Sediment Toxicity Near Gas Works Park, Lake Union, Seattle

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Sediment Toxicity Near Gas Works Park, Lake Union, Seattle

by
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Waterbody No. WA-08-9340 (Lake Union)

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Abstract

The Washington State Department of Ecology analyzed sediments using chronic bioassays at 11 sites across northern Lake Union. This analysis was conducted to determine the nature and extent of sediment contamination associated with prior coal and oil gasification and other industrial activities nearby. Two reference sites on Lake Washington also were sampled.

The 11 Lake Union sites were located across a projected gradient of contaminant concentrations to attempt to describe the magnitude and limits of toxic effects associated with the area; however, the actual chemical concentrations in the test sediments are unknown.

All of the *Chironomus tentans* bioassay results document sediment toxicity above the cleanup screening level criteria as defined in Ecology's Sediment Management Standards. One of the test stations also had a cleanup screening level exceedance for *Hyalella azteca*. Results indicate that sediments in the vicinity of Gas Works Park are toxic and probably adversely impact the benthic community.

Acknowledgements

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- Pam Covey, Manchester Environmental Laboratory, for managing contract laboratories and quality assurance.

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- Kirby Donnelly, Texas A&M University; and Keith Seiders, Ecology, for assisting with the field sample collection.

Introduction

Lake Union is a heavily urbanized watershed in Seattle, Washington. The lake has been substantially altered through shoreline filling and by the dredging of two channels, one into Lake Washington and one into Salmon Bay. Water levels in the Lake Washington/Lake Union system have been altered due to the disruption of the Black River in Renton, and salinities vary due to the operation of the Ballard Locks along the Lake Washington Ship Canal (Figure 1). Despite these alterations which changed Lake Union from a spring-fed lake into a regional waterway, salmon migrate through Salmon Bay and Lake Union.

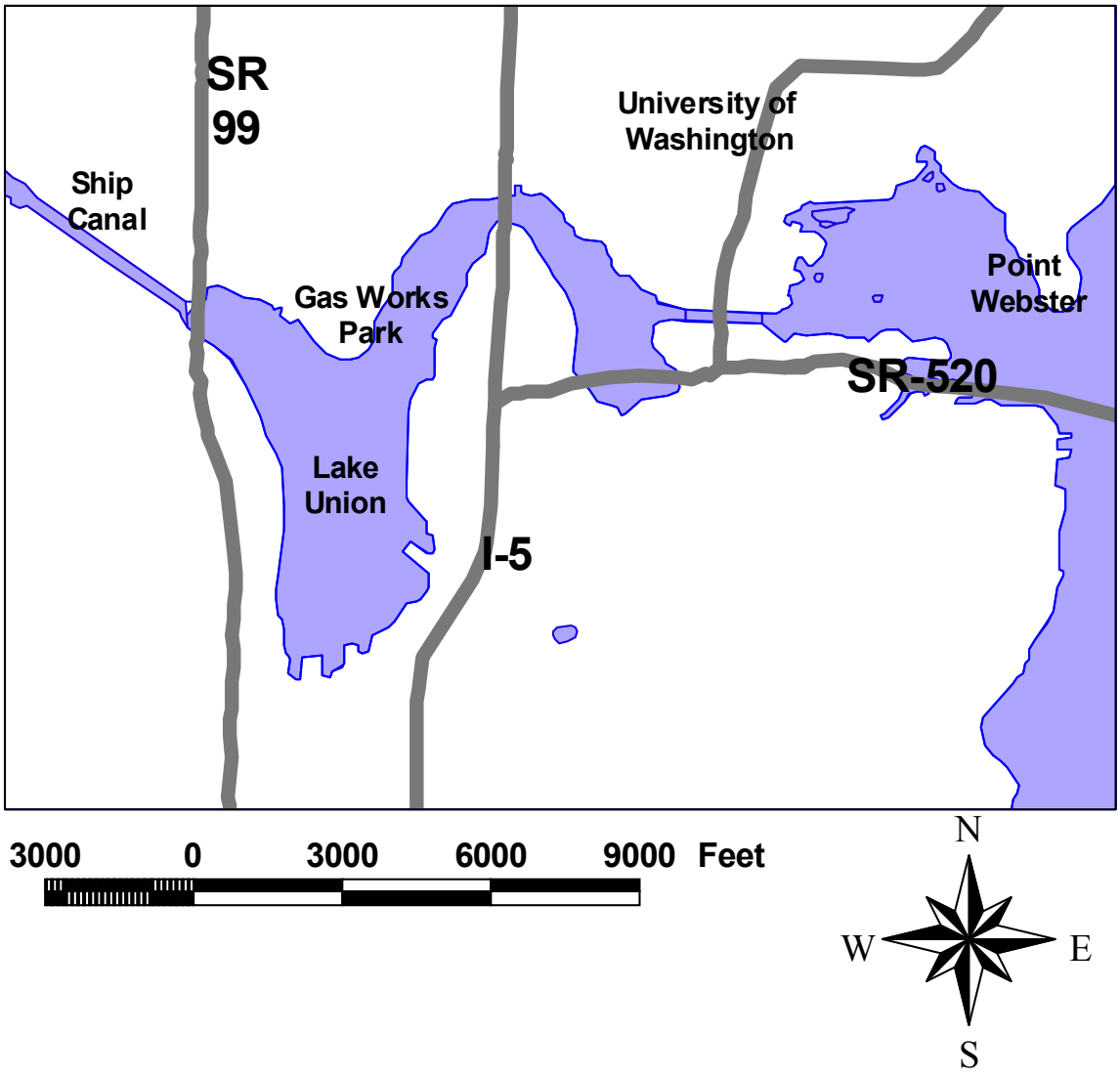

Figure 1. Lake Union and vicinity

Gas Works Park is a 20-acre city park located on the north shoreline of Lake Union (Figure 2). Industrial facilities were developed on the site in 1903, and gasification began in 1906. In 1956 the Seattle Gas Company ceased operations when natural gas became available, and in 1962 the facility was sold to the city of Seattle. Wastes found at the site include solvent-soaked wood chips, slag, lampblack carbon, coal by-products, and tar.

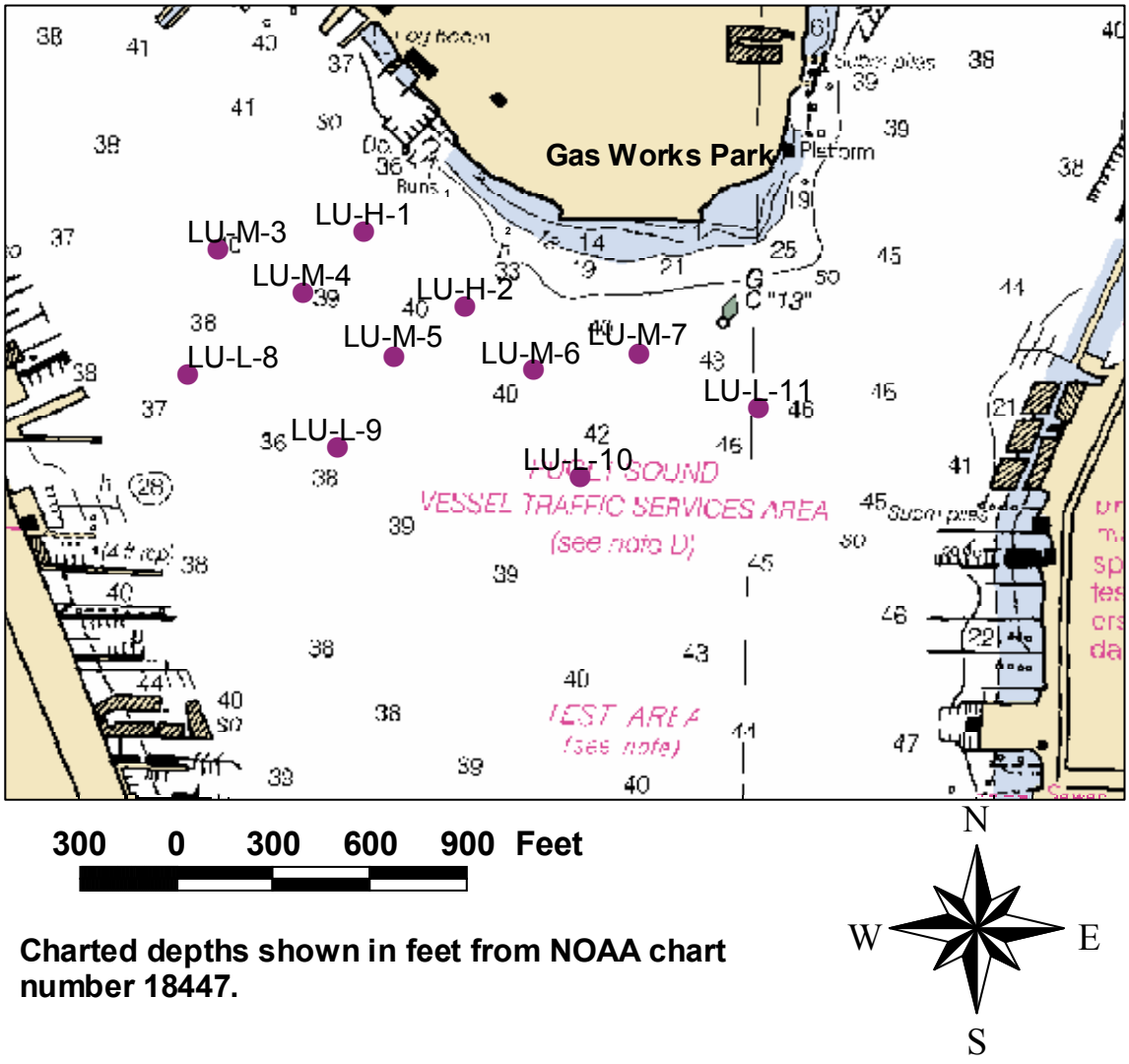

Figure 2. Lake Union near Gas Works Park with sampled test stations.

Study stations are shown in Figure 2, and reference stations are shown on Figure 3.

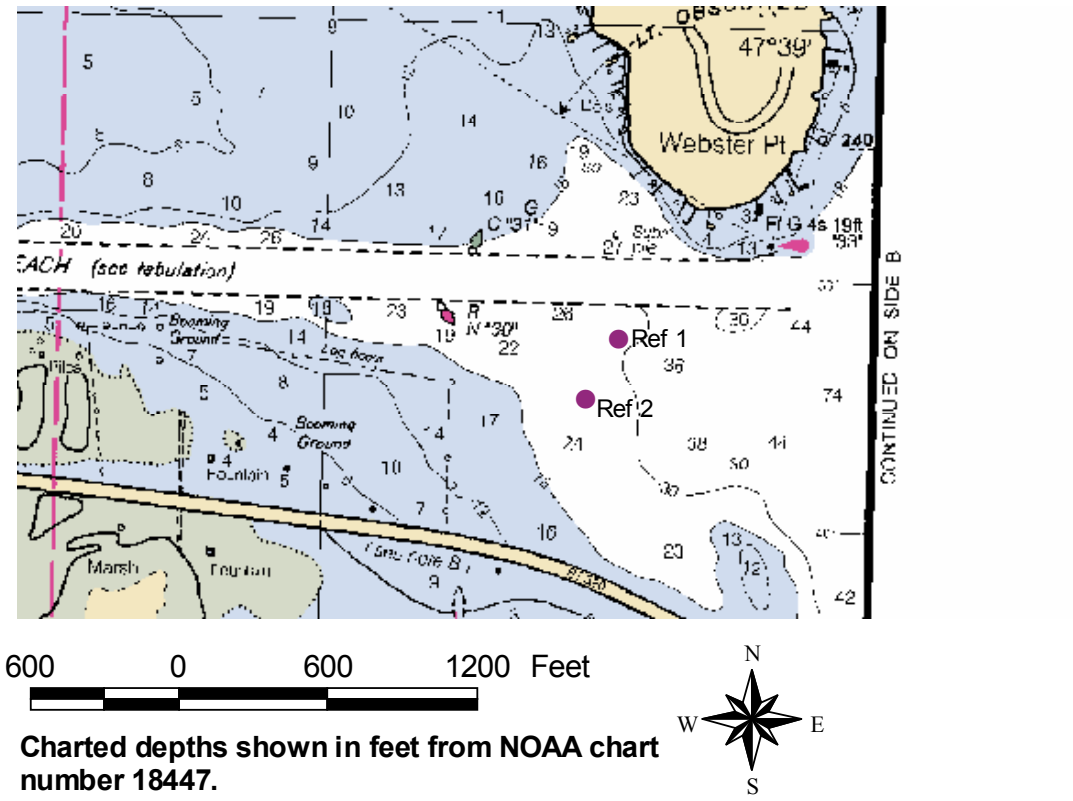

Figure 3. Lake Union reference station locations near Point Webster, Lake Washington.

Studies published by the Washington State Department of Ecology (Ecology) and the United States Environmental Protection Agency (USEPA) have documented sediment contamination in Lake Union (Hileman et al., 1985; Yake et al., 1986; Cubbage, 1992). Analysis of sites along the north shore of Lake Union in the vicinity of Gas Works Park found high levels of polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and elevated concentrations of arsenic, copper, lead, zinc, and other metals.

A number of other agencies also have collected sediment chemistry and bioassay data in Lake Union (Tomlinson et al., 1977; Hansen, 1993; Donnelly, 2001). This study is intended to determine the nature and extent of sediment toxicity using conventional bioassays. The investigation was intended to be a cooperative effort between Ecology and Texas A&M University (TAMU), who was funded by the Superfund Basic Research Program of USEPA to develop biomarkers of DNA mutagenic activity. TAMU was to perform the following chemical analyses: 8 priority pollutant metals and parent PAHs, tributyltin, and PCBs.

Some of the selected sampling locations were also chosen for additional various types of DNA mutagenic analysis. Some of the proposed types included: flow cytometric analysis of fingerling Coho Salmon DNA or via ^{32}P postlabeling methods, and characterization of mutagenicity via the

Ames test, a microsomal bioassay. TAMU was also to conduct Microtox® bioassays at all of the selected stations.

TAMU has not yet provided Ecology with a validated data package. Consequently, this report was not able to include results from their analyses.

Study Design and Goals

This project was a cooperative effort between Ecology, TAMU, and the USEPA. Both Ecology and TAMU conducted field and analytical analyses, while USEPA provided coordination and oversight. The cooperative study was funded through an USEPA grant to TAMU and by Ecology funds. The report elements below address the *Hyalella* and *Chironomus* bioassays, as well as the sediment field collection components under Ecology's direction.

Ecology analyzed sediments using a suite of chronic bioassays at 11 sites across northern Lake Union to determine the nature and extent of sediment toxicity associated with prior gasification and other industrial activities nearby. Two reference sites on Lake Washington were also sampled. The 11 Lake Union sites were located across a projected gradient of contaminant concentrations to attempt to describe the magnitude and limits of toxic effects associated with the site. However the actual chemical concentrations in the test sediments are unknown.

Sediments were initially collected and submitted for bioassay testing in March 2002. The quality control parameters for these sediments were outside of specifications (USEPA, 2000), particularly for dissolved oxygen and laboratory control sediment survivorship. These quality control issues were not discovered until the end of the 3-4 week testing period. The quality control issues invalidated the results from the first attempt at bioassay testing. At this time, sediments had been held for approximately 5-8 weeks since collection. This timeframe is significantly longer than the recommended holding time of 14 days.

Due to the holding time exceedances, the original sediments could not be reanalyzed to correct the bioassay quality control issues. Thus, sediments were recollected on July 16, 2002 from the same differentially corrected GPS located stations and submitted for reanalysis. The methods used for sediment collection were identical for both events.

The conventional parameter methods and results are from the initial sediment collection event, and the bioassay results reported are only from the reanalysis. The different collection dates are not believed to influence the results in any way, as identical methods for collection were used for both events and the conventional parameters are not expected to exhibit seasonal variation.

Methods

Field Collections

Samples from all sites were collected from an Ecology boat, using a 0.1 m^2 stainless steel van Veen grab sampler. Sampling sites were located using differentially corrected GPS and upland landmarks. Target coordinates for each station were generated prior to the field collection, and a field log was maintained during sampling. See Appendix A for the log book documentation.

Two grabs were collected from each station, and grabs were considered acceptable if the sampler was not overfull, overlying water was present and not significantly turbid, the sediment/water interface was relatively flat, and at least 11 cm of sediment depth was present. Most of the grabs overpenetrated the sediment, completely filling the van Veen. This was due to the very low solids content of the sediment and its inability to support the weight of the van Veen. These grabs were considered acceptable, as sediment did not appear to overflow through the doors of the samplers. The upper sediment layers may have been compressed slightly by the van Veen. The maximum penetration depth of the van Veen is 17 cm, so those stations with a penetration depth of 17 cm in Appendix A had material touching the doors of the van Veen.

Hyalella and *Chironomus* bioassays, and conventional sediment samples, were composited from two individual grabs per station. The top 10 cm of sediment from each acceptable grab was removed with stainless steel spoons, placed in a stainless steel mixing bowl, and homogenized. Material touching the sides of the van Veen sampler was not used. For the TAMU's Microtox® bioassay, relatively undisturbed sediment was collected, and not homogenized. Sample containers for Microtox® testing were filled completely to minimize alterations in pore water chemistry.

Homogenized *Hyalella* and *Chironomus* bioassay sediments and analytical chemistry sediment samples were placed in laboratory clean glass jars with Teflon lid liners.

Prior to sampling, stainless steel sampling implements were cleaned by sequentially:

1. Washing in Liquinox detergent and hot tap water
2. Rinsing with hot tap water
3. Rinsing with 10% nitric acid
4. Rinsing with deionized water
5. Rinsing with pesticide grade methanol
6. Air-drying

After drying, equipment was wrapped in aluminum foil until used in the field. Sampling spoons and bowls were dedicated to each station to avoid field decontamination procedures.

Except for the surface sediments potentially contacting the van Veen doors, only sediments not in contact with the van Veen sampler were removed for homogenization and analysis. All samples were cooled to 4ºC immediately after collection and transported under chain-of-custody

protocols. For analyses conducted by TAMU, samples were shipped to Texas via overnight courier.

Sampling occurred from the reference stations towards the areas closest to Gas Works Park. This minimized the potential for stations with higher PAH concentrations to contaminate samples from cleaner areas. Between sampling stations, the van Veen grab was rinsed with onsite water. At the most contaminated stations, where sheening was observed, the van Veen was washed with Liquinox and brushed clean.

Analytical Methods

The analysis methods used for the Ecology-funded portions of the project are listed in Table 1. Total organic carbon was measured by Puget Sound Estuary Program (PSEP, 1996) protocols.

Table 1. Analytical methods and laboratories used for Lake Union sediments

Analysis	Method	Laboratory
Bioassay		
Chironomus tentans 20-day	Method 100.5 (USEPA, 2000)	MEC Analytical
Hyalella azteca 28-day	Method 100.4 (USEPA, 2000)	MEC Analytical
Chemistry		
Total organic carbon	Combustion (PSEP, 1996)	Manchester
Grain Size (gravel, sand, silt, clay fractions)	Sieve & Pipet (PSEP, 1996)	Rosa Environmental
Percent Solids	Gravimetric (PSEP, 1996)	Manchester

Table 2 summarizes the test conditions and monitoring used in the bioassays. MEC Analytical, the contract laboratory for this analysis, generally performed more monitoring than required. This was to allow for the early detection of potential problems to avoid repeating the quality assurance issues which invalidated the initial bioassay results.

Table 2. Test conditions for Lake Union sediment bioassays.

Test Species	Water Quality Monitoring Frequency				Control Limits			Laboratory Controls	Test Acceptability
	Conductivity, pH	Hardness, Alkalinity, NH_3	Temperature, Dissolved O_2	Temperature	Dissolved O_2 (%)	Negative Control	Reference Toxicant	Reference Sediment	
Hyalella azteca	3x week	Day 1, 28	Daily	23 C ±1	>2.5 mg/L	Yes, clean sand or reference	$CuSO_4$	Yes	Mean control survival ≥80%; mean weight of surviving controls ≥0.1 mg
Chironomus tentans	3x week	Day 1, 20	Daily	23 C ±1	>2.5 mg/L	Yes, clean sand or reference	$CuSO_4$	Yes	Mean control survival ≥70%; mean weight of surviving controls ≥0.6 mg

Data Quality Assessment

This study was conducted to determine the nature and extent of sediment toxicity in the vicinity of Gas Works Park, Seattle. Field duplicates, matrix spikes, and spike duplicates were extremely limited as only total organic carbon (TOC), percent solids, and grain size are metrics suitable for evaluating bias and precision. Bioassay results were compared to internal controls and method performance criteria to evaluate data quality (Table 3).

Table 3. Quality assurance field and/or lab duplicates, and matrix spikes.

Analyte	Sample ID	Value	Duplicate # 1	Duplicate # 2	RPD	LCS Recovery
% TOC (70ºC)	02118082	15.6	14.3	15.6	65%	98.7
% TOC (104ºC)	02118082	15.5	14.4	16.0	30%	98.9
% Solids	02118082	17.0	17.0	16.8	10%	-
% Gravel	02118080	10.2	10.1	-	5%	-
% Sand	02118080	60.5	58.9	-	80%	-
% Silt	02118080	24.8	26.0	-	60%	-
% Clay (<4 µm)	02118080	4.6	5.0	-	20%	-

RPD = relative percent difference
LCS = laboratory control sample
Gravel (>2,000 µm), sand (2,000<X<62.5 µm), silt (62.5<X<4 µm), clay (<4 µm)

The laboratory results of matrix spike and matrix spike duplicates recoveries were compared across the various media and analytes to evaluate for bias. Duplicates were used to evaluate precision. The limited number of samples and the inherent uncertainty associated with these particular methods make comparisons with the Quality Assurance Project Plan (Jack, 2002) difficult.

However, the general concordance of the conventionals analysis between duplicates suggests that the composites were adequately homogenized prior to splitting the aliquots for the analyses. Some sample heterogeneity was present for duplicate grain size analyses, particularly for the sand fraction. This may be due to the very low percent solids content of the samples allowing the coarser fractions to settle during shipment or between analyses. Given the limitations of the methods used, the duplicates exhibit satisfactory precision.

All duplicates for the grain size analysis were within the overall method limits of 80-100%. For TOC, the percent recoveries of the laboratory control samples were better than 98% suggesting little bias is present. In summary, the conventionals data appear to meet the intent of the quality control limits specified in the Quality Assurance Project Plan; therefore, all of the analytical data are considered useable.

Several quality control issues were present with the second round of bioassay sampling. The contract laboratory measured individual sample temperatures upon arrival. All of the one-gallon

sample containers exceeded the recommended 4ºC. Temperatures varied from 5 to 11.6ºC. This was despite the use of considerable blue ice during shipment and probably a function of the July temperatures. Immediately after receipt, the sample coolers were placed in a 4ºC walk-in cooler prior to test initiation. Based on shipping documentation, the samples were probably exposed to elevated temperatures for about 12-20 hours. Because the contaminants in Lake Union are typically long-lived organics such as high molecular weight PAHs and metals such as copper and tin, this brief exposure to warmer conditions is not expected to influence the usability of the results.

Both bioassay tests were initiated within 15 days of collection, one day over the suggested holding time of 14 days. This deviation from the protocols also is not expected to influence the results, due to the nature of the contaminants present.

Water quality parameters were monitored more frequently during the second testing period in an attempt to allow for potential corrective measures to be initiated. Dissolved oxygen (DO) and temperature were monitored daily. Conductivity and pH were monitored three times a week. Hardness, alkalinity, and interstitial and overlying ammonia were recorded at the beginning and the end of each test. All of these test conditions were within method limits throughout the *H. azteca* bioassay.

For the *C. tentans* test, the DO dropped in all reference site and study site chambers to approximately 20% saturation on day 1 of the test. The minimum DO concentrations in USEPA method 100.5 is 2.5 mg/L or about 24% saturation for allowable chamber temperatures. Laboratory control sediments consisting of a mixture of sand and peat moss were unaffected. For Ref 2 test chambers, DO also dropped below protocol values on days 18 and 19.

These depressed DO concentrations affected all reference and test stations roughly the same on day 1. The reduced oxygen concentrations were probably related to the high organic content of the sediments and their low percent solids. Prior to settlement, relatively large quantities of organic matter were suspended in the initial overlying water. After the first water renewal, residual suspended organic matter was removed and oxygen concentrations were able to remain high for the duration of the test. Test sediments were not exposed to conditions different from the reference sediments and the fact that both reference and test sediments experienced this initial oxygen saturation drop suggests they behave similarly to disturbance. The depressed DO on day 1 does not influence the validity of the bioassays.

The reduction in DO concentrations on days 18 and 19 in Ref 2 is unexplained. The DO reduction probably led to the reduced survivorship observed at this station. However, the survivorship was an order of magnitude higher than for any test sediment and statistically different from all test sediments. Thus, the validity of Ref 2 does not appear to be negated by the transient reduction in DO on days 18 and 19.

The concentration of reference toxicant expected to induce 50% mortality (LC_{50}) in *H. azteca* was 504.8 µg/L, within 2 standard deviations of the specified species mean. For *C. tentans*, nominal concentrations of 250, 500, 1000, 2000, and 4000 Cu^{+2} µg/L were used (as copper sulphate). Greater than 80% survival was found in all reference toxicant concentrations. This

resulted in an LC_{50} of >4000 µg/L. The substrate used for the reference toxicant tests was a mixture of sand and peat moss, and the contract laboratory speculated that some of the copper may have bound with the organic matter in the substrate. Regardless of the causative agent for the elevated reference toxicant LC_{50}, it had little bearing on test responses, as survival in all of the test sediments was significantly reduced compared to reference and laboratory control sediments.

In summary, problems related to elevated sediment shipping temperatures, DO, and reference toxicant response were encountered. These issues do not impair the validity of the test results because of: 1) the general nature of the contaminants involved, 2) the consistency of the DO depressions, and 3) the magnitude of the observed responses relative to references. The bioassay results are usable despite these methodological and performance shortcomings.

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Results

Station Locations and Conventional Parameters

Appendix B shows the lab numbers and locations of all stations. Appendix C provides the numeric grain size values. Figure 4 summarizes the conventional parameter results by station. Both reference stations had higher proportions of sand than the Lake Union test sediment stations. Additionally, the reference sediment stations had more variable TOC percentages than the test sediments. The reference TOC concentrations bracket the Lake Union test sediment TOC concentrations. All TOC percentages are relatively high, averaging 13.7%.

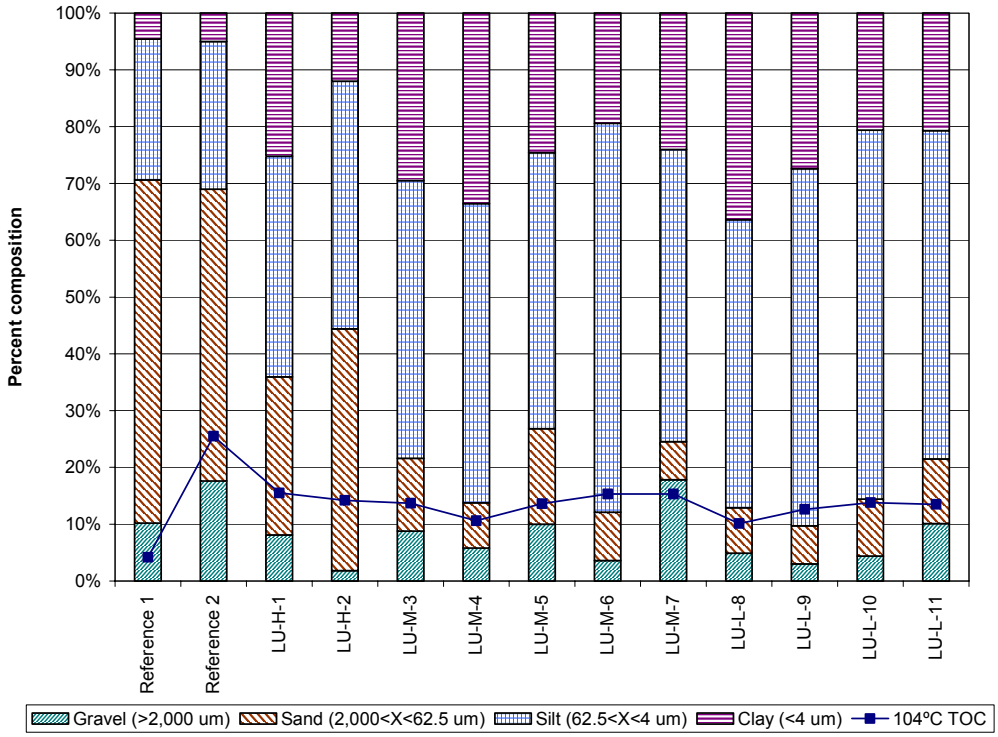

Figure 4. Lake Union grain size and percent TOC by station.

Bioassay Results

Percent Survival

Bioassays were entered into and analyzed using Ecology's SEDQUAL interface, a database with imbedded statistical tools and linked with Arcview geographical information system (GIS) spatial information. Table 4 summarizes the mortality results from both the *H. azteca* and *C. tentans* bioassays.

Table 4. Mortality of *H. azteca* and *C. tentans* relative to reference sediments and laboratory control.

Station	*H. azteca* mortality and (S.D.)	*C. tentans* mortality and (S.D.)
Laboratory control	0.2000 (0.1265)	0.2333 (0.1528)
Reference 1	Not used by SEDQUAL	0.3167 (0.1225)
Reference 2	0.0200 (0.0400)	Not used by SEDQUAL
LU-H-1	0.1400 (0.1200)	1.0000 C, R1
LU-H-2	0.5800 (0.1600) C, R2	1.0000 C, R1
LU-M-3	0.0800 (0.0400) R2	1.0000 C, R1
LU-M-4	0.0800 (0.1166)	1.0000 C, R1
LU-M-5	0.0000 (0.0000) C	0.9500 (0.0667) C, R1
LU-M-6	0.0400 (0.0800)	0.9500 (0.0408) C, R1
LU-M-7	0.0200 (0.0748)	0.9667 (0.0408) C, R1
LU-L-8	0.0200 (0.0400)	1.0000, C, R1
LU-L-9	0.0600 (0.0800)	0.9500 (0.0667) C, R1
LU-L-10	0.0400 (0.1356)	0.9833 (0.0333) C, R1
LU-L-11	0.0800 (0.0748)	0.9500 (0.0408) C, R1

Mortality is reported as a fraction. To convert to percent, move the decimal place two positions to the right.
S.D. = standard deviation
C = statistically different from laboratory controls
R1 = statistically different from reference station 1
R2 = statistically different from reference station 2

Mortality deviated from normality when tested with a Shapiro-Wilks test. Arcsine transformed mortalities also were not normal. Thus, the untransformed data were used when comparing test station survival against the laboratory control or reference stations. Because the mortality and growth data were not normally distributed and arcsine transformations failed to provide a normal distribution, SEDQUAL converted the mortality data to normalized ranks (rankits). Rankits are z scores normalized to that expected for the rank in a normal distribution. The rankits were tested for differences using a one-tailed *t*-test. An alpha level of 0.05 was used.

Significant differences in survival are shown with a "C" if they were different from laboratory controls, an "R1" if they were different from reference station one (Ref 1), and an "R2" if they were different from reference station two (Ref 2). The choice of which reference station to compare against was performed automatically by the SEDQUAL interface based on bioassay performance, grain size, and other factors.

Sublethal Effects

Weight gain data, a surrogate for growth, are shown in Table 5. Test sediment net growths were statistically compared to laboratory controls and reference sediments using the SEDQUAL

interface. Because the growth data were not normally distributed and arcsine transformations failed to provide a normal distribution, SEDQUAL converted the growth data to normalized ranks (rankits). Rankits are z scores normalized to that expected for the rank in a normal distribution. The rankits were tested for differences using a one-tailed *t*-test with an alpha level of 0.05. Both *H. azteca* and *C. tentans* were similar in that few of the estimated individual dry weights were significantly different from either reference station, the exception being those stations with no surviving organisms and station LU-L-10.

Table 5. Net weight gain of *H. azteca* and *C. tentans* relative to reference sediments and laboratory control.

Station	*H. azteca* mean estimated individual dry weight growth in mg (S.D.)	*C. tentans* mean estimated individual ash free dry weight in mg (S.D.)
Laboratory control	0.0879 (0.0335)	1.6340 (0.2556)
Reference 1	Not used by SedQual	Not used by SedQual
Reference 2	0.1140 (0.0242)	2.4800 (1.0118)
LU-H-1	0.1316 (0.0173)	0 survivors C, R2
LU-H-2	0.1660 (0.0612)	0 survivors C, R2
LU-M-3	0.1020 (0.0293)	0 survivors C, R2
LU-M-4	0.1620 (0.0194)	0 survivors C, R2
LU-M-5	0.1420 (0.0293)	1.2280 (1.5451)
LU-M-6	0.1300 (0.0219)	1.9380 (1.6990)
LU-M-7	0.1020 (0.0271)	1.1860 (1.4886)
LU-L-8	0.1360 (0.0273)	0 survivors C, R2
LU-L-9	0.1520 (0.0519)	1.1800 (1.4584)
LU-L-10	0.1560 (0.0102)	0.4440 (0.8880) R2
LU-L-11	0.1440 (0.0206)	1.1060 (0.9833)

S.D. = standard deviation
C = statistically different from laboratory controls
R1 = statistically different from reference station 1
R2 = statistically different from reference station 2

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Discussion

Bioassay Toxicity Thresholds

Significant toxicity as indicated by the bioassays was defined using the guidelines described in Ecology (2002). The definitions of impact are provided at two levels, a sediment quality standard (SQS) and cleanup screening level (CSL). For the *H. azteca* and *C. tentans* bioassays used in this investigation, the SQS and CSL definitions from Ecology (2002) are provided in Table 6.

Table 6. SQS and CSL definitions from Ecology (2002).

Test	SQS	CSL
H. azteca, 28-day mortality	T – R > 10%	T – R > 25%
H. azteca, 28-day growth	T/R < 0.75	T/R < 0.6
C. tentans, 20-day mortality	T – R > 15%	T – R > 25%
C. tentans, 20-day growth	T/R < 0.75	T/R < 0.6

T = Test sediment
R = Reference or laboratory control sediment

Bioassay Hits

The statistically significant differences were compared with the "hit" definitions provided via Ecology (2002) to develop a list of toxic stations and their degree of toxicity. Table 7 lists the stations by their degree of toxicity. There were no stations with only an SQS and not a CSL exceedance.

All test sediments exhibited severe impairments in *C. tentans* survival. More than 50% of these sediments also exhibited impairments to *C. tentans* growth. This illustrates that Lake Union sediments are unlikely to support normal benthic communities. *Chironomus tentans* larva may be considered an infaunal invertebrate, thus they are continuously in contact with the sediment and are directly exposed to pore water.

For *H. azteca*, only one station was classified as a bioassay hit. *Hyalella azteca* are considered epifauna; they live on the surface of the sediment. While they are often intimately associated with the sediment surface, they are less likely to be adversely impacted by contaminants which are closely associated with the solid phase and/or may not readily partition into the overlying water column. This may explain the absence of bioassay hits in the *H. azteca*, while the *C. tentans* results illustrate severe impairments throughout the study area.

Table 7. Lake Union bioassay hits and magnitude by organism and endpoint.

Station	*Hyalella azteca*		*Chironomus tentans*	
	survival	growth	survival	growth
Laboratory control	NA	NA	NA	NA
Reference 1	NA	NA	NA	NA
Reference 2	NA	NA	NA	NA
LU-H-1			CSL	CSL
LU-H-2	CSL		CSL	CSL
LU-M-3			CSL	CSL
LU-M-4			CSL	CSL
LU-M-5			CSL	
LU-M-6			CSL	
LU-M-7			CSL	
LU-L-8			CSL	CSL
LU-L-9			CSL	
LU-L-10			CSL	CSL
LU-L-11			CSL	

Total organic carbon (TOC) in Lake Union sediments was relatively elevated, with values ranging from 10.1 to 15.5%. These concentrations are relatively high, and the elevated TOC may have led to depressed pore water dissolved oxygen (DO) concentrations. Depressed pore water DO concentrations would be more likely to impact infaunal species such as *C. tentans*, as the daily water renewals do not directly exchange pore water.

Concentrations of TOC also were elevated in both reference station sediments. The composition of this organic material was visibly different from the organic material in Lake Union stations. The reference stations had large pieces (> 1 cm) of bark and wood fragments, potentially related to prior log storage activities or peat deposits nearby. Lake Union organic carbon was much finer in composition, and few if any wood fragments were visible. The role of these potentially disparate carbon sources on pore water DO is unknown.

Grain size composition is relatively consistent across the study area, except for two stations, LU-H-1 and LU-H-2. These stations are closest to the shoreline and the shallowest. The shoreline in this area has been armored with riprap and concrete bulkheads, and this has likely accentuated the wave action in this area. A combination of natural and accentuated wave actions in the nearshore areas, and possibly some historic filling, produced slightly higher percent sand in stations LU-H-1 and LU-H-2. The slight changes in grain size composition do not appear to influence sediment toxicity in the bioassays.

The reference stations chosen in the vicinity of Point Webster in Lake Washington exhibit reduced survivorship relative to laboratory sand and sand/peat controls. The sediments at this location had high levels of woodwaste, including bark chips and wood fibers. This area appears to be either an extension of the nearby natural peat deposits or a former log storage area. This organic matter is markedly different in composition from the organic matter in Lake Union, which was predominantly algae, diatoms, and other organic limnetic detritus. While this

substrate change is poorly reflected in the TOC percentages reported, it may have influenced the bioassay organisms. For instance, a reduced pH may have been present within the woodwaste dominated reference sediments.

Comparisons with Previous Results

The SEDQUAL database was queried for prior bioassay results in the vicinity of Gas Works Park. Various bioassays were conducted during four previous investigations, and their data are available via the SEDQUAL interface:

- Biological Report on Sediment and Water Bioassays and Benthic Community Determination at Unimar Yard 1 Dry Dock Facility
  - *Hyalella azteca* 14-day mortality, two stations: 5 and 8

- Lake Union University Regulator CSO Post Separation Study, 2000
  - *Hyalella azteca* ten-day mortality
  - *Chironomus tentans* ten-day mortality
  - *Chironomus tentans* ten-day growth
  - Microtox® bioluminescence, 50% dilution, all tests at one station: 527

- Survey of Contaminants in Lake Union and Adjoining Waters
  - *Hyalella azteca* ten-day mortality
  - *Daphnia magna* 48-hour mortality, both tests at two stations: 9 and 11

- Application of the Triad Approach to Freshwater Sediment Assessment: An Initial Investigation of Sediment Quality Near Gas Works Park, Lake Union
  - *Hyalella azteca* ten-day mortality, at one station: GWP

These additional bioassays have been mapped in conjunction with the bioassay data from this investigation. These combined data have been mapped using Arcview and are shown in Figure 5. Stations which were queried from historic investigations are shown as squares, while stations from this investigation are shown as circles.

All of the stations shown on Figure 5 have one or more CSL bioassay 'hits' as defined in Ecology (2002). This illustrates that toxicity to benthic organisms is widespread in Lake Union, and it extends beyond the limits of the current investigation. The sediment toxicity exhibited by the current data set is comparable to sediment toxicity found in the other investigations, and there are no apparent changes in sediment toxicity over time.

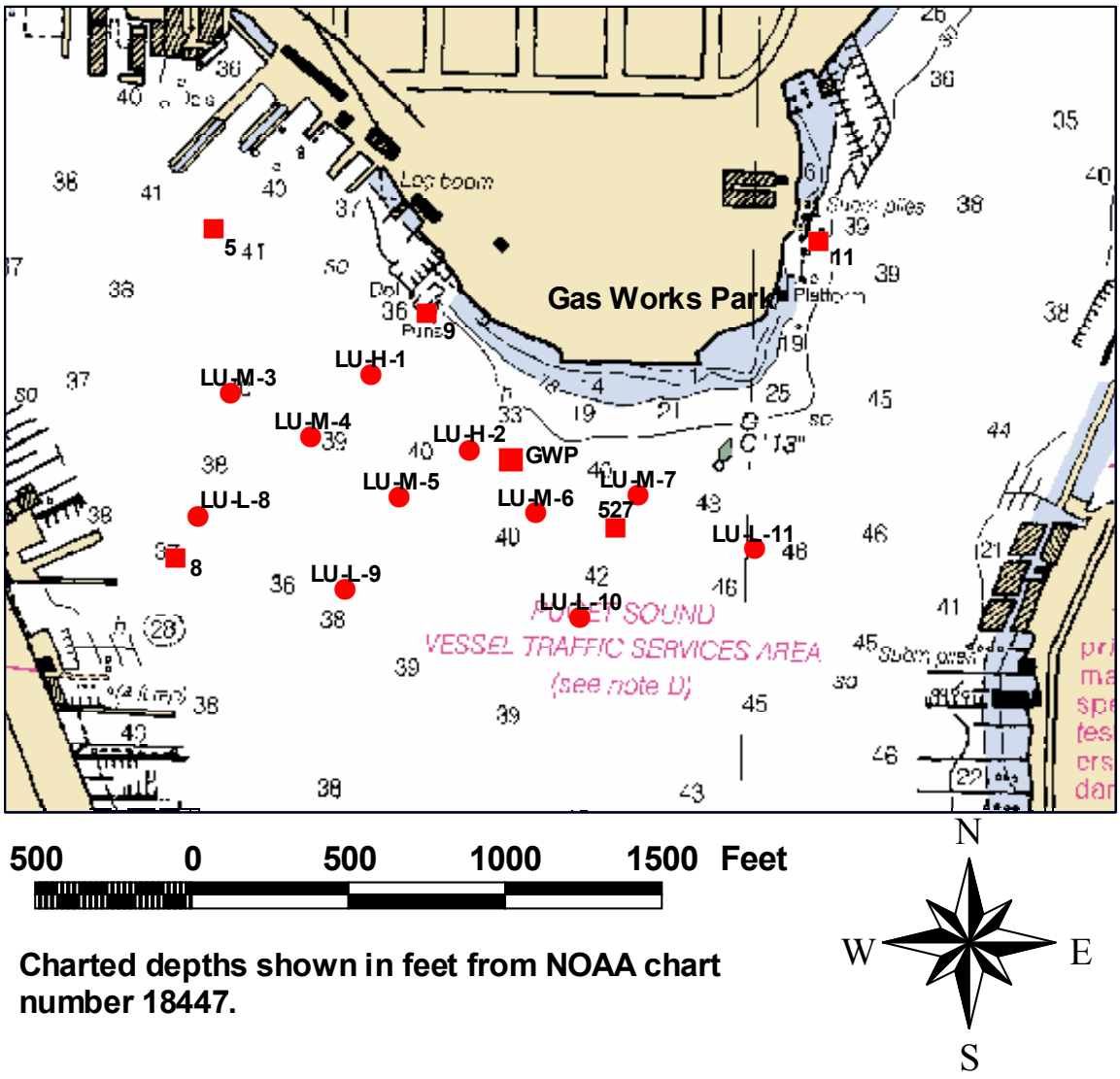

Figure 5. Historic and current bioassay data in the vicinity of Gas Works Park. Historic bioassays are shown as squares, current data set as circles.

Conclusions and Recommendations

Conclusions

This investigation evaluated the toxicity of Lake Union sediments in the vicinity of Gas Works Park using conventional bioassays. The bioassays chosen represent the influence of some chronic effects due to their duration, although they are not considered full lifecycle tests.

All of the *C. tentans* bioassays document toxicity above the cleanup screening level (CSL) criteria as defined in Ecology (2002). One of the test stations also had a CSL magnitude hit for *H. azteca*. This illustrates that the benthic community in the vicinity of Gas Works Park is probably heavily impaired, although this investigation is unable to define causative agents.

Recommendation

Reference sediments at Point Webster in Lake Washington should be evaluated for additional parameters such as pH. This is to ensure their representativeness relative to study sediments which may contain different organic matter types.

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Appendix A

Sediment Field Log

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Sediment Sample Log

Site: Lake Union

Station	Grab No.	Depth (m)	Date	Time	Sediment Penetration (cm)	Sample Description
Ref 1	1	12	7/16	10:15	14	peaty silt on sand
Ref 1	2	11		10:35	12	"
Ref 2	1	11		11:00	17	[redacted] silty peat
Ref 2	2	11		11:10	16	silty peat
L-11	1	15		11:40	17	[redacted] gritty/silt Black/Brown
L-11	2	15		11:50	17	silt/gritty "
L-10	1	14		12:00	17	gritty/silt Black/Brown
L-10	2	14		12:08	17	gritty/silt [redacted]lack/Brown
L-9	1	14		12:17	17	Black to Brown Silt w/ some Sand
L-9	2	14		12:23	17	"
L-8	1	13		13:35	17	Dark Brown Silt w/ Some gray lens
L-8	2	13		13:39	17	" No sheen
M-7	1	12.5		13:47	17	Dark Brown silt no sheen - no gray lenses
M-7	2	12.5		13:52	17	"
M-6	1	13.5		14:08	17	"
M-6	2	13.5		14:14	17	"
M-5	1	13		14:21	17	" but with gray lenses
M-5	2	13		14:27	17	" "

Recorder: Richard Jack

Sediment Sample Log

Site: Lake Union

Station	Grab No.	Depth (M)	Date	Time	Sediment Penetration (cm)	Sample Description
M-4	1	13	7/16	14:35	17	Gloppy Brown to Black Silt
	2	13	"	14:40	17	"
M-3	1	13	"	14:47	17	Black to Brown Silt Organic Some PAH odor
	2	13	"	14:51	17	"
H-2	1	10	"	1500	17	Black Sand Some Sheen + odor Wood, Bottles
H-2	2	10	"	1505	17	Black Sand w/ Some Silt Strong odor of PAH Sheen
H-1	1	13	"	1510	17	Black Silt w/ Slight Sheen Strong odor of H_2S
H-1	2	13	"	1515	17	"

Recorder: Dale Norton

Appendix B

Station Names, Laboratory Identification, and Locations

Table B-1. Site names, lab identification numbers, and coordinates for Lake Union bioassay and conventional samples.

Station	Conventionals lab number	Bioassay lab number	Latitude (N)	Longitude (W)
Reference 1	11-8080	29-8105	47 38.801	122 16.640
Reference 2	11-8081	29-8106	47 38.761	122 16.671
LU-H-1	11-8082	29-8107	47 38.666	122 20.223
LU-H-2	11-8083	29-8108	47 38.628	122 20.145
LU-M-3	11-8084	29-8109	47 38.655	122 20.332
LU-M-4	11-8085	29-8110	47 38.633	122 20.268
LU-M-5	11-8086	29-8111	47 38.602	122 20.198
LU-M-6	11-8087	29-8112	47 38.596	122 20.093
LU-M-7	11-8088	29-8113	47 38.606	122 20.013
LU-L-8	11-8089	29-8114	47 38.590	122 20.354
LU-L-9	11-8090	29-8115	47 38.553	122 20.239
LU-L-10	11-8091	29-8116	47 38.541	122 20.056
LU-L-11	11-8092	29-8117	47 38.579	122 19.922

All coordinates are degrees, decimal-minutes, NAD 1983/WGS 1984.

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Appendix C

Sediment Grain Size

Table C-1. Lake Union sediment grain size (in %).

Site Name	Gravel (>2,000 um)	Sand (2,000<X <62.5 um)	Silt (62.5<X <4 um)	Clay (<4 um)	70ºC TOC	104ºC TOC	Solids
Ref 1	10.2	60.5	24.8	4.6	4.05	4.16	33.2
Ref 2	17.6	51.4	26	5	25.1	25.5	10.4
LU-H-1	8.1	27.8	38.8	25.2	15.6	15.5	17
LU-H-2	1.8	42.6	43.6	12	14	14.2	19.6
LU-M-3	8.8	12.8	48.9	29.5	13.7	13.7	15.1
LU-M-4	5.8	8	52.7	33.6	10.5	10.6	14.8
LU-M-5	10	16.8	48.6	24.6	13.4	13.6	11
LU-M-6	3.6	8.5	68.5	19.4	15.1	15.3	10.8
LU-M-7	17.8	6.7	51.4	24	15.1	15.3	10.9
LU-L-8	4.9	8	50.7	36.4	10.1	10.1	14.8
LU-L-9	3	6.7	62.8	27.4	12.4	12.6	12.1
LU-L-10	4.4	10	64.9	20.6	14.1	13.8	12
LU-L-11	10.1	11.4	57.8	20.7	13.2	13.5	11.8