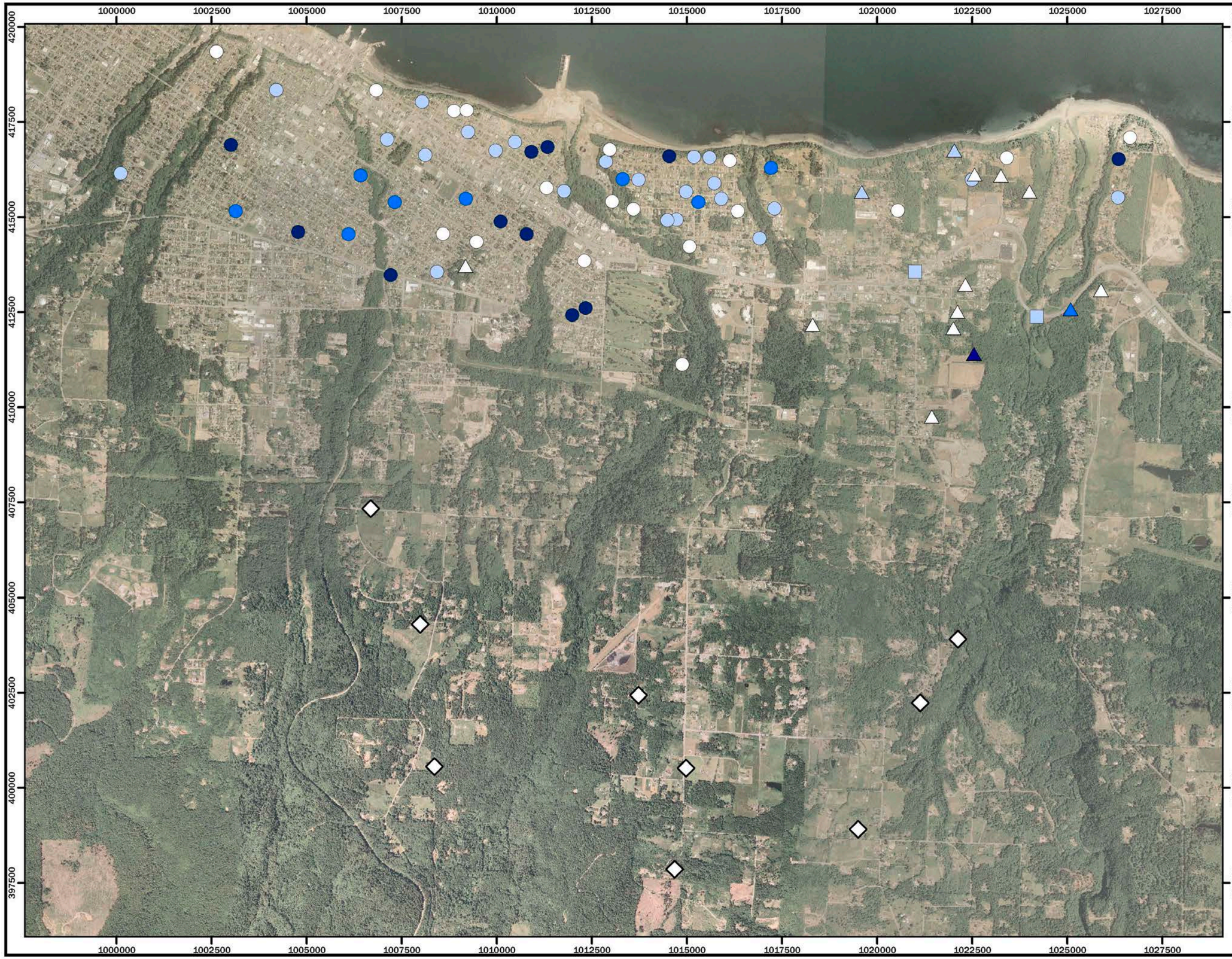

Figure 8-21.
Unmixing model Souce 1 plus Source 2 TEQ increments
Rayonier Mill Off-Property Soil Dioxin Study
Port Angeles, WA

Legend

TEQ (ND = 1/2 DL) concentrations shown in ng/kg

- 0 to 3
- 3 to 7
- 7 to 11
- > 11

Soil sample type

- Forested
- Grid
- Highway
- Transect

Note: Contour plots used in these data evaluations cannot predict values at unsampled locations. Rather, they help visualize the large-scale distribution of the Port Angeles soils data. Local variability in dioxin/furan concentrations may be high and is likely to reflect individual property histories.

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HERRERA ENVIRONMENTAL CONSULTANTS

0 1,250 2,500 5,000 feet

Coordinates: Washington State Plane South
NAD 83 (feet)
Aerial: USDA, 2006

N

Produced By: GIS (RDR)
Project:
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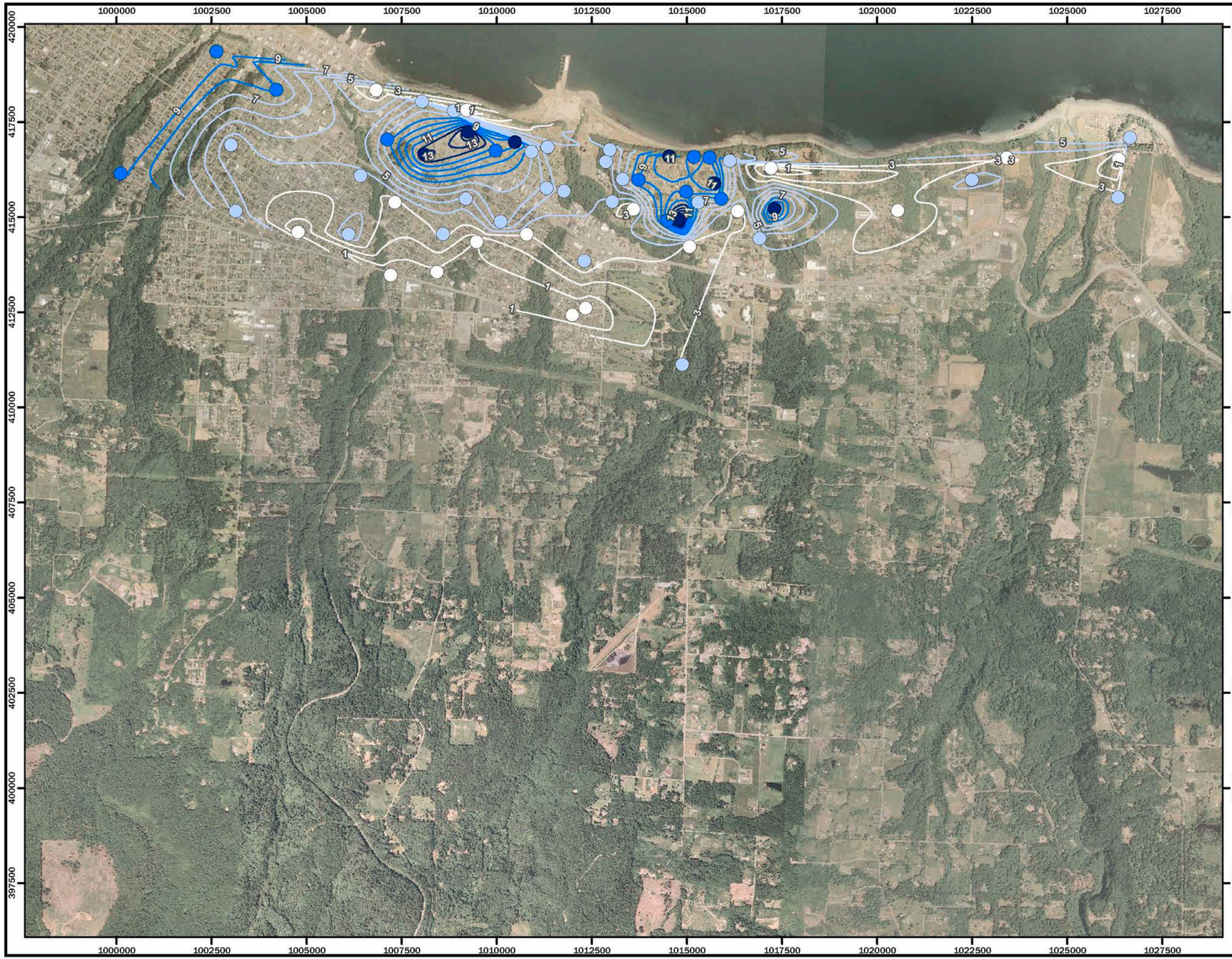

Figure 8-22.
Unmixing model Souce 3 TEQ increments: contour map - grid samples
Rayonier Mill Off-Property
Soil Dioxin Study
Port Angeles, WA

Legend

TEQ (ND = 1/2 DL) concentrations shown in ng/kg

- 0 to 3
- 3 to 7
- 7 to 11
- > 11

Soil sample type

- Forested
- Grid
- Highway
- Transect

Note: Contour plots used in these data evaluations cannot predict values at unsampled locations. Rather, they help visualize the large-scale distribution of the Port Angeles soils data. Local variability in dioxin/furan concentrations may be high and is likely to reflect individual property histories.

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HERRERA ENVIRONMENTAL CONSULTANTS

0 1,250 2,500 5,000 feet

Coordinates: Washington State Plane South
NAD 83 (feet)
Aerial: USDA, 2006

N

Produced By: GIS (RDR)
Project:
K:\Projects\06-03386-006\Collected_Samples\TEQ_Calc\TEQ Increment Grid Dots and Contours.mxd

Mass Balance – Exploratory Analysis

- Source 3 TEQ increments contribute an estimated 7.5 grams TEQ (Source 3 profile only) to study area
- Local deposition from dioxin air emissions is limited; long range transport for much of mass emissions
- Source 3 cumulative mass emissions at tens of grams TEQ required to account for sampling results and modeled Source 3 contributions

Mass Balance (continued)

- Direct measurements to estimate Port Angeles facility mass emissions lacking
- Exploratory evaluations indicate Rayonier HFB a credible source for tens of grams TEQ cumulative mass emissions
- Other Port Angeles wood-burning industrial facilities also possible sources, individually or collectively, for similar mass emissions
- Residential wood burning not a credible source
- Medical waste incinerator not a credible source, and that emissions class has a distinct profile

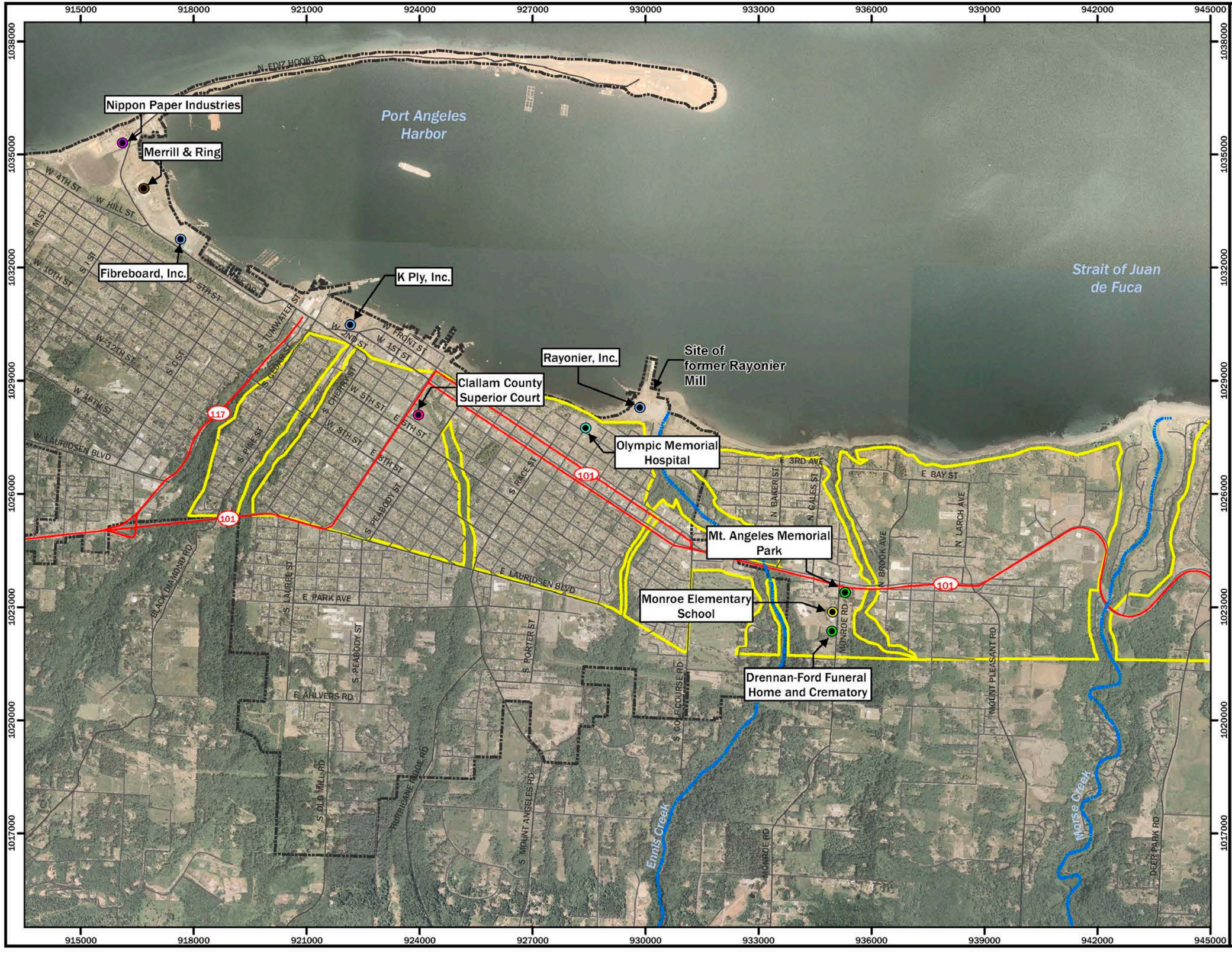

Figure 2-1.
Potential Fixed Sources of Dioxins/Furans in Port Angeles
Rayonier Mill Off-Property Soil Dioxin Study
Port Angeles, WA

Legend

Potential Dioxins/Furans Sources

- Current Boiler
- Current Crematoria
- Current Diesel Boiler
- Current Hog Boiler
- Current Propane Boiler
- Historic Sawmill
- Historic Hog Boiler
- Historic medical waste incinerator
- River
- Highway
- Arterial or Collector Road
- Road
- Study Area Boundary
- Port Angeles City Limits

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0 1,250 2,500 5,000 feet

Coordinates: Washington State Plane South
NAD 83 (feet)
Aerial: USDA, 2006

N

Produced By: GIS (JAS)
Project:
K:/Projects/06-03386-006/Projects/Dioxin and Furan Sources.mxd (06/22/2011)

Conclusions

- Soil samples from this study area include frequent results moderately above the MTCA Method B value of 11.1 ng TEQ/kg
- Total TEQ results in this study appear somewhat higher than other urban soil dioxin studies
- Unmixing analyses identify one source profile similar to the pattern from HFBs burning salt-laden wood

Conclusions (continued)

- Contributions from the HFB source profile show a spatial relationship to the Rayonier HFB stack
- Contributions from the HFB source profile have the largest overall impact on sample total TEQs in this study
- A separate source profile similar to the herbicide 2,4,5-T (Silvex) has the largest contribution to a subset of higher TEQ samples, with otherwise low contributions study-wide

Conclusions (continued)

- A third source profile has moderate and relatively uniform TEQ increments at values typical of total TEQs in other urban soil studies
- Rayonier HFB emissions have impacted soil dioxin/furan concentrations beyond the Rayonier Mill property boundary

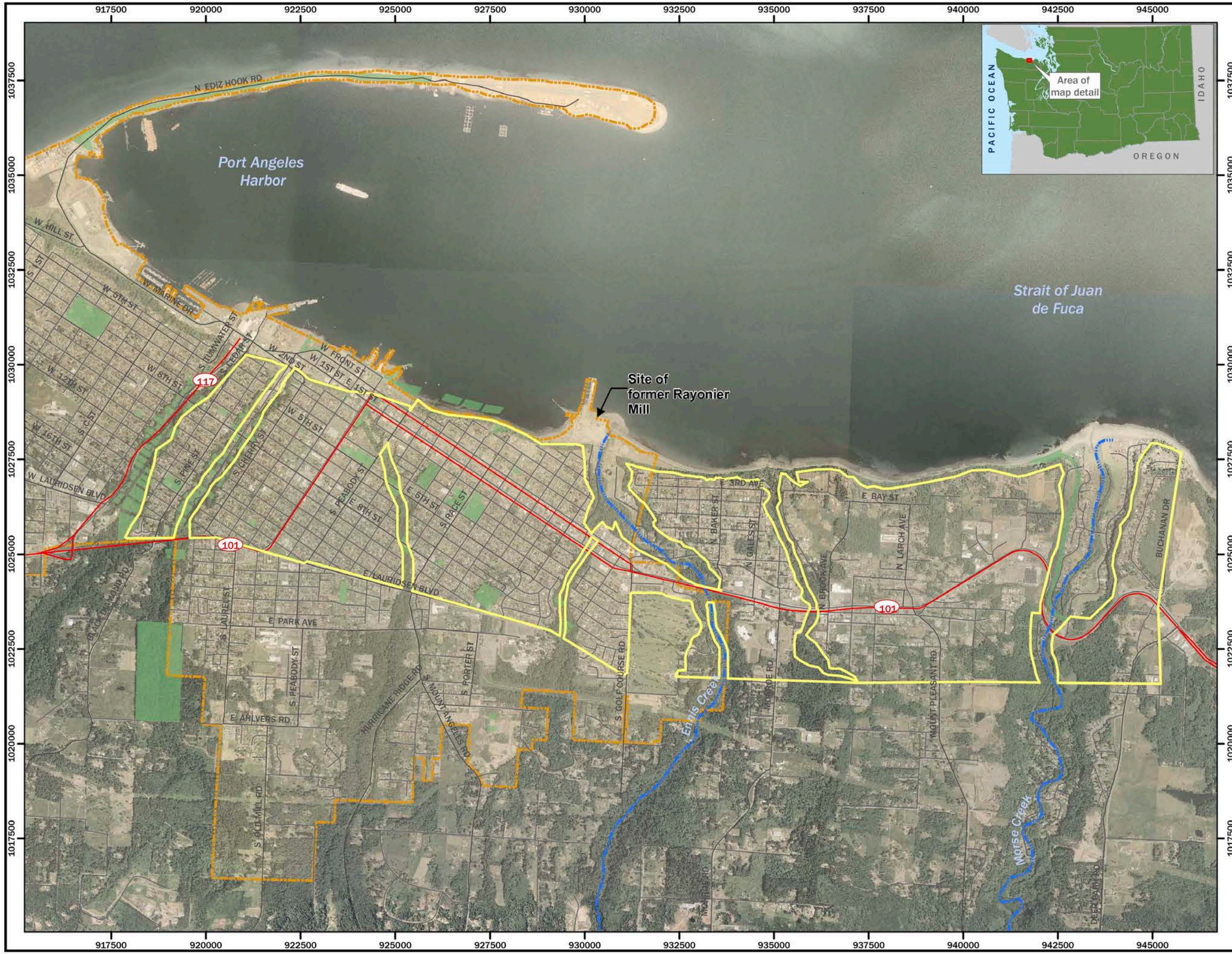

Figure 3-1
Study Area Boundary
Rayonier Mill Off-Property
Soil Dioxin Study
Port Angeles, WA

Legend

- Study Area Boundary
- River
- Highway
- Arterial or Collector Road
- Road
- Port Angeles City Limits
- Park

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HERRERA ENVIRONMENTAL CONSULTANTS

0 1,250 2,500 5,000 feet

Coordinates: Washington State Plane South
NAD 83 (feet)
Aerial: USDA, 2006

N

Produced By: GIS (JAS)
Project:
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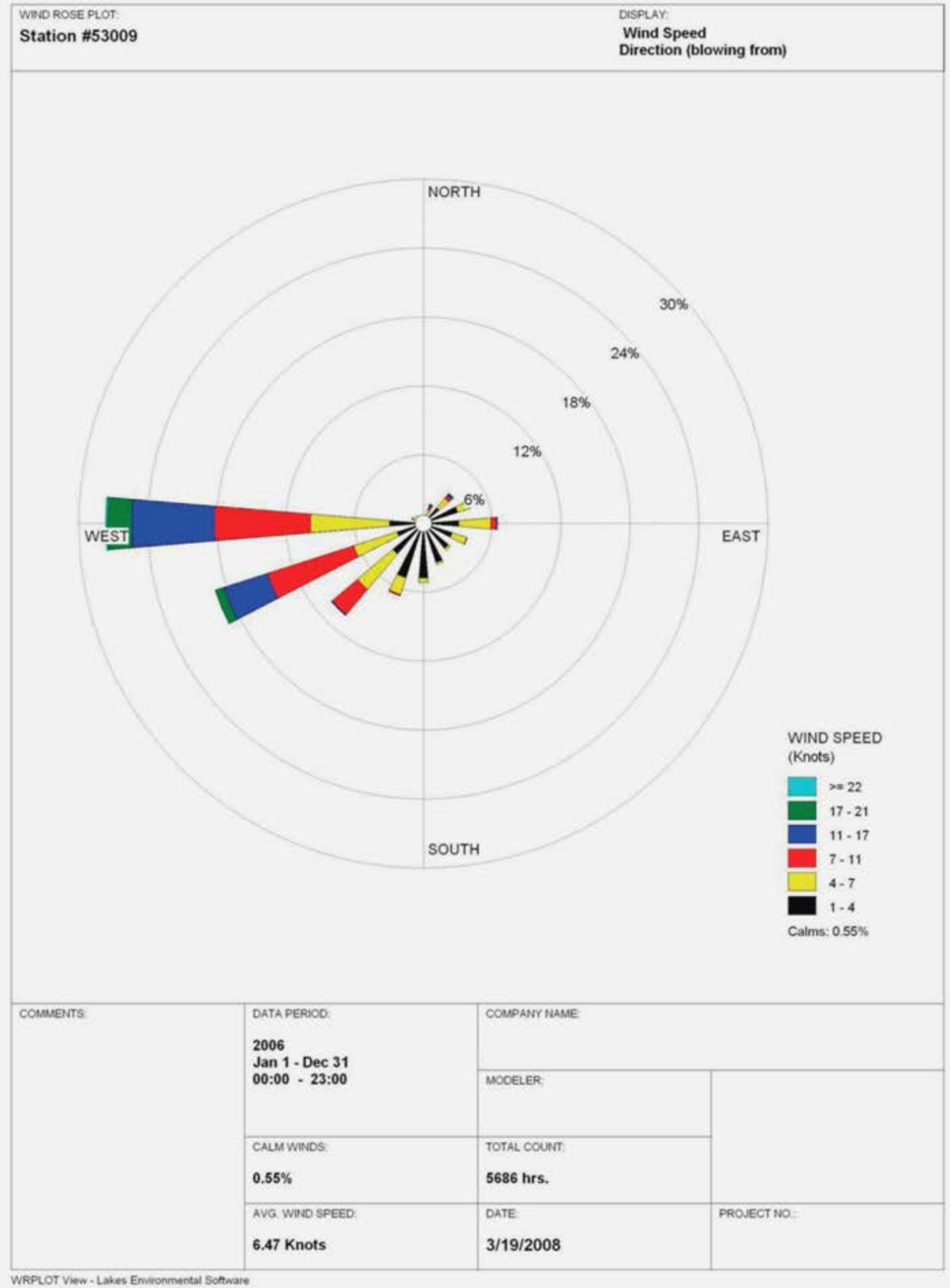

Figure 3-2 Wind rose for Ediz Hook, Port Angeles – 2006

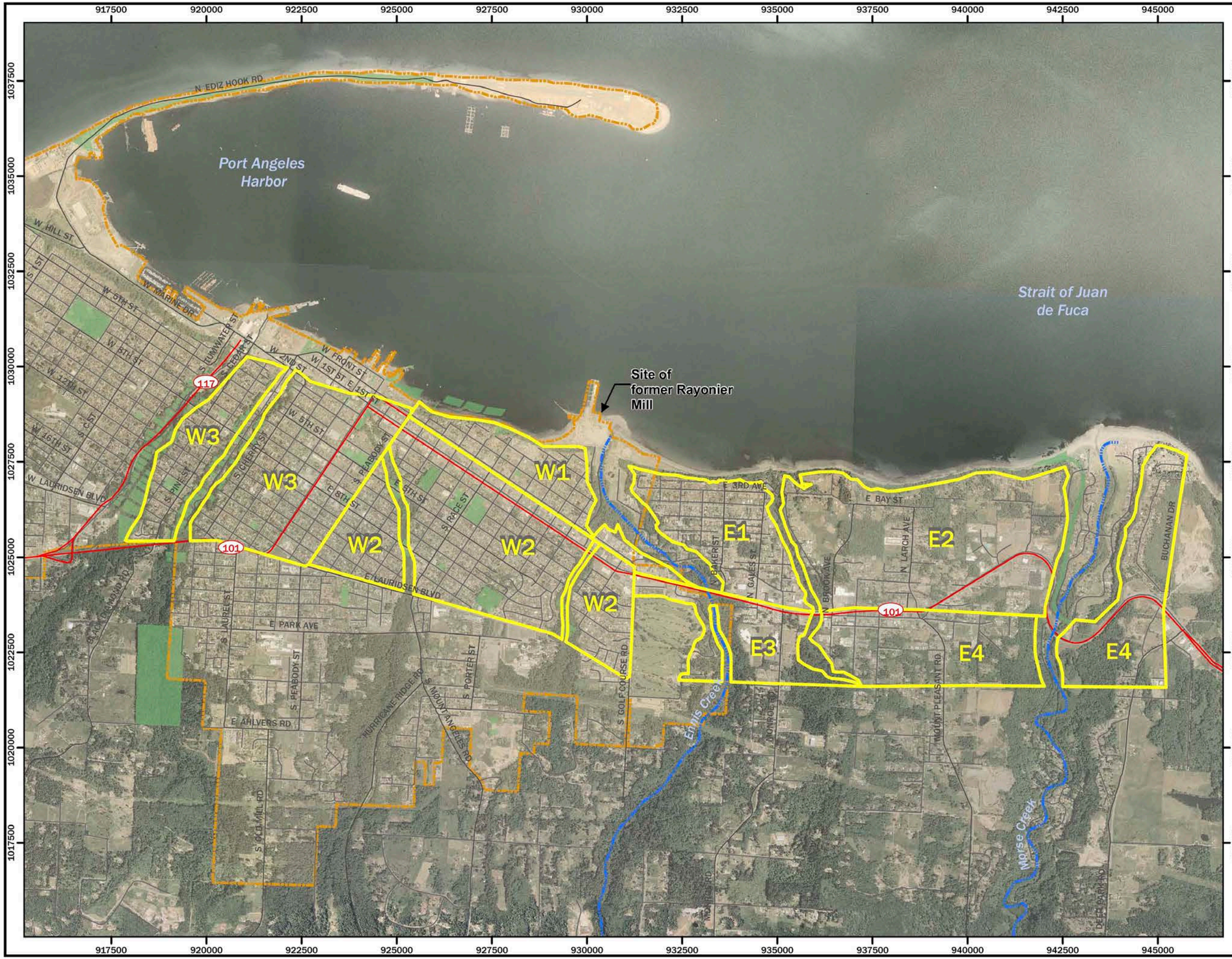

Figure 3-3
Sample Zones
Rayonier Mill Off-Property
Soil Dioxin Study
Port Angeles, WA

Legend

- Sample Zone Boundary
- River
- Highway
- Arterial or Collector Road
- Road
- Port Angeles City Limits
- Park

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HERRERA ENVIRONMENTAL CONSULTANTS

0 1,250 2,500 5,000 feet

Coordinates: Washington State Plane South
NAD 83 (feet)
Aerial: USDA, 2006

N

Produced By: GIS (JAS)
Project:
K:/Projects/06-03386-006/Projects/Study Area Zones.mxd (06/06/2008)

Figure 4-1
Samples collected in zone W1.
Rayonier Mill Off-Property
Soil Dioxin Study
Port Angeles, WA.

Legend

Soil sample type

- Forested
- Grid
- Highway
- Transect
- Grid cell boundary
- Arterial or Collector Road
- Road

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0 325 650 1,300 feet

Coordinates: Washington State Plane South
NAD 83 (feet)
Aerial: USDA, 2006

N

Produced By: GIS (RDR)
Project:
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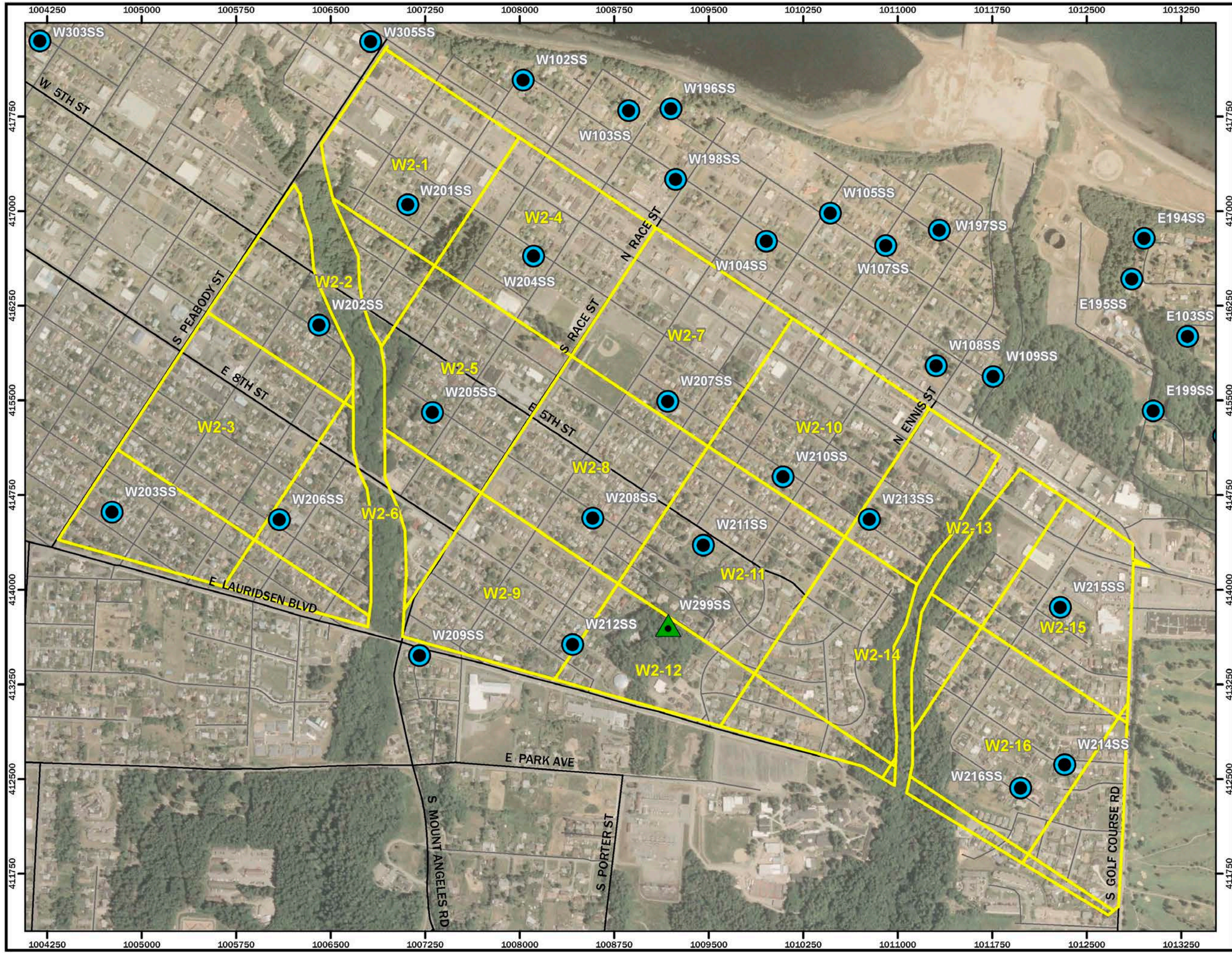

Figure 4-2
Samples collected in zone W2.
Rayonier Mill Off-Property
Soil Dioxin Study
Port Angeles, WA.

Legend

Soil sample type

- Forested
- Grid
- Highway
- Transect
- Grid cell boundary
- Arterial or Collector Road
- Road

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HERRERA ENVIRONMENTAL CONSULTANTS

0 375 750 1,500 feet

Coordinates: Washington State Plane South
NAD 83 (feet)
Aerial: USDA, 2006

N

Produced By: GIS (JAS)
Project:
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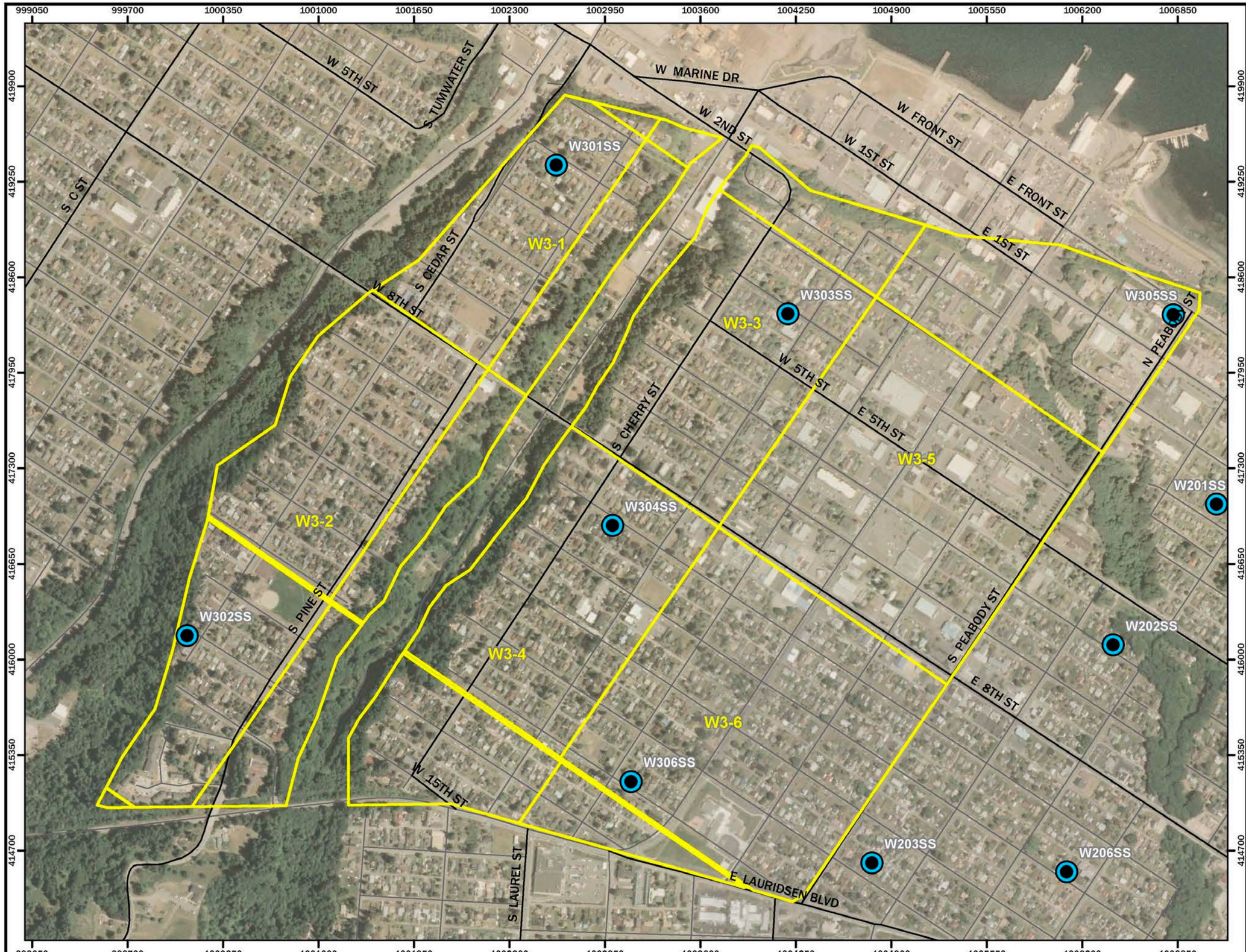

Figure 4-3.
Samples collected in zone W3
Rayonier Mill Off-Property
Soil Dioxin Study
Port Angeles, WA.

Legend

Soil sample type

- Forested
- Grid
- Highway
- Transect
- Grid cell boundary
- Arterial or Collector Road
- Road

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HERRERA ENVIRONMENTAL CONSULTANTS

0 325 650 1,300 feet

Coordinates: Washington State Plane South
NAD 83 (feet)
Aerial: USDA, 2006

N

Produced By: GIS (RDR)
Project:
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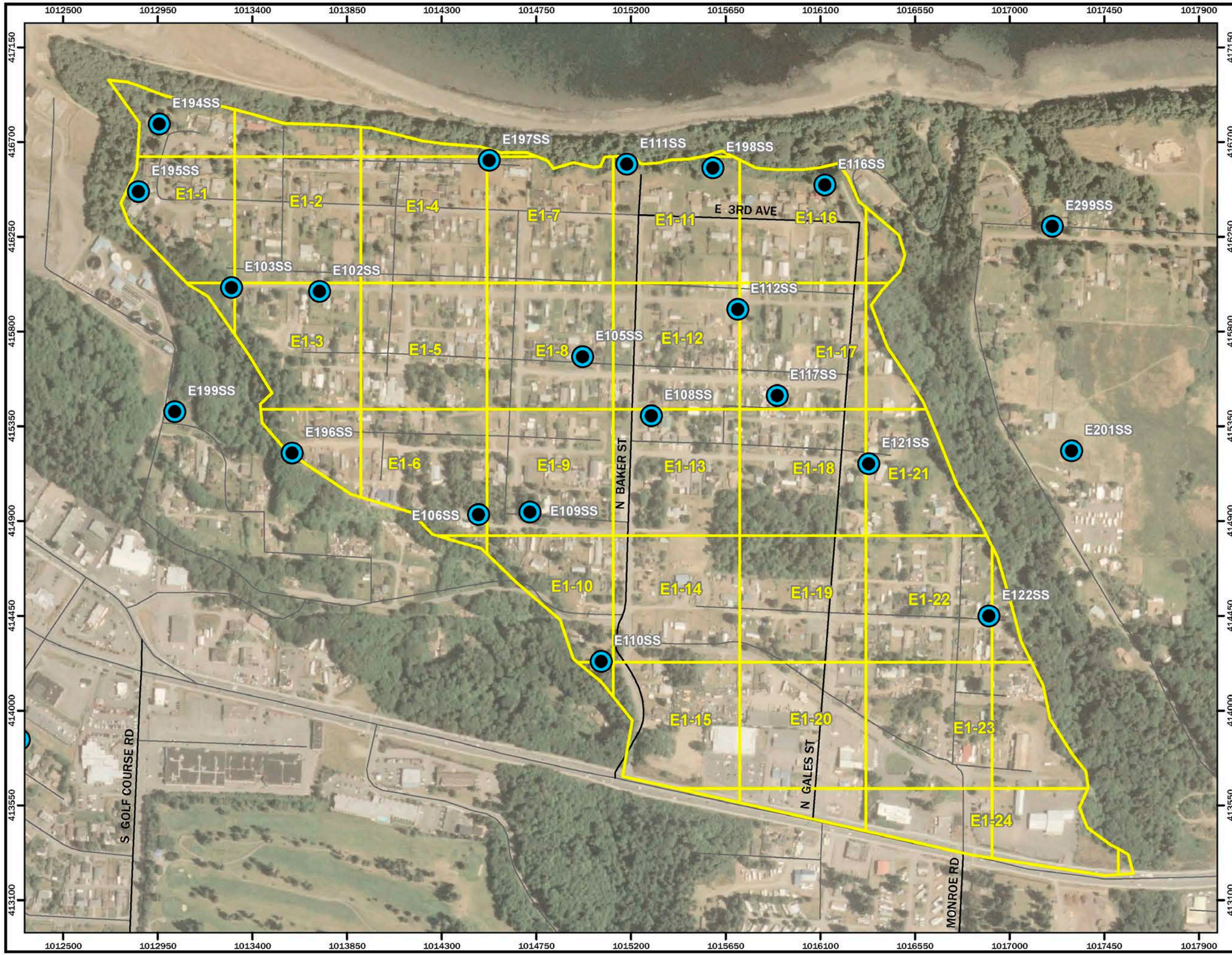

Figure 4-4.
Samples collected in zone E1
Rayonier Mill Off-Property
Soil Dioxin Study
Port Angeles, WA

Legend

Soil sample type

- Forested
- Grid
- Highway
- Transect
- Grid cell boundary
- Arterial or Collector Road
- Road

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HERRERA ENVIRONMENTAL CONSULTANTS

0 225 450 900 feet

Coordinates: Washington State Plane South
NAD 83 (feet)
Aerial: USDA, 2006

N

Produced By: GIS (RDR)
Project:
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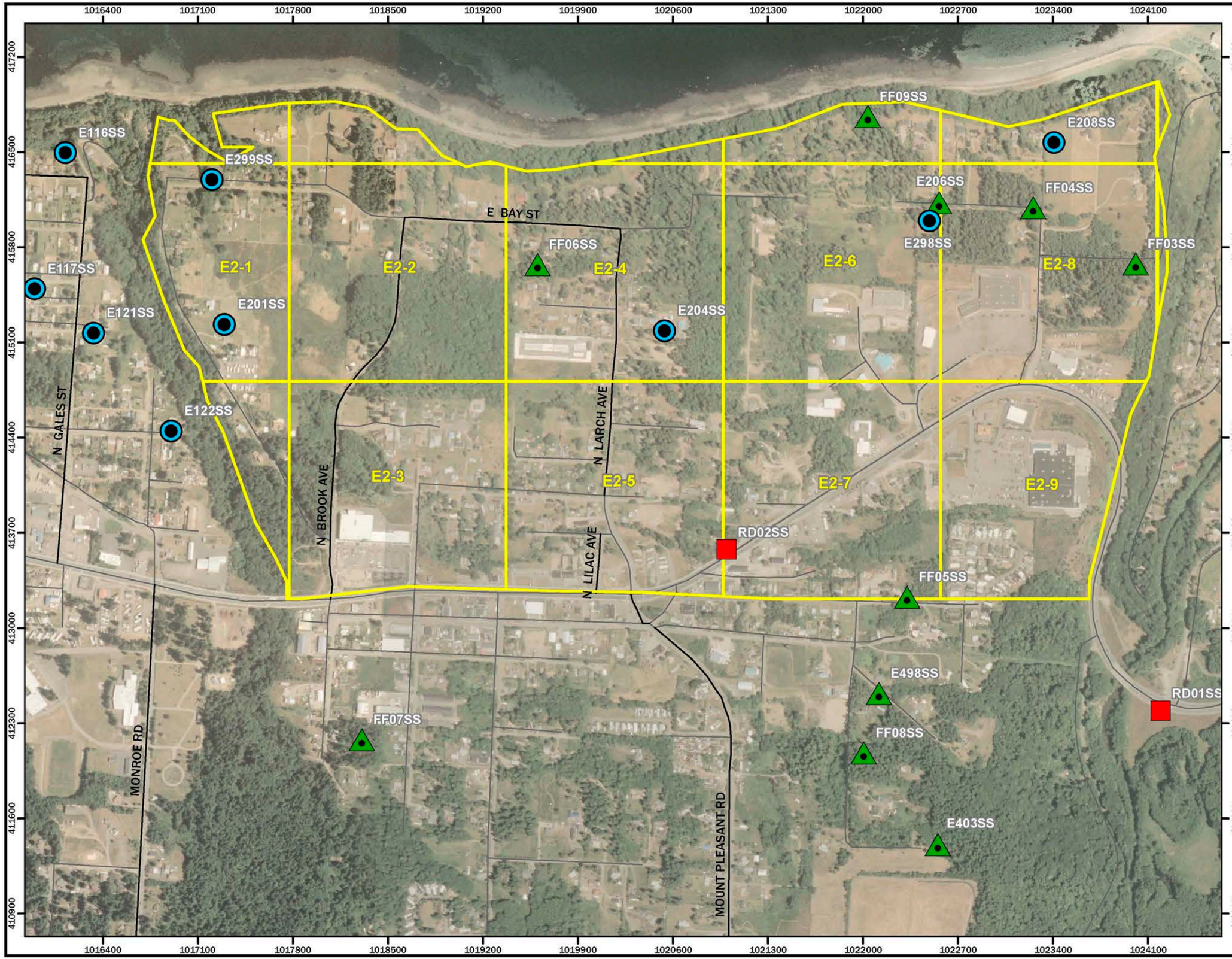

Figure 4-5.
Samples collected in zone E2.
Rayonier Mill Off-Property
Soil Dioxin Study
Port Angeles, WA

Legend

Soil sample type

- Forested
- Grid
- Highway
- Transect
- Arterial or Collector Road
- Road

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HERRERA ENVIRONMENTAL CONSULTANTS

0 350 700 1,400 feet

Coordinates: Washington State Plane South
NAD 83 (feet)
Aerial: USDA, 2006

N

Produced By: GIS (JAS)
Project:
K:/Projects/06-03386-006/Collected_Samples/Samples Collected in Zone E-2.mxd (11/23/2009)

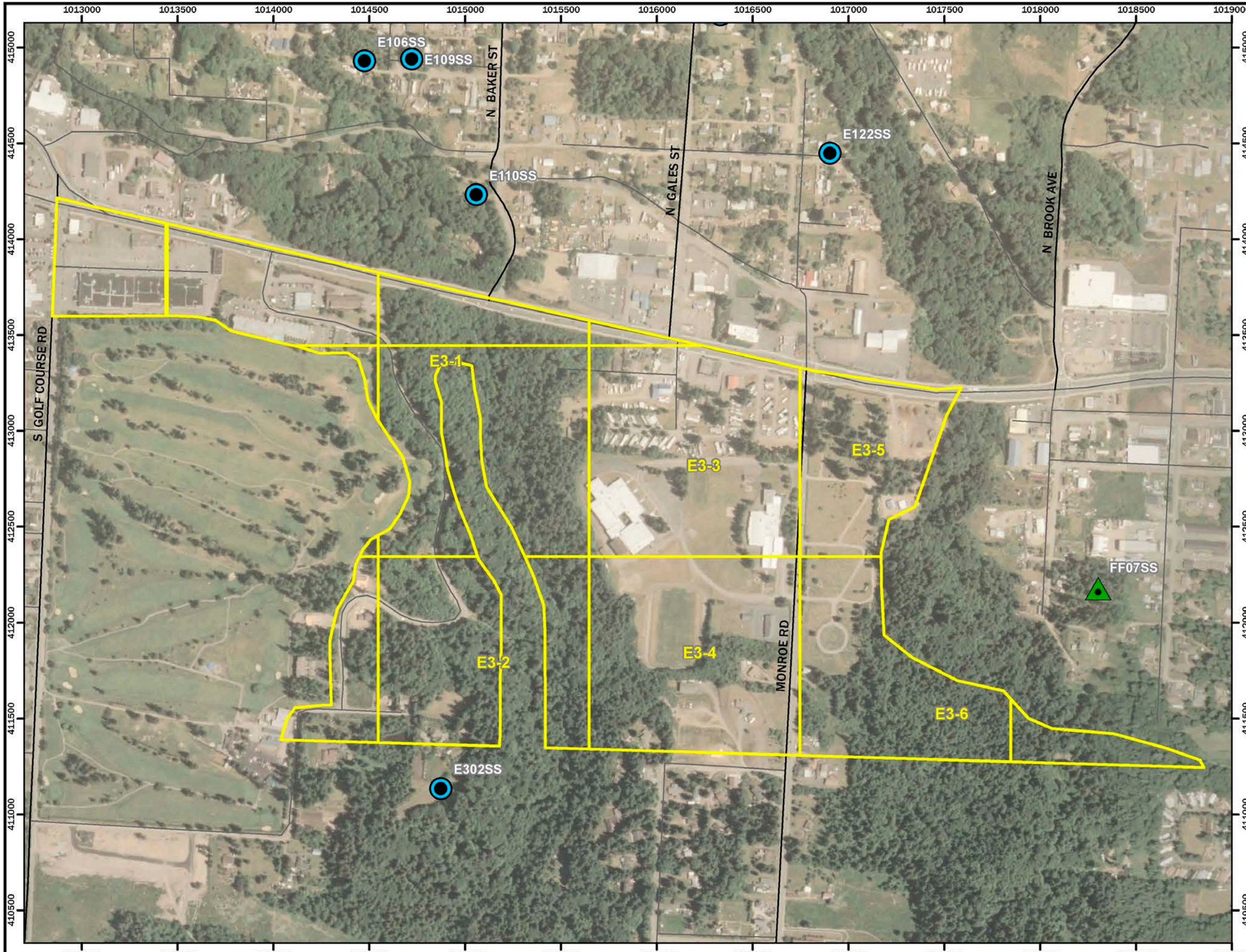

Figure 4-6.
Samples collected in zone E3
Rayonier Mill Off-Property
Soil Dioxin Study
Port Angeles, WA

Legend

Soil sample type

- Forested
- Grid
- Highway
- Transect
- Grid cell boundary
- Arterial or Collector Road
- Road

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0 250 500 1,000 feet

Coordinates: Washington State Plane South
NAD 83 (feet)
Aerial: USDA, 2006

N

Produced By: GIS (RDR)
Project:
K:/Projects/06-03386-006/Collected_Samples/Samples Collected in Zone E-3.mxd (02/19/2009)

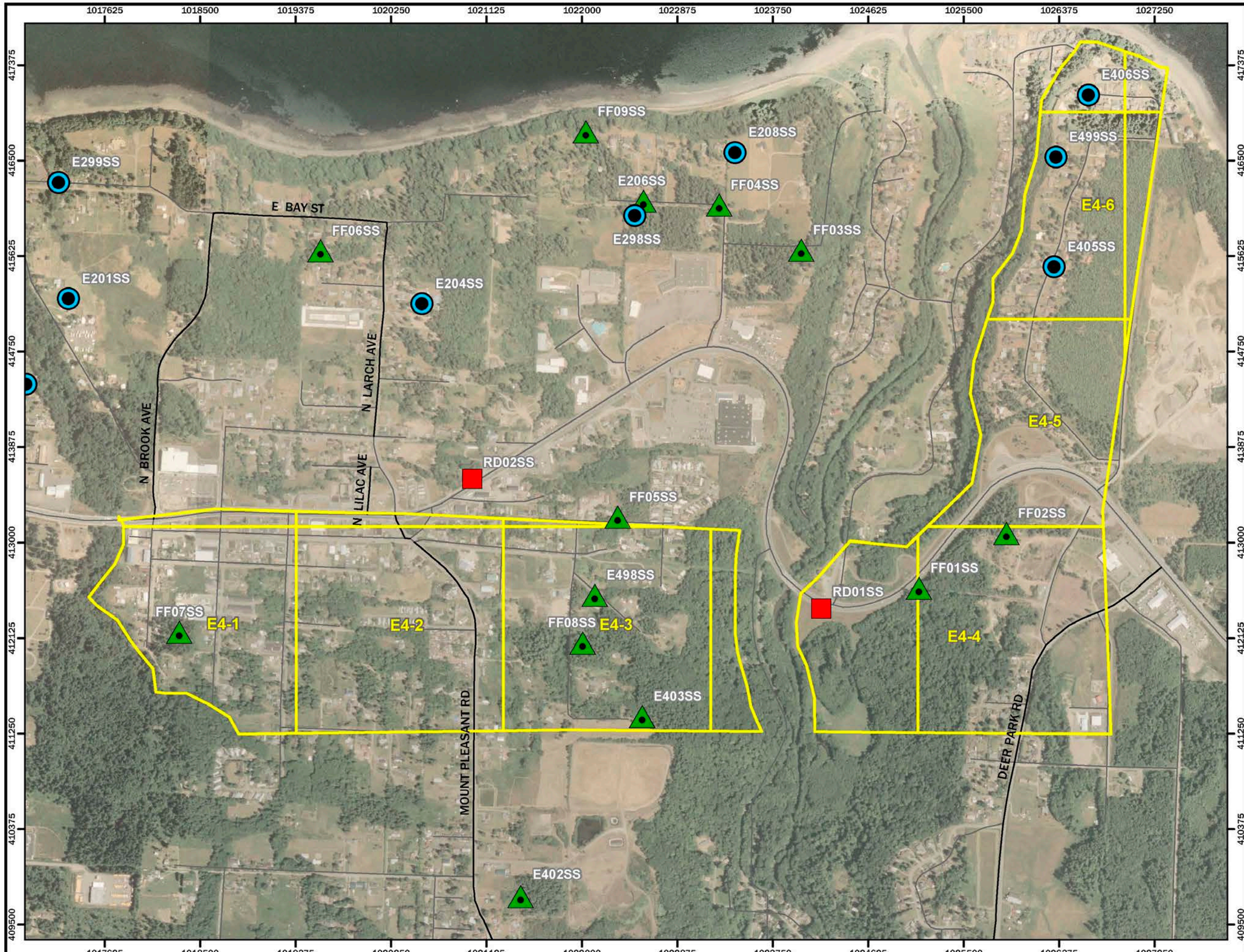

Figure 4-7
Samples collected in zone E4
Rayonier Mill Off-Property
Soil Dioxin Study
Port Angeles, WA

Legend

Soil sample type

- Forested
- Grid
- Highway
- Transect
- Grid cell boundary
- Arterial or Collector Road
- Road

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0 437.5 875 1,750 feet

Coordinates: Washington State Plane South
NAD 83 (feet)
Aerial: USDA, 2006

N

Produced By: GIS (RDR)
Project:
K:/Projects/06-03386-006/Collected_Samples/Samples Collected in Zone E-4.mxd (02/19/2009)

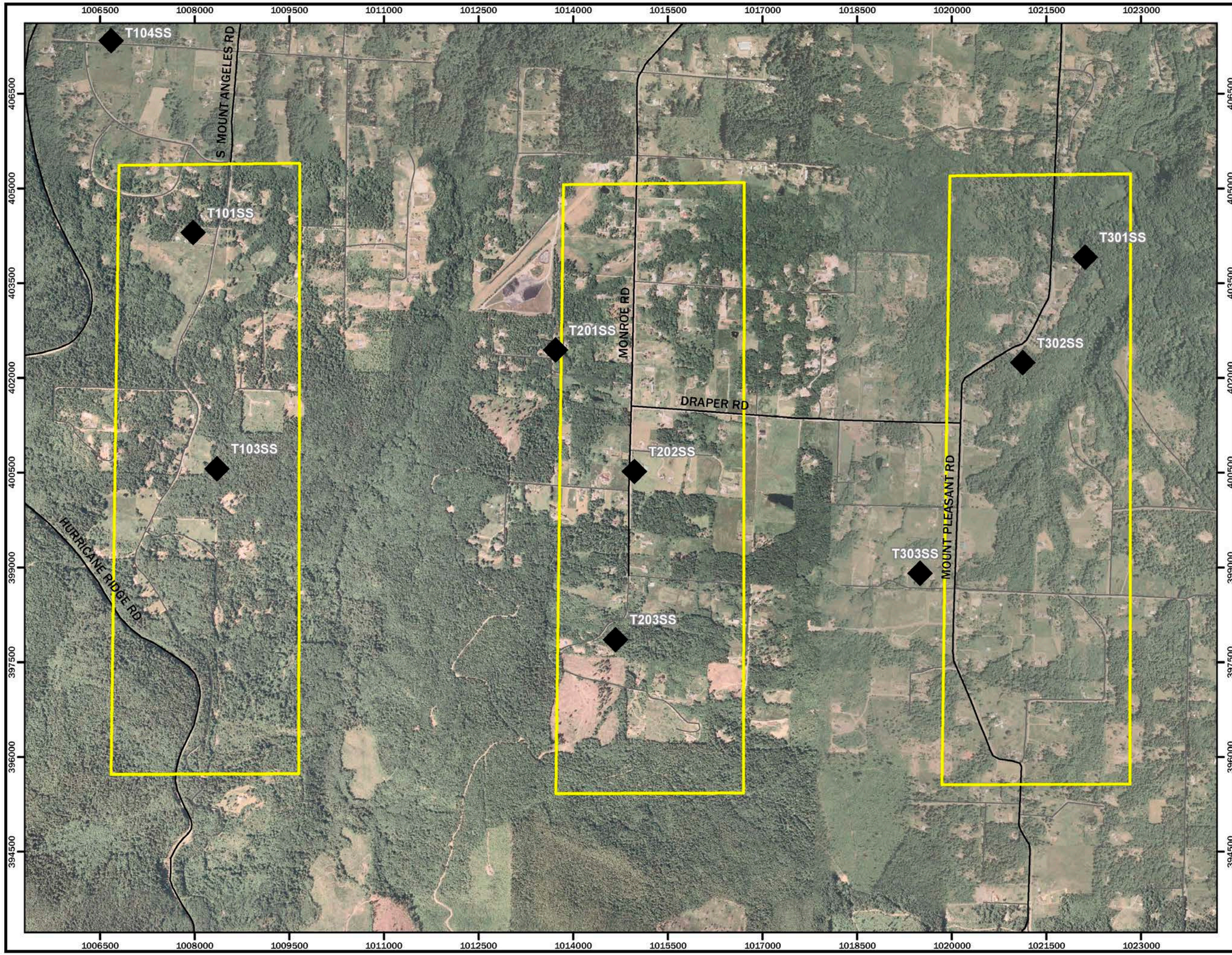

Figure 4-8.
Samples collected in upslope transect areas
Rayonier Mill Off-Property
Soil Dioxin Study
Port Angeles, WA

Legend

Soil sample type

- Forested
- Grid
- Highway
- Transect
- Upslope transect boundary
- Arterial or Collector Road
- Road

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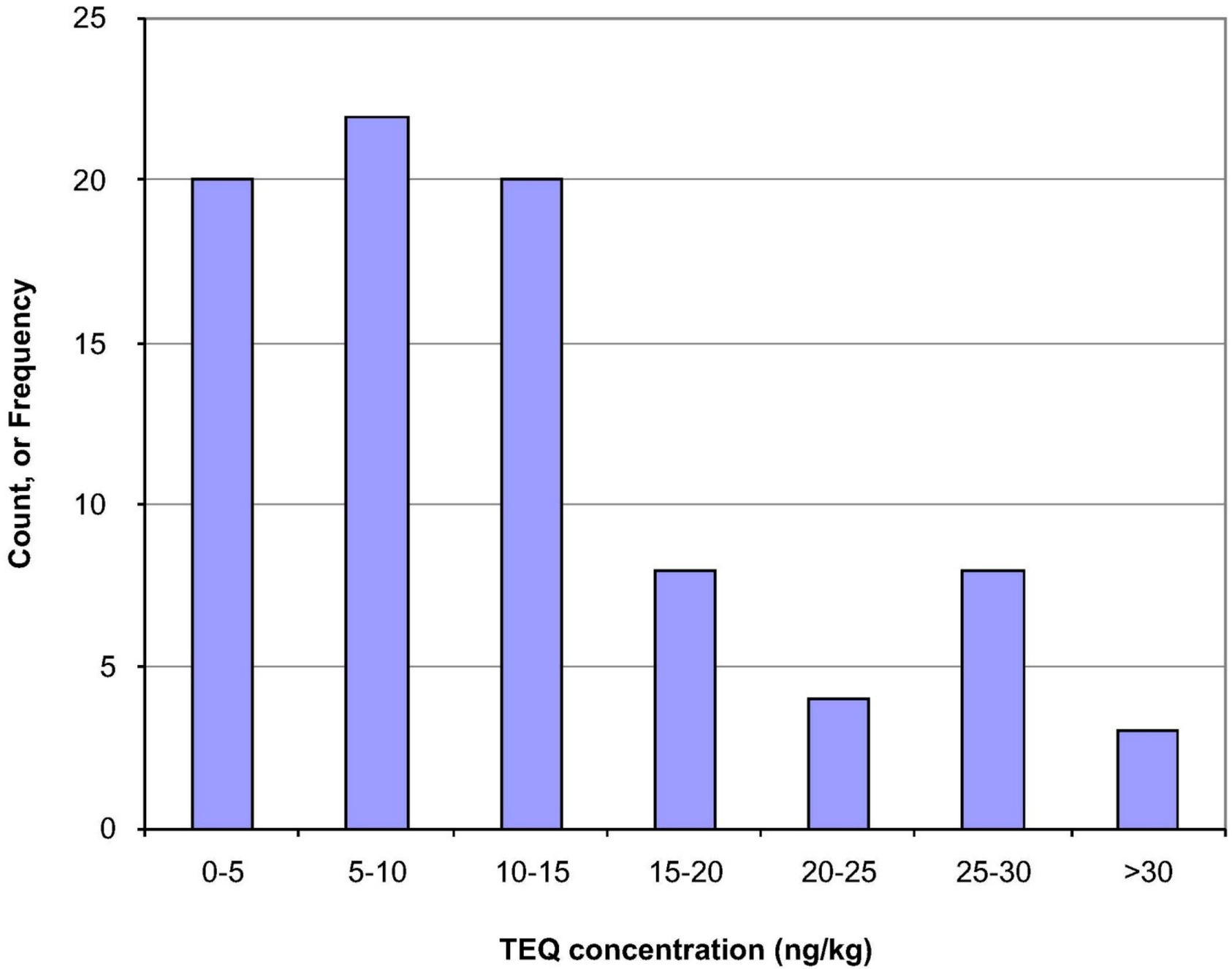
0 750 1,500 3,000 feet

Coordinates: Washington State Plane South
NAD 83 (feet)
Aerial: USDA, 2006

N

Produced By: GIS (RDR)
Project:
K:/Projects/06-03386-006/Collected_Samples/Samples Collected in Upslope Transects.mxd (02/19/2009)



Notes: Total sample count is 85.
TEQs based on ND=1/2DL.

Figure 6-1 Histogram of TEQ concentrations

Figure 6-3.
TEQ concentrations in Western zones
Rayonier Mill Off-Property
Soil Dioxin Study
Port Angeles, WA.

Legend

TEQ (ND=1/2 DL) concentrations shown in ng/kg

- 0 to 11
- 11 to 20
- 20 to 30
- > 30

Soil sample type

- Forested
- Grid
- Highway
- Transect
- Grid cell boundary
- Arterial or Collector Road
- Road

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0 600 1,200 2,400 feet

Coordinates: Washington State Plane South
NAD 83 (feet)
Aerial: USDA, 2006

N

Produced By: GIS (RDR)
Project:
K:/Projects/06-03386-006/Collected_Samples/Samples Collected in Western Zone.mxd (02/19/2009)

Figure 6-4.
TEQ concentrations in Eastern zones
Rayonier Mill Off-Property
Soil Dioxin Study
Port Angeles, WA

Legend

TEQ (ND=1/2 DL) concentrations shown in ng/kg

- 0 to 11
- 11 to 20
- 20 to 30
- > 30

Soil sample type

- Forested
- Grid
- Highway
- Transect
- Grid cell boundary
- Arterial or Collector Road
- Road

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HERRERA ENVIRONMENTAL CONSULTANTS

0 600 1,200 2,400 feet

Coordinates: Washington State Plane South
NAD 83 (feet)
Aerial: USDA, 2006

N

Produced By: GIS (RDR)
Project:
K:/Projects/06-03386-006/Collected_Samples/TEQ_Calc/TEQ Samples Collected in Eastern Zone.mxd

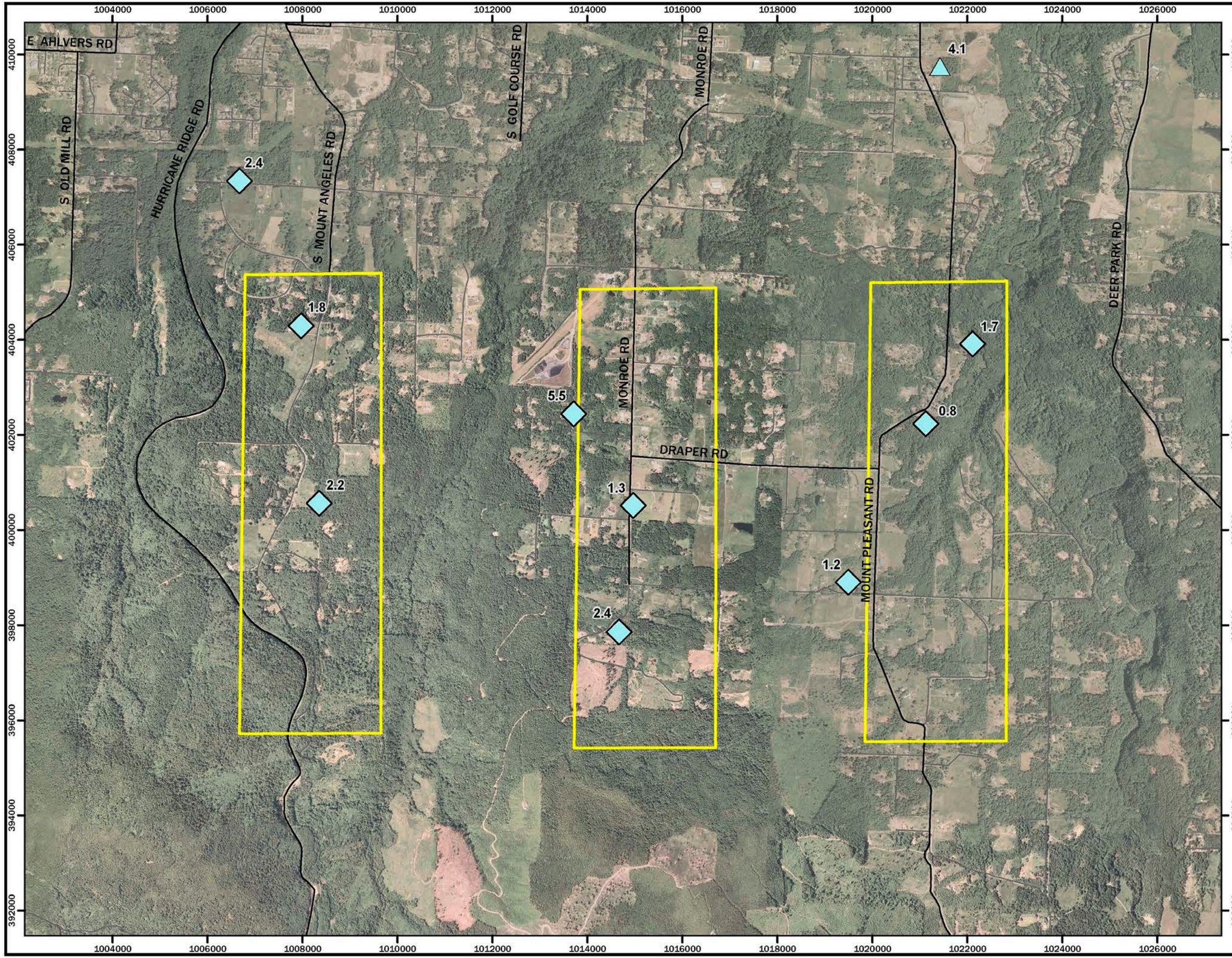

Figure 6-5.
TEQ concentrations in upslope transect areas
Rayonier Mill Off-Property
Soil Dioxin Study
Port Angeles, WA

Legend

TEQ (ND=1/2 DL) concentrations shown in ng/kg

- 0 to 11
- 11 to 20
- 20 to 30
- > 30

Soil sample type

- Forested
- Grid
- Highway
- Transect
- Upslope transect boundary
- Arterial or Collector Road
- Road

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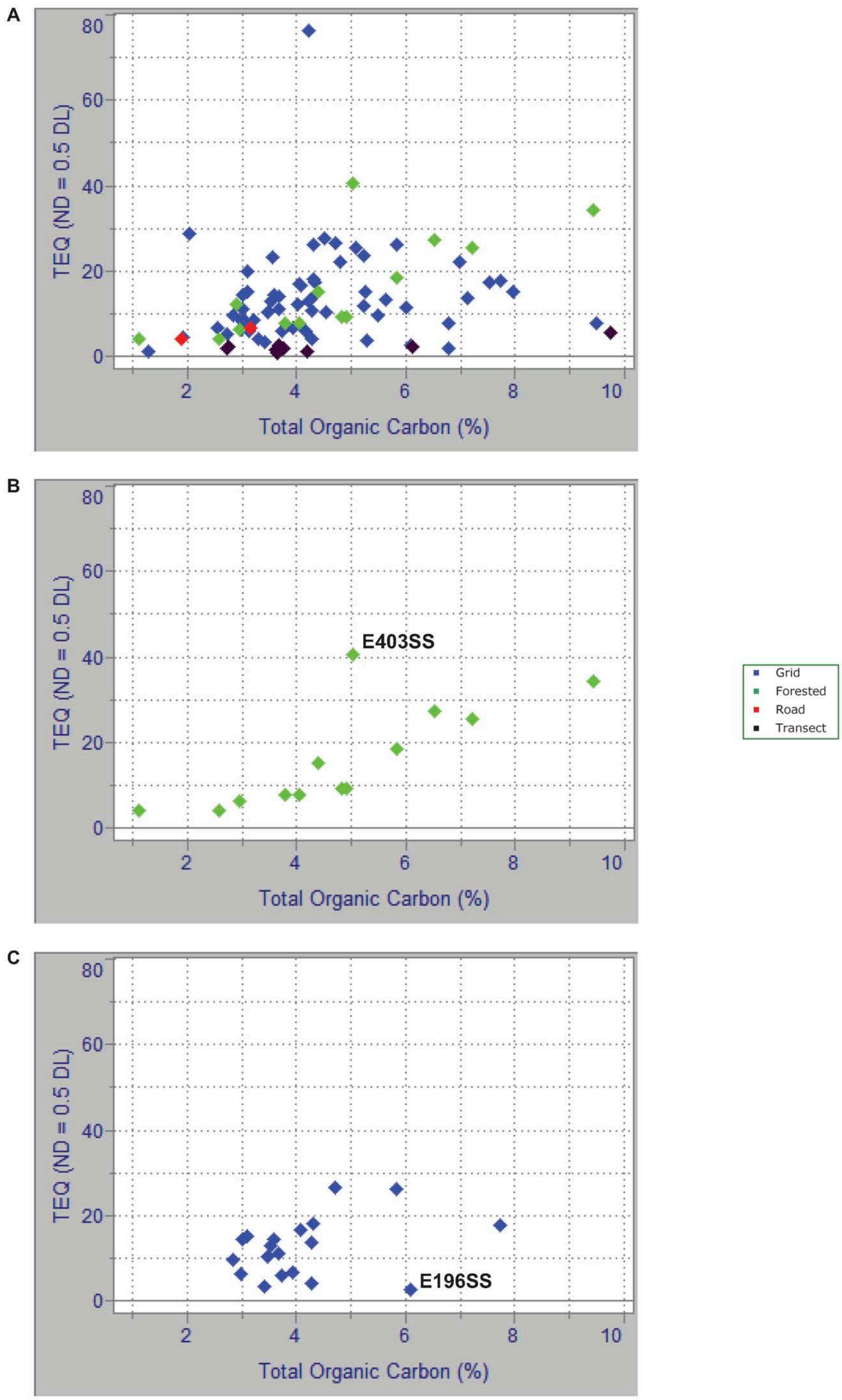
HERRERA ENVIRONMENTAL CONSULTANTS

0 1,000 2,000 4,000 feet

Coordinates: Washington State Plane South
NAD 83 (feet)
Aerial: USDA, 2006

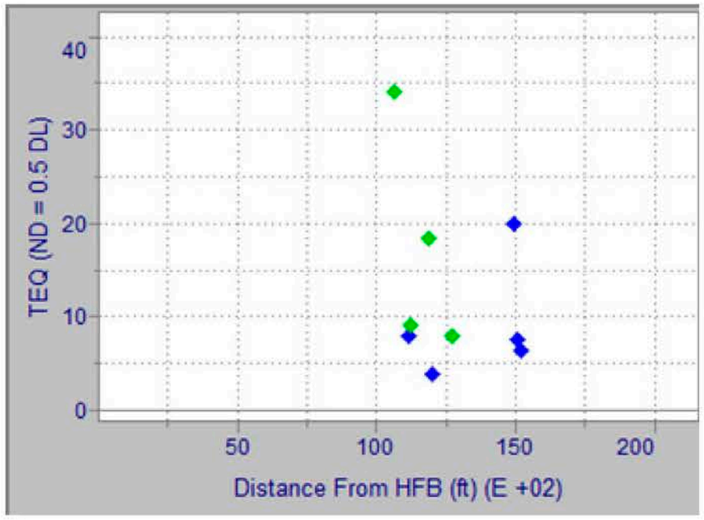
N

Produced By: GIS (RDR)
Project:
K:/Projects/06-03386-006/Collected_Samples/TEQ_Calc/TEQ Samples Collected in Upslope Transects.mxd

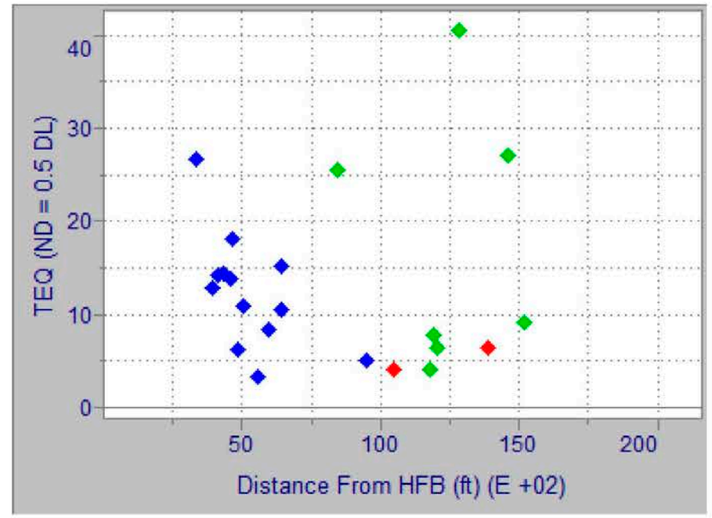


Notes: TEQ (ND = 0.5 DL) calculated assuming non-detected congeners present at one-half of the EDL or SDL, as appropriate. Concentrations are in ng/kg, dry weight.

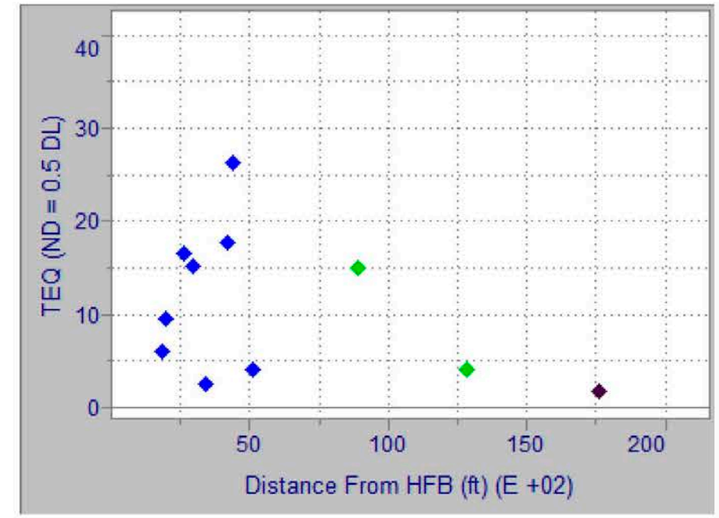
Figure 6-6 Scatter plots showing TEQs and percent TOC



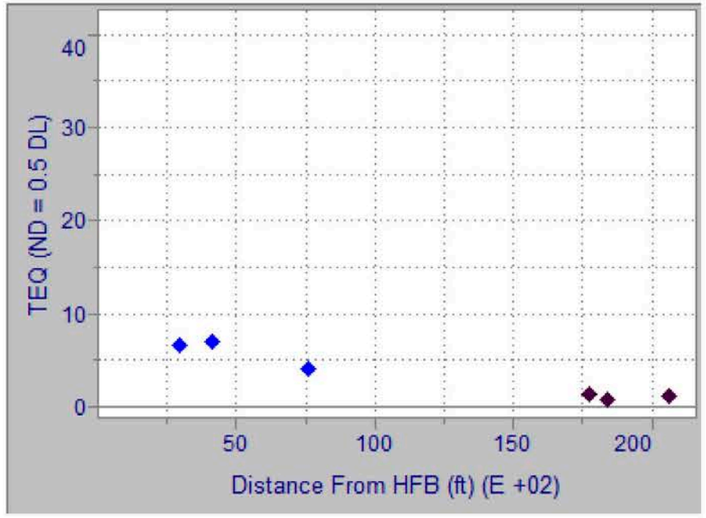
East Wind Sector



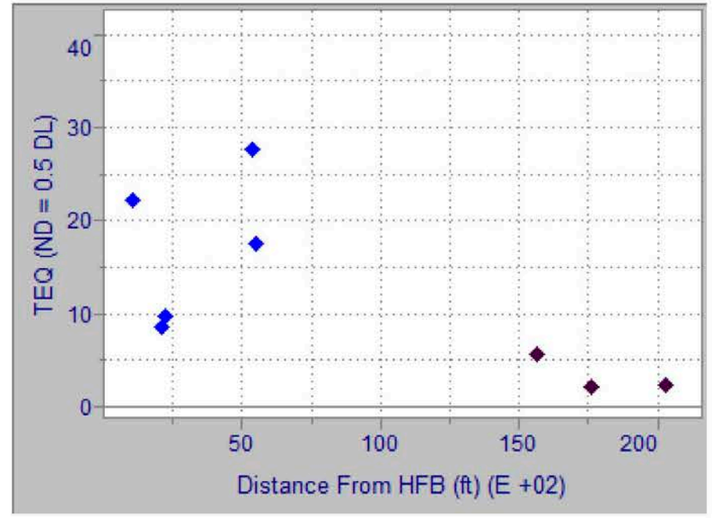
East-Southeast Wind Sector



Southeast Wind Sector



South-Southeast Wind Sector

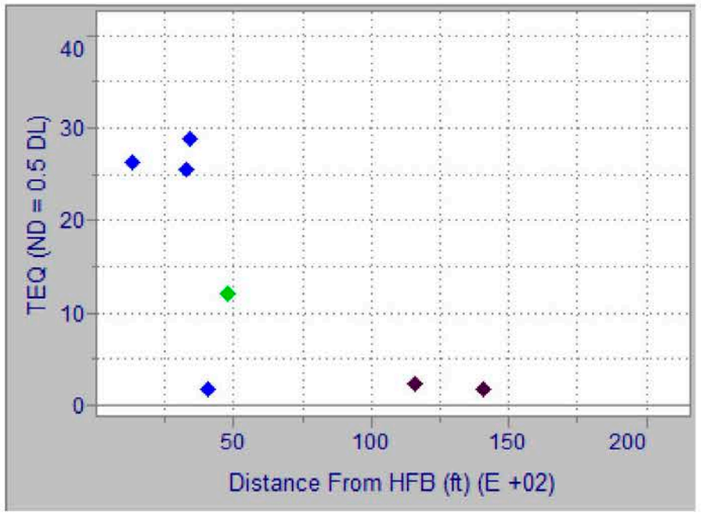


South Wind Sector

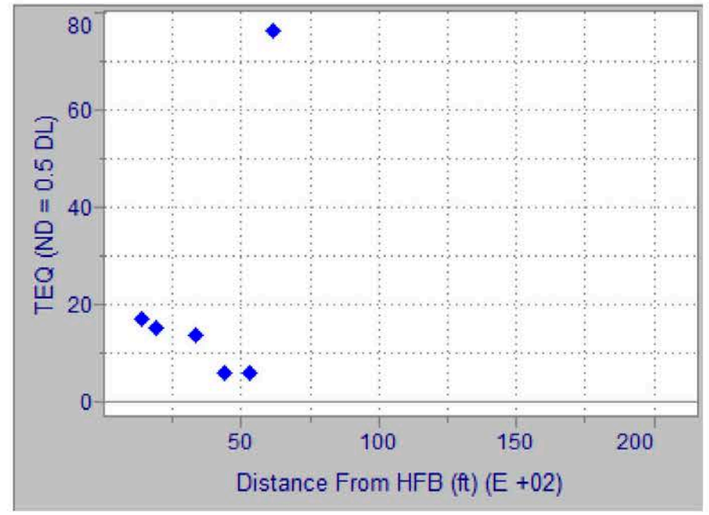
Key:

- = Grid sample
- = Upslope transect sample
- = Roadside sample
- = Forested sample

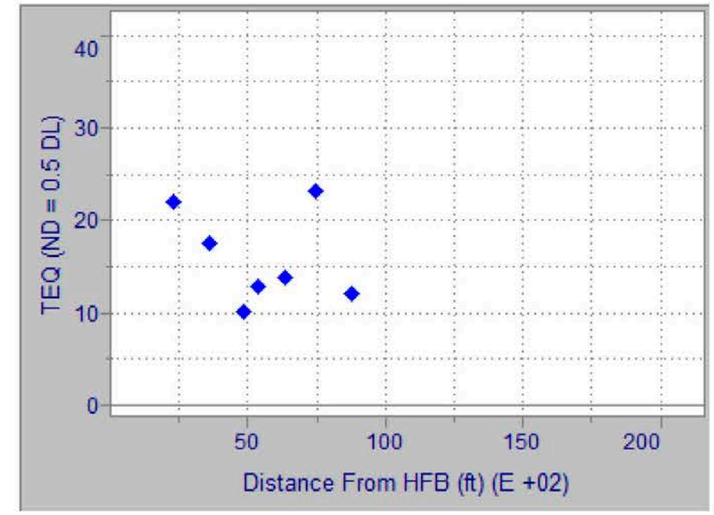
Figure 6-9 Scatter plots showing TEQ concentrations and distance by wind sector



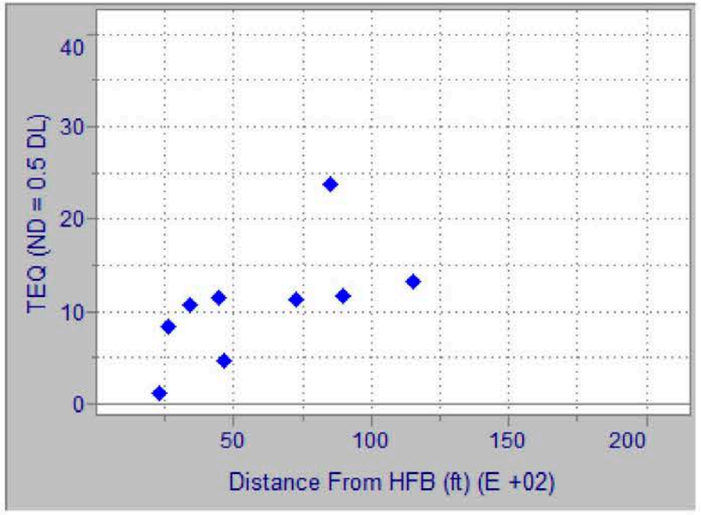
South-Southwest Wind Sector



Southwest Wind Sector



West-Southwest Wind Sector



West Wind Sector

Key:

- = Grid sample
- = Upslope transect sample
- = Roadside sample
- = Forested sample

Figure 6-9 (continued) Scatter plots showing TEQ concentrations and distance by wind sector

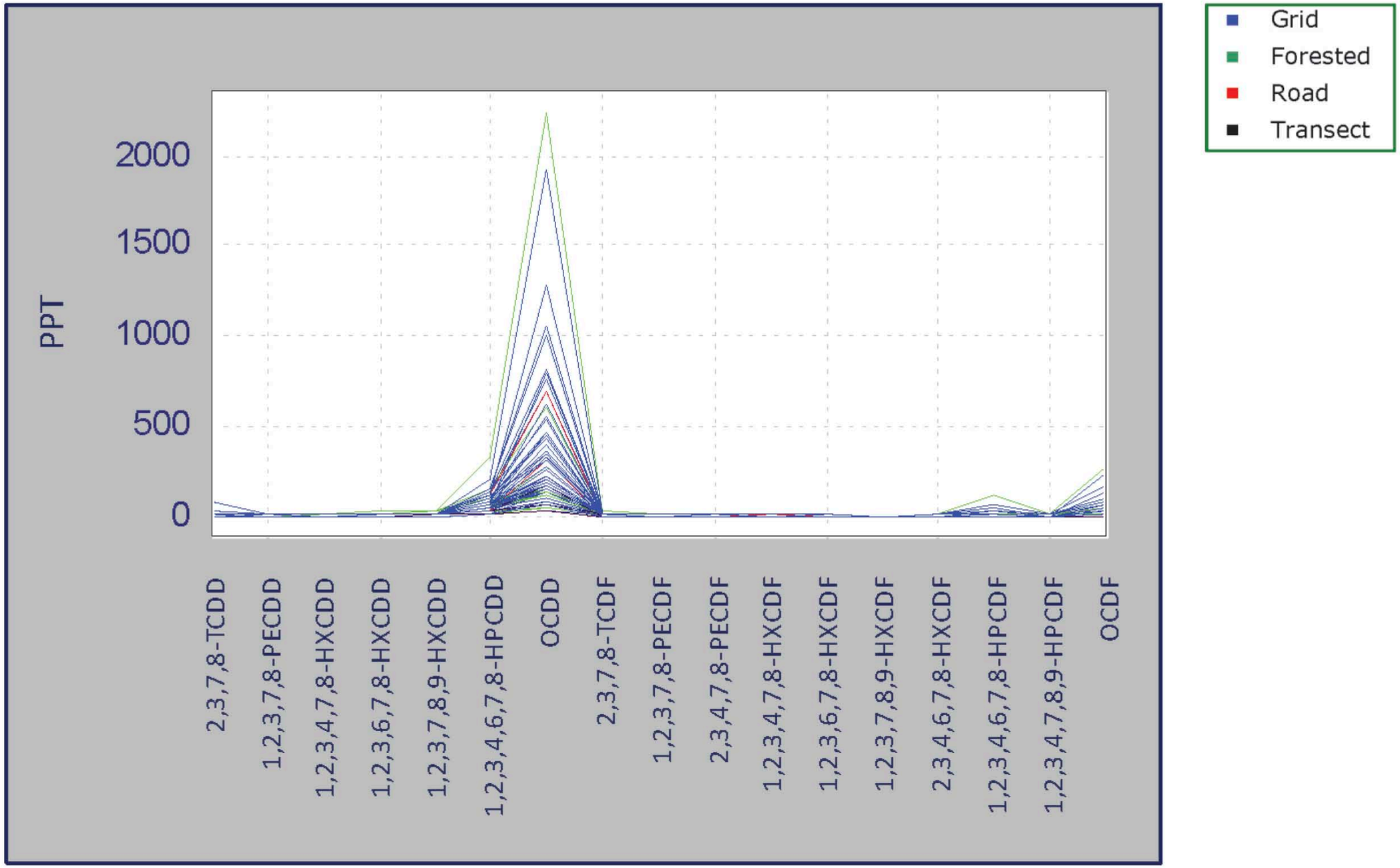


Figure 8-6 Port Angeles samples: bulk congener profiles

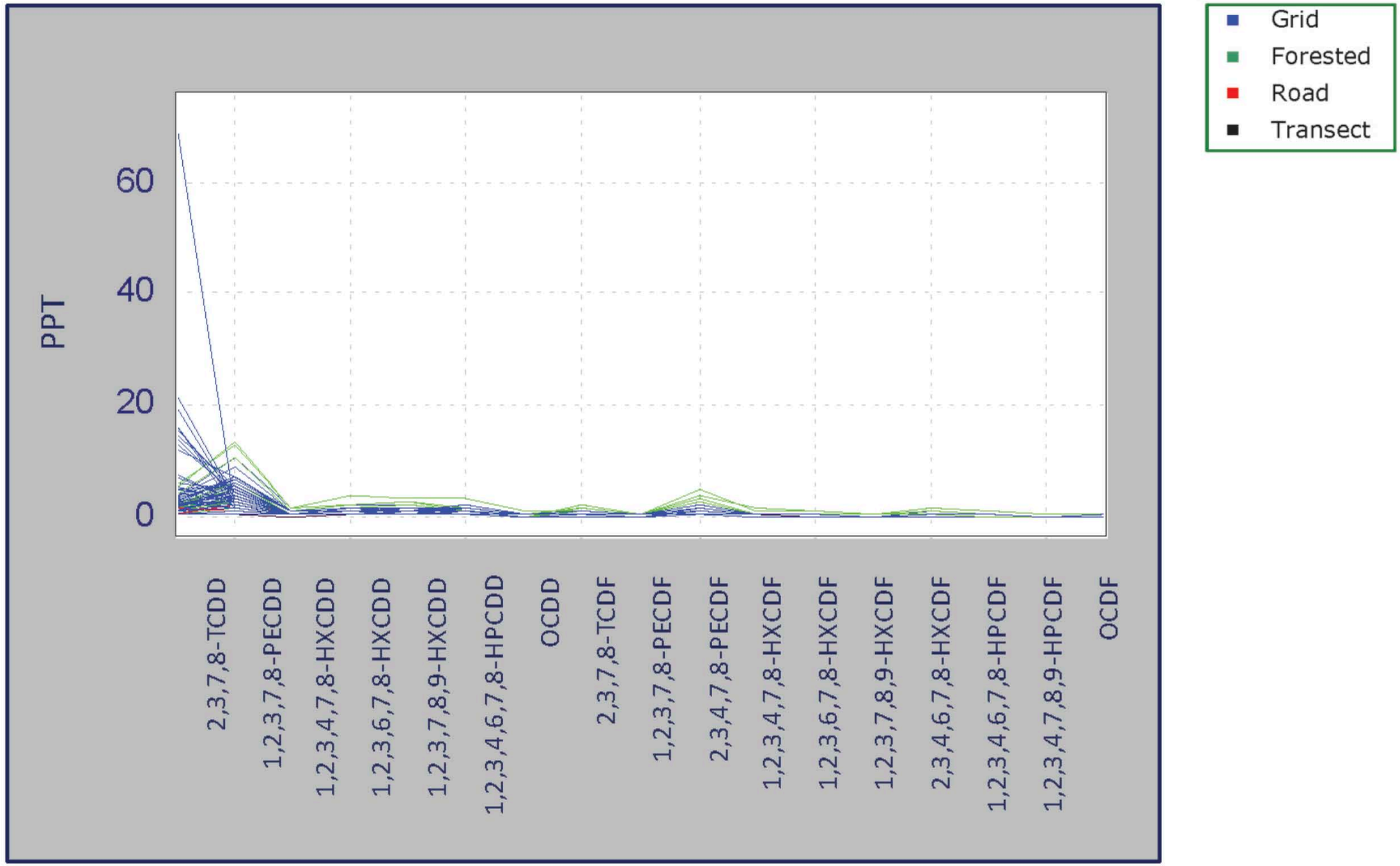


Figure 8-7 Port Angeles samples: TEQ profiles

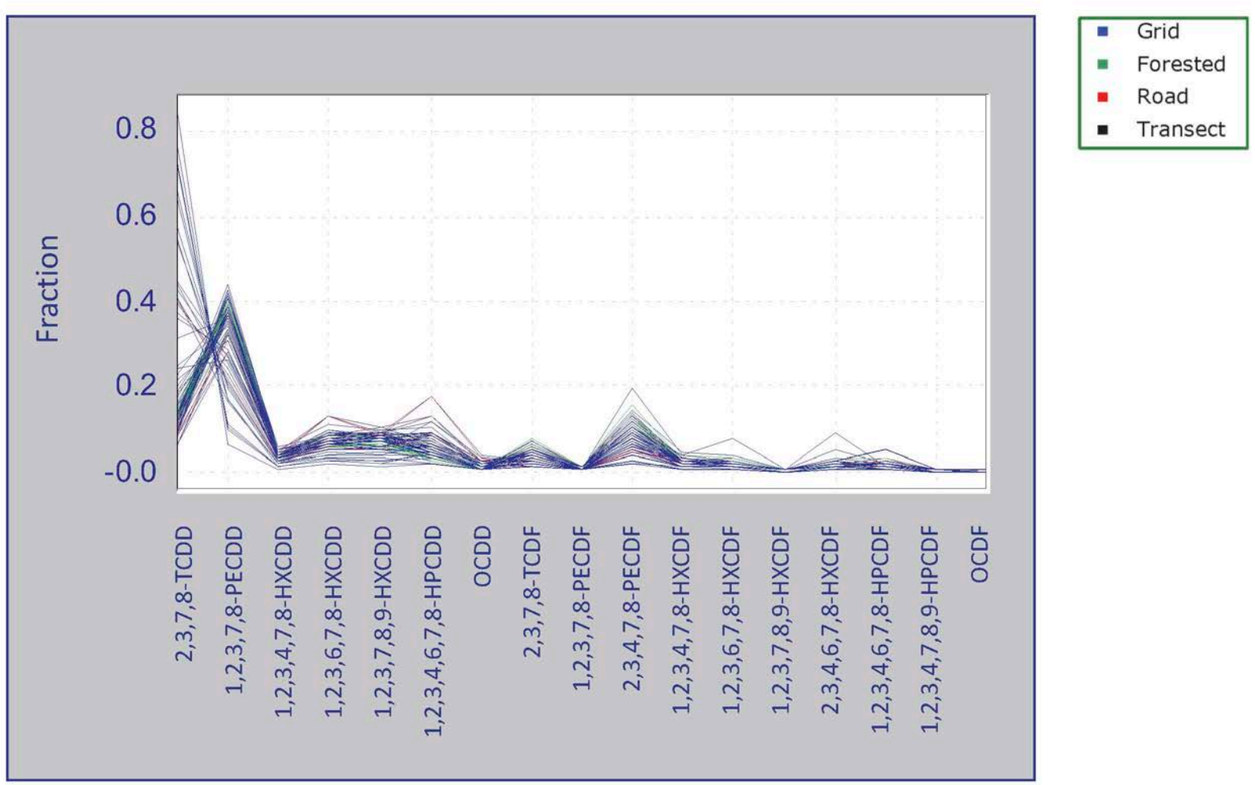


Figure 8-8 Port Angeles soil samples: normalized TEQ profiles

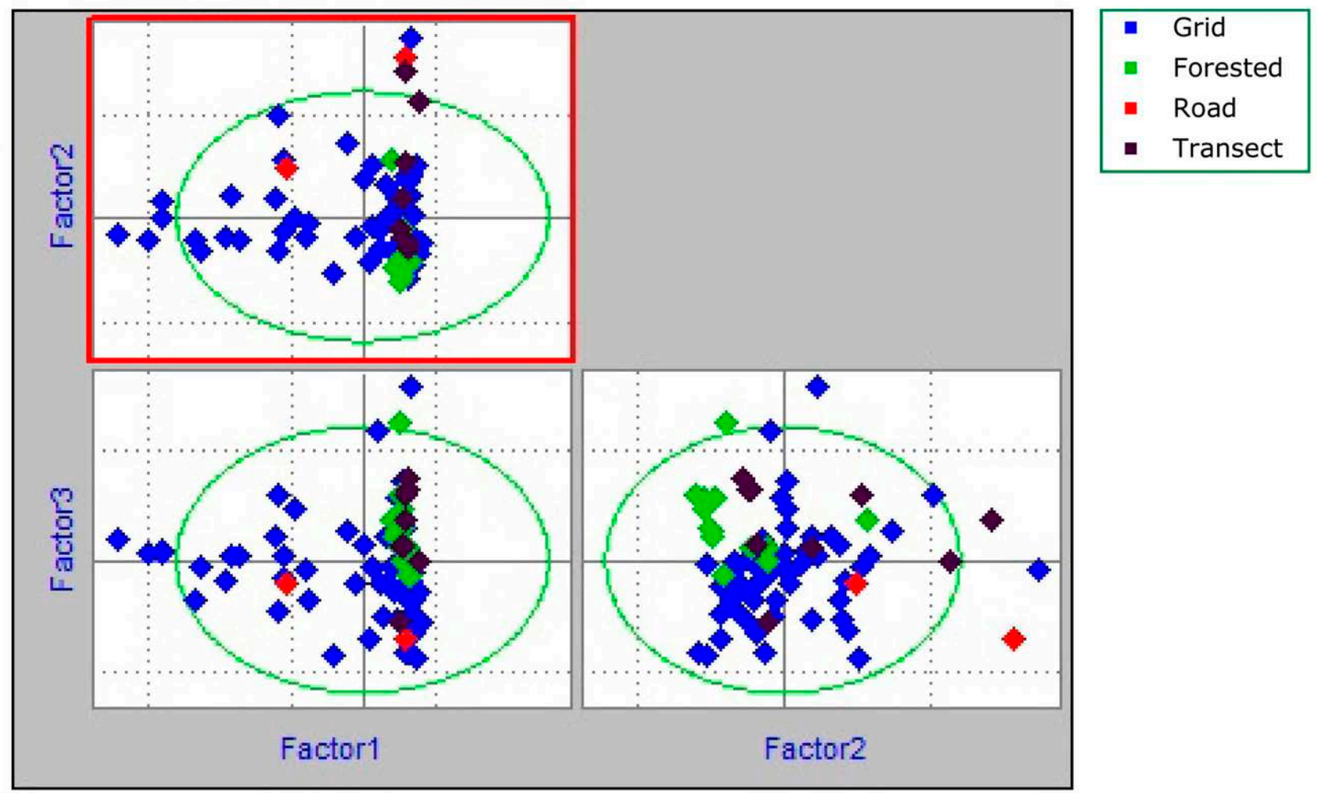


Figure 8-9 Port Angeles soil samples: PCA plot

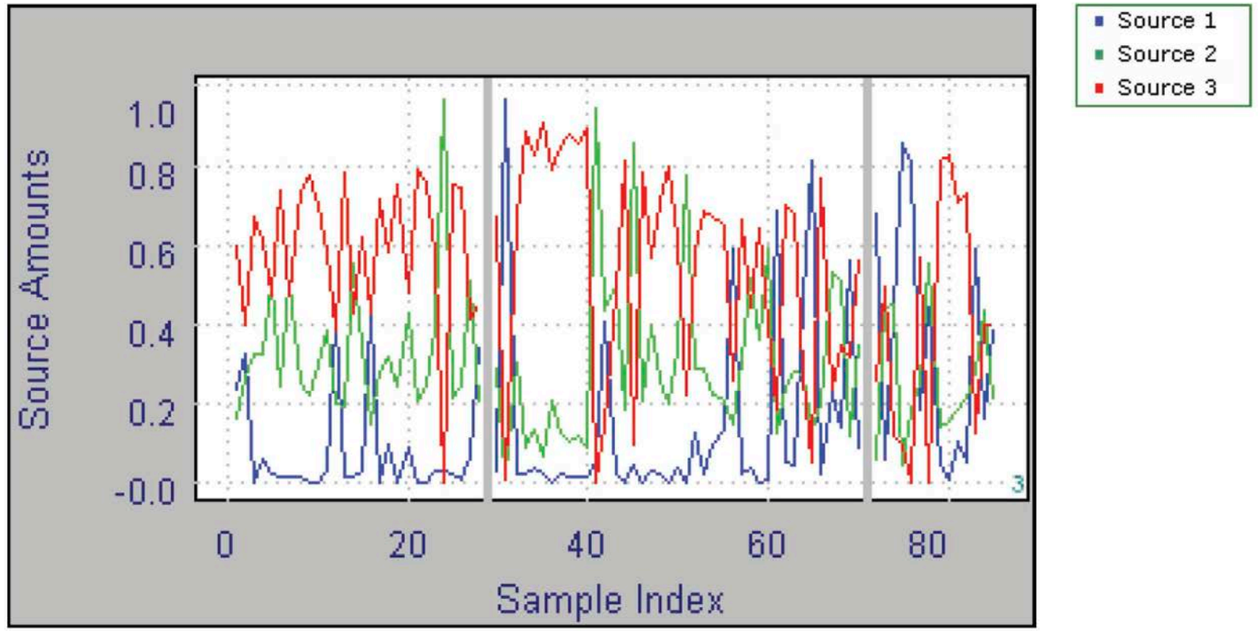


Figure 8-11 Unmixing model source contribution to samples

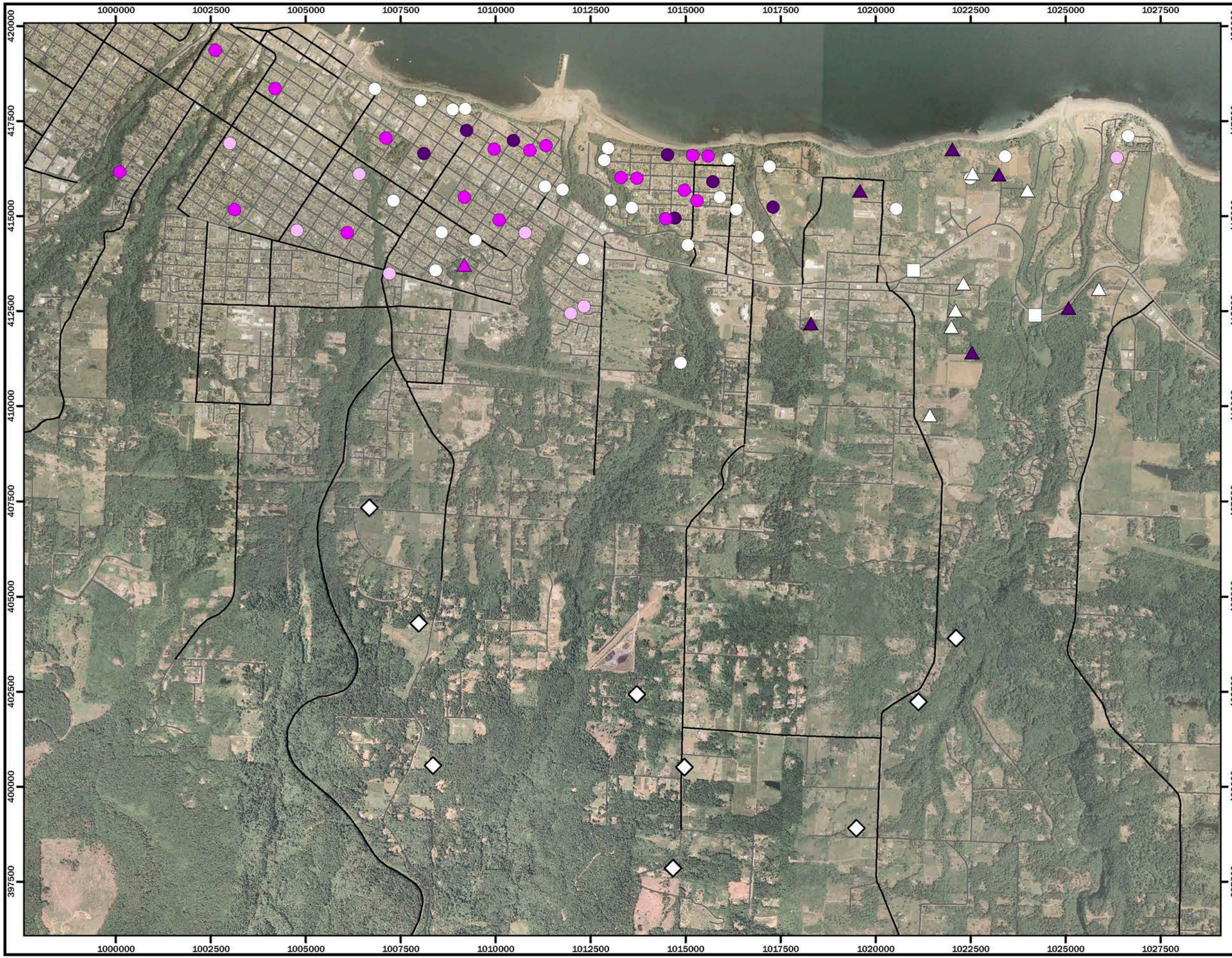


Figure 8-17.
Total TEQ Concentrations and Source 3 contributions
Rayonier Mill Off- Property
Soil Dioxin Study
Port Angeles, WA

Legend

Total TEQ and Source 3 Contributions

- TEQ < 11, S3 (any)
- TEQ > 11, S3 < 4
- TEQ > 11, S3 > 4 and < 11
- TEQ > 11, S3 > 11

Soil sample type

- Forested
- Grid
- Highway
- Transect

- Arterial or Collector Road
- Road

Notes:
1. Source 3 contributions to locations with total TEQs less than 11 ng TEQ/kg are not shown.
2. TEQ concentrations shown in ng/kg.

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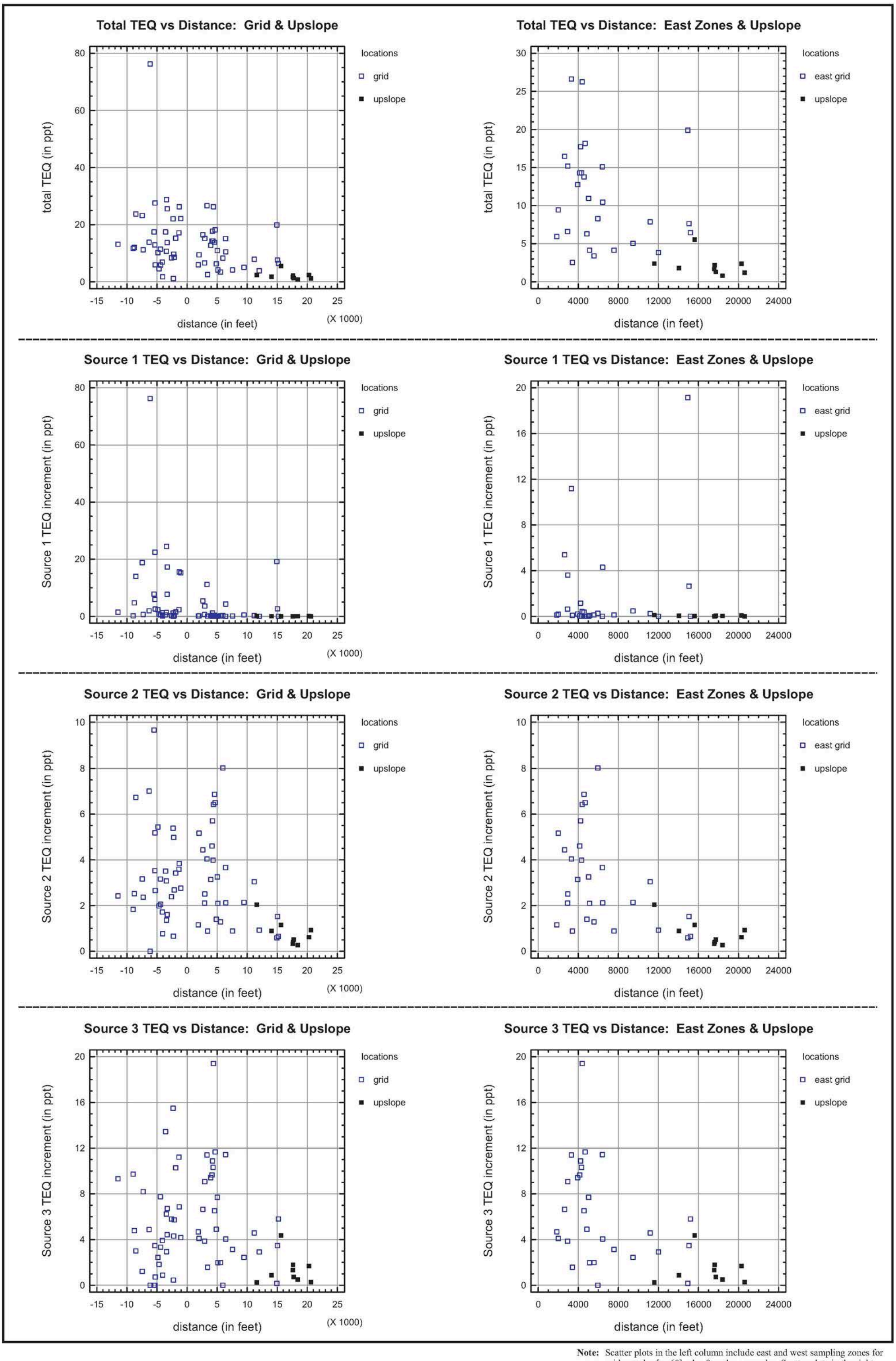
0 1,250 2,500 5,000 feet

Coordinates: Washington State Plane South
NAD 83 (feet)
Aerial: USDA, 2006

N

Produced By: GIS (RDR)
Project:
K:\Projects\06-03286-006\Collected_Sampled\TEQ_Calc\Combined Total TEQ - Source 3 TEQ - Overview.mxd



Note: Scatter plots in the left column include east and west sampling zones for grid samples [n=60], plus 9 upslope samples. Scatter plots in the right column include only east sampling zones for grid samples [n=28], plus 9 upslope samples. Axes in right hand column plots are rescaled to better show data patterns.

Figure 8-23 Scatter plots showing spatial trends for source increments

Study Objectives

- Magnitude of soil dioxin/furan TEQs in off-property soils potentially impacted by Rayonier Mill operations
- Contribution of Rayonier Mill air emissions versus other potential sources to soil TEQs (source apportionment study)
- Beyond study scope:
  - Defining boundary of off-property impacts
  - Determining exposure concentrations for risk assessment
  - Determining relevant background concentrations
  - Interpolating soil TEQs from sampled to unsampled properties