Appendix I
SMA Uncertainty Analysis

December 2023
Gasco Sediments Project Area

SMA Uncertainty Analysis

Prepared for NW Natural

December 2023
Gasco Sediments Project Area

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Prepared for
NW Natural
250 SW Taylor Street
Portland, Oregon 97204-3038

Prepared by
Anchor QEA, LLC
6720 South Macadam Avenue, Suite 300
Portland, Oregon 97219

Project Number: 000029-02.85

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ABBREVIATIONS

bml	below mudline
BODR	Basis of Design Report
COC	contaminant of concern
Draft RDGC	Draft *Remedial Design Guidelines and Considerations*
EPA	U.S. Environmental Protection Agency
Project Area	Gasco Sediments Site Project Area
PTW	principal threat waste
NAPL	nonaqueous phase liquids
NRC	not reliably contained
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
RAL	remedial action level
Revised BODR	*Revised Sediment Remedy Basis of Design Report*
ROD	*Record of Decision – Portland Harbor Superfund Site*
SMA	sediment management area

1 Introduction

As part of the continuing development of the Draft *Remedial Design Guidelines and Considerations* (Draft RDGC; EPA 2021) for the Portland Harbor Superfund Site, the U.S. Environmental Protection Agency (EPA) issued updated guidelines and considerations to evaluate the uncertainty in sediment management area (SMA) delineations to support remedial design (EPA 2022a). Consistent with these updates (Appendix B to the Draft RDGC), a geostatistical uncertainty analysis was performed to support the data gaps analysis for SMA delineation at the Gasco Sediments Site Project Area (Project Area). The updated Draft RDGC states the following:

> *SMA refinement during remedial design should incorporate an uncertainty evaluation that includes using maps to identify areas of higher and lower reliability (i.e., degree of spatial variability, analytical variability, and sediment heterogeneity) in the delineation of contaminant deposits.*
>
> *Uncertainties identified in this process would be mitigated through either additional infill sampling or expansion of the SMA footprint to ensure that target sediments are captured reliably.* (EPA 2022a)

This SMA Uncertainty Analysis, an appendix to the *Revised Sediment Remedy Basis of Design Report* (Revised BODR), presents the spatial correlation analysis of Project Area sediment data, interpolations of surface and subsurface sediment indicator parameters representing the probability that sediment concentrations will exceed *Record of Decision – Portland Harbor Superfund Site* (ROD; EPA 2017) Table 21 remedial action levels (RALs[1]) and principal threat waste (PTW) thresholds[2] (collectively referred to herein as contaminants of concern [COCs]), and recommendations as to whether any additional infill sampling is needed to help reduce the uncertainty of the SMA boundary at the Project Area. Because the prevailing correlation scales of both COCs and indicators are much longer than the existing inter-sample spacings, no additional infill sampling is necessary.

[1] Table 21 as modified in Errata #3 for the ROD (EPA 2022b).

[2] On September 7, 2022, EPA issued Errata #3 (EPA 2022b) to address the change in the PTW threshold for 1,2,3,4,7,8- HxCDF resulting from a previous error in the calculation of the PTW concentration threshold. The evaluation presented herein includes exceedances for HxCDF based on the updated thresholds.

2 Semivariogram and Interpolation Methodology

In accordance with the updated Draft RDGC, semivariograms were developed to assess spatial correlation structures of Project Area COCs and indicator variables. For the COC semivariograms, surface sediment concentrations were used as specified in the Draft RDGC. Indicator variables and semivariograms were developed for surface and subsurface sediment data as described in Section 2.2. Indicator variables were created and interpolated to examine the uncertainty of SMA boundaries within the Project Area. As detailed in Section 4 of the Revised BODR, the Project Area was delineated based on multiple lines of evidence, including SMA indicator boundaries, the extents of PTW-nonaqueous phase liquids (NAPL)/not reliably contained (NRC) materials, the presence of functional structures, and the locations of adjacent River Mile 7 West and US Moorings Project Areas. The uncertainty of the indicator interpolations (expressed as probabilities of exceedance) and the range of the spatial correlation structures relative to the inter-sample spacings were used to determine if additional infill data need to be collected to allow refinement of the Project Area SMA boundary.

2.1 Source Data

In 2021, Anchor QEA created a sediment management database to provide a single, comprehensive repository for all data relating to and required for sediment work associated with the Project Area. This geostatistical analysis was performed for all COCs exceeding a ROD Table 21 RAL (EPA 2017), including the following:

- Polychlorinated biphenyls (PCBs)
- Total polycyclic aromatic hydrocarbons (PAHs)
- Dioxins/furans
  - 2,3,7,8-TCDD
  - 1,2,3,7,8-PeCDD
  - 2,3,4,7,8-PeCDF

This geostatistical analysis also included additional COCs in ROD Table 21 that exceed PTW thresholds, including the following:

- Naphthalene
- Carcinogenic PAHs, based on benzo(a)pyrene toxic equivalents
- Dioxins/furans
  - 2,3,7,8-TCDF
  - 1,2,3,4,7,8-HxCDF
- Chlorobenzene

All surface and subsurface sediment data were preprocessed to facilitate variographic analyses. For this effort, preprocessing involves filtering out the relevant COCs, using the maximum detected or, if no detections, maximum non-detected value when multiple values are available for a given sample location, and log-normalizing chemistry data to account for log-normal COC distributions.

Anchor QEA used a conservative approach in developing the dataset for surface sediment concentration variography. Both detected and non-detected concentrations were considered for each sample location. If only non-detected concentrations were available for a given surface sediment sample location, the highest non-detected concentration was used for the variography analysis. If both detected and non-detected results existed for a given surface sediment location, the highest detected result was used for the variography analysis. In the subsurface sediment dataset, samples that were composited over depth intervals greater than 1 foot were not used for variography because of their lack of depth specificity.

The interpolation and semivariograms used surface and subsurface sediment data from within and surrounding the Project Area (i.e., from the remedial design dataset, as described in Section 2.9 of Revised BODR). The Project Area dataset was supplemented with nearby sediment data 350 feet upstream and downstream of the Project Area and extending from the shoreline to the northeast boundary of the navigational channel to develop more accurate interpolations across the Project Area boundary (i.e., boundary conditions).

2.2 Indicator Variables

The Draft RDGC guidance states that indicator variables should be used for evaluating uncertainty in proposed SMA refinements. For a given sample location, if there was an exceedance of any of the ROD COCs, that location was assigned a value of one (1.0); otherwise, if there were no exceedances of any ROD Table 21 contaminants, it was assigned a value of zero (0.0). The indicators are not chemical-specific but represent exceedances of any and all contaminants, and the COCs causing the exceedances vary from location to location.

Indicator variables were generated separately for surface sediment samples (0 to 1 foot [0 to 30 centimeters] below mudline [bml]) and subsurface sediment samples (all depths greater than 1 foot bml). These interpolations were performed separately for the following reasons: 1) surface and subsurface data are not always co-located; and 2) surface sediment samples that do not exceed any RAL or PTW thresholds but do not have co-located subsurface sediment data do not provide sufficient information regarding subsurface sediment exceedances.

An additional merged indicator variable was generated by combining all surface and subsurface sediment exceedances at all depths, as recommended in the Draft RDGC. However, the merged indicator variable is not recommended for delineating the Project Area boundary because of the deficiencies listed above.

The three different datasets of indicator variables include the following:

1. Surface sediment exceedances
2. Subsurface sediment exceedances for all subsurface depths
3. Merged exceedances for surface and subsurface sediment depths (combined 1 and 2)

2.3 Semivariograms

Semivariograms are a tool that can be used to assess the spatial correlation structures within a geostatistical dataset and the range of influence expected between sampling locations during the interpolation process. Semivariograms are also used to define weighting factors for spatial interpolation during kriging.

2.3.1 Surface Sediment Concentration Semivariograms

As specified in the RDGC Appendix B SMA Delineation Evaluation, semivariograms of surface sediment concentrations were generated for all of the ROD Table 21 COCs, as shown in Figures 1a through 1k. Because the surface sediment concentrations are approximately log-normally distributed, as shown in the probability plots in the bottom panels of Figure 1a through 1k, the concentrations were log-transformed prior to generating the semivariograms. Traditional semivariograms are not robust to outliers. Therefore, Cressie's robust estimator was used to generate the semivariograms (Cressie 1993). This robust estimator down-weights concentrations that are unusually large or small compared to neighboring values.

2.3.2 Indicator Semivariograms

Semivariograms were also generated for each of the three indicator variables in surface sediments, subsurface sediments, and combined surface and subsurface sediments (Figures 2a through 2c, respectively). For the indicator variables, the classical semivariogram estimator was used (Cressie 1993) because the robust estimator does not work well with indicator variables. There was no need to log-transform indicator variables prior to generating the indicator semivariograms.

2.3.3 Methodology

Directional anisotropy was investigated using variogram maps in ArcGIS Geostatistical Analyst. Figure 3 shows variogram maps for log-transformed surface sediment total PAHs and for the three indicator variables. The center of each map represents the semivariance of nearby data points; farther out from the center, the semivariance of data with larger separation distances is represented along with its directional properties. The blue line is at 305 degrees, which is the approximate strike of the bathymetric contours and presumed direction of flow. These maps provide evidence of directional anisotropy because there is a lower semivariance gradient (i.e., uniformly cool colors at all distances from centroid) in the direction of flow and a higher semivariance gradient (i.e., grading to warmer colors with distance from centroid) in the cross-flow direction, perpendicular to the blue line. This indicates a stronger correlation in the direction of flow than in the cross-flow direction. For other surface sediment COCs, anisotropy was similarly evident, with the exception of 2,3,7,8-TCDD.

Because the seimivariogram maps in Figure 1 show that the data exhibit longer spatial correlation distances in the direction of flow (i.e., parallel to the river alignment, approximately along an azimuth of 305 degrees) than in the cross-flow or down-slope direction (approximately 35 degrees), three types of semivariograms[3] were generated to further examine anistotropy in the COCs and indicator variables:

1. Omnidirectional semivariograms (isotropic) that examine spatial correlation structures in all directions (top left panel on semivariogram figures)
2. Semivariograms in the direction of flow (anisotropic, primary axis) that examine the spatial correlation structures along an azimuth of 305 degrees with a tolerance of +/- 20 degrees (top middle panel on semivariogram figures)
3. Semivariograms in the cross-flow direction (anisotropic, secondary axis) that examine the spatial correlation structures along an azimuth of 35 degrees with a tolerance of +/- 20 degrees (top right panel on semivariogram figures)

The semivariogram plots represent the linear separation distance between pairs of data points on the x-axis versus the semivariance between pairs of data points on the y-axis (i.e., a measure of the statistical differences between pairs of data points) (Figures 1a through 1k and Figures 2a through 2c). Pairs of data points are binned by separation distance, and the average for each bin is shown as a red dot on the semivariogram. The orange numbers below each red dot show the number of data pairs in each bin. The blue dashed line represents the population variance of the data. The black line on the semivariogram represents the model that R fit to the data using a least squares regression. A spherical model was used in both the surface sediment semivariograms and the indicator semivariograms. The choice of the model was based on visual inspection of the shape of the binned data supporting the semivariograms. Table 1 summarizes the semivariogram model parameters.

2.3.4 Spatial Correlation Ranges

In the semivariograms, the spatial correlation range is the distance in feet along the x-axis at which the semivariance on the y-axis stops rising and levels off at a value approaching the global population variance. This range is crucial for understanding how data points are correlated in space and is summarized in Table 1. When the separation between data points is greater than this spatial correlation range, they are no longer significantly correlated. This represents the spatial correlation

[3] Semivariograms were generated using the geoR package in the program R.

range and is summarized in Table 1. At separation distances greater than the spatial correlation range, samples are no longer spatially correlated and cannot be reliably used for geostatistical predictions over such distances.

Draft RDGC guidance recommends that inter-sample spacings should not be greater than two-thirds of the spatial correlation range because, at larger separation distances, inter-sample correlations are diminished and interpolations would be less reliable. In this uncertainty analysis, the inter-sample spacings of the existing data will be compared to the spatial correlation range to determine if and/or where additional infill data may be needed.

Spatial correlation ranges in the Project Area are discussed in Section 2.3.4.1 for COCs and Section 2.3.4.2 for indicator variables.

2.3.4.1 COCs Spatial Correlation Ranges

For the COCs, spatial correlation structures and semivariogram models are presented in Figures 1a through 1j. The omnidirectional (isotropic) spatial correlation distance ranged from 420 feet (2,3,4,7,8-PeCDF) to 700 feet (total PCBs). As is typical of sedimentary deposits in river systems, which are sculpted by directional currents, the spatial correlation distances along the direction of flow (middle panel) were longer and ranged from 690 feet (1,2,3,7,8-PeCDD) to over 2,000 feet (multiple COCs).

In the cross-flow direction (i.e., downslope or offshore direction, as shown in the right panels of Figures 1a through 1i), the spatial correlation distances in the semivariogram models ranged from approximately 500 to 800 feet. Cross-flow correlation ranges greater than 800 feet are not expected because at those separation distances, samples would be on opposite sides of the navigation channel. The differences between along-flow and cross-flow correlation distances generally represent anisotropy ratios between 2-to-1 and 4-to-1, averaging approximately 3-to-1.

On several of the cross-flow semivariograms, the semivariogram model (black line) crosses above the population variance of the data (blue dashed line), which could indicate potential cross-flow (i.e., offshore) trends in the data. Potential cross-flow trends in the data will be investigated further during subsequent phases of remedial design.

The 2,3,7,8-TCDD experimental semivariogram (red symbols on Figure 1j) exhibits similar spatial correlation distances in the omnidirectional and flow direction variogram; therefore, a model (black line) was only fit to the omnidirectional variogram.

The lack of structure in the chlorobenzene semivariogram (Figure 1k) is likely due to a high percentage of non-detects in this dataset. Chlorobenzene has very limited PTW-NRC exceedances that are solely based on elevated detection limits for undetected concentrations. Therefore, chlorobenzene is not a COC requiring remediation in the Project Area.

2.3.4.2 Indicator Variables

For the indicator variables, spatial correlation structures and semivariogram models are presented in Figures 2a through 2c. The ranges of the spatial correlations for the indicator variables are similar to the ranges observed in the surface sediment concentrations. The omnidirectional (isotropic) spatial correlation distances (left panels) ranged from 340 to 660 feet. The spatial correlation distances along the direction of flow (middle panels) ranged from approximately 1,000 to 1,600 feet, and in the cross-flow direction (right panels), the spatial correlation distances were approximately 500 feet, with anisotropy ratios between 2-to-1 and 3-to-1.

On the cross-flow variograms, the semivariogram model (black line) crosses above the population variance of the data (blue dashed line), which could indicate a trend in the data in the cross-flow (offshore) direction, similar to what was observed in the surface sediment concentrations. Potential trends in the data will be further investigated in subsequent phases of remedial design. However, trends in the data do not impact natural neighbor interpolations performed on the indicator variables.

2.4 Indicator Interpolations

Interpolations were performed separately for each indicator variable using ArcGIS Spatial Analyst. As recommended in the Draft RDGC (EPA 2021), the indicator variables were interpolated using the natural neighbor algorithm on a 10-foot by 10-foot interpolation grid to determine whether existing sampling densities are sufficient to reliably delineate the SMA boundary. However, kriging or other alternative interpolation methods may be considered in subsequent phases of remedial design to delineate the depth of contamination given the inherent limitations of the natural neighbor interpolation method (ITRC 2016).

Interpolations of COC exceedance indicators for surface sediments, subsurface sediments, and combined surface and subsurface sediments are shown in Figures 4, 5, and 6, respectively. These maps delineate the median (50%) probability of exceedance, as well as areas with higher probabilities of exceedance (50% to 80%, shown in yellow) and lower probabilities of exceedance (20% to 50%, shown in green). In general, probabilities of exceedance between 20% and 80% represent the uncertainty range for the SMA boundary.

NW Natural does not propose using the combined surface and subsurface sediment indicator map (Figure 6) because samples containing only surface sediment data and no subsurface sediment data exert inappropriate constraints on the SMA boundary without sufficient subsurface sediment quality information.

3 SMA Uncertainty Evaluation and Data Gaps Analysis

This section summarizes the SMA uncertainty evaluation and data gaps analysis. One line of evidence for assessing SMA uncertainty is determined through inspection of surface and subsurface sediment indicator probability contour maps (Figures 4 and 5). Areas where the indicator probability contours diverge and separate, in particular, the contours between 20% and 80% probabilities of exceedance, are indicative of greater SMA boundary uncertainty. In surface sediments (Figure 4), there are no significant areas of uncertainty, such that all COC exceedances are well bounded by adjacent surface sediment samples containing no exceedances.

In subsurface sediments (Figure 3), there is one notable area where indicator probability contours diverge and extend across the Project Area boundary, near the northeastern (downstream and riverward) corner of the boundary. This is an administratively defined boundary because the offshore area will be addressed separately by NW Natural as part of the B1 Navigation Channel Project Area pursuant to the ASAOC (EPA 2020). NW Natural will coordinate the remediation between the B1 Navigation Channel Project Area and the Gasco Sediments Site Project Area to ensure the remedial designs are compatible and achieve the ROD requirements. All other parts of the subsurface SMA boundary are reliably bounded and constrained.

A second line of evidence for assessing SMA uncertainty and whether additional infill sampling is necessary is determined by comparing existing sample separation distances to the correlation ranges of the semivariograms (Table 1). Draft RDGC guidance (EPA 2022a) recommends that inter-sample spacings should not be greater than two-thirds of the correlation range because, at larger separation distances, inter-sample correlations are diminished and interpolations would be less reliable. Omnidirectional correlation scales in the Project Area for both COCs and indicator variables range from approximately 340 to 700 feet. Cross-flow correlation scales are comparable in magnitude, and along-flow correlation scales are generally two to four times greater. In comparison, the largest inter-sample separation distance along the proposed Project Area SMA boundary (at PDI-036SC-A) is 160 feet, which is approximately 20% to 50% of the shortest (i.e., worst case) omnidirectional or cross-flow correlation scales, indicating the existing data density is sufficient to support strong, near-field correlations throughout the Project Area. Therefore, no additional infill samples are necessary.

The proposed Project Area SMA boundaries were delineated in Section 4 of the Revised BODR and are shown on the indicator interpolation figures (Figures 4, 5, and 6). The SMA boundary has been adjusted to circumscribe, at a minimum, the median (50%) probability of exceedance for all indicators. The presence of PTW-NAPL was also evaluated to ensure the proposed SMA boundary circumscribed the extent of PTW-NAPL throughout the Project Area, as described in Section 4 of the

Revised BODR. In some areas, probabilities of exceedance less than 50% are enclosed within the Project Area boundary.

The Project Area boundary was delineated by adopting the SMA boundary and refining it in isolated areas using the following secondary lines of evidence, as detailed in Sections 4.3.1 and 4.3.2 of the Revised BODR:

- Location of the B1 Navigational Channel Project Area boundary
- Location of the River Mile 7 West Project Area boundary
- Presence of functional structures

In summary:

1. Semivariograms were developed and spatial correlation scales were defined for surface sediment COC concentrations and indicator variables denoting COC exceedances in surface and subsurface sediments;
2. Natural neighbor interpolations were performed for surface and subsurface COC exceedance indicators, as recommended in the Draft RDGC (EPA 2022a);
3. No significant areas of SMA boundary uncertainty were identified, except for an administratively defined boundary on the downstream part of the Project Area, which NW Natural will address separately as part of the B1 Navigation Channel Project Area;
4. Inter-sample spacings along the Project Area boundary were significantly less than even the shortest correlation scales, indicating existing data density is sufficient to support strong, near-field correlations throughout the Project Area;
5. No additional infill sampling is needed to reduce SMA boundary uncertainty throughout the Project Area based on an analysis of indicator probability contours and spatial correlation scales;
6. The proposed Project Area SMA boundary circumscribes, at a minimum, the 50% probability of exceedance contour for surface and subsurface sediments and the full extent of PTW-NAPL.

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Table

Table 1
Semivariogram Parameters

Figure Number	Parameter Type	Parameter Plotted	Spherical Variogram Model Parameters								
			Omnidirectional			Flow Direction			Cross-Flow		
			Nugget	Range	Partial Sill	Nugget	Range	Partial Sill	Nugget	Range	Partial Sill
1a	Surface Sediment Concentrations	Naphthalene	2.0	652	6.1	2.8	1,273	4.7	0	600	12.1
1b		Total DDx	0.43	533	2.4	0.91	1,979	1.5	0	841	13.8
1c		Total PAHs	0.99	587	5.1	1.7	943	3.5	0	758	13.2
1d		Total cPAH/BaPEq TEQ	0.65	584	4.9	1.3	836	3	0	841	13.8
1e		Total PCBs	0.95	701	1.2	1.2	2,941	1.4	0.46	600	3.3
1f		1,2,3,7,8-PeCDD	0.54	500	1.1	0.49	694	0.87	0	524	2.9
1g		2,3,4,7,8-PeCDF	0.91	423	2.9	1.6	957	1.4	0	614	10.5
1h		1,2,3,4,7,8-HxCDF	1.1	428	3.2	2.2	2,379	1.9	0	564	11.8
1i		2,3,7,8-TCDF	0.82	466	2.9	1.6	2,111	1.8	0	616	12
1j		2,3,7,8-TCDD[1]	0.41	458	0.74	NA	NA	NA	NA	NA	NA
1k		Chlorobenzene[2]	NA	NA	NA	NA	NA	NA	NA	NA	NA
2a	Indicator Variable	Surface Sediment Exceedances	0.15	600	0.12	0.13	1,000	0.13	0.13	500	0.20
2b		Subsurface Sediment Exceedances	0.06	338	0.12	0.08	1,441	0.09	0.06	519	0.25
2c		Merged Dataset of Surface and Subsurface Sediment Exceedances	0.16	658	0.08	0.14	1,600	0.09	0.14	500	0.19

Notes:
1. A model was only fitted to the omnidirectional variogram for 2,3,7,8-TCDD.
2. The Chlorobenzene variogram did not show evidence of spatial correlation, so a model was not fitted to this variogram.

BaPEq: benzo(a)pyrene equivalent
cPAH: carcinogenic polycyclic aromatic hydrocarbon
DDx: the sum of DDD, DDE, and DDT
HxCDF: hexachlorodibenzofuran
NA: not applicable
PAH: polycyclic aromatic hydrocarbon
PCB: polychlorinated biphenyl
PeCDD: pentachlorodibenzo-p-dioxin
PeCDF: pentachlorodibenzofuran
TCDF: tetrachlorodibenzo-p-dioxin
TEQ: toxic equivalency quotient

Figures

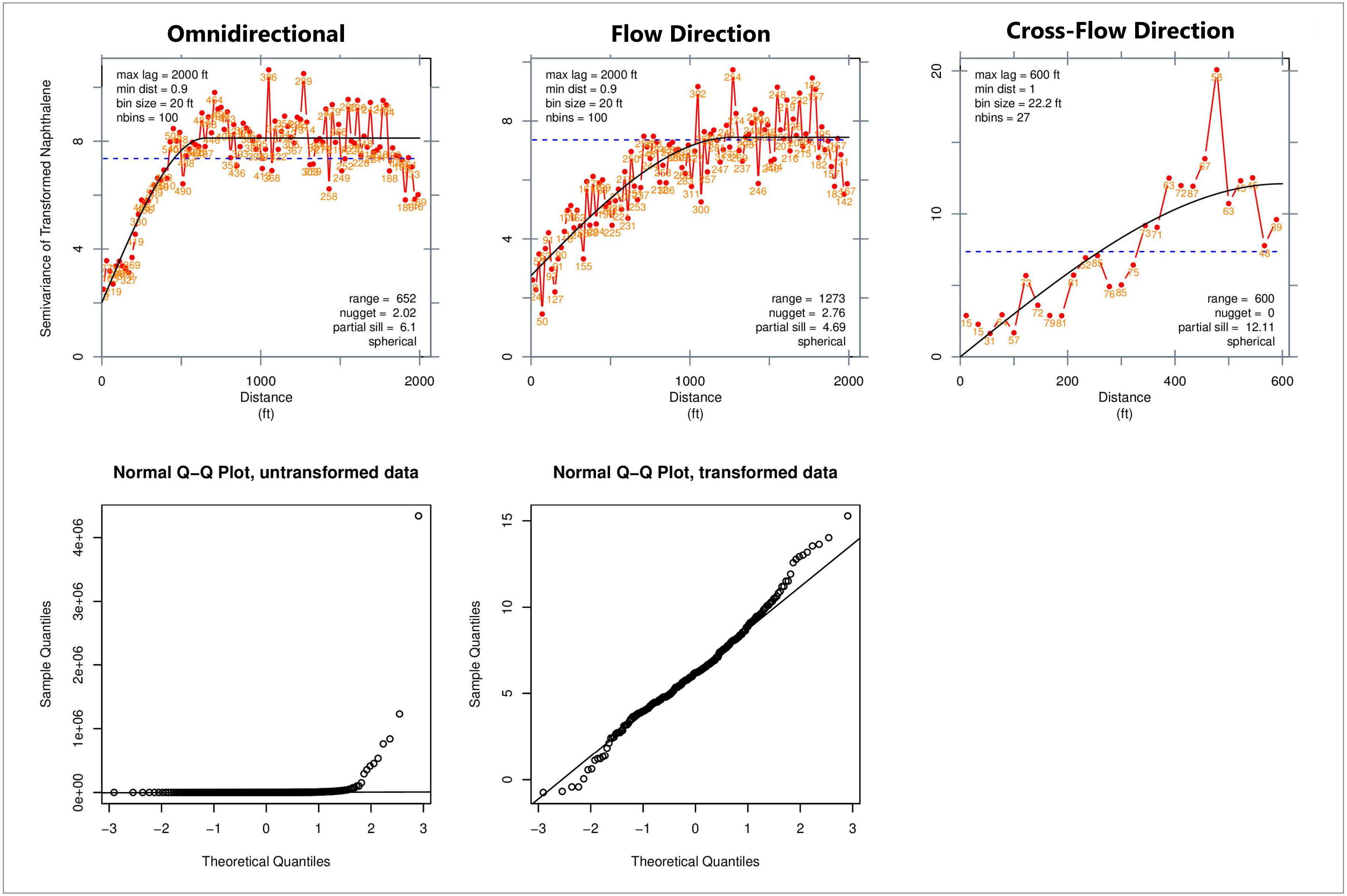

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Figure 1a
Semivariogram of Log-Transformed Naphthalene in Surface Sediments
SMA Uncertainty Analysis
Gasco Sediments Project Area

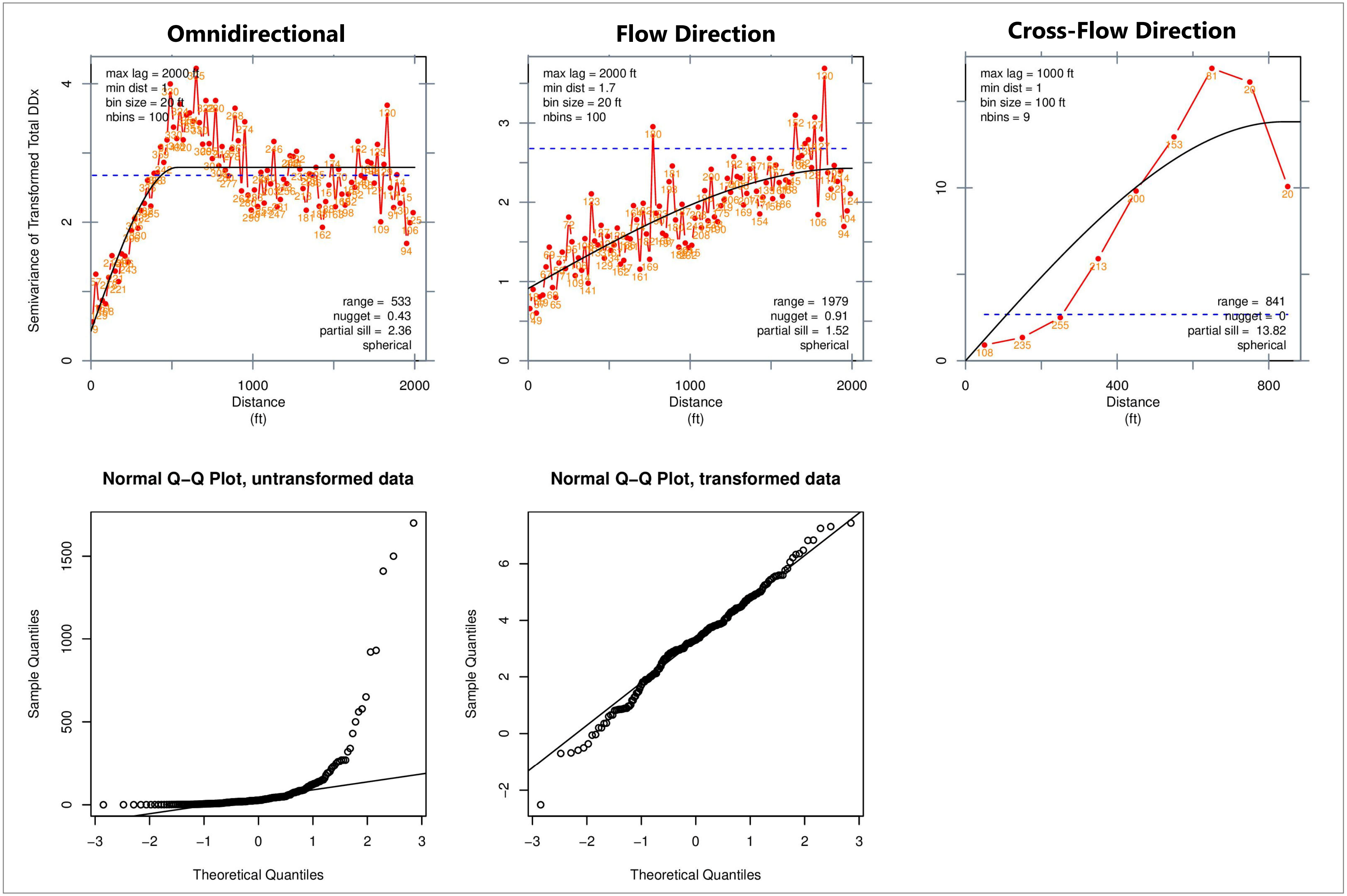

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Figure 1b
Semivariogram of Log-Transformed Total DDx in Surface Sediments
SMA Uncertainty Analysis
Gasco Sediments Project Area

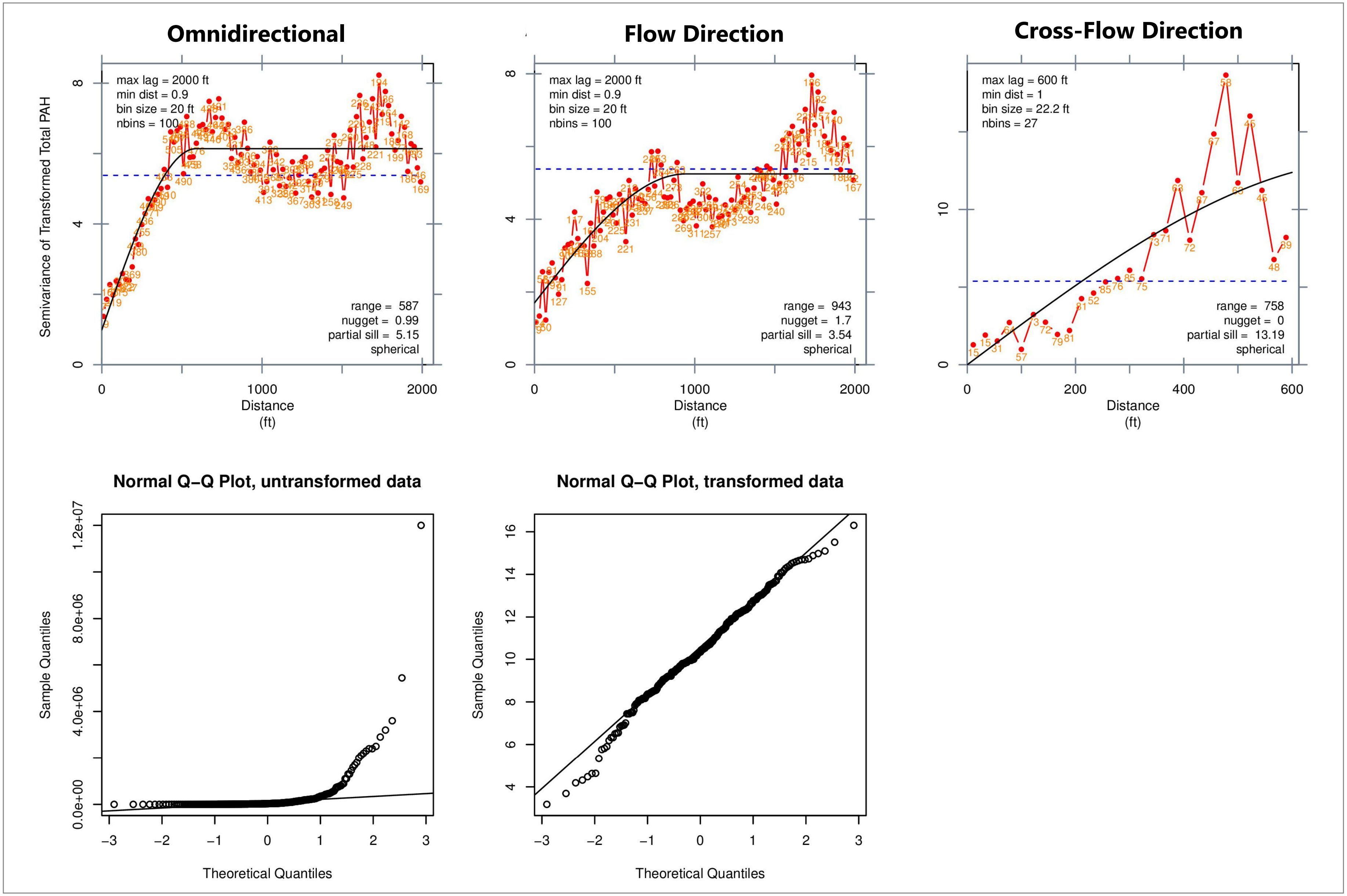

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Figure 1c
Semivariogram of Log-Transformed Total PAHs in Surface Sediments
SMA Uncertainty Analysis
Gasco Sediments Project Area

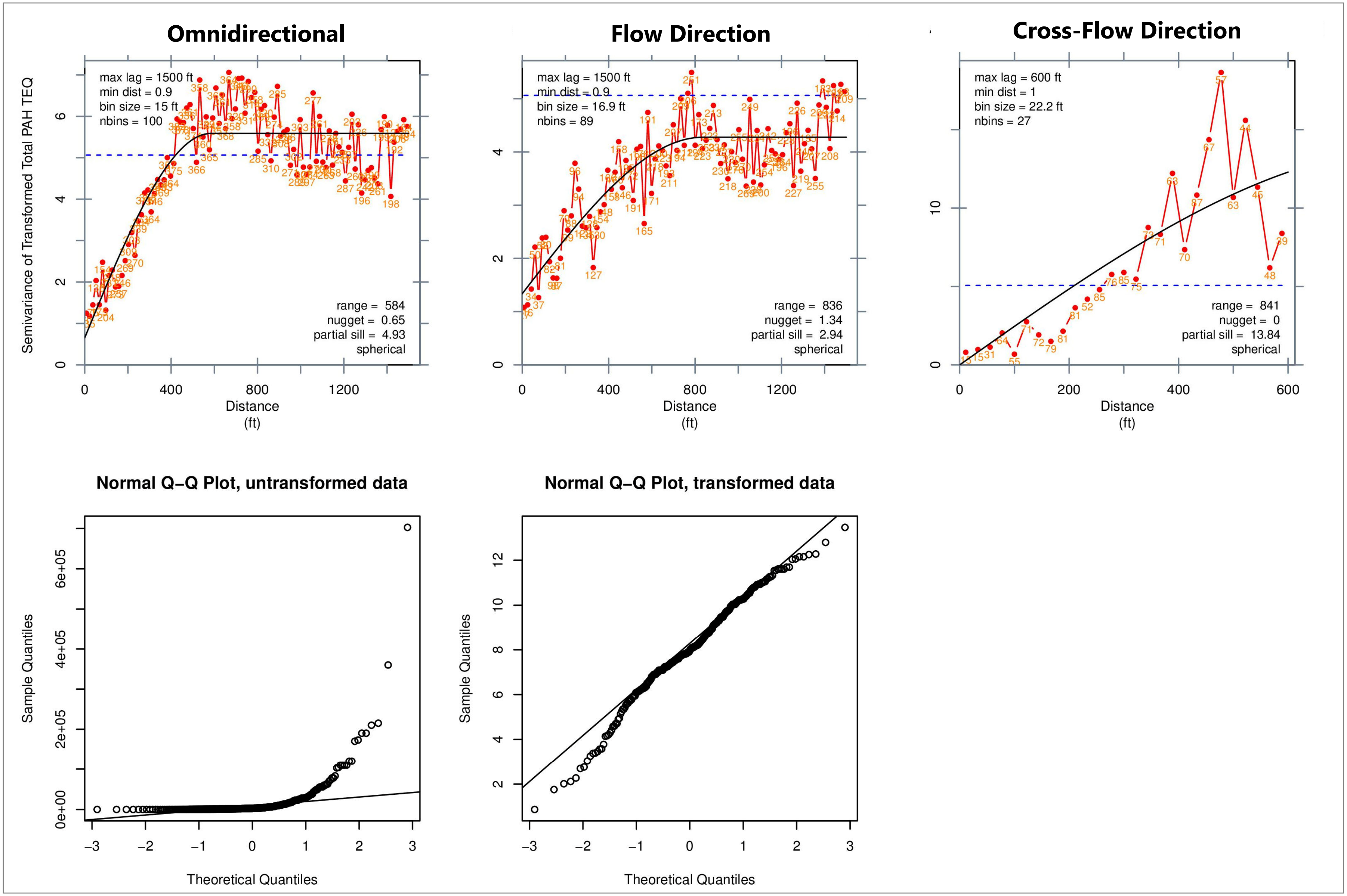

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Figure 1d
Semivariogram of Log-Transformed Total cPAH/BaPEq TEQ in Surface Sediments
SMA Uncertainty Analysis
Gasco Sediments Project Area

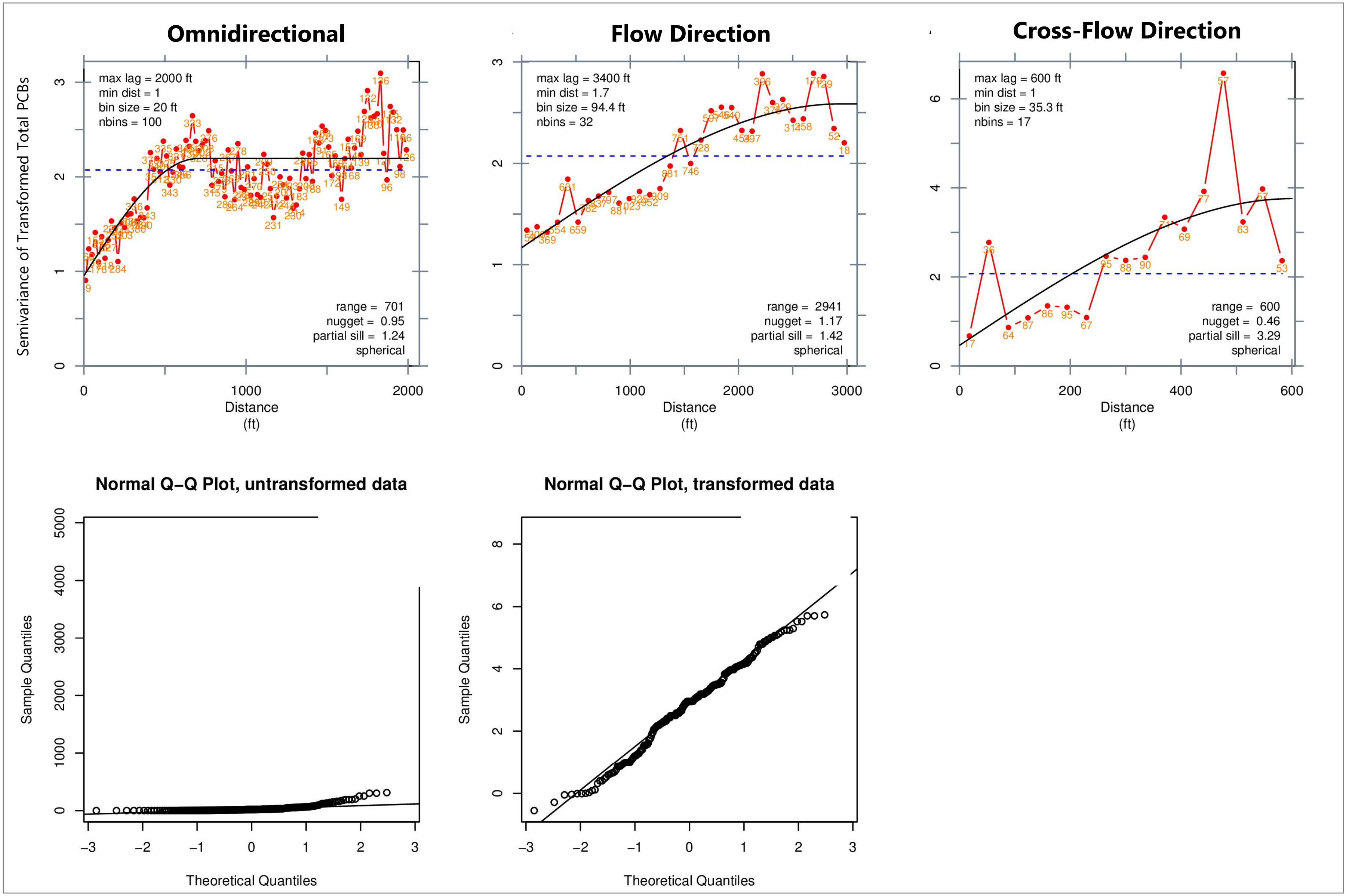

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Figure 1e
Semivariogram of Log-Transformed Total PCBs in Surface Sediments
SMA Uncertainty Analysis
Gasco Sediments Project Area

GASCO0067430

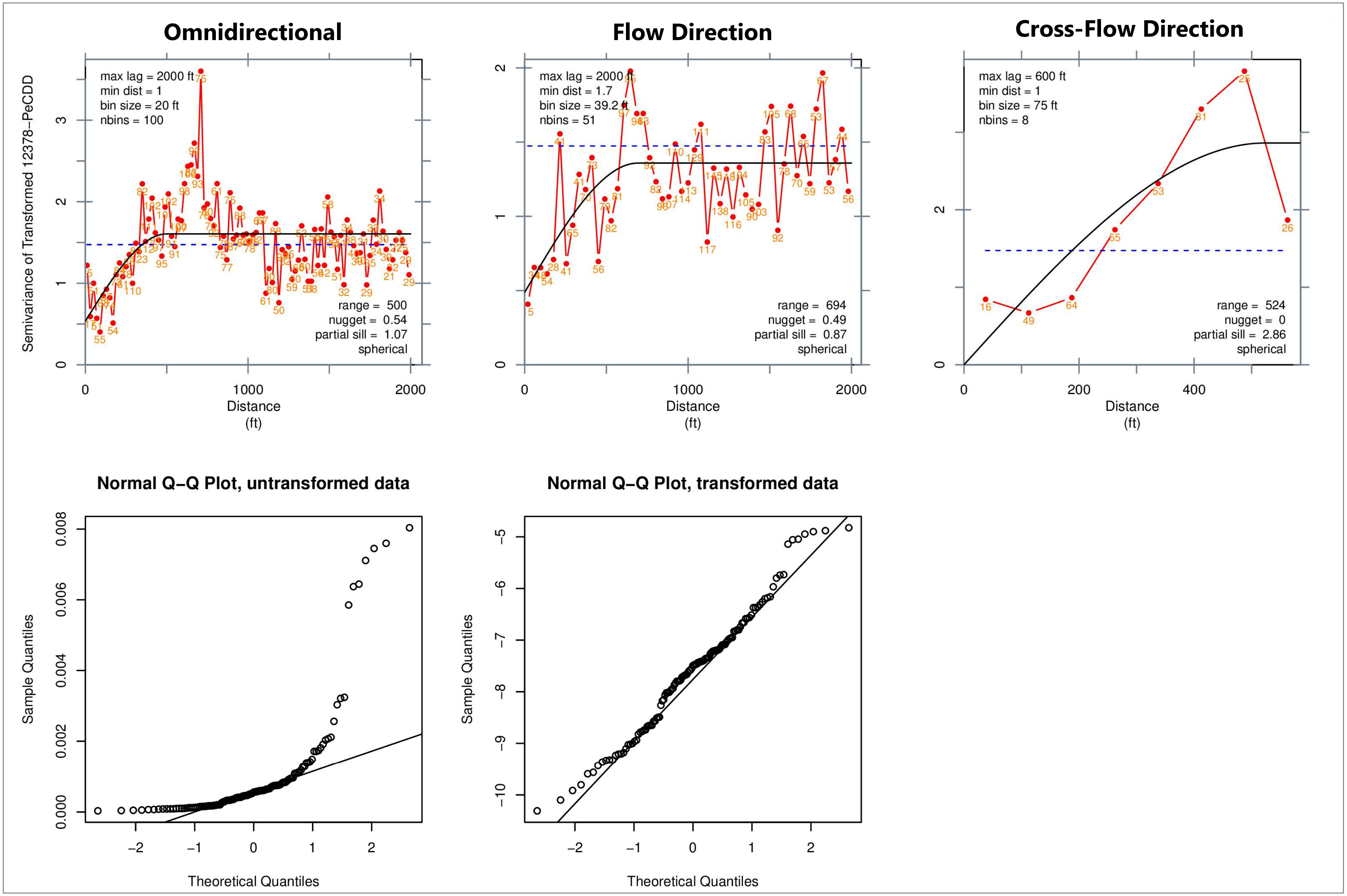

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Figure 1f
Semivariogram of Log-Transformed 1,2,3,7,8-PeCDD in Surface Sediments
SMA Uncertainty Analysis
Gasco Sediments Project Area

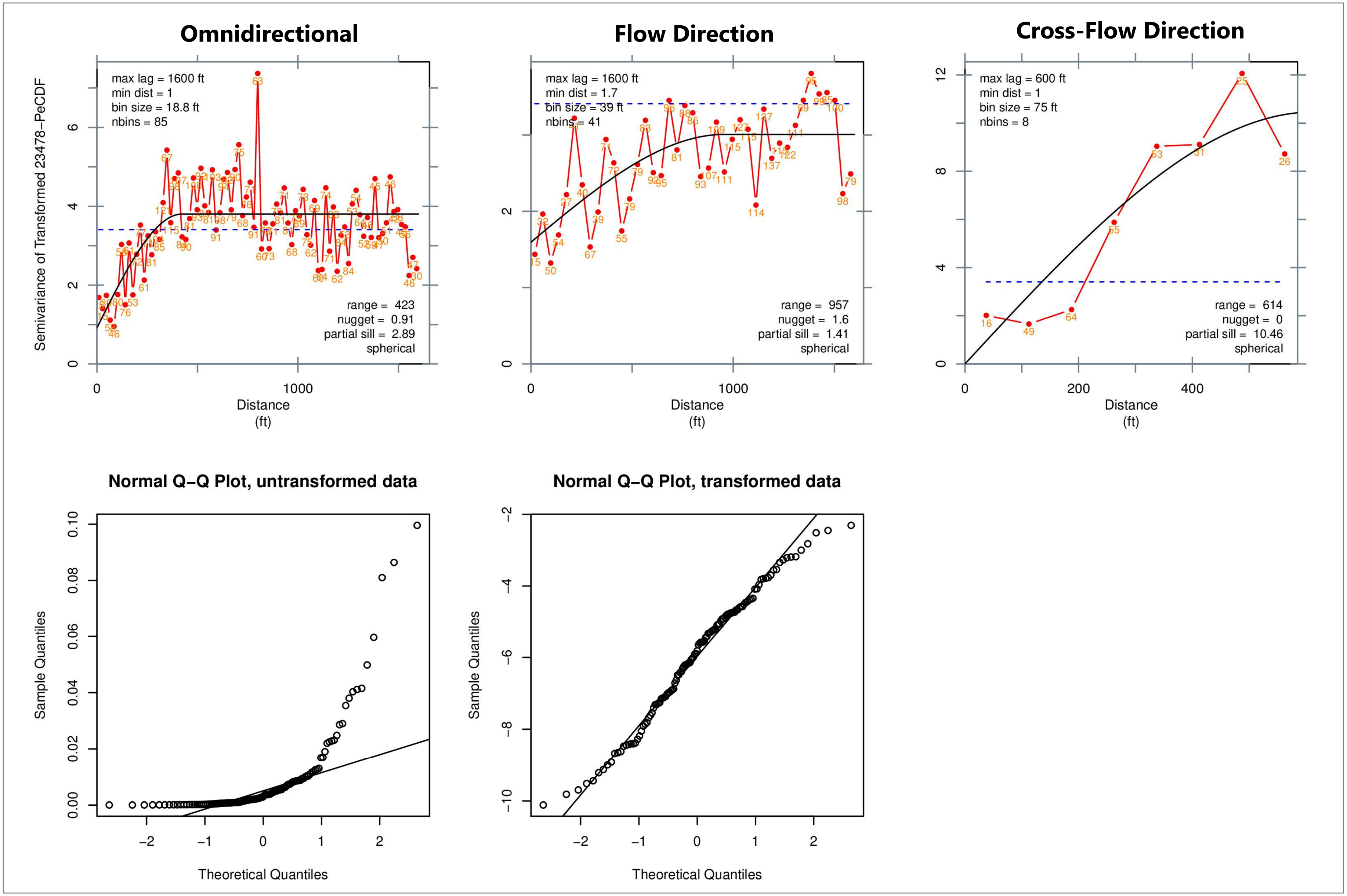

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Figure 1g
Semivariogram of Log-Transformed 2,3,4,7,8-PeCDF in Surface Sediments
SMA Uncertainty Analysis
Gasco Sediments Project Area

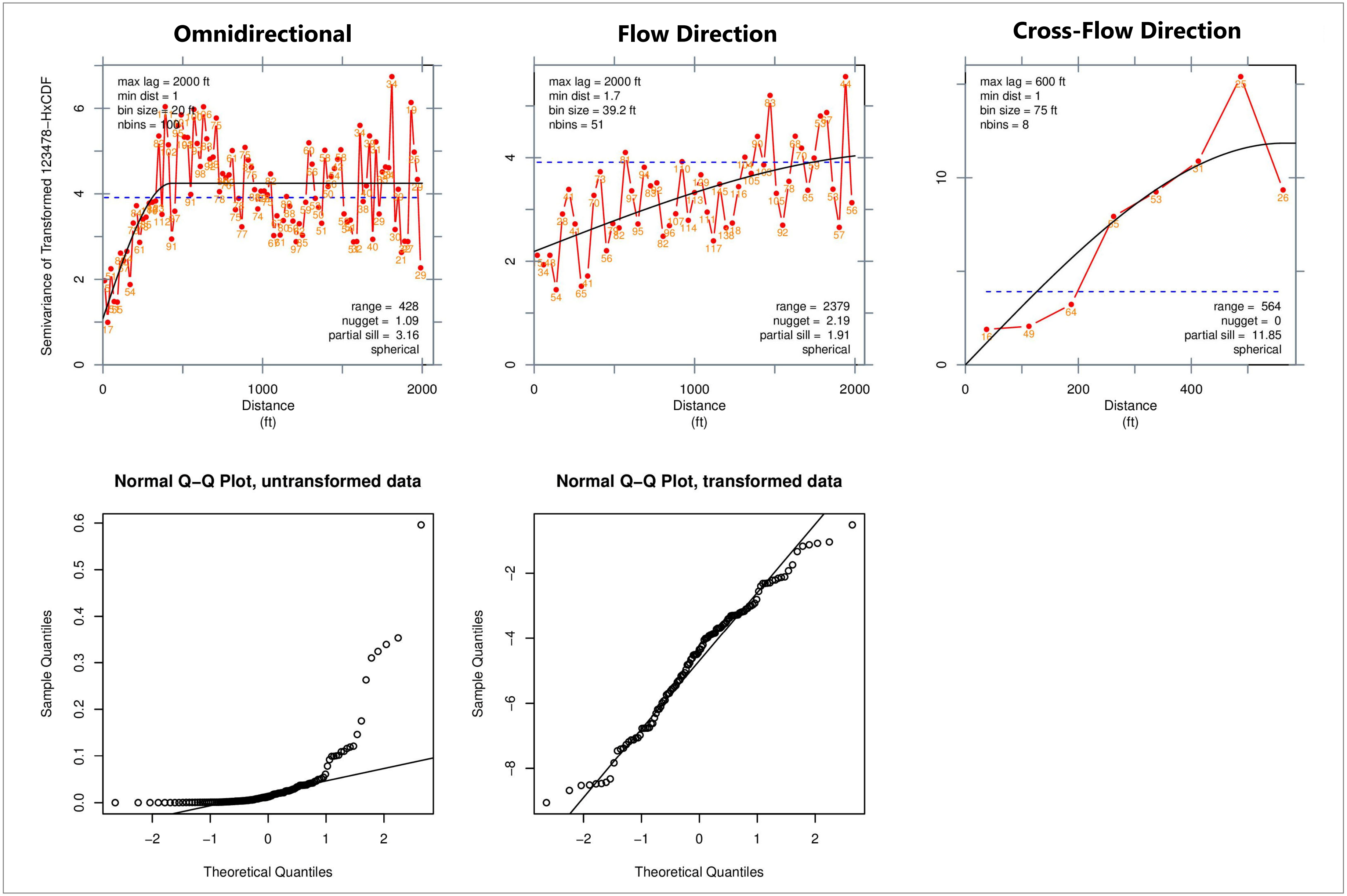

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Figure 1h
Semivariogram of Log-Transformed 1,2,3,4,7,8-HxCDF in Surface Sediments
SMA Uncertainty Analysis
Gasco Sediments Project Area

GASCO0067433

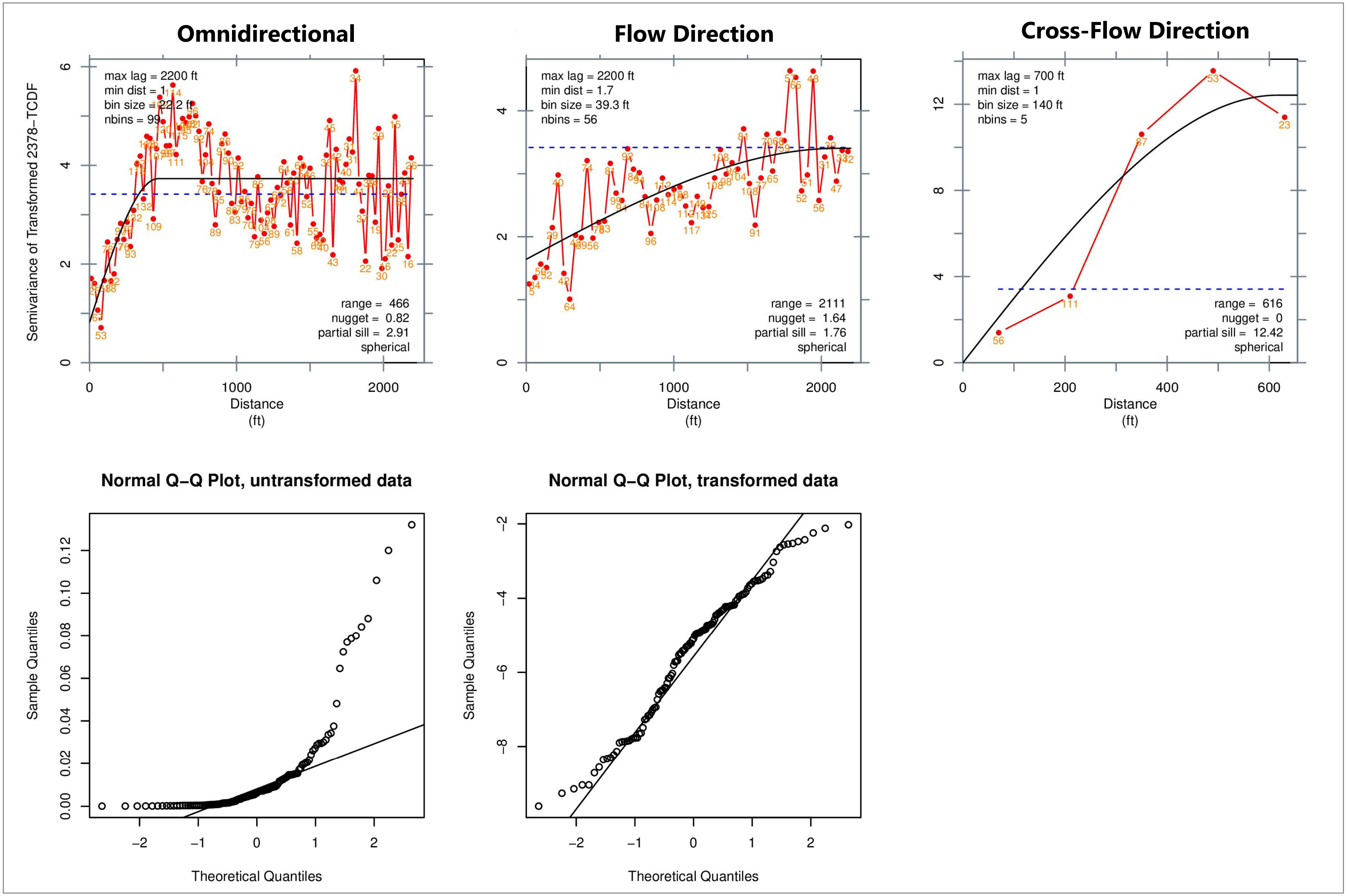

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Figure 1i
Semivariogram of Log-Transformed 2,3,7,8-TCDF in Surface Sediments
SMA Uncertainty Analysis
Gasco Sediments Project Area

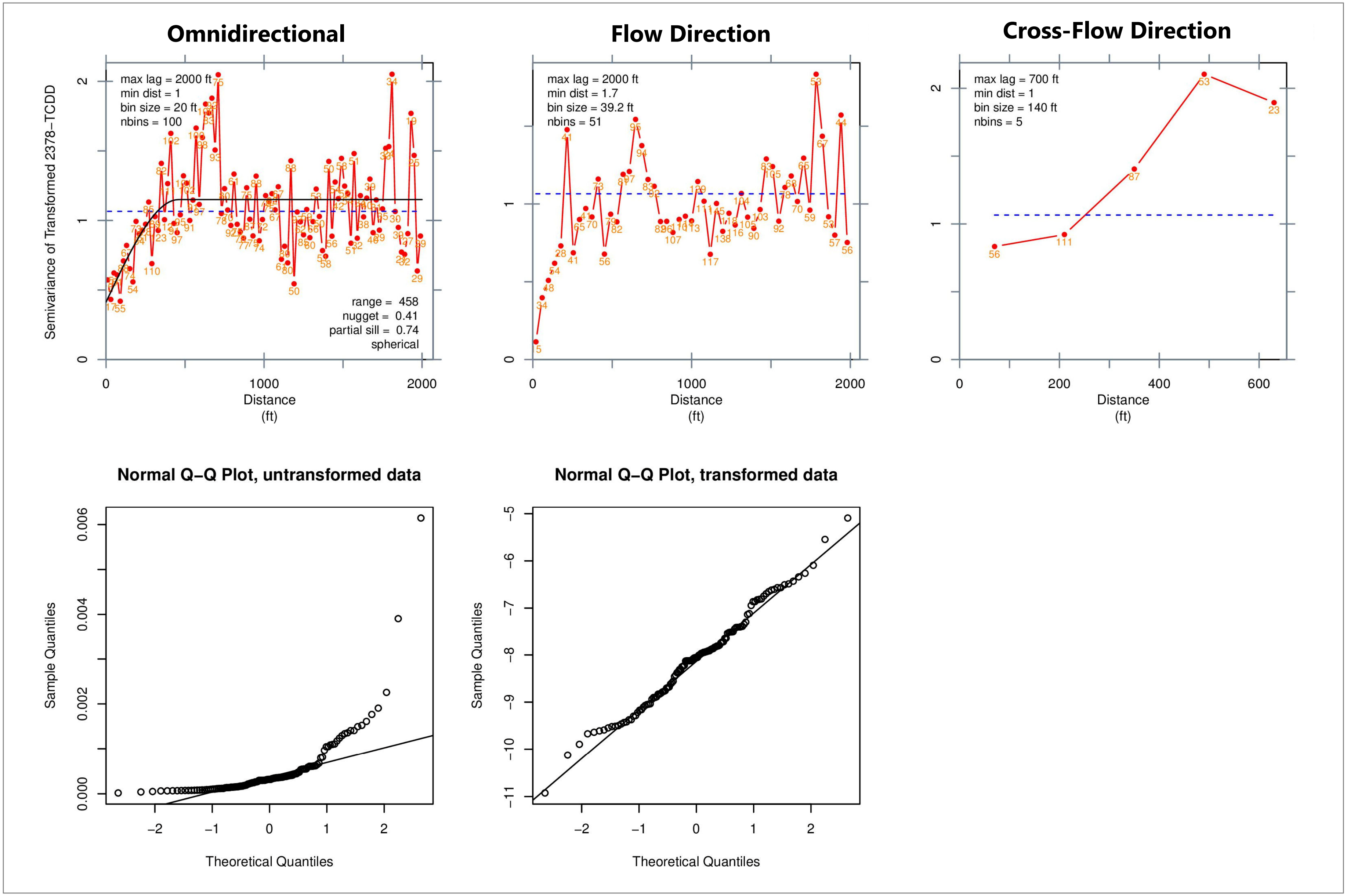

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Figure 1j
Semivariogram of Log-Transformed 2,3,7,8-TCDD in Surface Sediments
SMA Uncertainty Analysis
Gasco Sediments Project Area

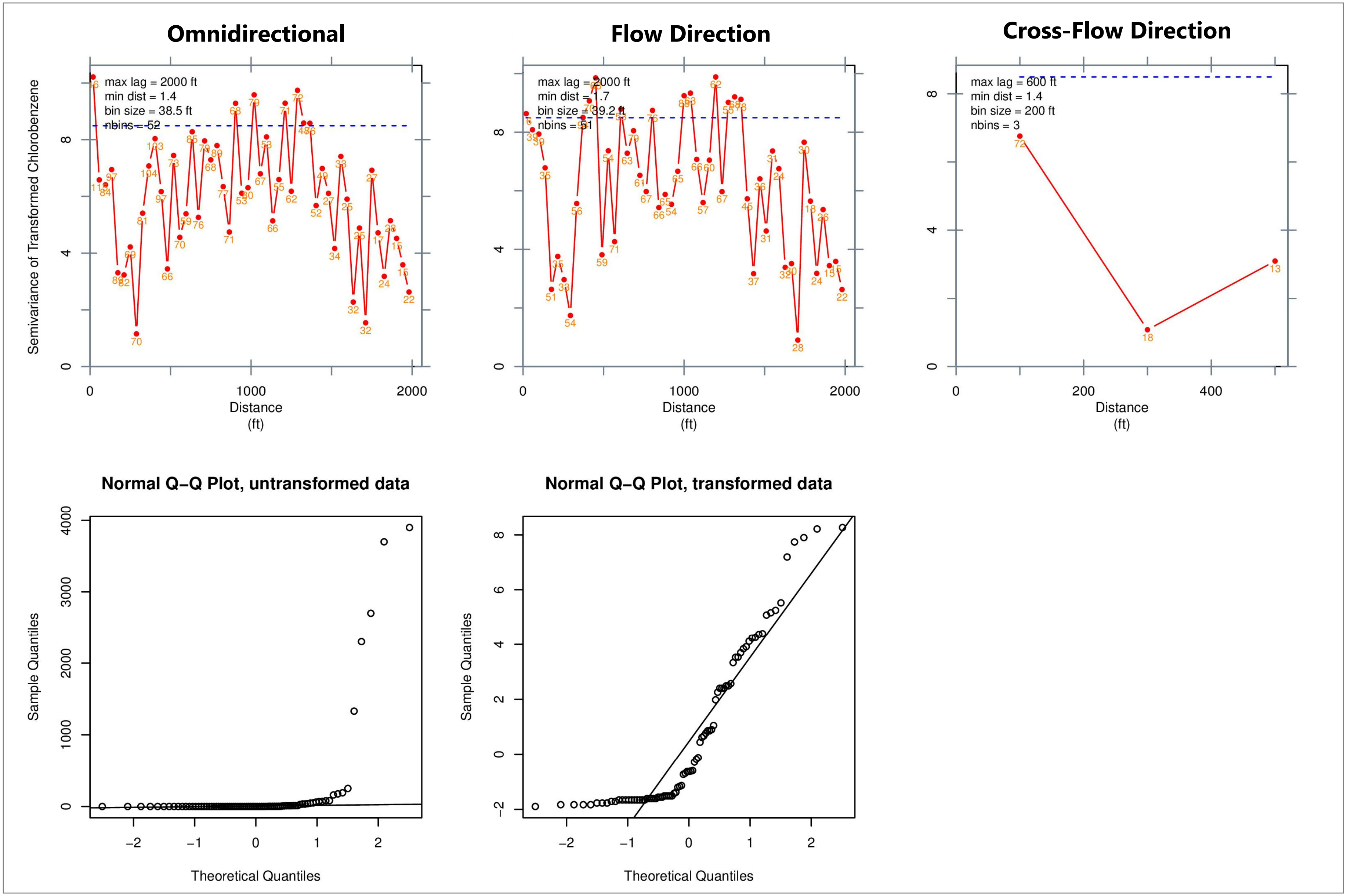

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Figure 1k
Semivariogram of Log-Transformed Chlorobenzene in Surface Sediments
SMA Uncertainty Analysis
Gasco Sediments Project Area

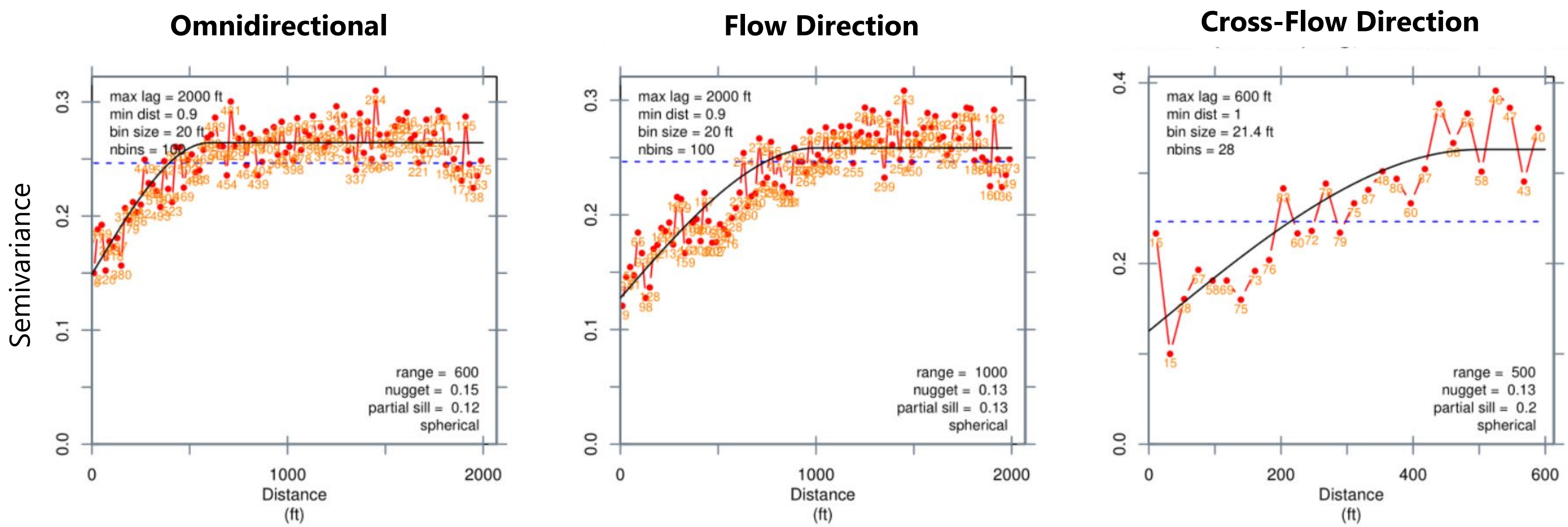

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Figure 2a
Semivariogram of Indicator Variable for Surface Sediment Exceedances
SMA Uncertainty Analysis
Gasco Sediments Project Area

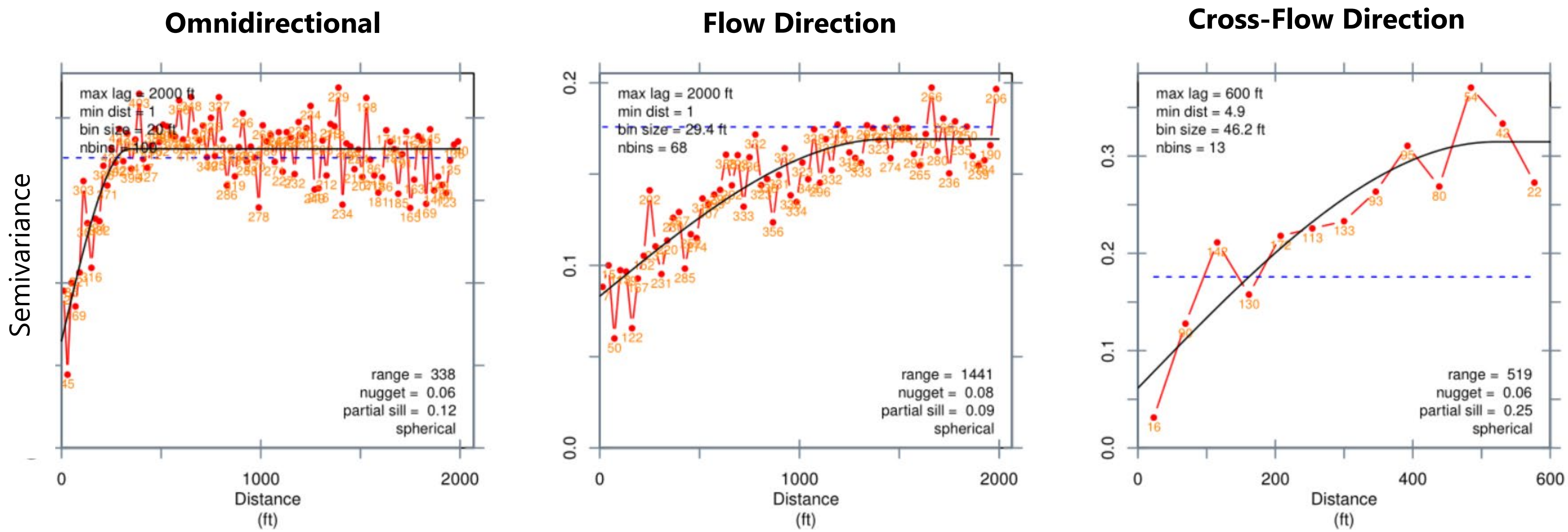

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Figure 2b

Semivariogram of Indicator Variable for Subsurface Sediment Exceedances

SMA Uncertainty Analysis

Gasco Sediments Project Area

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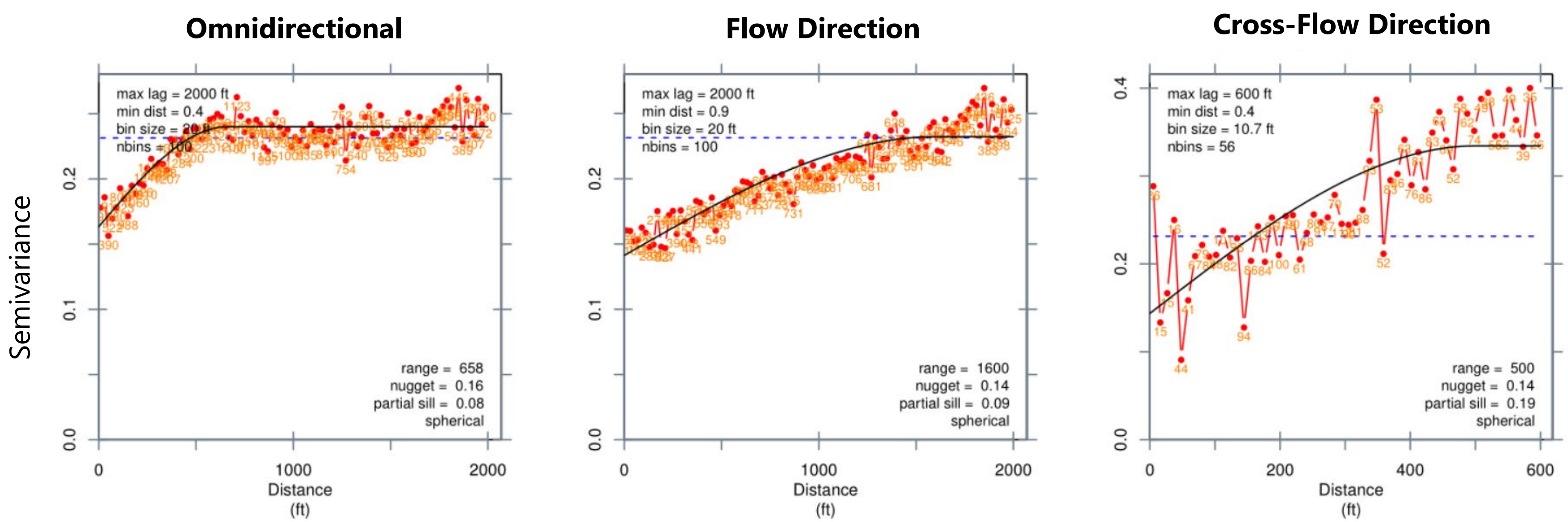

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Figure 2c
Semivariogram of Indicator Variable for Merged Surface and Subsurface Sediment Exceedances
SMA Uncertainty Analysis
Gasco Sediments Project Area

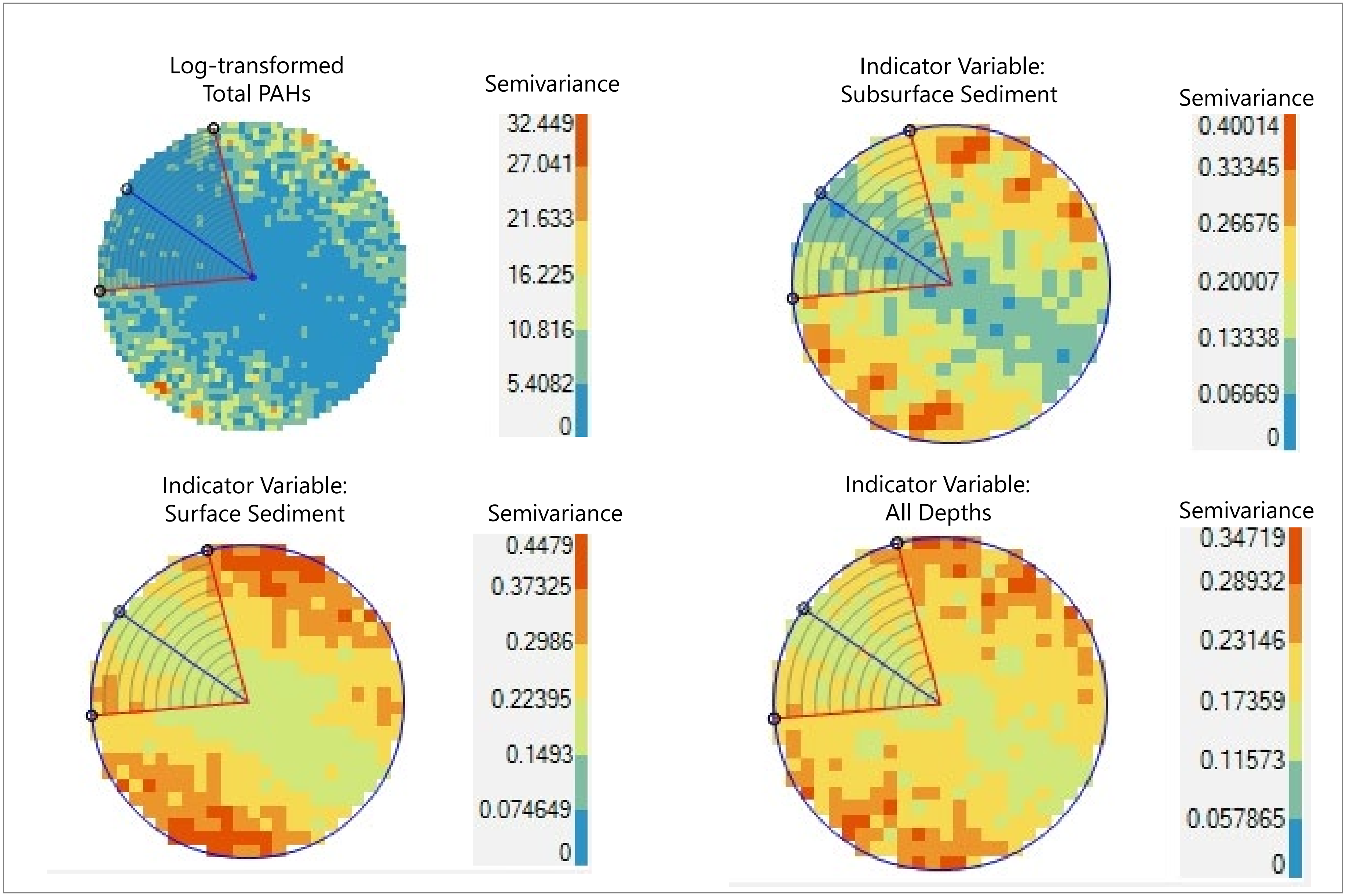

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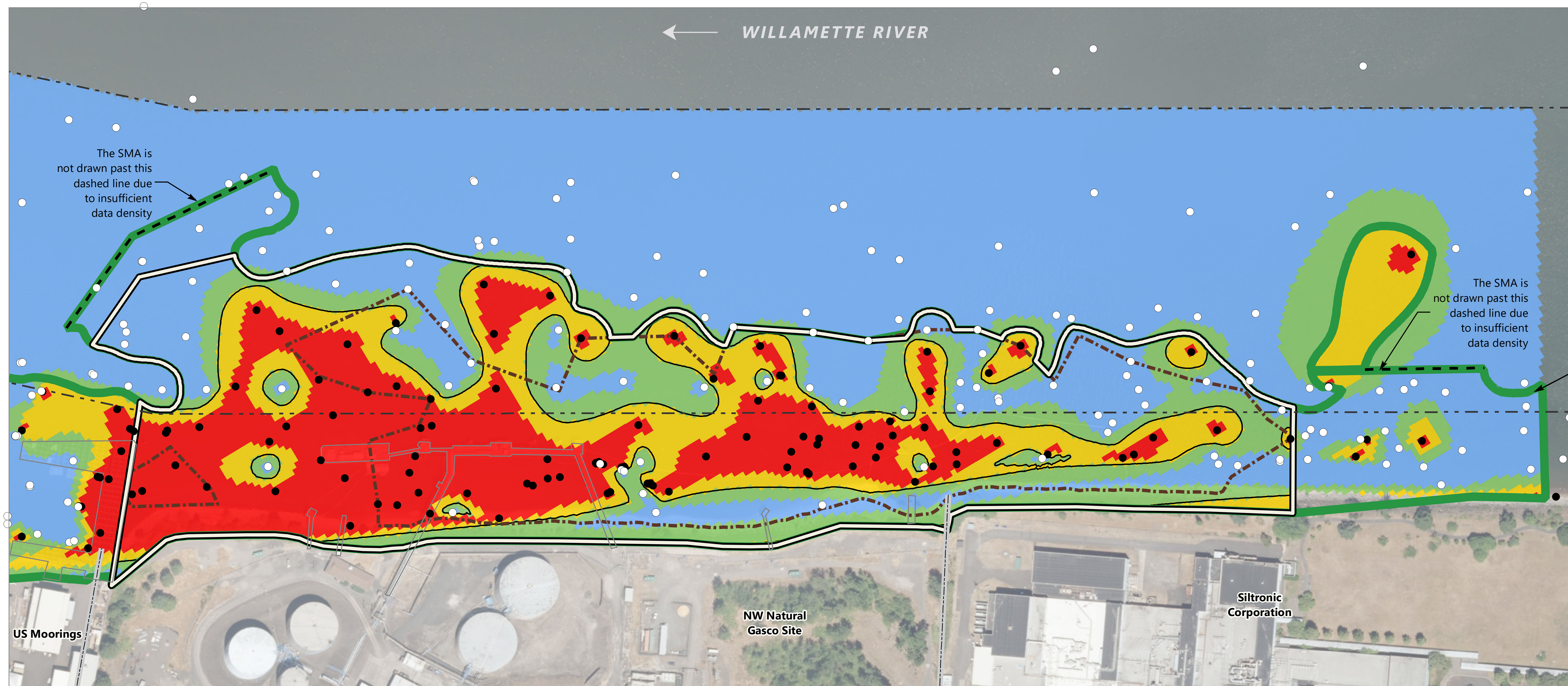
Figure 3
Semivariogram Maps Showing Evidence of Directionality at an Angle of 305 Degrees
SMA Uncertainty Analysis
Gasco Sediments Project Area



LEGEND:

Surface Sampling
- Does Not Exceed
- Exceeds

SMA Uncertainty - Surface Probability of Exceedance (%)
- 0 - 20
- 20 - 50
- 50 - 80
- 80 - 100
- Median Probability of Exceedance

- Navigation Channel
- Structures
- Property Line
- Refined PTW-NAPL Boundary
- Gasco Sediments Site Final Project Area
- SMA Boundary

NOTES:
1. Arrow indicates direction of flow of river.
2. Horizontal datum is NAD83 (HARN 91) Oregon State Plane North, International Feet.
3. Vertical datum is City of Portland (COP), Feet.
4. Aerial imagery from City of Portland 2018.

0 200
Feet

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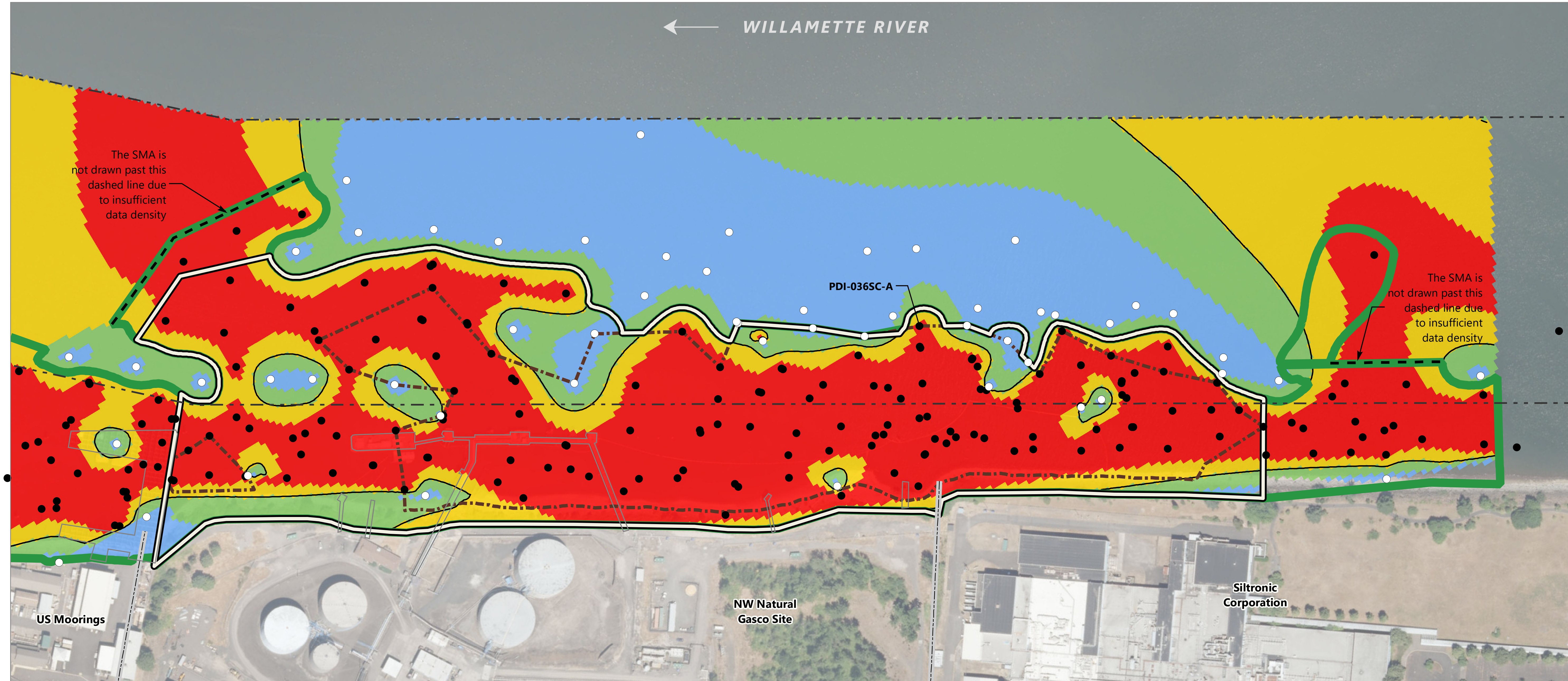
Figure 4
Exceedance Probability – Surface Sediment Only
SMA Uncertainty Analysis
Gasco Sediments Project Area

GASCO0067441



LEGEND:

Subsurface Sampling
- Does Not Exceed
- Exceeds

SMA Uncertainty - Subsurface Probability of Exceedance (%)
- 0 - 20
- 20 - 50
- 50 - 80
- 80 - 100
- Median Probability of Exceedance

- Navigation Channel
- Structures
- Property Line
- Gasco Sediments Site Refined Project Area
- Refined PTW-NAPL Boundary
- SMA Boundary

NOTES:
1. Arrow indicates direction of flow of river.
2. Horizontal datum is NAD83 (HARN 91) Oregon State Plane North, International Feet.
3. Vertical datum is City of Portland (COP), Feet.
4. Aerial imagery from City of Portland 2018.

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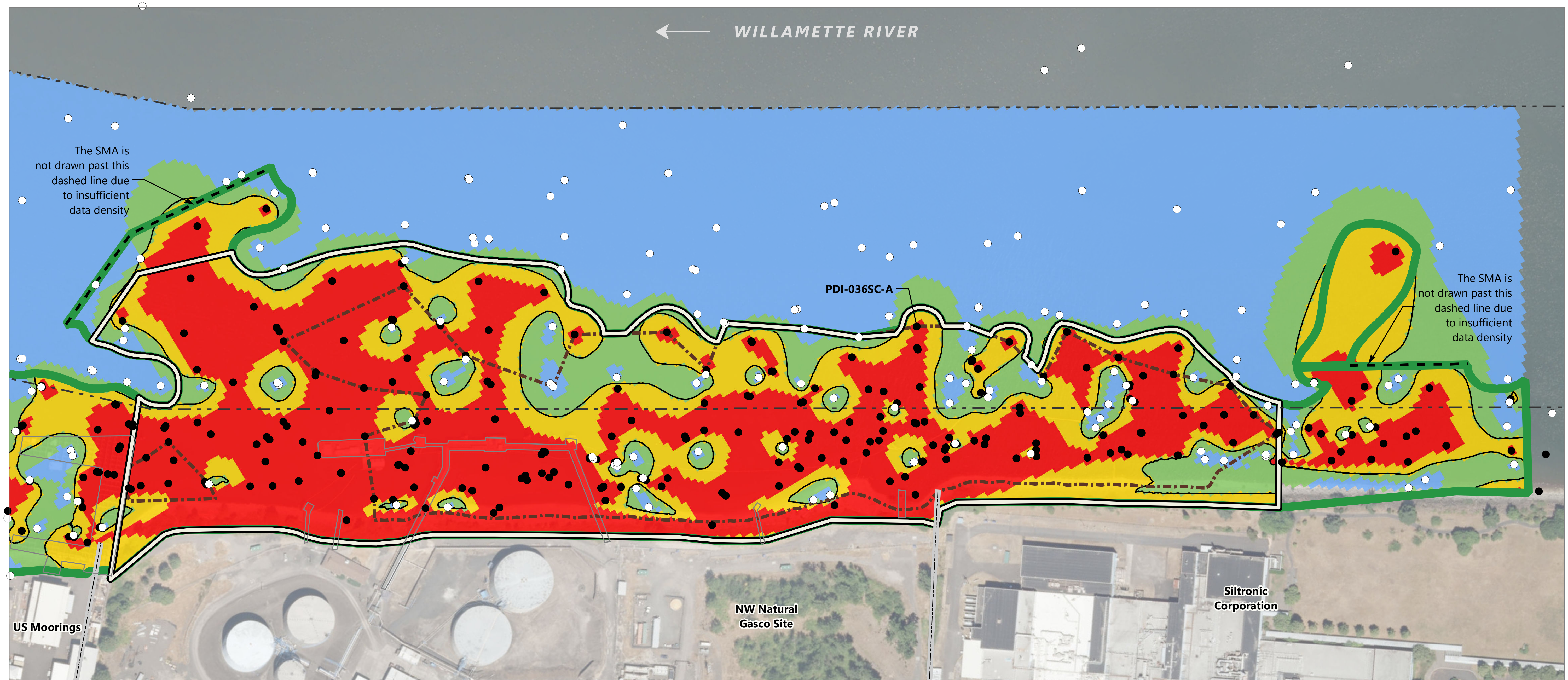
Figure 5
Exceedance Probability - Subsurface Sediment Only
SMA Uncertainty Analysis
Gasco Sediments Project Area



LEGEND:

Sampling at All Depths
- Does Not Exceed
- Exceeds

SMA Uncertainty - All Depths
Probability of Exceedance (%)
- 0 - 20
- 20 - 50
- 50 - 80
- 80 - 100
- Median Probability of Exceedance

- Navigation Channel
- Structures
- Property Line
- Gasco Sediments Site Refined Project Area
- Refined PTW-NAPL Boundary
- SMA Boundary

NOTES:
1. Arrow indicates direction of flow of river.
2. Horizontal datum is NAD83 (HARN 91) Oregon State Plane North, International Feet.
3. Vertical datum is City of Portland (COP), Feet.
4. Aerial imagery from City of Portland 2018.

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Figure 6
Exceedance Probability - Surface and Subsurface Sediment Combined
SMA Uncertainty Analysis
Gasco Sediments Project Area