Gas Works Park Sediment Area

AOI Package
June 3, 2004

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EXHIBIT D

Gas Works Park Sediment Area
Area of Investigation

Introduction

The City of Seattle and Puget Sound Energy have voluntarily agreed to undertake an investigation of impacts to sediments associated with releases from historical activities on the uplands Gas Works Park (GWP) Site. The 1999 Consent Decree for the GWP Site included only the terrestrial uplands areas and explicitly excluded any submerged or seasonally submerged areas (the sediments) of the waters of Lake Union.[1] These sediments are now the focus of the RI/FS and are generally located offshore of what is now GWP and the City of Seattle Harbor Patrol facility.

In accordance with the Agreed Order Section IV (Work to be Performed), and Exhibit B (Remedial Investigation/Feasibility Study (RI/FS) Statement of Work), the investigation will occur in an "Area of Investigation" (AOI). The AOI identifies an area of sediments containing hazardous substances, primarily polycyclic aromatic hydrocarbons (PAHs), associated with releases from historical activities on the upland GWP Site. The AOI is not a site boundary. Instead, it describes the area where the RI/FS will be focused. During the RI/FS process, the AOI may expand or contract to address the extent of hazardous substances associated with the upland GWP Site. This exhibit describes the parameters and summarizes the analytical methods and results used to define the AOI (Figure D-1) for the facility located in the submerged shorelands and bed of Lake Union, generally in the vicinity of the GWP Site.

Parameters and Analytical Methods Used to Define the AOI

The parameters used to define the AOI include:

- GWP Site COCs and historical sources.
- Ambient PAHs in Lake Union
- Distributions of elevated GWP Site-related PAHs in the vicinity of the GWP Site
- Distribution of metals and other contaminants from non-GWP Site sources
- Bathymetry

Major sediment investigation activities were conducted in north Lake Union between 1995 and 2002 to determine the nature and extent of PAHs and other contaminants in the vicinity of the GWP Site. The data from these efforts (including voluntary sediment surveys in the vicinity of the GWP Site and an EPA 1995 investigation) were used to establish the Lake Union sediment sample populations (Floyd Snider McCarthy, 2004).

[1] See Consent Decree, King County Cause No. 99-2-52532-9SEA, filed December 23, 1999, Sections IV(A) and XXVII.

These investigations have documented the presence of elevated PAH concentrations in the GWP Site vicinity and throughout Lake Union.

To define the AOI, the distribution of PAH concentrations in the vicinity of the GWP Site were compared to the ambient concentrations in Lake Union. Three analytical methods (see Appendices A and B) were used to define the AOI including: MTCAStat, Population Statistics, and Principal Components Analysis (PCA).

Washington State Department of Ecology guidance (Ecology) defines the area background as the concentration of hazardous substances that are consistently present in the environment in the vicinity of a site, and are the result of human activities unrelated to releases from that site (Ecology, 1992). Due to the working nature and multitude of sources to Lake Union, an area background analysis was conducted using Ecology's MTCAstat software (Ecology, 2004a) to determine an ambient Lake Union (ALU) concentration (see Appendix A). The calculated ALU concentration was then compared to concentrations from the Gas Works Park Sediments (GWPS) area. An AOI line was established to ensure that the AOI included areas exceeding the ALU concentration.

Additional methods used to confirm the accuracy of the AOI included:

- Comparison of the ALU sediments and GWPS sample concentrations through a statistical population test;

- PCA using individual PAH concentrations. This analysis compares the amount of individual PAHs to the sum of all the individual PAHs (TPAH) by sample. PCA focuses on the relative abundance of individual PAHs in each sample (PAH types), rather than PAH concentrations.

Gas Works Park Site COCs and Historical Sources

The AOI is the area where unrefined Manufactured Gas Plant (MGP) raw materials, products and by-products associated with the various types of manufactured gas processes (ER&T, inc., 1984), tar refining activities, and other historical activities on the GWP Site have caused elevated contaminant concentrations and potential sediment impacts.

Potential chemicals of concern (COCs) identified as part of the uplands GWP Site RI/FS process are listed in the table below.

Chemicals of Concern and Possible Sources for the Gas Works Park Site (1)

PAHs	Refined and unrefined tar from MGP and other sources PAHs attributable to tar refining operations and MGP operations Other hydrocarbons related to tar refining and MGP operations
Arsenic	Arsenic concentrations associated with GWP Site historical operations

Note:

1. These COCs are based on the GWP Site Focused Feasibility Study (Parametrix, 1998)

Ambient PAHs in Lake Union

PAHs are ubiquitous in the environment and are typically present at elevated concentrations in sediments near urbanized areas. PAHs are formed from the incomplete combustion of organic matter via natural (e.g., volcanic activity, forest fires) and anthropogenic processes. A variety of anthropogenic activities produce PAHs, including burning of coal or petroleum products for heat and power, gas manufacture, coke production (e.g., iron and steel industry), tar refining, the production and release of petroleum products, and use of combustion engines (especially diesel engines) in cars or vessels.

By the 1920s, Lake Union was firmly established as an industrial "working lake." Numerous sources of PAHs have existed for more than 80 years in the form of over 150 businesses and/or industries operating around the lakeshores. Of these, potential contributors of PAHs to north Lake Union sediments likely include, but are not limited to, the former United Marine Shipbuilding (Unimar/Northlake Shipyard), the Metro/Chevron bulk fuel storage facility, the former American Tar Refinery Company (ATCO) facility and predecessor tar refining operations, the former North American Tar Refinery Company (NORTAR) facility, former MGP operations including coal gasification, water-gas process, oil gasification and solvent manufacturing, asphalt manufacturing, other shipyards, marinas, boatyards/marine outfitting, municipal incineration, fires, vessel sources (diesel and gasoline engines), and storm water/CSO outfalls. Other areas of concern for sediment contamination in Lake Union are identified in Ecology's Sediment Cleanup Status Report (2004b). Consequently, the origin and distribution of PAHs and other contaminants present in sediments throughout this "working lake" is complex.

Results and AOI Determination

Calculations using MTCAStat and Other Analytical Methods

Preliminary MTCAstat analyses indicated an ALU TPAH concentration of approximately 100 mg/kg (Appendix A). This calculated ALU concentration was then used to identify stations with TPAH concentrations exceeding ambient conditions in the vicinity of the GWP Site. A preliminary AOI line was drawn to encompass all sampling stations containing elevated TPAHs in the GWPS area.

Additional statistical tests show that TPAH concentrations within the AOI are significantly elevated (t-test value of 7.52 and probability 0.00) relative to the concentrations in ALU (refer to Figure D-2 and Appendix A). PCA was used to further evaluate the distribution of PAHs in the vicinity of the GWP Site as a tool to classify stations based on the type of PAHs present, not solely on summed TPAH concentration. This PCA analysis allows an evaluation of whether ambient PAH "patterns" are distinguishable from GWPS area PAH "patterns", and thus whether the AOI line generally separates the two. PCA confirmed the presence of two sediment sample populations with different PAH characteristics. The two populations represent ALU sediment and GWPS stations with some overlap of lower concentration stations included within the AOI as a conservative measure (Appendix B). These additional methods confirm that the AOI includes all the areas of elevated TPAH near the GWP Site. The AOI is considered conservative as it includes TPAH concentrations lower than ALU concentrations (Figure D-3) and characteristic of ALU PAHs (Appendix B).

Distribution of Elevated GWP Related PAHs in the Vicinity of GWP

TPAH concentrations greater than 100 mg/kg are found within 400 feet of the eastern GWP Site shoreline, and within 500 feet of the southern GWP Site shoreline. There is a steep concentration gradient separating elevated PAHs in a narrow band near the GWP Site from PAHs less than 100 mg/kg range associated with ALU conditions (note the steady decrease in TPAH concentrations with distance from shoreline in Figure D-3). TPAH concentrations greater than 100 mg/kg are found within 800 feet of the western GWP Site/western shipyard shoreline.

Distribution of Metals and Other Contaminants from Non-GWP Sources

Based upon an extensive evaluation of data from sediment investigation efforts conducted between 1995 and 2002, the extent of metals (e.g., arsenic, copper, lead, and zinc) and other non-GWP Site contaminants in the vicinity of the GWP Site can generally be distinguished from areas impacted by GWP Site PAHs and/or related to non-GWP Site sources. In some cases, the distribution of non-PAH contaminants indicates a specific source; in other cases, impacts are widespread or the distribution complex, rendering the identification of specific non-GWP Site sources more difficult (e.g., polychlorinated biphenyls [PCBs] and mercury, see chemical contour mapping, RETEC, 2004). PCBs and mercury illustrate the ubiquitous nature of bioaccumulative contaminants of concern in Lake Union (Ecology, 2004b).

One example of impacts associated with a specific source, or sources is the area of elevated metals concentrations in the vicinity of the former and existing shipyards west of GWP Site (refer to Figures D-4). The shipyard area of elevated metals and other contaminants (e.g., PCBs) help delineate the western extent of GWP Site-related impacts.

Bathymetry

The AOI is also consistent with bathymetry and potential down slope transport of PAHs from the uplands GWP Site. Figure D-5 shows the AOI line superimposed on the

bathymetry map for north Lake Union. The AOI line is outside of the area of steep slopes (marked by closely spaced bathymetric contours) offshore of the GWP Site and within the relatively flat lake bottom area. Therefore, the AOI encompasses any steep bathymetric features and extends well into the level lake bottom, ensuring that potential down slope transport from the GWP Site is well inside the AOI.

AOI Determination

Based upon an extensive evaluation of data from sediment investigation efforts conducted between 1995 and 2002, the PAHs attributable to historical GWP Site sources can be encompassed by a narrow band of sediments containing elevated PAHs wrapping around the GWP Site. The extent of the AOI is constrained by TPAH gradients, bathymetry, and the existence of contamination from other sources.

As determined and verified by the analytical methods described above, the AOI shown on Figure D-1 delineates chemical concentrations indicative of the GWPS and those indicative of ALU sediments.

The AOI line was further refined to adhere to existing property boundaries related to the GWP Site, eastern (marina area), and western (shipyard). For the existing and former shipyards to the west of the GWP Site, there is a consent decree already governing sediment work. Because the area covered by the shipyard consent decree is to be remediated by the parties to the decree, this eastern consent decree boundary serves as a logical western boundary for the AOI. The area of elevated TPAH southwest of the consent decree area is also included as a conservative measure.

Conclusions

Analysis of key parameters by the analytical methods summarized above indicate:

- Based upon historical activities at the GWP Site, chemicals of potential concern, primarily PAHs, have been used as a basis for defining the AOI.

- The origin of PAHs and other contaminants in the sediments of this “working lake” is complex; however, the GWPS area PAH “patterns” are generally distinguishable from ALU sediments, and therefore the AOI boundary serves as a delineation between PAH concentrations indicative of the GWPS versus the ALU sediments.

- Based upon the evaluation of sediment investigation data collected between 1995 and 2002, the extent of sediments containing elevated PAHs can be clearly delineated as a narrow band wrapping around the shoreline of the GWP Site.

- The distribution of metals and other non-GWP Site contaminants in sediments in the vicinity of the GWP Site indicates the presence of non-GWP Site sources that further help to delineate the extent of GWP Site-related impacts,

especially to the west where the shipyard consent decree boundary defines a logical boundary.

Based upon these conclusions, the AOI that will be the subject of the RI/FS studies for the Gas Works Park Agreed Order is shown on Figure D-1.

References

Ecology, 2004a. MTCAStat software package. Version 3.0. Washington State Department of Ecology Toxics Cleanup Program. Electronic version available February, 2004.

Ecology, 2004b. *2003 Sediment Cleanup Status Report*. Washington State Department of Ecology Toxics Cleanup Program. 2004.

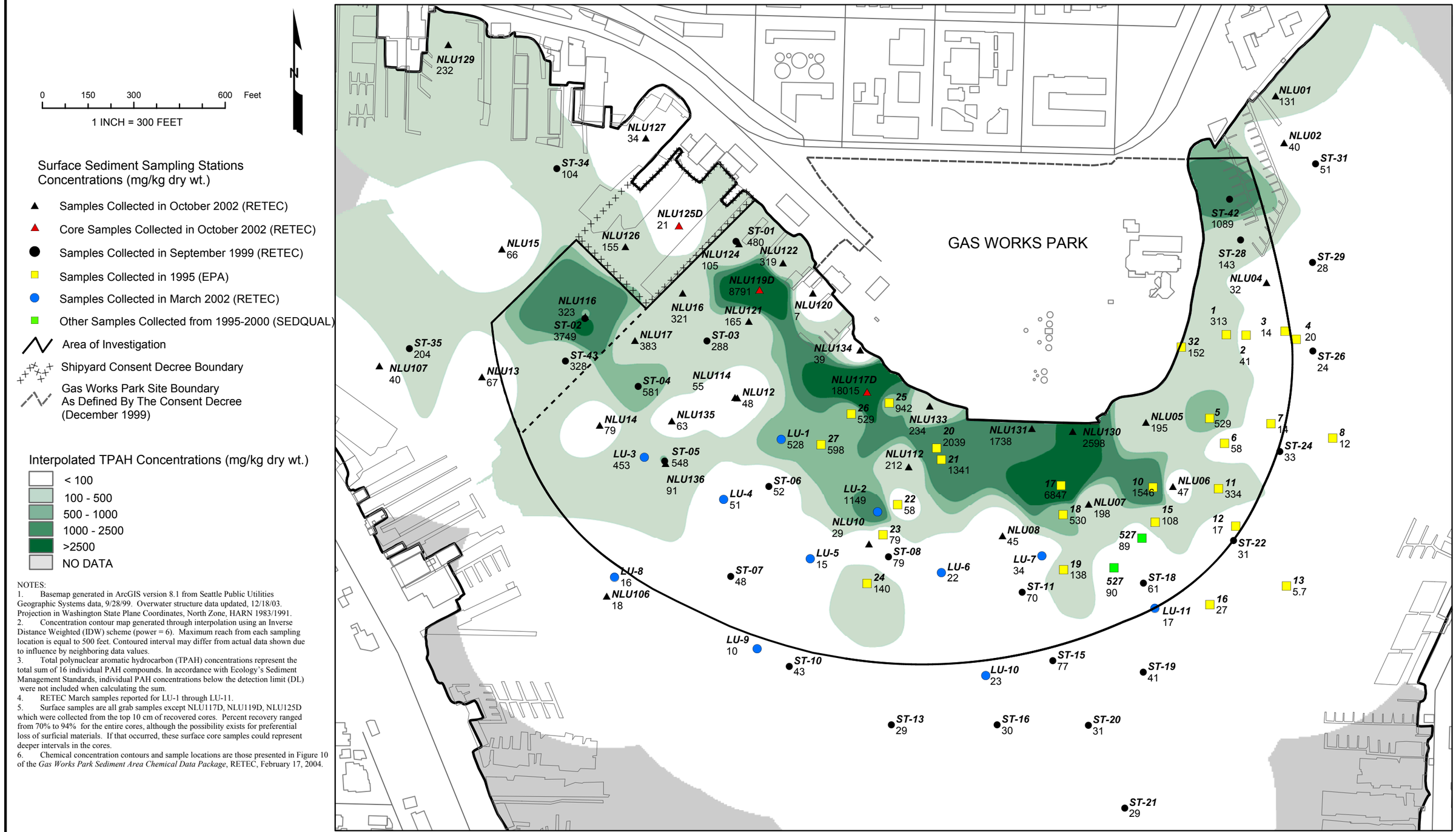
Ecology, 1992. *Statistical Guidance for Ecology Site Managers.* Washington State Department of Ecology Toxics Cleanup Program. August, 1992.

Environmental Research & Technology, Inc. and Koppers Company, Inc., 1984. *Handbook on Manufactured Gas Plant Sites*. Report P-D215. Utility Solid Waste Activities Group and Edison Electric Institute. 1984.

Floyd Snider McCarthy, 2004. *Revisions to SEDQUAL Historic Dataset.* May 13, 2004.

Parametrix Inc. and Key Environmental Inc., 1998. *Gas Works Park Environmental Cleanup: Focused Feasibility Study Report.* Prepared for City of Seattle and Puget Sound Energy. 1998.

RETEC, 2004. *GWP Sediment Area Chemical Data Package.* Submitted to Washington State Department of Ecology. February 17, 2004.



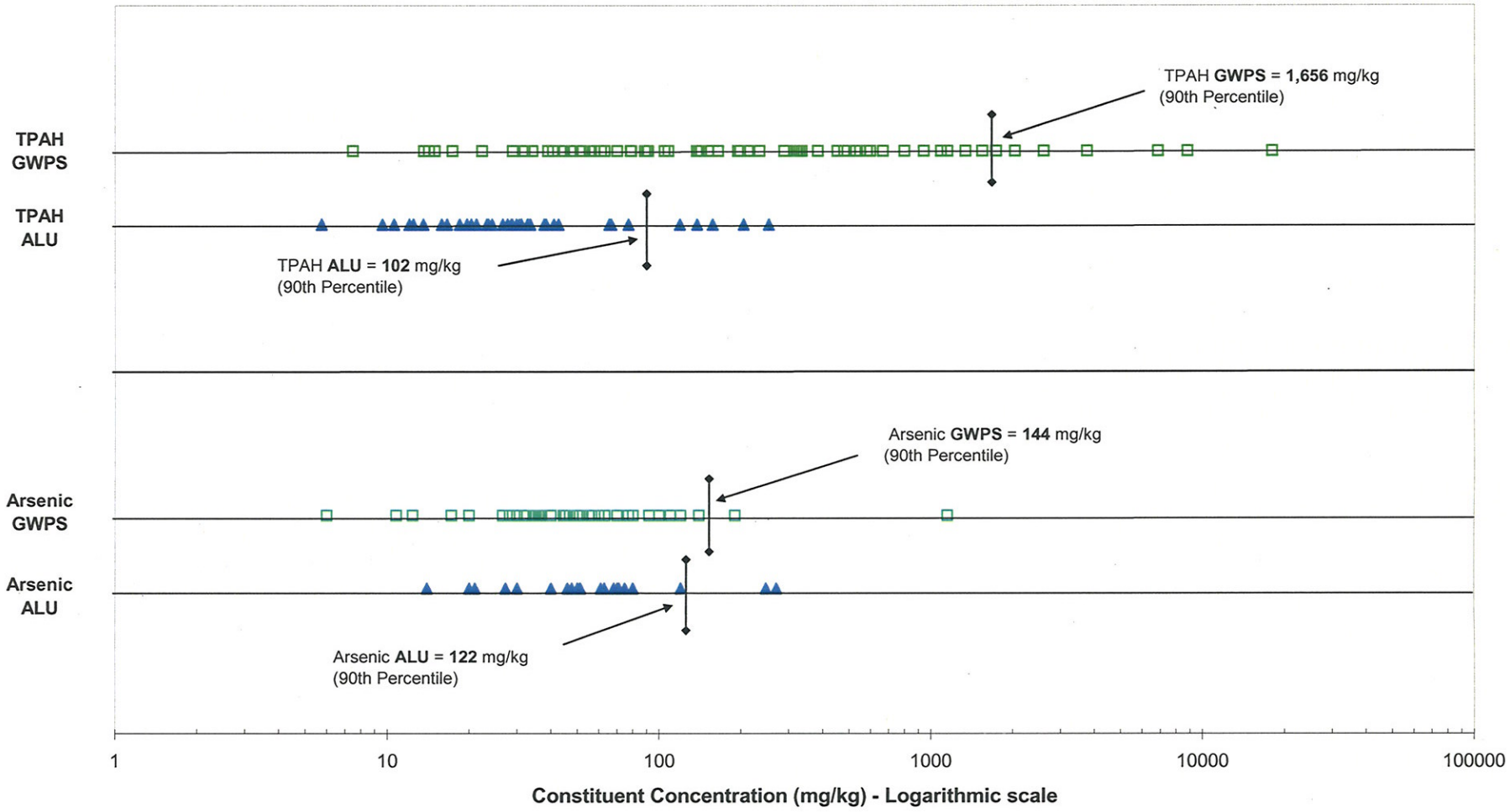
NOTES:

1. Basemap generated in ArcGIS version 8.1 from Seattle Public Utilities Geographic Systems data, 9/28/99. Overwater structure data updated, 12/18/03. Projection in Washington State Plane Coordinates, North Zone, HARN 1983/1991.
2. Concentration contour map generated through interpolation using an Inverse Distance Weighted (IDW) scheme (power = 6). Maximum reach from each sampling location is equal to 500 feet. Contoured interval may differ from actual data shown due to influence by neighboring data values.
3. Total polynuclear aromatic hydrocarbon (TPAH) concentrations represent the total sum of 16 individual PAH compounds. In accordance with Ecology's Sediment Management Standards, individual PAH concentrations below the detection limit (DL) were not included when calculating the sum.
4. RETEC March samples reported for LU-1 through LU-11.
5. Surface samples are all grab samples except NLU117D, NLU119D, NLU125D which were collected from the top 10 cm of recovered cores. Percent recovery ranged from 70% to 94% for the entire cores, although the possibility exists for preferential loss of surficial materials. If that occurred, these surface core samples could represent deeper intervals in the cores.
6. Chemical concentration contours and sample locations are those presented in Figure 10 of the *Gas Works Park Sediment Area Chemical Data Package*, RETEC, February 17, 2004.

RETEC

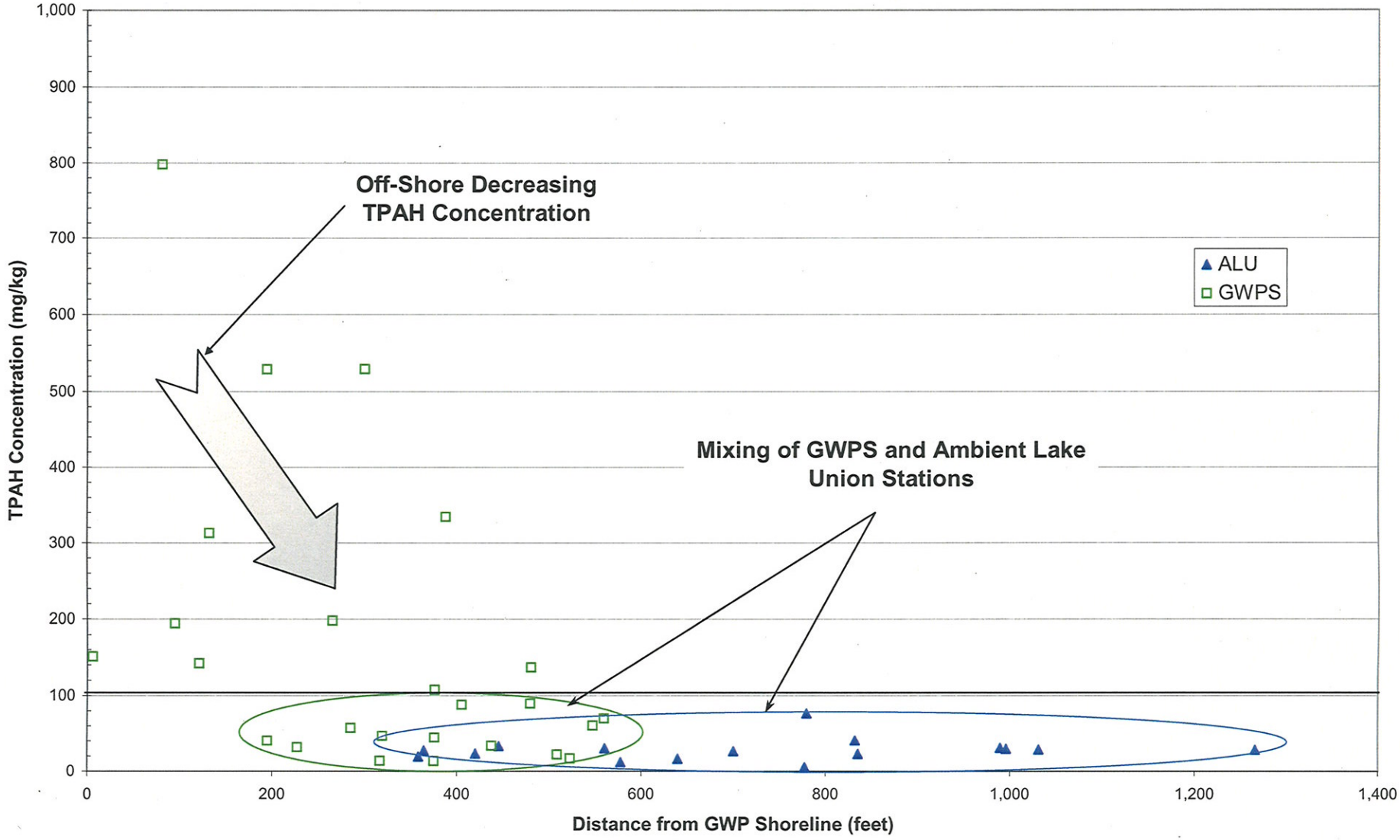
GAS WORKS PARK SEDIMENT AREA		**SURFACE SEDIMENT TPAH CONCENTRATIONS WITH AREA OF INVESTIGATION**
PSE10-18064-330		
DATE: 5/27/04	DWN. BY: KBL/ftc	FILE: T:/LakeUnion_N83/Projects/NLU/AOIpackage/tpah_int_wAOI_d1.mxd **FIGURE D-1**

Figure D-2
Ambient Lake Union and Gas Works Park Sediment
TPAH and Arsenic MTCAStat Calculations



Note: The 90th percentile calculations presented above were calculated using the Ecology MTCAStat Background Module.
The TPAH GWPS 90th percentile is presented above, however the MTCAStat Background Module calculated a 4 x 50th percentile of 776 mg/kg.
Both the ALU and GWPS TPAH and arsenic data sets were entered into the MTCAStat background module only for purposes of a statistical comparison of the 90th percentile calculations (i.e., not for compliance purposes).

Figure D-3
TPAH Concentration vs. Distance from GWP Shoreline



Note: Only TPAH concentrations in the east and south areas less than 1,000 mg/kg shown above. Refer to Figure A-2 for a plot of the complete data set.

N

0 150 300 600 Feet

1 INCH = 300 FEET

Surface Sediment Sampling Stations
Concentrations (mg/kg dry wt.)

- Samples Collected in October 2002 (RETEC)
- Core Samples Collected in October 2002 (RETEC)
- Samples Collected in September 1999 (RETEC)
- Samples Collected in 1995 (EPA)
- Other Samples Collected from 1995-2000 (SEDQUAL)
- Area of Investigation
- Shipyard Consent Decree Boundary
- Gas Works Park Site Boundary
  As Defined By The Consent Decree
  (December 1999)

Interpolated Arsenic Concentrations (mg/kg dry wt.)

- <75
- 75 - 150
- 150 - 500
- 500 - 1000
- >1000
- NO DATA

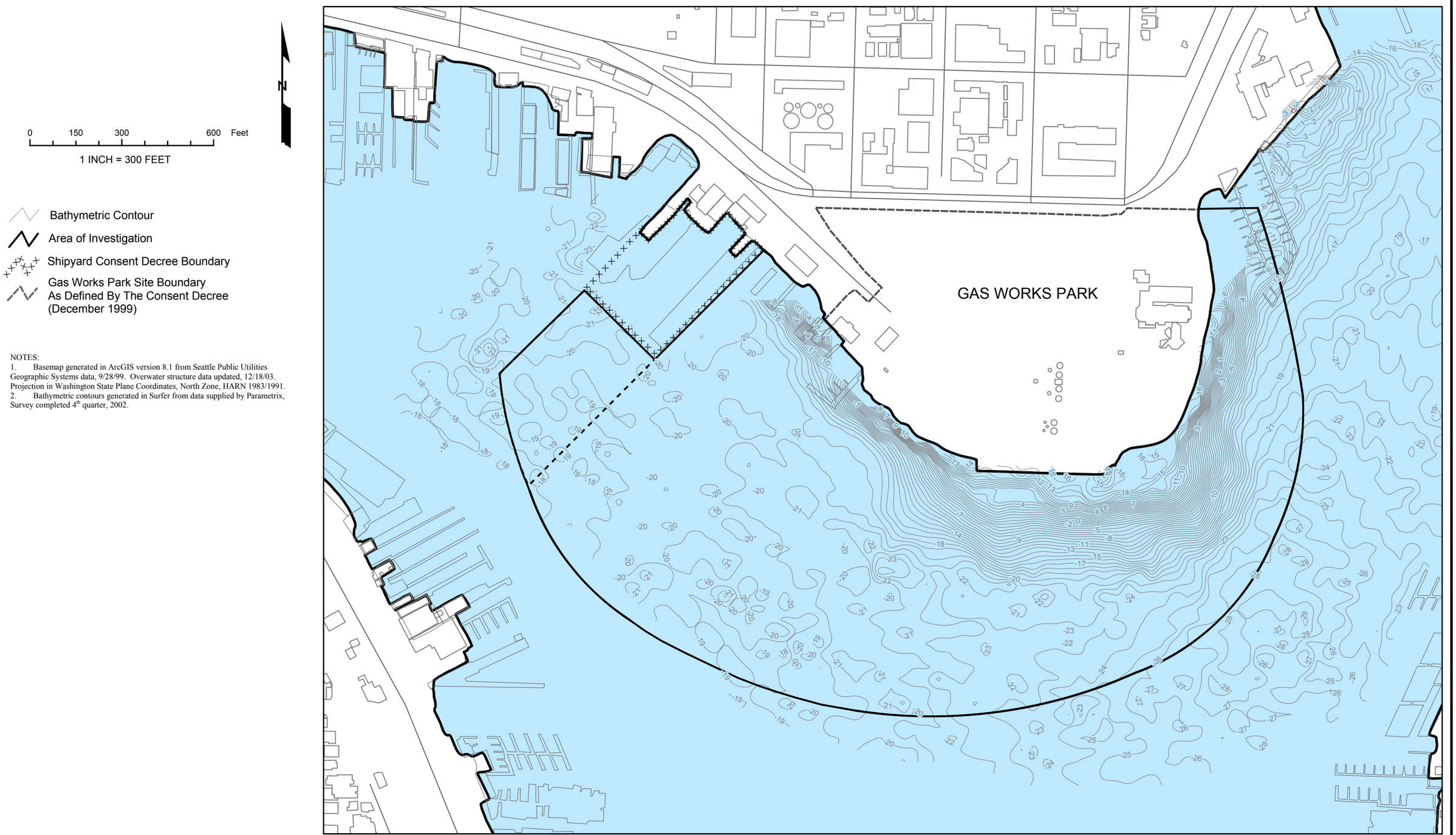
NOTES:
1. Basemap generated in ArcGIS version 8.1 from Seattle Public Utilities Geographic Systems data, 9/28/99. Overwater structure data updated, 12/18/03. Projection in Washington State Plane Coordinates, North Zone, HARN 1983/1991.
2. Concentration contour map generated through interpolation using an Inverse Distance Weighted (IDW) scheme (power = 6). Maximum reach from each sampling location is equal to 500 feet. Contoured interval may differ from actual data shown due to influence by neighboring data values.
3. Surface samples are all grab samples except NLU117D, NLU119D, NLU125D which were collected from the top 10 cm of recovered cores. Percent recovery for these cores ranged from 70% to 94% for the entire cores. The possibility exists for preferential loss of surface sediment. If that occurred, the surface sediment samples collected from cores could represent deeper intervals.

GAS WORKS PARK

NLU129 300
NLU127 2920
ST-34 150
NLU125D 50
ST-01 110
NLU15 80
NLU126 760
NLU124 51
NLU122 40
NLU120 6.0 U
NLU119D 40
NLU16 140
NLU116 110
ST-02 190
NLU121 70
NLU17 70
ST-03 100
ST-35 270
NLU107 36
ST-43 190
NLU13 50
ST-04 120
NLU12 50 U
NLU14 110
NLU117D 40
26 63.1
25 36.5
27 46.9
20 34.5
21 35
ST-05 60
ST-06 40
22 91.8
NLU10 50 U
23 77.1
ST-08 50
NLU08 50 U
ST-07 50
24 80.1
NLU106 21
ST-10 50
ST-13 30
ST-16 30
ST-20 40
ST-15 30 U
ST-19 40
ST-11 30 U
NLU01 30
NLU02 40 U
ST-31 20 U
ST-42 60
ST-28 40
ST-29 20 U
NLU04 50 U
3 36.9
4 27.2
32 12.4
1 52.5
2 35.3
ST-26 20
NLU05 6.0 U
5 36
7 32
8 47.7
6 45.3
ST-24 20 U
10 17.2
NLU06 50 U
11 56.5
17 10.8
NLU07 50 U
15 28.2
18 45.1
12 44.5
527 35.18
ST-22 20 U
19 55.4
527 26.58
ST-18 20 U
13 51.3
16 74.6

RETEC

GAS WORKS PARK SEDIMENT AREA PSE10-18064-330			SURFACE SEDIMENT ARSENIC CONCENTRATIONS
DATE: 5/17/04	DWN. BY: KBL/ftc	FILE: T:/LakeUnion_N83/Projects/NLU/AOIpackage/ARSENIC_int_d4.mxd	FIGURE D-4



NOTES:
1. Basemap generated in ArcGIS version 8.1 from Seattle Public Utilities Geographic Systems data, 9/28/99. Overwater structure data updated, 12/18/03. Projection in Washington State Plane Coordinates, North Zone, HARN 1983/1991.
2. Bathymetric contours generated in Surfer from data supplied by Parametrix, Survey completed 4th quarter, 2002.

RETEC

GAS WORKS PARK SEDIMENT AREA GJRW1-04403-963			**AREA OF INVESTIGATION AND BATHYMETRIC CONTOURS**
DATE: 5/17/04	DWN. BY: KBL/ftc	FILE: T:/LakeUnion_N83/Projects/AOIproject/BATHwAOI_d5.mxd	**FIGURE D-5**

APPENDIX A

Supporting Statistical Calculations

1. Introduction and Background

This appendix summarizes the statistical analyses used to define and support an Area of Investigation (AOI) for study during the Gas Works Park Sediment (GWPS) area remedial investigation and feasibility study process. The determined AOI reflects the collective evaluation of chemical concentrations indicative of the GWPS and those indicative of ambient Lake Union (ALU) sediments. This appendix describes the methods used to compare GWPS concentrations to those of ALU sediments.

To distinguish between ALU concentrations and potential sediment contamination from the uplands Gas Works Park (GWP) Site, a weight-of-evidence approach was used. The weight-of-evidence approach integrates the results of various statistical methods. The first method is that recommended in the Washington State Department of Ecology statistical guidance (Ecology, 1992), the calculation of the 90th percentile of the ALU samples as the ambient or area background concentration. The second method is to statistically evaluate the ALU sediment and GWPS samples through a comparative statistical population test (i.e., t-test or non-parametric variant).

2. Sediment Sample Populations

Lake Union sediment sample results were evaluated to determine the ALU and GWPS area data sets. The sample population consists of analytical results exported from Ecology's SEDQUAL database and results not yet imported to the SEDQUAL database including more recent data collected by RETEC and Texas A&M University (TAMU) (RETEC 1999 and 2002 and TAMU 2002, respectively). Results from SEDQUAL were reviewed for quality assurance purposes and the accepted results were used as described in the SEDQUAL Memorandum (Floyd Snider McCarthy, 2004).

The sediment sample population was first screened to determine the preliminary ALU and GWPS area data sets. MTCAstat was used to calculate the 90th percentile of the preliminary ALU data set. Ecology guidance defines the area background as the concentration of hazardous substances that are consistently present in the environment in the vicinity of a site, and are the result of human activities unrelated to releases from that site. Due to the industrial history and multitude of historical and current sources to Lake Union, a MTCAstat analysis was conducted as described in Section 3 below.

Preliminary calculations indicated an ALU total polycyclic aromatic hydrocarbons (TPAH) concentration of approximately 100 mg/kg. Surface sediment TPAH concentrations were then contoured to evaluate the distribution of TPAH in the vicinity of the GWP Site as presented on Figure D-1 in the AOI memorandum. The concentration contour map was generated through interpolation using an inverse distance weighted (IDW) scheme. The selection of the IDW method and assumptions used in the IDW map

are described in the Introduction to Chemical Maps (RETEC, 2004). The contour intervals were selected to cover the full range of the data. Contoured intervals may vary from numerical values due to the influence of neighboring values. TPAH concentrations represent the total sum of 16 individual PAHs, not including those that were below detection limits as per Ecology guidance (WAC 173-204).

The TPAH contours were plotted and a preliminary AOI line was established to encompass all sampling stations in the vicinity of the GWP Site exceeding 100 mg/kg TPAH and most areas with TPAH contours greater than 100 mg/kg.

Based on these results, the MTCAstat ambient calculation was then repeated to ensure that the AOI included all stations with results exceeding the ALU concentration. The ALU and GWPS area data sets were further refined as described below.

ALU Sediment Samples

Several steps were taken to ensure that the ALU data set was representative of ambient or background conditions. Proximity to overwater structures and distance from shoreline were used as tools to screen samples associated with specific sources out of the ALU data set. The ALU data set is presented on Figure A-1 and was determined based on the following:

- **Presence of Overwater Structures:** The presence of overwater structures surrounding the shorelines of Lake Union were considered potential sources to Lake Union sediments. Any sediment sample located beneath an overwater structure or between adjacent overwater structures was excluded from the ALU data set.

- **Distance from Shoreline and Nearshore Sources:** A distance of 300 feet from the Lake Union shoreline was used to exclude sediment samples from the ALU data set. Generally, a distance of 300 feet from shoreline provided a "buffer" distance from overwater structures and other potential upland and near shore point sources (e.g., within Ecology listed Sites). Any sediment sample within 300 feet of the shoreline was excluded from the ALU data set.

- **Bathymetry:** Bathymetry data was evaluated to determine if sediment samples were located on the slopes forming the perimeter of Lake Union. This criterion was used to exclude sediments impacted by down slope transport from upland or near shore point sources. The ALU data set is located in the area beyond the shoreline slope in what could generally be called the central portion of the Lake. Bathymetry in the central portion of the lake is generally flat. Any sediment sample within the sloped area was excluded from the ALU data set.

GWPS Samples

The GWPS area data set is presented on Figure A-1 and was determined based on the following:

- **Distance from Shoreline:** TPAH concentrations and distance from the GWP Site shoreline were assessed to determine the distance at which TPAH concentrations declined to a plateau consistent with the ambient concentrations in the central portion of Lake Union. Figure A-2 presents the sediment sample locations used to evaluate TPAH concentrations versus the distance from the GWP Site shoreline. Figure A-3 graphically presents a scatter plot of TPAH concentration versus distance from the GWP Site shoreline to the east and south of the site. TPAH concentrations greater than 100 mg/kg are found within 400 feet to the east, 500 feet to the south, and 800 feet to the west of the GWP Site shoreline (Figure A-4).

- **Bathymetry:** The AOI line was compared to the bathymetry in the area of the GWP Site to ensure the AOI encompassed all slope areas offshore of the GWP Site. This criterion was used to ensure sediments impacted by down slope transport in the vicinity of the GWP Site were included in the GWPS area data set.

- **Shipyard Sediment Samples:** Sediment samples within and directly southwest of the Shipyard consent decree boundary (Ecology, 1994) were excluded from the ALU and GWPS area data sets.

3. Statistical Methods and Results

ALU Concentration Calculations and MTCAStat Results

Ecology's Statistical Guidance (Ecology, 1992) and subsequent Supplement S-6 (Ecology, 1993) provide a framework for calculating ambient concentrations of constituents in various media. The guidance recommends that the 90th percentile of data represent the ambient concentration provided that the total number of samples exceeds 20 (which is the case for both the ALU and GWPS area data sets).

The guidance and associated model (MTCAStat Background Module, Ecology, 2004) were used to calculate the 90th percentile of assumed ambient concentrations using the ALU data set. Procedures for using the Ecology MTCAStat module were followed as described in the module guidance and help worksheets.

- **Data Entry:** The ALU or GWPS area data set was copied directly into the MTCAStat module. Non-detects (censored data) were entered with a less-than (<) symbol in front of the reported detection limit if applicable.

- **Data Distribution:** The "Evaluate Data Distribution" button was then selected to determine the data set distribution. If a non-parametric distribution was assumed, this was verified using the MTCAStat Site module (W-test or D'Agostino's test if n>50).

- **90th Percentile Calculation:** The appropriate distribution was selected and the "Calculate Percentile" button was then selected to calculate the 90th percentile of the data set. When the 4 x 50th percentile was lower than the 90th percentile, this calculation was noted as indicated in Ecology guidance.

Table A-1 provides a statistical summary of the ALU and GWPS area data sets as calculated using the MTCAStat background module. Both the ALU and GWPS area TPAH and arsenic data sets were entered into the MTCAStat background module only for purposes of a statistical comparison of the 90th percentile calculations (i.e., not for compliance purposes). The results are presented on Figure A-5.

The MTCAStat 90th percentile TPAH calculations for the ALU and GWPS area data set were 102 mg/kg and 1,656 mg/kg, respectively. The 4 x 50th percentile for the TPAH GWPS area data set was calculated at 776 mg/kg. These results indicate a substantial difference between the 90th percentiles for the ALU and GWPS area TPAH sample populations.

The MTCAStat 90th percentile arsenic calculations for the ALU and GWPS area data sets were 124 mg/kg and 144 mg/kg, respectively. These results indicate no apparent difference between the 90th percentiles for the ALU and GWPS area arsenic sample population.

The noted sample population (ALU and GWPS area) differences for TPAH were verified using population statistics.

Population Statistics

The ALU and GWPS area data sets were further compared statistically through a population comparison test (i.e., t-test), or non-parametric variant (i.e., Mann-Whitney test which is a nonparametric test that can accommodate non-Gaussian and other non-standard distributions that often occur with environmental data). The results of the population tests indicate whether the ALU samples are significantly similar or different from concentrations occurring in the GWPS area. A summary of population testing results is presented in Table A-1.

Data sets were tested to verify the type of data distribution as calculated with the MTCAStat background module by using the Shapiro-Wilks W-test. If the Shapiro-Wilks W-test results for the log-transformed (natural logarithm) data indicated that it was not log-normally distributed, the original data was re-run. If the original data was not normally distributed, then it was assumed to be distribution-free (i.e., non-parametric). Ecology guidance states that data sets with greater than 50% censored (non-detect) values

are assumed to be distribution-free (non-parametric). No data sets were determined to be distribution-free based on the number of censored data.

If both data sets to be compared were log-normally distributed, a t-test was conducted on the log-transformed data. If both data sets were determined to be normally distributed, then the t-test was conducted on the original data. If one or both of the data sets were non-parametric, then the Mann-Whitney test was used. All tests were conducted at the 95% confidence level. Descriptions of the t-test and Mann-Whitney test are discussed in Gilbert (1987) and Daniels (1990).

The statistical software program NCSS (NCSS, 1999) was used to calculate the Shapiro-Wilks W-test results, as well as the t-test and Mann-Whitney test results. When both data sets to be tested were either normally or log-normally distributed, variance equality was checked by the Modified Levene Equal Variance Test. This test was also conducted using NCSS. If this test indicated that the variances are assumed to be equal, then an equal-variance t-test was used to compare the ALU and GWPS area data sets. However, if the variances were assumed to be unequal, then the Aspin-Welch Unequal Variance t-test was used.

Both the GWPS area and ALU TPAH data sets were determined to be log-normally distributed by the MTCAStat background module and Shapiro-Wilks W-test. The Modified Level Equal Variance Test indicated that the variances of these two data sets were most likely not equal, and therefore the Aspin-Welch Unequal Variance t-test was conducted on the log-transformed data. The t-test using the log-transformed data indicated that the TPAH concentrations were significantly different (t-test value of 7.52 and probability 0.00). The GWPS area data set had a larger 90^{th} percentile than the ALU data set, and therefore the GWPS area data set has significantly higher TPAH concentrations.

The ALU and GWPS area arsenic data sets were both determined to be log-normally distributed using the MTCAStat background module, however the GWPS area data set was determined to be neither normally nor log-normally distributed using the Shapiro-Wilks W-test. The t-test using the log-transformed data indicated that the arsenic concentrations for the GWPS area and ALU data sets were not significantly different (t-test value of 0.00 and probability 0.99). In addition, the Mann-Whitney test also indicated that the arsenic concentrations were not significantly different (z-test value of 0.13 and probability of 0.89).

4. Conclusions

Using a weight of evidence approach, datasets for ALU and the GWPS area were established. Statistical verification of these datasets was then conducted using two statistical methods (MTCAstat and population statistics). Based on this analysis, the AOI represents a conservative delineation between chemical concentrations indicative of the GWPS and those indicative of ALU sediments.

5. References

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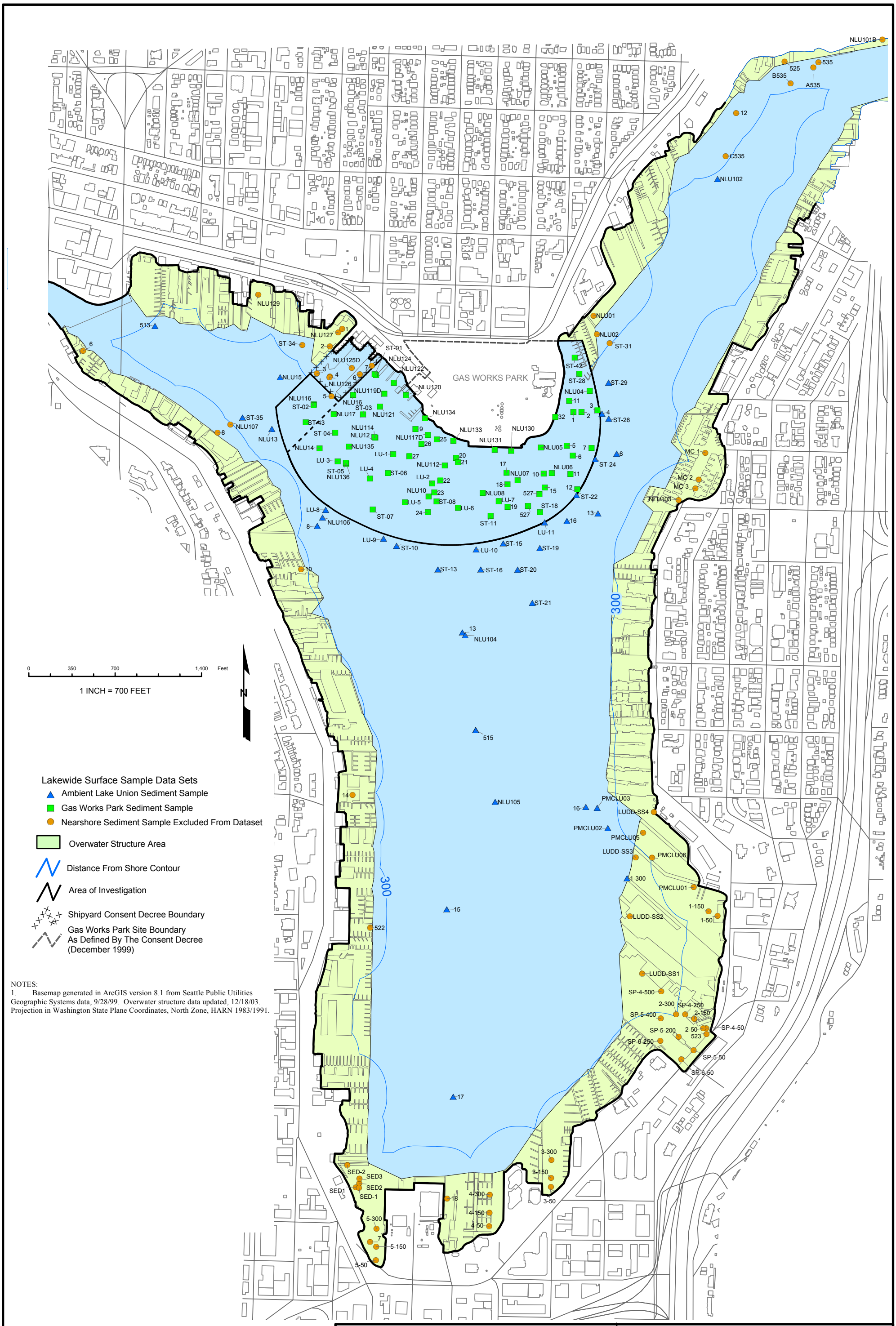
WAC, 1995. Washington Administrative Code. Chapter 173-204. Sediment Management Standards. December 29, 1995.

Attachments:

Figures:

Figure A-1: Ambient Lake Union and Gas Works Park Sample Populations
Figure A-2: Distance to Shoreline Sediment Sample Population
Figure A-3: TPAH Concentration vs. Distance from GWP Shoreline
Figure A-4: TPAH Concentration vs. Distance from GWP Shoreline – East, South and West
Figure A-5: Ambient Lake Union and Gas Works Park Sediment TPAH and Arsenic MTCAstat Calculations

Tables:



NOTES:
1. Basemap generated in ArcGIS version 8.1 from Seattle Public Utilities Geographic Systems data, 9/28/99. Overwater structure data updated, 12/18/03. Projection in Washington State Plane Coordinates, North Zone, HARN 1983/1991.

RETEC

GAS WORKS PARK SEDIMENT AREA PSE10-18604-310		**AMBIENT LAKE UNION AND GAS WORKS PARK SAMPLE POPULATIONS**
DATE: 5/28/04	DWN. BY: KBL/ftc	FILE: T:/LakeUnion_N83/Projects/NLU/AOIpackage/DOCKCONTw300FT_a1.mxd

FIGURE A-1

0 150 300 600 Feet

1 INCH = 300 FEET

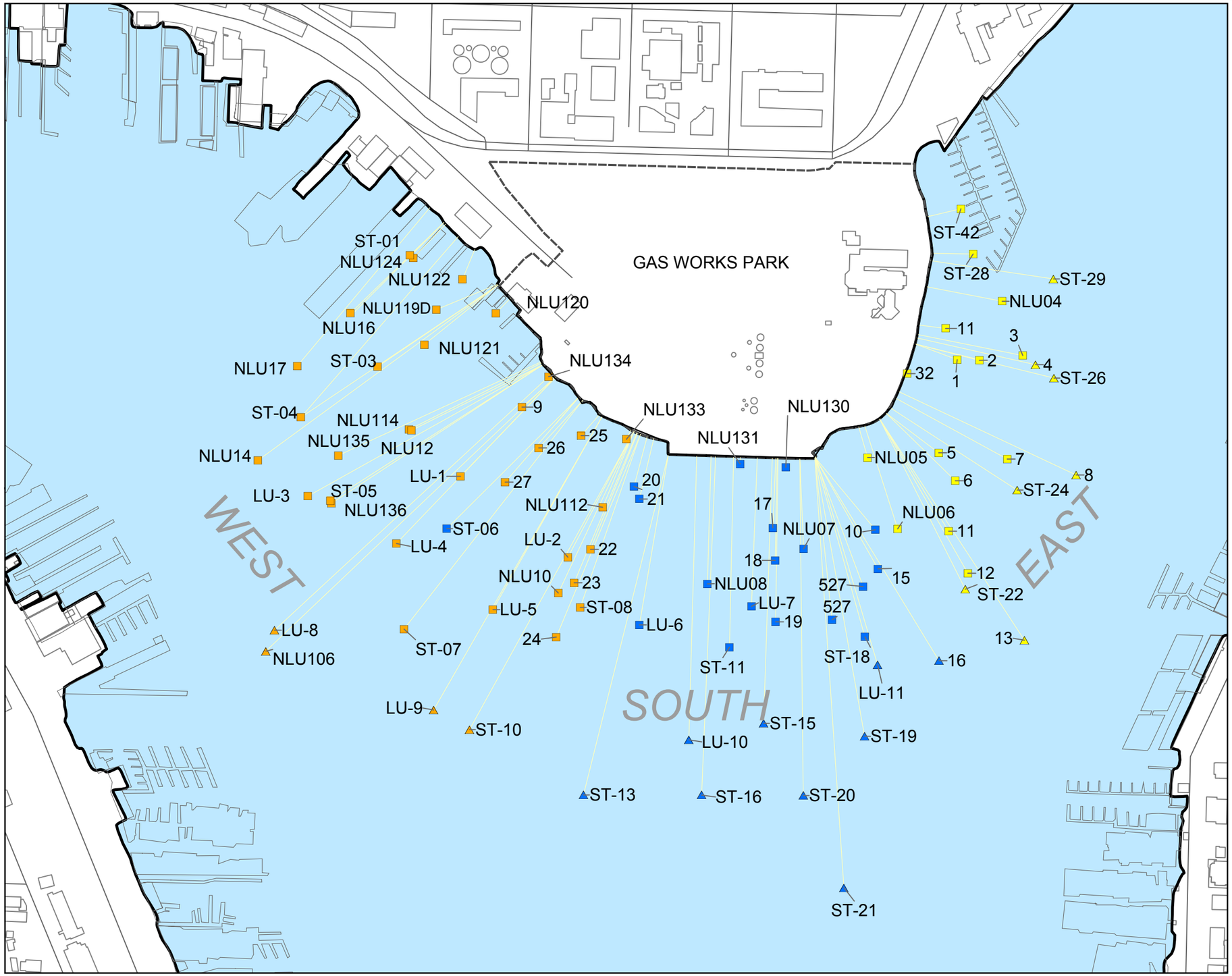
N

Ambient Lake Union Sediment Samples
- West
- South
- East

Gas Works Park Sediment Samples
- West
- South
- East

Gas Works Park Site Boundary
As Defined By The Consent Decree
(December 1999)

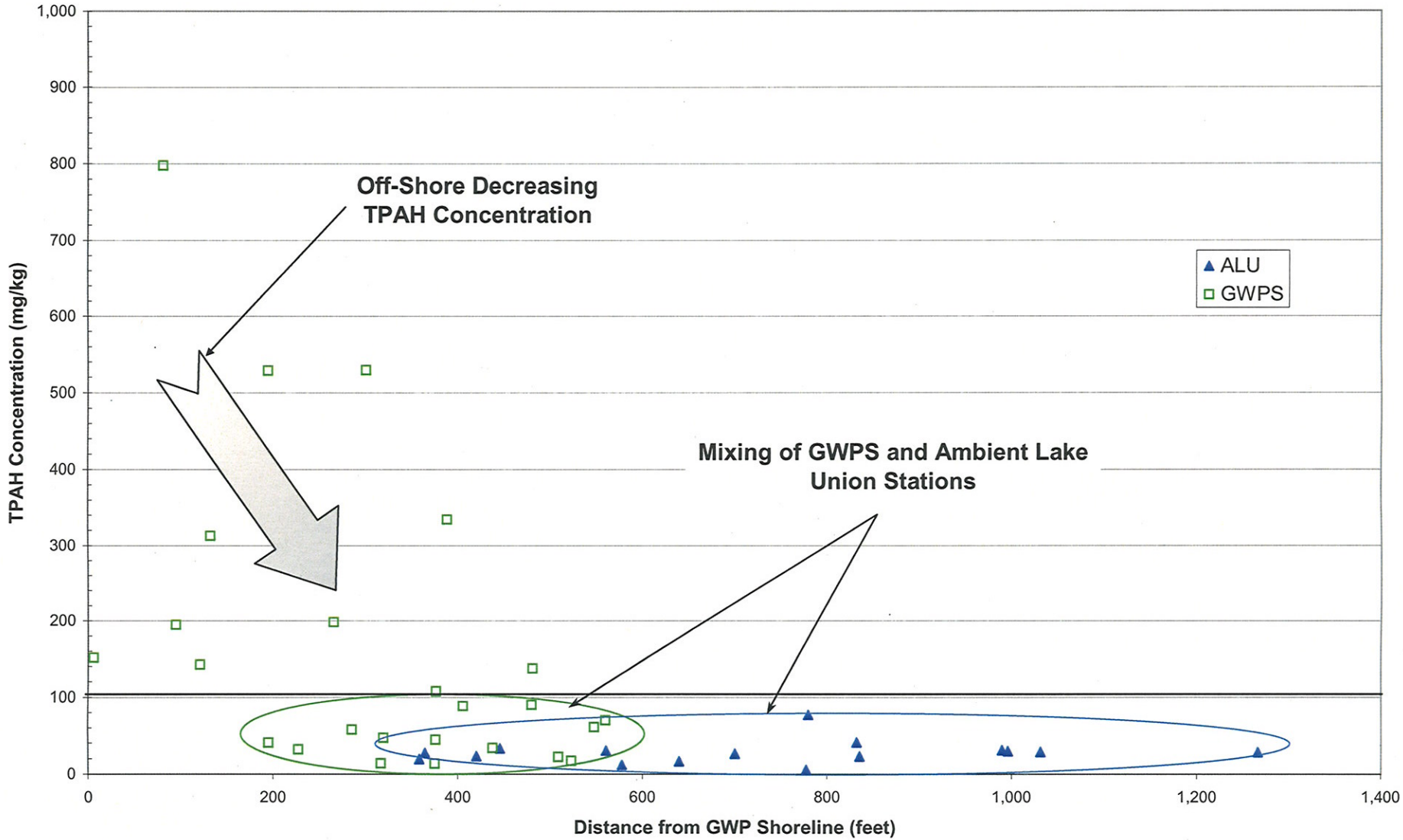
NOTES:
1. Basemap generated in ArcGIS version 8.1 from Seattle Public Utilities Geographic Systems data, 9/28/99. Overwater structure data updated, 12/18/03. Projection in Washington State Plane Coordinates, North Zone, HARN 1983/1991.
2. Approximate distance to shore calculated by snapping a line between the sample location and the nearest shoreline nodal point. Distance is calculated as horizontal distance, slope is not taken into account.



RETEC

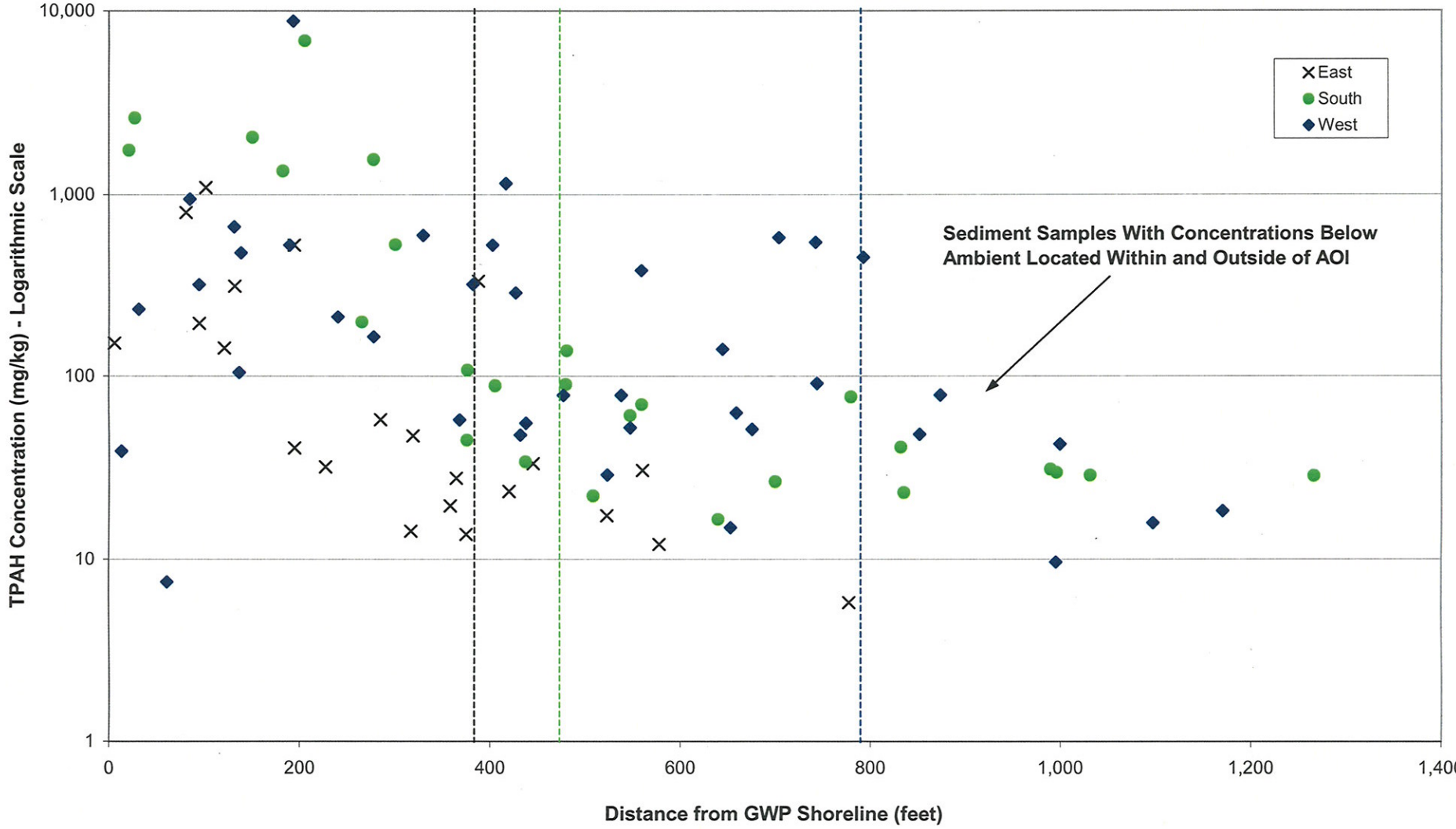
GAS WORKS PARK SEDIMENT AREA PSE10-18064-330	**DISTANCE TO SHORELINE SEDIMENT SAMPLE POPULATION**	
DATE: 5/17/04	DWN. BY: KBL/ftc	FILE: T:/LakeUnion_N83/Projects/AOIpackage/distanceTOshore2_a-2.mxd **FIGURE A-2**

Figure A-3
TPAH Concentration vs. Distance from GWP Shoreline



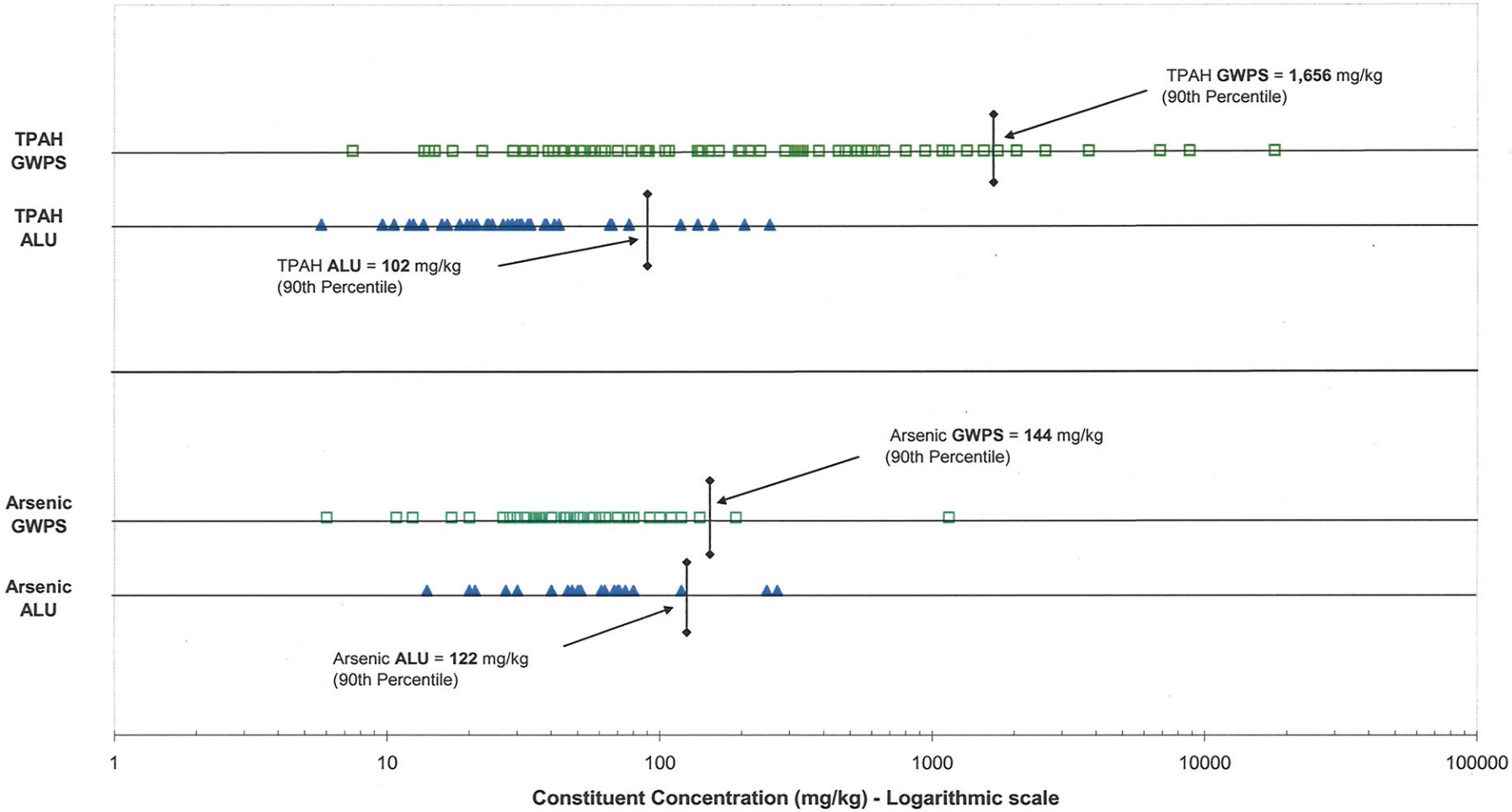
Note: Only TPAH concentrations in the east and south areas less than 1,000 mg/kg shown above. Refer to Figure A-2 for a plot of the complete data set.

Figure A-4
TPAH Concentration vs. Distance from GWP Shoreline - East, South and West



Note: Vertical dashed lines represent the furthest sediment station from the GWP shoreline with a TPAH concentration greater than 100 mg/kg in each of the three groupings (east, south and west).

Figure A-5
Ambient Lake Union and Gas Works Park Sediment
TPAH and Arsenic MTCAStat Calculations



Note: The 90th percentile calculations presented above were calculated using the Ecology MTCAStat Background Module.
The TPAH GWPS 90th percentile is presented above, however the MTCAStat Background Module calculated a 4 x 50th percentile of 776 mg/kg.
Both the ALU and GWPS TPAH and arsenic data sets were entered into the MTCAStat background module only for purposes of a statistical comparison of the 90th percentile calculations (i.e., not for compliance purposes).

Table A-1. ALU and GWPS Data Set Summary Statistics and Population Testing Results

MTCAStat Background Module Summary Statistics

Constituent	Data set	n = total	n = censored	% censored	mean (mg/kg)	min. (mg/kg)	max (mg/kg)	Distribution	R squared	Percentile	MTCAStat Background Module Calculation (mg/kg)
TPAH	ALU	37	0	0.0	48.4	5.7	253	Lognormal	0.95	90	102
	GWPS	71	0	0.0	872	7.5	18,015	Lognormal	0.98	90	1,656
Arsenic	ALU	31	4	12.9	65.3	14	270	Lognormal	0.93	90	124
	GWPS	56	11	19.6	85.9	10.8	1,150	Lognormal [1]	0.91	90	144

Population Testing Results - NCSS Statistical Software

Constituent	Data set	Test Method	Test Value	Probability	Significant Difference
TPAH	ALU and GWPS	t-test	7.52	0.00	Yes
Arsenic	ALU and GWPS	t-test [2]	0.00	0.99	No

Notes: Data set distributions were identified using Ecology's MTCAStat Background module and verified using the Shapiro-Wilks W-test (NCSS statistical software).

1) The arsenic data set distribution was determined to be log-normal using the MTCAStat Background module, however the Shapiro-Wilks W-test indicated a non-parametric distribution.

2) The Mann-Whitney test method was also performed on the arsenic data set and no significant difference was determined (z-test value of 0.13 and probability of 0.89).

Appendix B
Principal Component Analyses

INTRODUCTION

This appendix summarizes the analytical method used to support an Area of Investigation (AOI) for study during the Gas Works Park Sediment (GWPS) area remedial investigation and feasibility study process. The determined AOI reflects the collective evaluation of chemical concentrations indicative of the GWPS area and those indicative of ambient Lake Union (ALU) sediments. This appendix describes another method, principal component analyses (PCA), used to compare GWPS to ALU sediment results. Appendix A details other methods used to discriminate between ALU sediment and GWPS area data.

Because each TPAH result consists of 15 individual PAH results summed, and because the type and amount of PAHs present can be indicative of different sources, multivariate analyses (in this case, PCA) was used to examine the relationship between the amount and type of PAHs present in GWPS area and ALU sediment results. The main utility of PCA is to reduce the complexity of a data set – in this case, complexity brought on by 15 individual PAH results per sample – while retaining the important information about major relationships within the data. The goal of these analyses was to determine if, after major gradients in PAH ratios were delineated, there were any observed geospatial groupings for AOI versus ALU stations. Importantly, this approach is not based on TPAH concentration, but instead on the "pattern" of PAH type and relative importance of each PAH within a sample. These PCA analyses therefore provide a separate, corroborative approach to deriving the AOI boundary.

DATA USED

Data was compiled from SEDQUAL historical surveys and RETEC surveys following the review detailed in the SEDQUAL Memorandum (Floyd Snider McCarthy 2004). The data set used for these analyses was identical to RETEC's, and excluded Lake Union samples taken in areas adjacent to or beneath overwater structures and/or within 300 feet from shoreline in areas outside the GWPS area. Data were coded as to whether they were located inside the AOI boundary or outside of the boundary (i.e. ALU). Sample results from the "inside the AOI" area with TPAH concentrations less than 100 ppm were excluded. This exclusion was done to avoid interference from ALU samples (i.e. lower level TPAH samples) that occur within the AOI.

Additionally, three samples were removed from the data set: sample results from Stations PMCL02 and PMCL03, and NLU119. In initial analyses performed using this data set, these samples were identified as outliers based on scatterplot location and affected the ability to visually resolve the overlap between "inside the AOI" and ALU samples. Samples PMCL02 and PMCL03 are located in far south end of Lake Union, and Sample NLU119 is adjacent to the north shore of Gas Works Park. These locations are considered less relevant to the AOI boundary, and therefore their exclusion not a concern.

Data were standardized between data sets by computing the ratio of each PAH component in a sample to the total PAH concentration in the sample. Thus, each sample had 15 associated PAH ratios, a unitless measure of the relative significance of each PAH within that sample.

PRINCIPAL COMPONENT ANALYSES DESCRIPTION AND RESULTS

Principal Components Analysis (PCA), an eigenvector ordination method, was used to determine the major gradients in PAH ratios in the combined data set and to determine if there were any observed spatial groupings with respect to these gradients. PCA was conducted in PCORD (McCune and Mefford, 1999, Version 2.7) and SPSS (Version 11.5) using the centered, variance-covariance matrix as the distance matrix. Axes were not rotated.

The main purpose of ordination is to "represent a data set containing many variables with a smaller number of composite variables (components or axes)" that explain most of the variation in the data set (McCune and Grace, 2002). "The most interesting and strongest covariation among variables emerges in the first few axes (components), hence 'principal components'" (McCune and Grace, 2002). PCA is analogous to linear regression of two variables. In that case, the regression line can be considered the principal component of the bivariate data set and data can be "scored" along that new, single axis, instead of according to its values of the original two variables. In PCA, the smallest number of axes through the multivariable "space" is found and each original data point is "scored" along each new axis. The correlation coefficient ® between each axis and the original variables used in the analysis helps to understand the input variables represented by each axis and the strength of their association with the axis.

For PCA analyses, correlations with the first four axes are reported in Table 1. Positive relationships with values greater than 0.5 are highlighted. For example, Axis 1 indicates a positive relationship between benzo(a)anthracene, benzo(a)pyrene, benzo(g,h,i)perylene, indeno(1,2,3-cd)pyrene, and total benzofluoranthenes, and a negative relationship with phenanthrene, anthracene, acenaphthene, flourene, and phenanthrene. The first four axes account for 84.9 percent of the variance; the first three axes, 76 percent, and the first two, 64 percent. Frequently, the first principal component axes are helpful for discovering "outliers" in a data set because the variables with outlier values will explain a great deal of the total variation in the data set. This becomes more obvious when viewing scatterplots.

Table 1
Correlation of PCA Axes with PAHs

	Component/Axes			
PAH	**1**	**2**	**3**	**4**
Acenaphthene	**-0.87**	0.35	0.05	0.08
Acenaphthylene	-0.35	**0.65**	0.23	**0.52**
Anthracene	**-0.71**	-0.23	-0.26	-0.06
Benzo(a)anthracene	**0.54**	-0.30	-0.32	0.22
Benzo(a)pyrene	**0.76**	0.05	-0.36	0.06
Benzo(g,h,i)perylene	**0.63**	0.29	0.44	**-0.55**
Benzofluoranthenes (total-calc'd)	**0.65**	0.30	**-0.65**	0.02
Chrysene	0.48	-0.18	-0.29	0.33
Dibenzo(a,h)anthracene	-0.17	**0.71**	0.44	0.28
Fluoranthene	0.20	**-0.82**	0.04	0.24
Fluorene	**-0.81**	0.46	0.12	0.17
Indeno(1,2,3-cd)pyrene	**0.65**	0.22	0.41	**-0.54**
Naphthalene	-0.41	0.29	0.12	0.10
Phenanthrene	**-0.78**	-0.41	-0.28	-0.37
Pyrene	0.28	**-0.84**	0.31	0.17

Figures 1A and 1B show scatterplots of the axis scores (sometimes called "biplots") showing Axis 1 versus Axis 2. In these plots, data are coded to clarify whether they are located inside or outside of the AOI. Additionally, the size of the triangles correlate to the TPAH concentration: larger symbols indicate a higher TPAH concentration. Figure 1A shows circles around each "population" – inside the AOI versus ALU. Figure 1B contains labels for some stations to orient the viewer. Major "outliers" in this scatterplot are the LKUNION samples 13, 15, 16, and 17 located in mid- to south Lake Union, and station/sample NLU117D, located immediately offshore of Gas Works Park.

Figure 2A and 2B scatterplots show Axis 2 versus Axis 3. Data are similarly are coded to clarify whether they are located inside or outside of the AOI, and the size of the triangles correlate to the TPAH concentration. Figure 2A shows circles around each "population" – inside the AOI versus ALU. Figure 2B contains labels for some stations to orient the viewer. These are the same stations as those labeled in Figure 1B for ease of comparison. Again, major "outliers" in this scatterplot are the LKUNION samples 13, 15, 16, and 17 located in mid- to south Lake Union, and station/sample NLU117D, located immediately offshore of Gas Works Park.

Because these scatterplots are comparing different axes, and each axes indicates different relationships between PAHs, the precise spatial grouping of the stations will change when

different axes are compared. However, in both cases (Axis 1 versus 2 or Axis 2 versus 3) there is a general spatial grouping of "inside the AOI" samples as distinct from ALU samples, with an area of overlap between the two. Importantly, this method is independent of TPAH concentration, and provides additional evidence that the many PAH "patterns" inside the AOI are different than ALU PAH "patterns", with some likely overlap. This corroborates the AOI samples as being generally distinguishable from the ALU samples, and therefore supports the AOI boundary as a delineation between PAH concentrations indicative of GWPS area versus the ALU.

References

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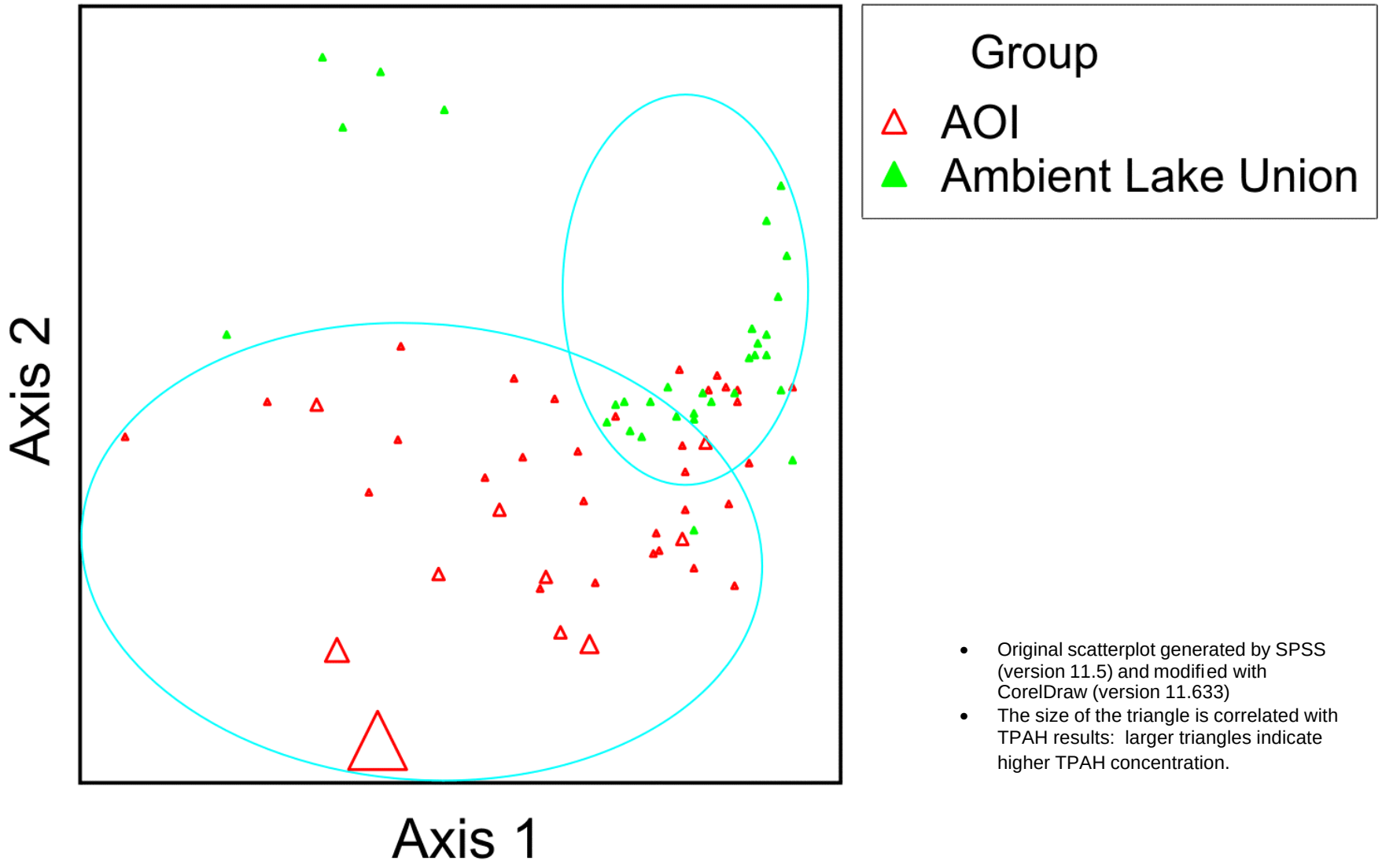
McCune, Bruce and James B. Grace. 2002. Analysis of Ecological Communities. MjM Software, P.O. Box 129, Gleneden Beach, Oregon, 97388 U.S.A.

McCune, B. and M. J. Mefford. 1999. PCORD. Multivariate Analysis of Ecological Data Version 4.27. MjM Software, P.O. Box 129, Gleneden Beach, Oregon, 97388 U.S.A. Copyright © 1999, MjM Software.

Statistical Package for the Social Sciences (SPSS) Version 11.5. SPSS Inc. Headquarters, 233 S. Wacker Drive, 11th floor, Chicago, Illinois 60606 U.S.A. Copyright © 2004, SPSS Inc.



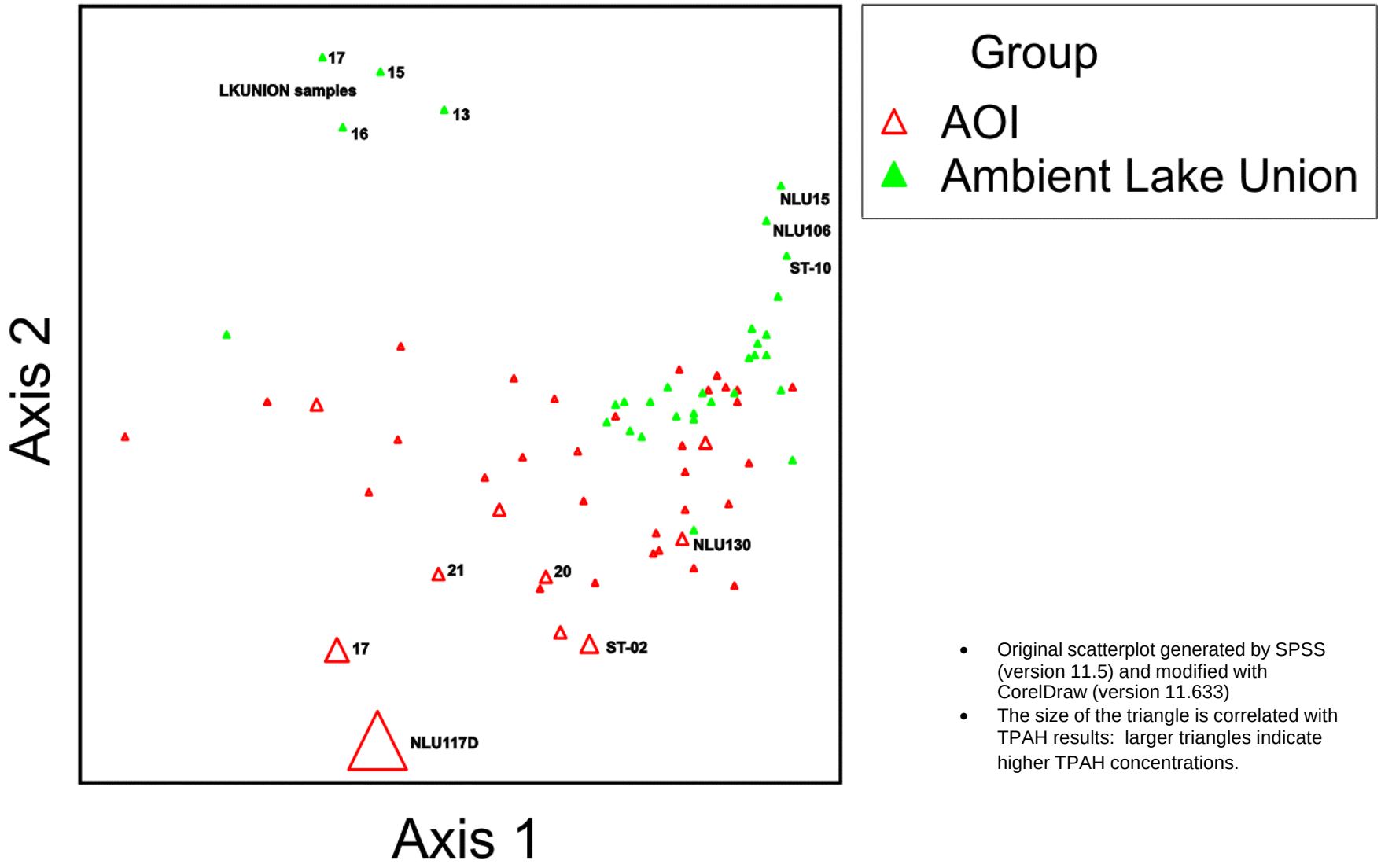
- Original scatterplot generated by SPSS (version 11.5) and modified with CorelDraw (version 11.633)
- The size of the triangle is correlated with TPAH results: larger triangles indicate higher TPAH concentration.

Floyd Snider McCarthy, Inc.

Gas Works Park Sediment Area

Figure 1A
Scatterplot of Axis 1 vs Axis 2

F/projects/coslawlus/AOI/FinalAOIMaterials/FinalAppB/Figure1A



- Original scatterplot generated by SPSS (version 11.5) and modified with CorelDraw (version 11.633)
- The size of the triangle is correlated with TPAH results: larger triangles indicate higher TPAH concentrations.

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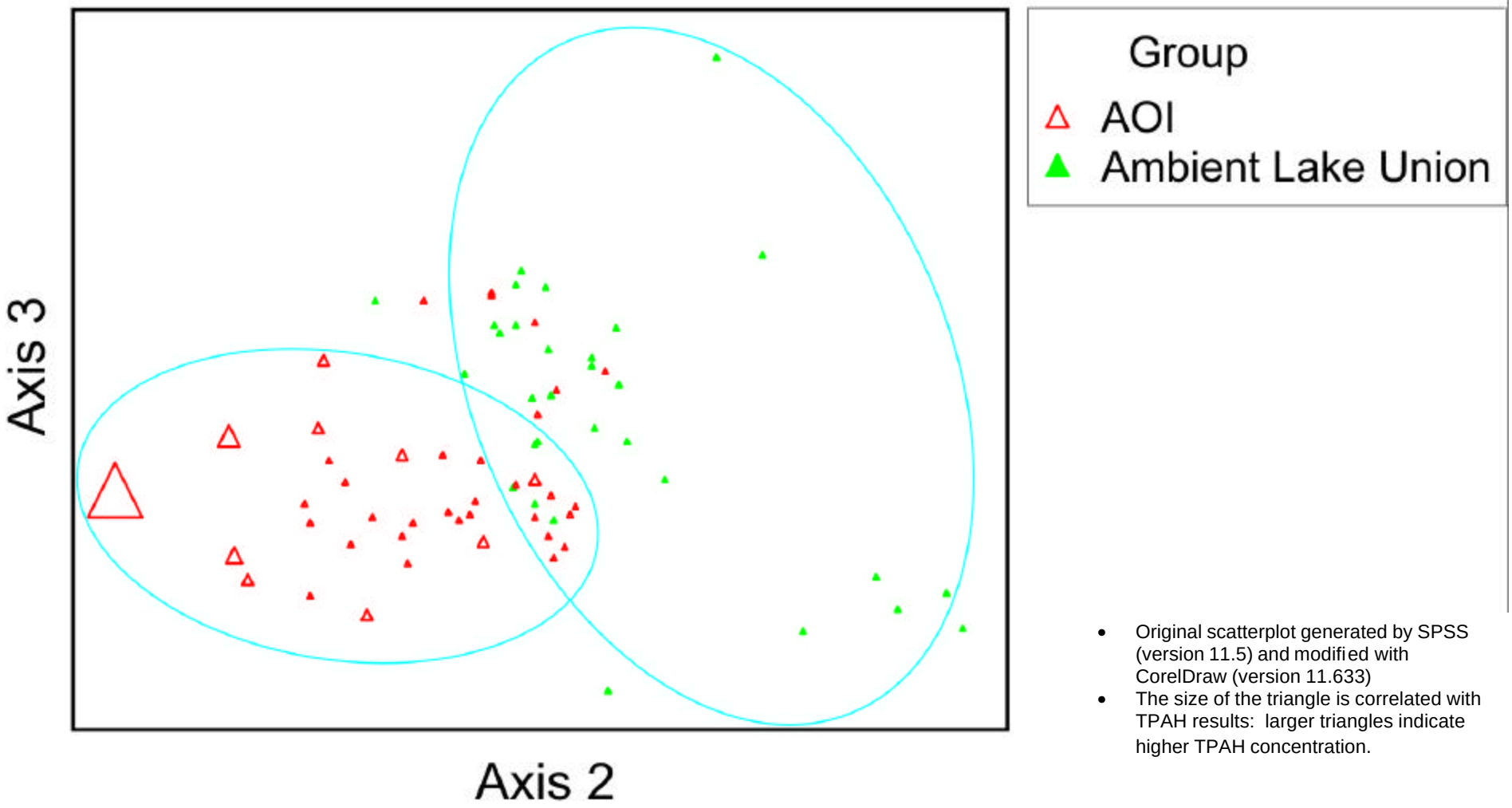
Gas Works Park Sediment Area

Figure 1B
Scatterplot of Axis 1 and 2 with Labels

F/projects/coslawlus/AOI/FinalAOIMaterials/FinalAppB/Figure1B



- Original scatterplot generated by SPSS (version 11.5) and modified with CorelDraw (version 11.633)
- The size of the triangle is correlated with TPAH results: larger triangles indicate higher TPAH concentration.

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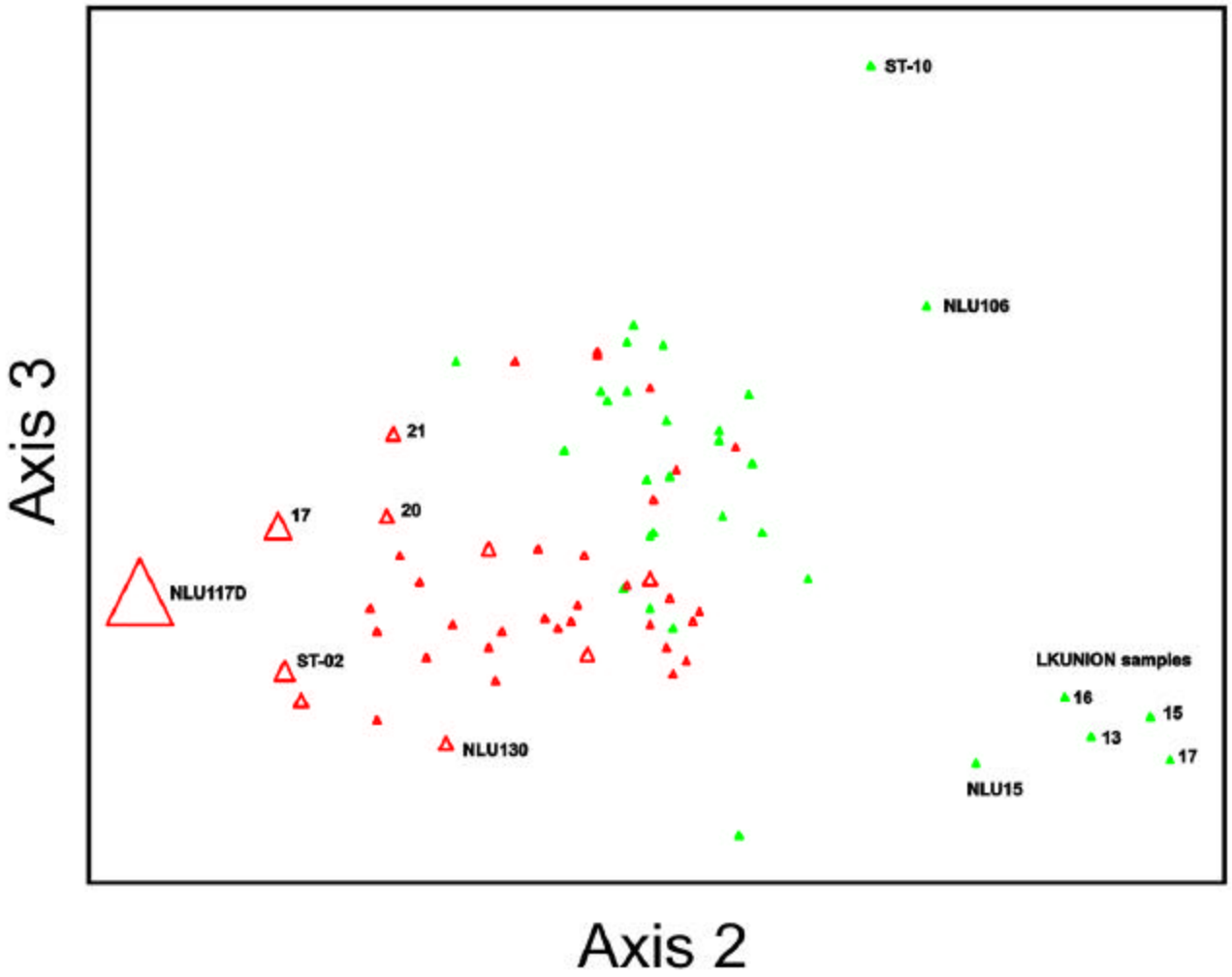
Gas Works Park Sediment Area

Figure 2A
Scatterplot of Axis 2 vs Axis 3

F/projects/coslawlus/AOI/FinalAOIMaterials/FinalAppB/Figure2 A



Group

AOI

Ambient Lake Union

- Original scatterplot generated by SPSS (version 11.5) and modified with CorelDraw (version 11.633)
- The size of the triangle is correlated with TPAH results: larger triangles indicate higher TPAH concentration.

Floyd Snider McCarthy, Inc.

Gas Works Park Sediment Area

Figure 2B
Scatterplot of Axis 2 vs Axis 3 with Labels

F/projects/coslawlus/AOI/FinalAOIMaterials/FinalAppB/Figure2B