U.S. Department of Energy
Hanford Site

September 22, 2020

20-SGD-0069

Ms. Alexandra K. Smith, Program Manager
Nuclear Waste Program
Washington State Department of Ecology
3100 Port of Benton Boulevard
Richland, Washington 99354

Dear Ms. Smith:

SUMMARY OF CALENDAR YEAR 2018 AND 2019 BIOREMEDIATION AT THE UPR-100-N-17 WASTE SITE

The technical memorandum on the Summary of Calendar Year 2018 and 2019 Bioremediation at the UPR-100-N-17 Waste Site is being provided to the Washington State Department of Ecology for your information.

This technical memorandum provides a summary of bioremediation and monitoring activities performed at the UPR-100-N-17 waste site in 2018 and 2019 and includes the results of the low river stage respirometry test conducted in November 2019.

If you have any questions, please contact me or your staff may contact, Steve Balone of my staff, on (509) 376-0236.

Sincerely,

Michael W. Cline
Digitally signed by Michael W. Cline
Date: 2020.09.22 12:02:49 -07'00'

Michael W. Cline, Director
Soil and Groundwater Division
Richland Operations Office

SGD:SNB

Attachment

cc: See page 2

cc w/attach:
J. Bell, NPT
A.L. Boyd, Ecology
R. Buck, Wanapum
D. R. Einan, EPA
S. Hudson, HAB
M. Johnson, CTUIR
R. Longoria, YN
N. M. Menard, Ecology
D. Rowland, YN
S. N. Schleif, Ecology
K.R. Welsch, Ecology
M. Woods, ODOE
Administrative Record (UPR-100-N-17 Waste Site)
Environmental Portal

cc w/o attach:
S. G. Austin, CHPRC
S. L. Brasher, MSA
S. W. Davis, MSA
R. E. Fox, CHPRC
L. K. O'Mara, CHPRC

CHPRC-04462
Revision 0

SUMMARY OF CALENDAR YEAR 2018 AND 2019 BIOREMEDIATION AT THE UPR-100-N-17 WASTE SITE

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Contractor for the U.S. Department of Energy
under Contract DE-AC06-08RL14788

CH2MHILL
Plateau Remediation Company

P.O. Box 1600
Richland, Washington 99352

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Revision 0

SUMMARY OF CALENDAR YEAR 2018 AND 2019 BIOREMEDIATION AT THE UPR-100-N-17 WASTE SITE

Date Published
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CH2MHILL
Plateau Remediation Company
P.O. Box 1600
Richland, Washington 99352

APPROVED
By Julia Raymer at 10:22 am, Sep 16, 2020

Release Approval Date

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TECHNICAL MEMORANDUM

Summary of Calendar Year 2018 and 2019 Bioremediation at the UPR-100-N-17 Waste Site

Prepared for:	100-NR-1
Prepared by:	Art Lee
CCs:	Bill Faught Steve Balone John Sands Correspondence Control – MSIN – G3-39
Date:	August 20, 2020
Doc ID	CHPRC-04462, REV. 0

1 Introduction

This technical memorandum provides a summary of bioremediation and monitoring activities performed at the UPR-100-N-17 waste site in 2018 and 2019. Results of the low river respirometry tests conducted in November 2019 are included in Appendix A.

2 Background

In accordance with DOE/RL-2005-93, *Remedial Design Report/Remedial Action Work Plan for the 100-N Area*, Appendix H, "Phase II Testing/Performance Monitoring Plan for the UPR-100-N-17 Bioremediation," the U.S. Department of Energy is operating a bioventing system to clean up petroleum-contaminated soil within the deep vadose zone (UPR-100-N-17 waste site) associated with an unplanned release of diesel oil that occurred between August 1965 and September 1966 at the 166-N Tank Farm (Figure 1). The bioremediation system consists of a blower system housed within a CONEX container that can operate continuously. The airflow induced by the blower system enhances the biodegradation of the petroleum-contaminated soils. Details about the design criteria and equipment selection are provided in WCH-576, *Operation and Maintenance Manual, Phase II Testing – Bioremediation Design for Deep Zone Petroleum Contamination (UPR-100-N-17) at the 100-N Area*.

3 Performance Monitoring

Quarterly vapor sampling was conducted in 2018 and 2019 at the two deep vadose zone monitoring wells 199-N-169 and 199-N-171. A respirometry test was conducted from October through November 2019 during the low river stage period. Groundwater samples were also collected from the bioremediation monitoring wells following the respirometry test.

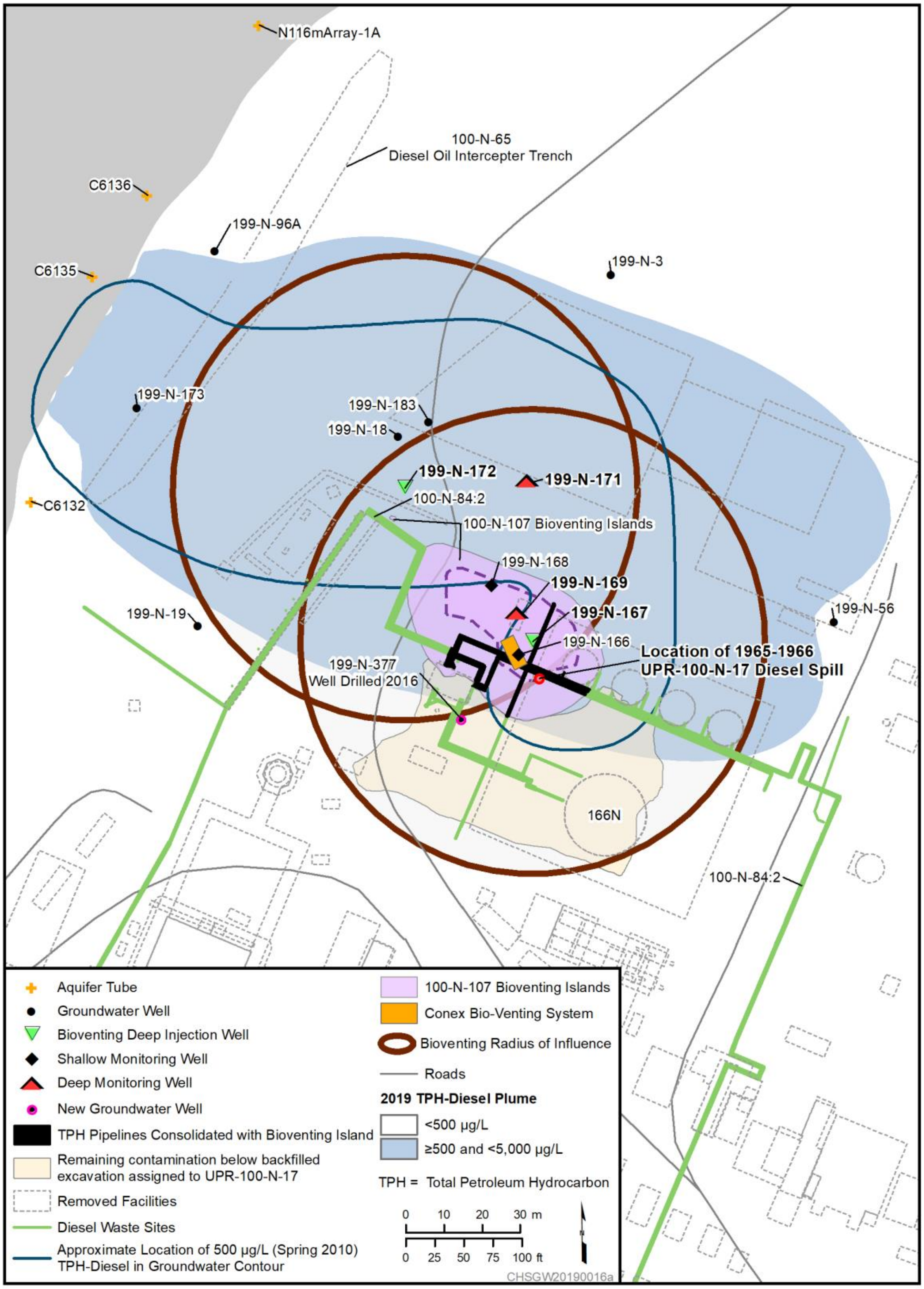

Figure 1. Bioventing System Location and Total Petroleum Hydrocarbon-Diesel Plume Map

3.1 Quarterly Soil Gas Measurements

Table 1 presents the quarterly soil gas measurements of the deep vadose zone that were collected in 2018 and 2019 from monitoring wells 199-N-169 and 199-N-171 (Figure 1) to provide indictors of biodegradation. Quarterly samples of soil gas are collected from these wells when the bioventing system is operating (i.e., injecting air) to measure oxygen, carbon dioxide, methane, volatile organic compound (VOC) concentration, and other parameters such as temperature and barometric pressure. As a general rule, decreasing oxygen levels and increasing carbon dioxide levels are indicators of biodegradation.

Table 1. Quarterly Vapor Monitoring

Date	O_2%	CO_2 (ppmv)	VOC (ppmv)	Methane (ppmv)
Monitoring Well 199-N-169				
1/30/2018	20.9	420	0.1	0.0
4/26/2018	20.9	530	0.5	0.0
9/27/2018	20.9	400	0.8	0.0
11/20/2018	20.9	500	0.2	0.0
3/14/2019	20.9	300	0.2	0.0
6/26/2019	20.9	400	0.1	0.0
9/30/2019	20.9	300	2.7	0.0
12/23/2019	20.9	400	0.0	0.0
Monitoring Well 199-N-171				
1/30/2018	18.5	14,800	0.8	0.0
4/26/2018	19.6	10,300	11.8	0.0
9/27/2018	18.5	19,700	4.5	4.0
11/20/2018	19.1	15,600	3.6	0.0
3/14/2019	19.4	10,900	6.9	4.0
6/26/2019	16.4	2,500	4.5	5.0
9/30/2019	21.3	23,400	13.4	5.0
12/23/2019	19.0	20,100	0.0	0.0

VOC = volatile organic compound

Data collected from well 199-N-169 indicate that very little biodegradation is occurring compared to well 199-N-171. Oxygen levels were constant (approximately 20.9%) throughout the reporting period, while carbon dioxide levels typically ranged from 300 to 590 ppm. VOC concentrations were <2.7 ppmv, and no methane was detected in the soil gas samples.

Changes in oxygen and carbon dioxide levels were much greater in well 199-N-171 compared to well 199-N-169. Oxygen levels ranged from 16.4% to 21.3%, while carbon dioxide levels ranged from

2,500 to 23,400 ppm. However, respirometry testing presented in Section 3.2 indicates that similar biodegradation rates occur at wells 199-N-169 and 199-N-171. This suggests that there may be a pathway within the vadose zone soils allowing injected air from nearby injection well 199-N-167 to enter into the well 199-N-169 casing. Well inspections and camera surveys have not been able to confirm this but remains a possible explanation due to the close proximity of the two wells (within 7.6 m [25 ft] of each other). The consistently higher carbon dioxide and lower oxygen levels in well 199-N-171 are indicators of greater biodegradation and microbial activity in the vicinity of well 199-N-171. The higher levels of VOCs detected (0.8 to 13.4 ppmv) and methane detection up to 5 ppmv are likely indicators of greater vadose zone contamination near well 199-N-171.

3.2 Respirometry Testing

An in situ respirometry test was performed from October 14 through November 19, 2019, to measure microbial respiration rates and estimate biodegradation rates. The test was initiated after the bioventing system was shut off to begin respirometry measurements. Field measurements of oxygen, carbon dioxide, total vapor hydrocarbons, and methane were collected from the following six monitoring wells:

- 199-N-167 (bioventing air injection well)
- 199-N-169 (bioventing monitoring well)
- 199-N-171 (bioventing monitoring well)
- 199-N-172 (bioventing air injection well)
- 199-N-183 (groundwater monitoring well)
- 199-N-18 (groundwater monitoring well)

The respirometry test results, including field measurements, are provided in Appendix A.

The respirometry test was conducted during the low river stage period where higher biodegradation rates are expected given the overall decline in the elevation of the water table at low river stages and the corresponding increase in the thickness of the smear zone available for oxygen delivery. This is consistent with the vapor monitoring data in Table 1 where higher levels of carbon dioxide (i.e., indication of respiration) are observed in monitoring well 199-N-171 during the low river periods (September through February) compared to higher river stage periods (March through August).

The biodegradation rates calculated from respirometry testing (Table 2) exhibit a declining trend from the initial rates measured in 2010. This may indicate a reduction in the bioavailable hydrocarbon food source in the treatment zone to levels that no longer support significant biological activity. Changes in subsurface conditions such as temperature, moisture, or nutrient availability may also have affected the rates shown, although only minor fluctuations are expected in temperature and moisture at depth above the water table. Table 2 presents a comparison of the biodegradation rates for the respirometry tests conducted in 2010 (pilot test) to rates calculated from tests performed since 2015. It appears that asymptotic levels have been achieved with respect to treatment within the unsaturated vadose zone near wells 199-N-167, 199-N-169, and 199-N-172. Current respirometry rates are generally below literature values for bioventing as a cost-effective remedial alternative with biodegradation rates typically above 1 mg/kg-d, although rates less than 1 mg/kg-d have been demonstrated to be effective. The rates of biodegradation in wells relative to the initial rate are shown in Chart 7 of Appendix A.

Table 2. Comparison of Biodegradation Rates Over Time Calculated from In Situ Respiration Testing

Monitoring Point	Biodegradation Rate (mg/kg-d)								
	Nov. 2019	Nov. 2017	Jul. 2017	Dec. 2016	Aug. 2016	Feb. 2016	Aug. 2015	Jan. 2015	Mar. 2010
199-N-167	-0.08	-0.14	-0.08	-0.06	-0.06	-0.07	-0.05	-0.05	-0.99
199-N-169	-0.17	-0.19	-0.11	-0.14	-0.07	-0.12	-0.12	-0.23	-0.97
199-N-171	-0.15	-0.11	-0.07	-0.22	-0.08	-0.19	-0.14	-0.23	-0.37
199-N-172	-0.06	-0.07	-0.08	-0.03	-0.02	-0.04	-0.04	-0.05	-0.54

Direct measurements through soil sampling and analysis are needed to determine existing levels of petroleum hydrocarbon throughout the vadose zone and the effectiveness of the bioventing system in situ bioremediation. A sampling and analysis plan (DOE/RL-2019-24, *Sampling and Analysis Plan for Bioventing Confirmation Sampling Boreholes*) was prepared in 2019 and issued on January 22, 2020. The sampling and analysis plan provides for collection of characterization soil samples in three boreholes to evaluate the effectiveness of the bioventing system for remediating deep vadose zone total petroleum hydrocarbon (TPH) contamination and determine the population of biodegrading bacteria in the subsurface. Drilling of the boreholes is planned for fiscal year 2021.

3.3 Groundwater Monitoring

Table 3 presents the total petroleum hydrocarbon-diesel (TPH-D) concentrations measured in groundwater samples collected from the bioremediation monitoring wells during the 2019 low river respirometry test. The groundwater data were used to interpret the 2019 TPH-D plume distribution shown in Figure 1. The two highest concentrations in 2019 were detected in wells 199-N-18 and 199-N-171 (81,900 and 29,000 µg/L, respectively). Additional information on TPH-D groundwater contamination at the 100-N Area is available in DOE/RL-2019-66, *Hanford Site Groundwater Monitoring Report for 2019*, and DOE/RL-2019-67, *Calendar Year 2019 Annual Summary Report for the 100-HR-3 and 100-KR-4 Pump and Treat Operations, and 100-NR-2 Groundwater Remediation*.

Table 3. TPH-D Concentrations (in µg/L) for Bioventing Performance Monitoring Wells and Aquifer Tubes

Type	Well Name	Low River Sampling (November 2019)
Bioventing air injection well	199-N-167	5,200 (N)
	199-N-172	—*

Table 3. TPH-D Concentrations (in µg/L) for Bioventing Performance Monitoring Wells and Aquifer Tubes

Type	Well Name	Low River Sampling (November 2019)
Bioventing monitoring well	199-N-3	43 (JN)
	199-N-19	76.4 (U)
	199-N-96A	610
	199-N-169	10,000 (N)
	199-N-171	29,000 (DN)
	199-N-173	5,200 (N)
	199-N-183	13,000
	199-N-377	72.8 (TU)
	199-N-56	75.3 (U)
	188-N-18	81,900 (D)
Aquifer tube	C6132	75 (TU)
	N116mArray-0A	572
	C6135	799

*Well could not be sampled because well screen split, causing filter pack material to fall in the well above the water level. Repairs will be attempted.

Data flags:

D = analyte was identified in an analysis at a secondary dilution factor.

J = estimated.

N = spike sample outside limits.

T = spike and/or spike duplicate sample recovery is outside control limits.

U = analyzed for but not detected above reporting limit.

Groundwater in well 199-N-18 typically displays some of the highest dissolved TPH concentrations of the test wells, while significant respiration is not measured at well 199-N-18. Oxygen concentrations in soil gas at monitoring well 199-N-18 remained above 20% throughout the test and exhibited insignificant oxygen depletion; therefore, a biodegradation rate was not calculated for this well. This may be due to the influence of shallow vadose zone air dominating the sample (carbon steel casing has perforations from 4 to 24 m [12 to 78 ft] deep); it is also possible that dissolved oxygen or other electron acceptors may be a limiting factor for biodegradation within the groundwater plume and smear-zone soils. Respiration is also relatively low at well 199-N-172 (Table 2). This assessment is supported by the fact that groundwater dissolved oxygen concentrations are much lower within the petroleum plume vicinity wells 199-N-18 and 199-N-172 than outside of the plume. Table 4 presents a summary of dissolved oxygen concentrations measured in the vicinity of the petroleum plume from March 2010 to November 2019.

Table 4. Dissolved Oxygen Concentrations in Groundwater from 2010 to 2019

Location Relative to Plume	Well/Range/ Average Concentration (mg/L)	Overall Average Concentration (mg/L)
Upgradient or cross-gradient	199-N-56 / 2.17 – 6.87 / 5.03	5.08
	199-N-3 / 2.71 – 6.95 / 5.14	
Upper margin	199-N-167 / 0.07– 4.37 / 1.67	1.65
	199-N-169 / 0.10 – 4.31 / 1.62	
Lateral margin (midportion)	199-N-183 / 0.015 – 7.08 / 1.49	2.49
	199-N-19 / 0.15 – 7.38 / 3.39	
Upper main	199-N-171 / 0.00 – 3.72 / 1.31	1.31
Middle main	199-N-18 / 0.0019 – 2.90 / 1.31	1.30
	199-N-172 / 0.06 – 3.93 / 1.30	
Lower main	199-N-173 / 0.22 – 4.24 / 2.02	2.02
Lateral margin (lower portion)	199-N-96A / 2.42 – 7.93 / 5.52	5.52

4 Summary and Conclusions

The respirometry rates from the 2019 event remain generally below literature values for recommending bioventing as a cost-effective remedial option. However, there is evidence that oxygen in the vadose zone is a limiting factor for microbial degradation in the area of monitoring wells 199-N-169 and 199-N-171 and that bioventing will help maintain this biodegradation, even if the rate is somewhat low. As is frequently the case with remediation systems, cleanup rates may become asymptotic and efficiencies decrease as target contamination is removed. It appears that asymptotic levels have been achieved with respect to treatment within the unsaturated vadose zone near wells 199-N-167, 199-N-169, and 199-N-172 (Chart 7 of Appendix A). Three boreholes are planned for fiscal year 2021 to obtain direct measurements through soil sampling and analysis to determine existing levels of petroleum hydrocarbon throughout the vadose zone and the effectiveness of the bioventing system in situ bioremediation.

The biodegradation rate in the vicinity of well 199-N-171 fluctuates seasonally with the river stage, and continuation of bioventing may continue to provide petroleum mass removal. Because the recent respirometry tests have shown consistent and predictable results, the frequency of respirometry testing is being reduced to a biennial basis as identified in TPA-CN-0815, *Tri-Party Agreement Change Notice Form: DOE/RL-2005-93, Remedial Design Report/Remedial Action Work Plan for the 100-N Area, Rev. 1*. The next respirometry testing event is planned in 2021.

While hydrocarbon reduction in vadose zone is likely continuing in a slow manner, the smear zone has better potential for increased biodegradation rates (i.e., petroleum removal) if more oxygen can be delivered to that zone. During high river stage periods, the system is prevented from delivering significant oxygen to the smear zone because the higher soil pore water saturation percentage creates a barrier to air flow. The air (oxygen) currently being delivered to the subsurface preferentially enters the drier, shallower vadose zone. While bioventing will continue to be beneficial as a remedial action for the unsaturated deep vadose zone, the system is not designed to effectively treat site groundwater or the smear zone. Remedial alternatives for remaining petroleum hydrocarbons in the deep vadose zone and groundwater are evaluated in DOE/RL-2012-15, *Remedial Investigation/Feasibility Study for the 100-NR-1 and 100-NR-2 Operable Units*.

5 Recommendations

The following are recommendations for future and ongoing activities for the bioventing system:

- Collect soil samples to determine the concentrations of hydrocarbons, population of hydrocarbon degrading bacteria, nutrients, and other geochemical properties.
- Consider groundwater biosparging (i.e., injection of air [oxygen] into groundwater) to increase biological degradation of hydrocarbons in the smear zone, capillary fringe, and groundwater. If biosparging is planned, conduct a pilot-scale test to evaluate the effectiveness of the system.
- Continue biennial respirometry testing to monitor for changes in overall biological activity to provide updates to biodegradation rates for the site. Groundwater monitoring should be conducted concurrently with the respiration testing so that results can be correlated against dissolved contaminant concentrations and the area of exposed smear zone soil (groundwater elevations).

6 References

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Modified by:

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Appendix A

November-December 2019 Respirometry Testing

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Wood Environment & Infrastructure Solutions, Inc.
15862 SW 72nd Ave., Suite 150
Portland, Oregon
USA 97224
T: 503-639-3400
www.woodplc.com

Memo

To: Art Lee, BTR
William Faught, CAM
CH2M HILL Plateau Remediation Company

Project: 6-61M-120343.02.1

From: John Kuiper, LG, Project Manager
Jack Spadaro, PhD, CHMM
Wood Environment & Infrastructure Solutions, Inc.

c: Project File

Date: May 21, 2020

Subject: Summary of October through November 2019 Respirometry Test Results for the Subsurface Bioventing Remediation System at the 100-N Hanford DOE Site, Benton County, Washington

Wood Environment & Infrastructure Solutions, Inc. (Wood), has prepared this technical memorandum for CH2M HILL Plateau Remediation Company (CHPRC) to summarize the results of the October to November 2019 in-situ respiration test performed at the subsurface bioventing remediation system located at the 100-N Hanford DOE Site in Benton County, Washington. Testing was conducted in accordance with the procedures detailed in the Subsurface Respirometry Test Plan (Test Plan) dated September 30, 2019 (Wood Environment and Infrastructure, Inc., 2019), with exceptions as noted below.

Since startup in November 2012, the bioventing system has been configured to supply air to an area of the subsurface impacted by petroleum hydrocarbons (diesel) via two injection wells: 199-N-167 and 199-N-172 (Figure 1). The system has been in continuous operation since startup in late 2012, except for periodic short-term shutdowns for maintenance and respirometry test events. The longest shutdown period was from September 30 to December 3, 2014, to replace the PVC air injection manifold with cast steel.

These wells are screened from 53 to 78 feet below ground surface (bgs) and 57 to 77 feet bgs, respectively. Both wells are screened exclusively within the Ringold Formation (Unit E), which consists of layers (slightly weathered and consolidated) of silty, sandy gravel (msG), sandy gravel (sG), sand (S), and gravelly sand (gS). The contact with the overlying Hanford Formation (unconsolidated msG and sG) ranges from approximately 45 to 51 feet bgs. Approximately 250 cubic feet per minute (cfm) of air is routed to each injection well through a custom fitted wellhead assembly. Based on previous studies, the predicted radius of influence (ROI) for each injection well is at least 200 feet.

As previously reported (Amec Foster Wheeler, 2016c), well borehole 199-N-377 was completed in August 2016, to a depth of about 120 feet bgs and is located near the treatment area (about 80 feet southwest of 199-N-167 and at the western edge of the former tank farm). TPH-impacted soil was encountered in this boring at depths ranging from 18 to 45 feet bgs, with the top of the Ringold Formation potentially having acted as a barrier to further downward migration. No evidence of TPH impact was identified below 45 feet bgs, and no sheen was apparent on the groundwater. Specifically, laboratory results indicate TPH diesel range concentrations exceed the soil cleanup level in the shallow soils, including greater than 2,000 mg/kg TPH-diesel at a depth of 18 feet bgs, greater than 200 mg/kg from 24 feet to 45 feet bgs, and less than 200 mg/kg from 45 feet bgs to the water table. It is noteworthy that 199-N-167 is a bioventing air-injection well that is screened entirely within the Ringold Formation whereas the TPH impacted soils at 199-N-377 are located within the shallower Hanford Formation. Therefore, it is unlikely that the bioventing system, as currently configured, will have much effect on the shallower impacted soil identified at 199-N-377. Well 199-N-377 was constructed with a screen at the water table for groundwater monitoring and a second screen section in the shallow vadose zone region to enable air injection to target the shallow (Hanford Formation) soils if future decisions include widescale bioremediation of the contaminated soil.

Testing Procedures

Respiration testing was initiated by turning off the bioventing system blower on October 14, 2019. Gas composition samples were then collected periodically, starting immediately after shut down and continuing through test completion on November 19, 2019. Sampling was conducted by Wood and CHPRC field staff from the six wells in the monitoring program (shown on Figure 1):

- 199-N-167 (air injection well),
- 199-N-169 (monitoring well),
- 199-N-171 (monitoring well),
- 199-N-172 (air injection well),
- 199-N-183 (monitoring well), and
- 199-N-18 (monitoring well).

The samples were collected and analyzed to evaluate soil gas concentrations of oxygen, carbon dioxide, carbon monoxide, and total volatile hydrocarbons (TVH).

Prior to blower shutdown on October 14, 2019, baseline readings were collected from the four monitoring wells (199-N-169, 199-N-171, 199-N-183, and 199-N-18), while the air injection wells were still in operation. Respiration testing was initiated at 9:15 am on October 14 when the blower was switched off.

Samples were collected over a period of approximately 862 hours (approximately 5 weeks). A minimum of one casing volume of air was extracted prior using a purge pump prior to monitoring. Readings were collected frequently for the first three days (at approximately 0, 2, 4, 22, 46 and 70 hours) and then at approximately 190 hours (7 days). The bioventing system then remained off for four additional weeks during which four additional sampling events occurred at approximately 360, 526, 694 and 862 hours at all six locations.

Daily field reports and field measurements are included as Attachment 1, and instrument calibration sheets are included as Attachment 2.

Biodegradation Rate Calculations and Results

The 2004 Air Force Center for Environmental Excellence bioventing guidance document (Parsons, 2004) was followed for interpretation of results and calculation of oxygen utilization and biodegradation rates. Oxygen utilization rates for each monitoring point were determined from the slope of the line obtained by plotting the measured oxygen concentration versus time for each monitoring point. Oxygen utilization rates are presented in Table 1 and supporting data and calculations are included as Attachment 3.

Biodegradation rates were calculated using the following equation (Parsons, 2004):

$$k_B = \frac{-k_o}{100} \frac{\theta_a \rho o_2 C}{(\rho_k)}$$

where (calculated or assumed values for the site follow each description):

- k_b: biodegradation rate calculated in mg hydrocarbon consumed per kg of soil per day
- k_o: oxygen utilization rate calculated for each monitoring point in $\%O_2$ consumed per day
- θ_a: gas-filled pore space (volumetric content at the vapor phase) = 0.19 cm^3 gas/ cm^3 soil (based on measured value)
- ρ_{O2}: density of oxygen at standard pressure and assumed soil temperature of 50ºF = 1,378 mg/L (United States Environmental Protection Agency, 1995)
- C: mass ratio of hydrocarbons to oxygen required for mineralization = 0.29 (calculated assuming diesel as $C_{10}H_{20}$ and stoichiometric relationship of $C_{10}H_{20} + 15O_2 => 10CO_2 + 10H_2O$)
- ρ_k: soil bulk density; measured value = 1.736 g/cm^3

Other values derived for the site include:

- θ: total porosity (where $\theta = 1 - \rho_k/\rho_T$) = 0.22 cm^3/cm^3 (based on measured value)
- θ_w: water filled porosity (where $\theta_w = M*\rho_k/\rho_T$) = 0.04 cm^3/cm^3 (based on measured value)
- ρ_T: soil mineral density; assumed value = 2.65 g/ cm^3
- M: moisture content; 3.13% (measured value) = 0.0313 g moisture per g soil

[Relevant Units: mg=milligram, kg= kilograms, %= percent, g= grams, cm= centimeter, mg/L=milligrams per liter, ºF= degrees Fahrenheit]

The values for soil bulk density (1.736 g/cm^3) and moisture content (3.13%) are based on the average of two representative soil samples collected from boring 199-N-183 at depth intervals of 53 to 55 feet and 63 to 65 feet bgs, as presented in Attachment 3 and described in detail in the January 2014 respirometry test results summary (AMEC Environment and Infrastructure, Inc., 2014). Calculations prior to January 2014 were made using the bulk density (2.063 g/cm^3) measured from a single soil sample collected from 58 to 60 feet bgs in boring 199-N-183. The updated soil bulk density value of 1.736 g/cm^3 is considered more representative of the overall site lithology. The values for θ_a, θ, and θ_w from all of the monitoring events were adjusted using the updated bulk density value.

For the five-week in-situ respirometry test initiated on October 14, 2019, calculated biodegradation rates and baseline measurements of oxygen are presented in Table 1.

Table 1. Soil Gas Monitoring Results, Oxygen Utilization and Biodegradation Rates Calculated from In-Situ Respiration Testing, October through November 2019

Monitoring Point	Initial Oxygen	Final Oxygen	Oxygen Utilization	Hydrocarbon Biodegradation Rate
	(%)	(%)	(%/day)	(mg/kg-day)
199-N-167 (injection)	20.8	15.9	0.10	-0.08
199-N-169	20.8	11.2	0.23	-0.17
199-N-171	18.4	11.2	0.20	-0.15
199-N-172 (injection)	20.7	17.0	0.08	-0.06
199-N-183	20.8	15.0	0.16	-0.12
199-N-18	20.9	21.5	NA	NA

NA = Not applicable; oxygen depletion insignificant and biodegradation rate not calculated.

Other Soil Gas and Site Parameters

Throughout the respiration test, TVH was detected in soil gas at most of the monitoring points at low concentrations (Attachment 1). The well with highest detected concentrations of TVH was 199-N-171 (maximum 24.6 parts per million volume [ppmv]), followed by those at 199-N-183 (maximum 19.9 ppmV), both observed as baseline readings. Wells 199-N-171 and 199-N-183 had the highest WTP-Gasoline range hydrocarbon concentrations (260 µg/L and 160 µg/L, respectively) of the wells sampled in November 2019, and among the highest WTP-Diesel range hydrocarbon concentrations (29,000 µg/L and 13,000 µg/L, respectively).

- TVH values at air injection well 199-N-167 were similar in range to values last observed November/December 2016.
- TVH values at air injection well 199-N-172 were similar in range to values last observed January 2016.
- TVH values at well 199-N-169 were similar in range to values last observed November/December 2016
- TVH values at well 199-N-171 were similar in range to values last observed November/December 2016
- TVH values at well 199-N-183 were in a higher range than those previously observed
- TVH values at well 199-N-18 were similar in range to values last observed November/December 2016

The baseline (blower on) TVH reading measured in well 199-N-183 in October 2019 (19.9 ppmV) was not higher than baseline readings from the previous sampling events in June 2016 (22.5 ppmV) and November 2016 (35 ppmV). The highest reading at well 199-N-183 following cessation of bioventing blower operation in October 2019 was 19.4 ppmV, which was higher than the highest post-baseline readings in either June 2016 (11.8 ppmV) or November 2016 (7.3 ppmV).

Groundwater Elevations and Petroleum Hydrocarbon Concentrations

Groundwater elevations and Petroleum Hydrocarbon Concentrations (Diesel and Oil Ranges combined as WTPH-D) from November 2017 and November 2019 are presented in Table 2.

Of the eleven groundwater elevations measured in November 2019, 10 were higher than those measured in November 2017 (Table 2). During the November 2019 sampling event, water elevations in site wells 199-N-167, 199-N-169, 199-N-171, 199-N-172, 199-N-183 and 199-N-18 (Charts 1 through 6, respectively, on the pages that follow) were nearly as low as any observed from 2011-2017.

Table 2. Groundwater Elevations, and Dissolved Petroleum Hydrocarbon Concentrations (Diesel/Oil Ranges combined as WTPH-D) at Wells at Varying Positions Relative to Columbia River

Well Name	Nov. 2017 (m)	Nov. 2019 (m)	Elevation Delta 2017 to 2019 (m)	Position Relative to River	WTPH-D Nov. 2017 (µg/L)	WTPH-D Nov. 2019 (µg/L)	WTPH-D Delta 2017 to 2019 (µg/L)	WTPH-D % Change
199-N-173	117.649	118.034	0.385	near	17,400	8,500	(8,900)	-51%
199-N-96A	117.591	117.567	-0.024	near	3,200	1,110	(2,090)	-65%
199-N-172	dry	dry	NA	mid	NA	NA	NA	NA
199-N-183	117.827	117.937	0.11	mid	8,900	16,700	7,800	88%
199-N-19	117.816	118.216	0.4	mid	307	192	(114)	-37%
199-N-3	117.813	118.096	0.283	mid	96	235	139	144%
199-N-18	117.805	118.142	0.337	mid	19,640	97,000	77,360	394%
199-N-167	117.96	118.154	0.194	far	17,700	8,600	(9,100)	-51%
199-N-169	117.947	118.129	0.182	far	11,100	15,900	4,800	43%
199-N-171	117.877	118.113	0.236	far	8,700	43,000	34,300	394%
199-N-56	118.088	118.148	0.06	far	283	151	(132)	-47%

The last groundwater sample at well 199-N-172 was collected in January 2018. The well was found dry when sampling was attempted in June 2019. Water levels in surrounding wells indicated water should have been present in the well 199-N-172. A camera survey found that the top of the well screen had separated from the well casing causing filter pack material to fall into the well to an elevation above the water level (see Figure 2). The cause of screen separation was likely the result of PVC fatigue from thermal expansion/contraction over its 10-year life (the well was constructed in January 2009) due to cold air injection in winter and hot air injection in summer. Well 199-N-172 still functions for air injection to the vadose zone and repair of the well is being evaluated.

Of the eleven groundwater elevations measured in 2019, 10 were higher than those measured in the prior bioventing monitoring round in November 2017. The only decrease in groundwater elevation was at well 199-N-96A near the Columbia River, which was very minor (0.024 m). The two wells nearer the Columbia River (199-N-173 and 199-N-96A) showed losses in petroleum hydrocarbon concentrations, whereas petroleum hydrocarbon concentrations increased at 3 of 4 wells toward the middle of the study area, and at 2 of 4 wells at the upgradient end of the study area. Overall, the petroleum hydrocarbon concentrations increased at 5 wells, and decreased at 5 wells.

Charts 1, 2, 3, 4, 5 and 6 (below) show dissolved diesel concentration trends in groundwater relative to groundwater elevations, for bioventing test wells 199-N-167, 199-N-169, 199-N-171, 199-N-172, 199-N-183 and 199-N-18, respectively, over an approximately ten-year period from late 2010 to late 2019. Together, these six wells provide coverage of the main portion of the petroleum hydrocarbon plume (Figure 3).

Chart 1 - Well 199-N-167 - Groundwater TPH-Diesel Concentrations and Head vs Time

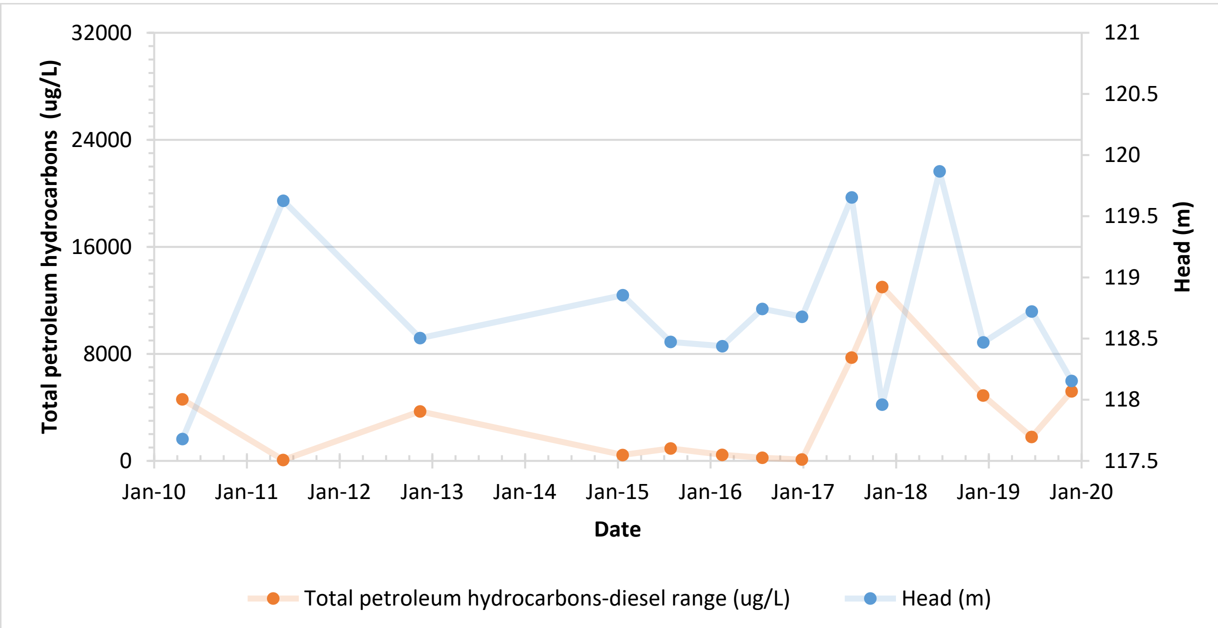


Chart 2 - Well 199-N-169 - Groundwater TPH-Diesel Concentrations and Head vs Time

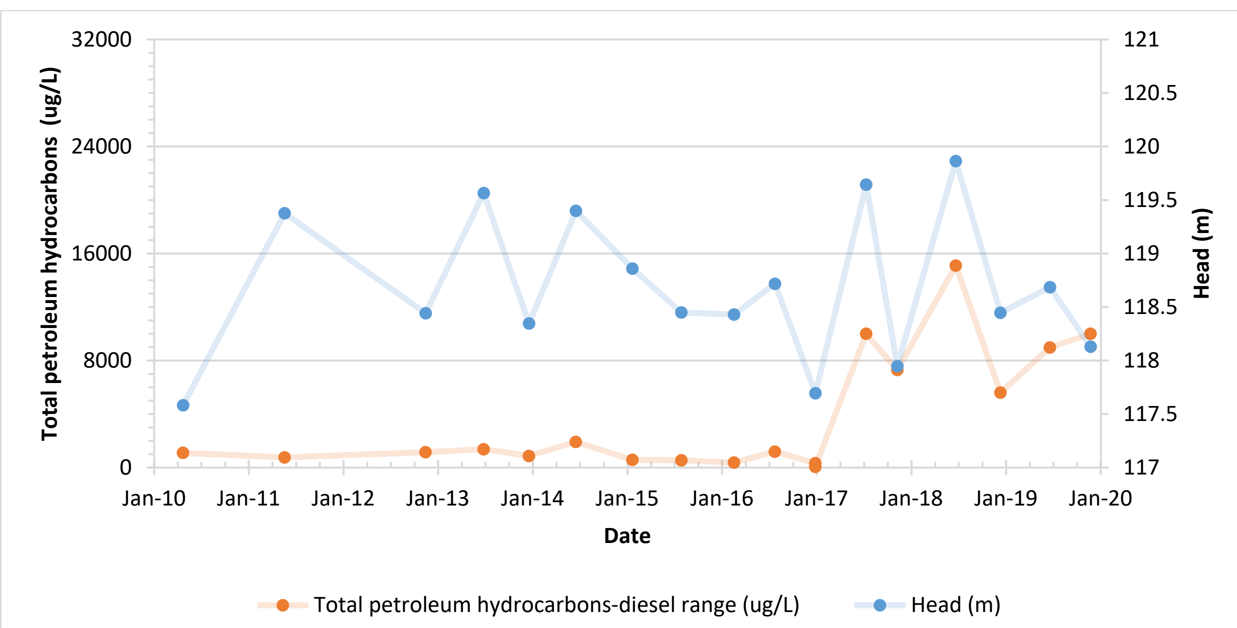


Chart 3 - Well 199-N-171 - Groundwater TPH-Diesel Concentrations and Head vs Time

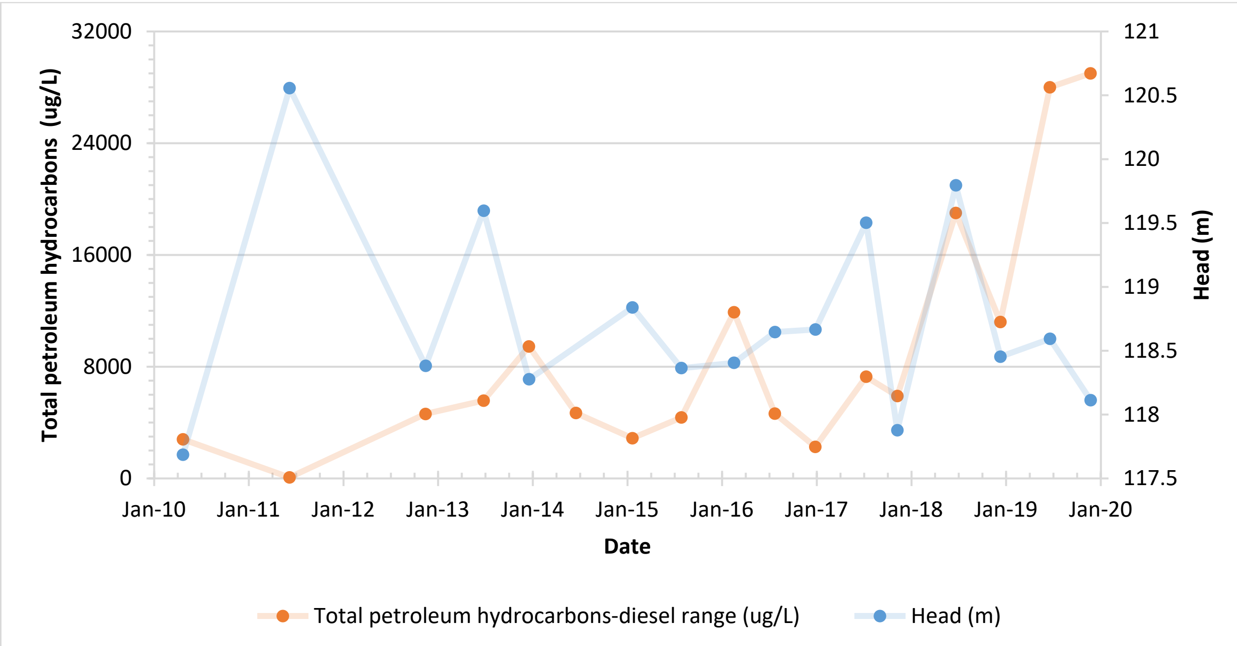


Chart 4 - Well 199-N-172 - Groundwater TPH-Diesel Concentrations and Head vs Time

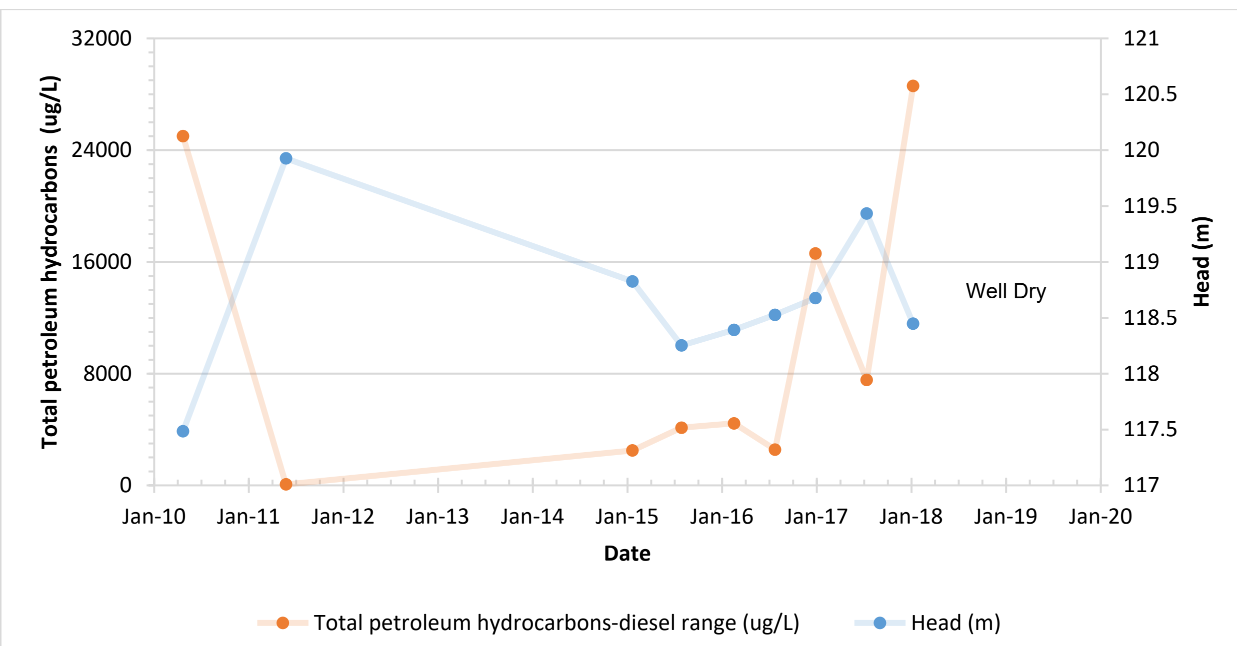


Chart 5 - Well 199-N-183 - Groundwater TPH-Diesel Concentrations and Head vs Time

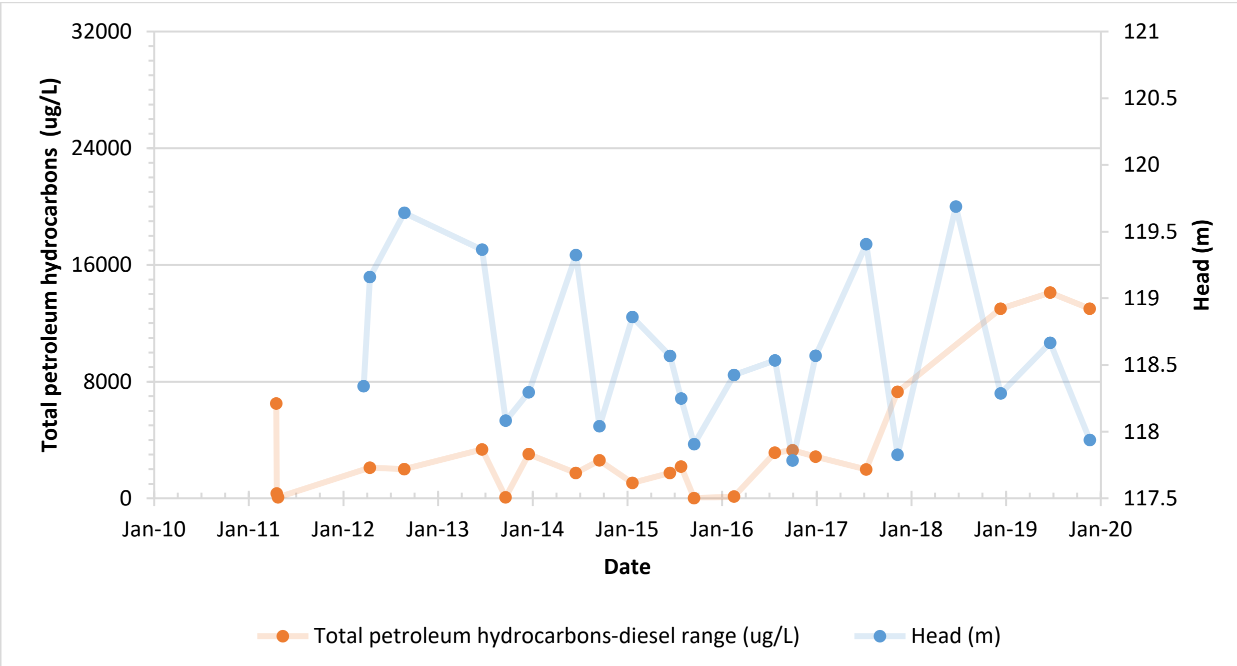
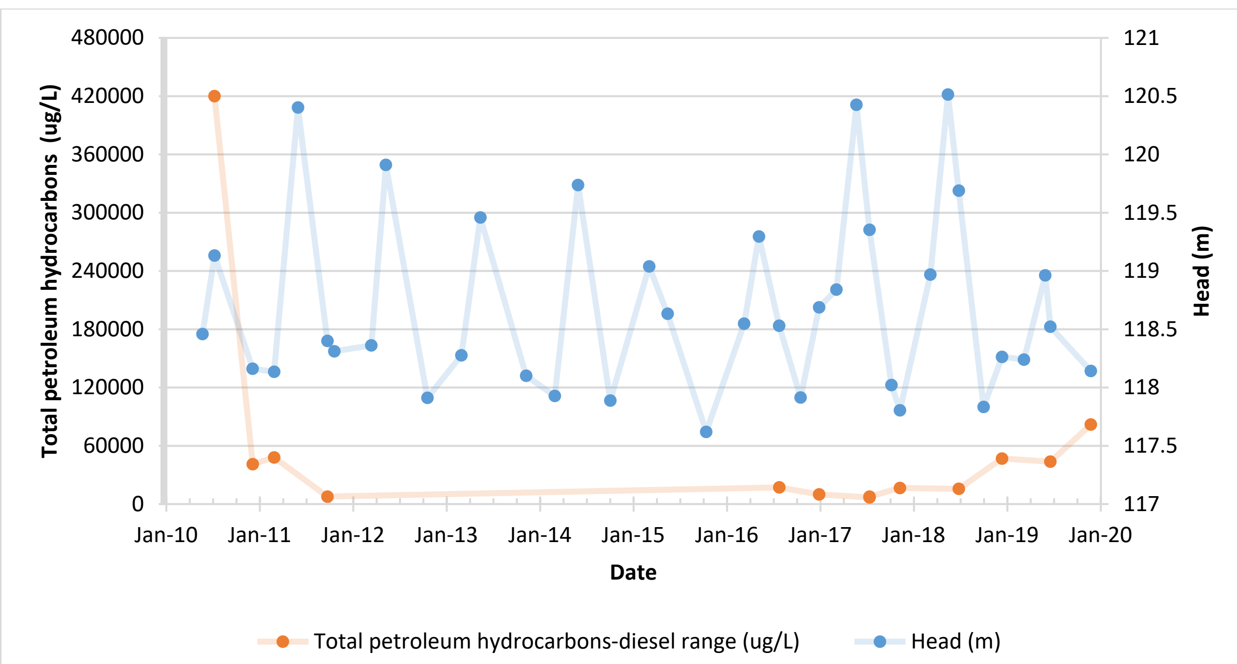


Chart 6 - Well 199-N-18 - Groundwater TPH-Diesel Concentrations and Head vs Time



From roughly upgradient to downgradient in the TPH plume, the following diesel concentration trends are observed:

- At well 199-N-167 the diesel concentration has fallen from a peak in 2017 and 2018, and is approximately the same as that observed in 2010.
- At well 199-N-169, the diesel concentration has fallen from a peak in 2017 and 2018, and remains above that observed in 2010.
- At well 199-N-171, the diesel concentration has exhibited a general upward trend beginning in 2010.
- At well 199-N-172, the diesel concentration initially fell significantly from 2010 to 2011, and had trended upward from 2015 to early 2018. The well was dry during November 2017 and November 2019 sampling events.
- At well 199-N-183, the diesel concentration initially fell in early 2011, and has been trending upward since 2016 to a level higher than in 2011.
- At well 199-N-18, the diesel concentration fell significantly in 2010, and remained diminished until a trend upward that began in 2019.

Distributions of Diesel and Electron Acceptors in Groundwater

A summary table of groundwater analytical results from the November 2019 sampling event was provided by Jacobs and is presented in Attachment 4 (Lee, 2020a). Jacobs provided plume distribution contour maps for petroleum as diesel (TPH-D), dissolved oxygen (DO), oxidation-reduction potential (ORP), nitrate, sulfate and alkalinity in groundwater, covering the years 2010 to 2019, and these are presented in Attachment 5 (Lee, 2020b). Dissolved oxygen, nitrate and sulfate can all act as terminal electron acceptors in the biodegradation of petroleum hydrocarbons, allowing for biological oxidation of petroleum hydrocarbons to occur (Rabus et al 2016; Wiedemeier et al 1999).

TPH-D Distribution in Groundwater

The maps indicate a fairly consistent area for the 500 µg/L concentration contour line during the time period. In 2010, the TPH-D concentrations at the center of the plume exceeded 50,000 µg/L, but then fell to less than 20,000 µg/L until 2018, when some concentrations again exceeded 20,000 µg/L, and 2019, when at last one concentration exceeded 50,000 µg/L.

Oxidation Reduction Potential Distribution in Groundwater

The ORP is a measure of electron activity in groundwater, indicates the relative tendency for acceptance or transfer of electrons by a solution, and often depends on and influences the rate of biodegradation in groundwater (Wiedemeier et al 1999). The maps indicate a consistent area of ORP >150 mV (generally recognized as aerobic) in groundwater on the site surrounding the TPH-D plume. Even within the TPH-D plume the ORP has often been >150 mV since bioventing began in 2012. In 2010, 2011, 2014 and 2017, the ORP in portions of the TPH-D plume was depressed to between -50 and -150 mV (generally recognized as anoxic to anaerobic conditions). During periods of aerobic groundwater conditions one would generally anticipate the microbial use of oxygen as the terminal electron acceptor during biodegradation of petroleum hydrocarbons, and during periods of anoxic or anaerobic groundwater conditions one would anticipate the microbial use of nitrate, manganese, iron, sulfate or carbon dioxide (generally in that order) as potential terminal electron acceptors (Wiedemeier et al., 1999).

Dissolved Oxygen Distribution in Groundwater

The maps indicate a consistent area of DO saturation (>8 mg/L) in groundwater on the site surrounding the TPH-D plume. The DO is consistently below 6 mg/L in the area of the TPH-D plume, and often less than 3 mg/L. The DO depletion area is variable across the site. The periods of higher DO within the plume area may be an indicator of river water flowing inland in response to dam-related changes in river stage.

Nitrate Distribution in Groundwater

The maps indicate an area of nitrate concentration consistently >10 mg/L in groundwater in large portions of the site surrounding the TPH-D plume. Nitrate concentrations less than 10 mg/L have been consistently present in portions of the TPH-D plume. Nitrate was a common component of wastes discharged in the site vicinity (CH2MHill Plateau Remediation Company, 2013b). Following oxygen depletion, nitrate can act as an electron acceptor during biological oxidation reactions that degrade TPH-D.

Sulfate Distribution in Groundwater

The maps indicate a consistent area of sulfate concentration >50 mg/L in groundwater on the site surrounding the TPH-D plume. Sulfate concentrations greater than 200 mg/L have been commonly present in portions of the TPH-D plume. A sulfate plume originated from sulfuric acid solutions used to regenerate ion exchange resins in a water treatment facility in an area approximately 2,000 feet southwest of the TPH-D plume (CH2MHill Plateau Remediation Company, 2013b). Over the years the sulfate plume migrated north/northeast toward the TPH-D plume, arrived at the edge of the TPH-D plume in approximately 1991, and then dissipated starting in 1997. In 2005 a calcium polysulfide injection test was initiated upriver of the 100-N leading to a sulfate plume in that region (CH2MHill Plateau Remediation Company, 2013b), and that sulfate plume has also traveled toward the TPH-D plume and has now largely dissipated. Following nitrate depletion, and chemical reduction of manganese IV and ferric iron, sulfate can act as an electron acceptor during biological oxidation reactions that degrade TPH-D.

Alkalinity Distribution in Groundwater

The maps indicate a consistent alkalinity concentration >250 mg/L in groundwater in the TPH-D plume. The alkalinity has exhibited concentrations greater than 500 mg/L in portions of the TPH-D plume every year except 2015. Alkalinity is a by-product of the generation of carbon dioxide during TPH-D biodegradation by microbes using various electron acceptors.

Interpretation

The groundwater and soil gas TPH results, and respirometry testing results, are suggestive of: 1) a potential residual source area remaining up-gradient of the main area of groundwater contamination, possibly in the vicinity of the former 166-N tank farm; and 2) residual hydrocarbon contamination within a "smear" zone resulting from groundwater elevation fluctuations. Hydrocarbons (dissolved and free-phase) associated with the fluctuating groundwater are likely creating a smear zone that continually re-contaminates soils within this zone. The result is that while the existing bioventing system continues to treat the smear zone (primarily during periods of low water table), the process is slow, and unless the system is upgraded (i.e. biosparging), it is expected to become progressively less efficient.

Baseline or initial oxygen concentrations in the soil gas were near atmospheric levels at five monitoring locations. At monitoring location 199-N-171 the initial oxygen concentration was only 18.4%.

The site oxygen consumption rates at all six wells tested ranged from 0.06 to 0.17 mg/kg-day in November 2019, and are relatively low compared to bioventing literature values ranging from 0.4 to 19 mg/kg-day (Lee et al. 2006; Hinchee and Ong 1992). The highest utilization in November 2019 was calculated for monitoring wells 199-N-169 and 199 N 171 at 0.17 and 0.15 mg/kg-day, respectively (Table 1). The highest oxygen utilization values would be expected in soil zones with greater levels of hydrocarbon "food" that would tend to support a higher mass of microbes.

Oxygen concentrations in soil gas at monitoring well 199-N-18 remained above 20% throughout the test and exhibited insignificant oxygen depletion; therefore, a biodegradation rate was not calculated for this well. The results for this well are consistent with previously conducted respirometry test results as shown in Attachment 3. Well construction information for 199-N-18 indicates that the eight-inch carbon steel casing has perforations from 12 to 78 feet deep, with a telescoping six-inch stainless steel 10-slot screen installed from 58.5 to 79 feet. Past studies have revealed that there are no significant residual concentrations of TPH-diesel detected in the shallow vadose zone (CH2MHill Plateau Remediation Company. 2013b). Since the well casing has perforations beginning at 12 feet bgs, the gas composition samples collected from this well are likely heavily influenced by the shallow vadose zone soil gas and not representative of deeper vadose zone conditions.

As already mentioned, significant respiration is not measured at 199-N-18, and while this may be due to the influence of shallow vadose-zone air dominating the sample, it is also possible that some other factor may be limiting bacterial activity in this area of the plume (e.g. lack of hydrocarbons within the vadose zone soils and contamination constrained to the saturated soils). Because groundwater in 199-N-18 typically displays some of the highest dissolved TPH concentrations of the test wells (indicating sufficient food source for bacteria) and has contained NAPL in the recent past (CH2MHill Plateau Remediation Company. 2013b) it is likely that dissolved oxygen or other electron acceptors may be a limiting factor for biodegradation within the groundwater plume and smear-zone soils. Respiration is also relatively low at well 199-N-172. (Table 1). This assessment is supported by the fact that groundwater dissolved oxygen concentrations are much lower within the petroleum plume vicinity wells 199-N-18 and 199-N-172 than outside of the plume. Table 3 presents a summary of dissolved oxygen concentrations measured in the vicinity of the petroleum plume from March 2010 to November 2019.

Table 3. Dissolved Oxygen Concentrations in Groundwater from 2010 to 2019 (results in mg/L)

Location Area Relative to Plume	Well # / Range / Average	Overall Average
Up-gradient or Cross-Gradient	199-N-56 / 2.17 – 6.87 / 5.03	5.08
	199-N-3 / 2.71 – 6.95 / 5.14	
Upper Margin	199-N-167 / 0.07– 4.37 / 1.67	1.65
	199-N-169 / 0.10 – 4.31 / 1.62	
Lateral Margin (mid-portion)	199-N-183 / 0.015 – 7.08 / 1.49	2.49
	199-N-19 / 0.15 – 7.38 / 3.39	
Upper Main	199-N-171 / 0.00 – 3.72 / 1.31	1.62
Middle Main	199-N-18 / 0.0019 – 2.90 / 1.31	1.30
	199-N-172 / 0.06 – 3.93 / 1.30	
Lower Main	199-N-173 / 0.22 – 4.24 / 2.02	2.02
Lateral Margin (lower portion)	199-N-96A / 2.42 – 7.93 / 5.52	5.52

Dissolved oxygen data in Table 3 was sourced from year-by-year files named ALLDATA.csv, all dated 02/24/2020 and received from Art Lee of Jacobs on 30 March 2020 (Lee, 2020c)

Comparison of Biodegradation Rates Over Time

Table 4 presents a comparison of site biodegradation rates over time, as measured in soil gas, including the initial 2010 data and the more recent data from 2014 to 2019. Measurements began with the 2010 pilot test (Amec Geomatrix, 2010), and then occurred roughly every six months from the end of 2012 through November 2017, and then in November 2019. For comparison, literature values ranged from 0.4 to 19 mg/kg-day (Lee et al. 2006; Hinchee and Ong 1992).

Table 4. Comparison of Biodegradation Rates over Time Calculated from In-Situ Respiration Testing

Monitoring Point	(mg/kg-day)										
	Nov. 2019	Nov. 2017	Jul. 2017	Dec. 2016	Aug. 2016	Feb. 2016	Aug. 2015	Jan. 2015	Jul. 2014	Jan. 2014	Mar. 2010
199-N-167	-0.08	-0.14	-0.08	-0.06	-0.06	-0.07	-0.05	-0.05	-0.06	-0.01	-0.99
199-N-169	-0.17	-0.19	-0.11	-0.14	-0.07	-0.12	-0.12	-0.23	-0.09	-0.07	-0.97
199-N-171	-0.15	-0.11	-0.07	-0.22	-0.08	-0.19	-0.14	-0.23	-0.09	-0.05	-0.37
199-N-172	-0.06	-0.07	-0.08	-0.03	-0.02	-0.04	-0.04	-0.05	-0.02	-0.01	-0.54
199-N-183	-0.12	-0.06	-0.02	NA	NA	NA	NA	NA	NA	-0.09	NT
199-N-18	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NT

Notes:

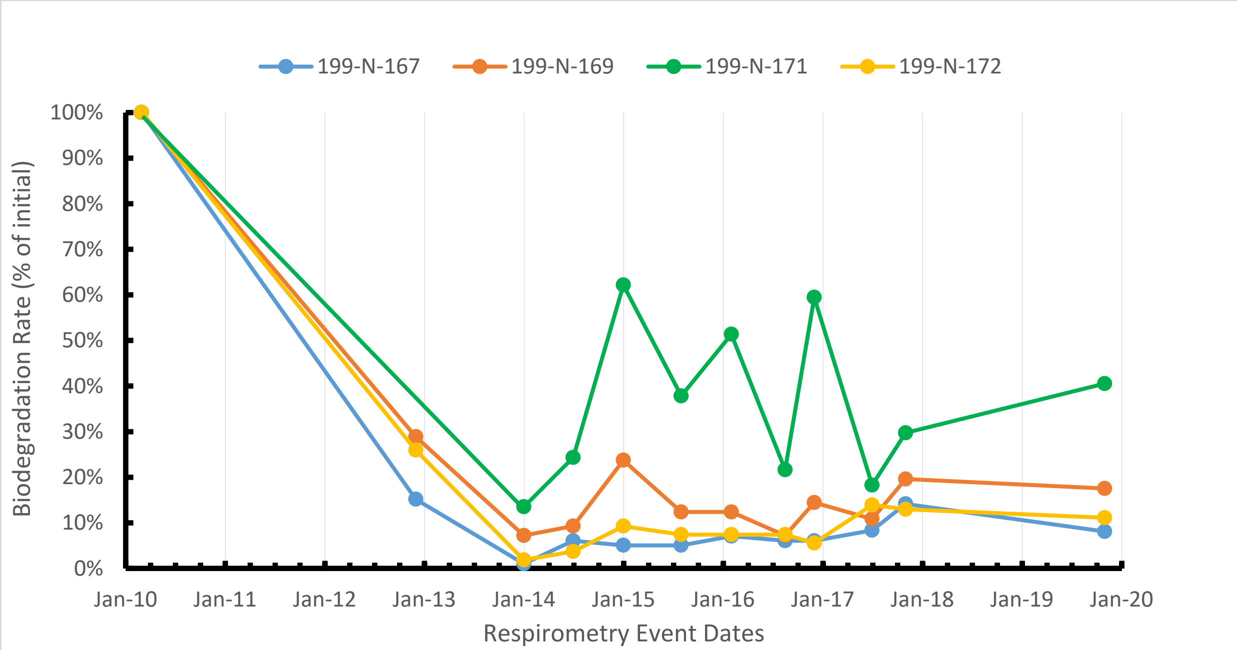
NA = Not applicable: oxygen depletion insignificant and biodegradation rate not calculated.
NT = Not tested
Focus of table is to compare initial data with more recent data. Results for all prior events have been provided previously: March 2010 (AMEC Geomatrix, 2010), December 2012 (AMEC Environment & Infrastructure, Inc., 2012), January 2014 (AMEC Environment & Infrastructure, Inc., 2014a), July 2014 (AMEC Environment & Infrastructure, Inc., 2014b), December 2014 to January 2015 (Amec Foster Wheeler, 2015a), June to August 2015 (Amec Foster Wheeler, 2015b), January to February 2016 (Amec Foster Wheeler, 2016a), June to August 2016 (Amec Foster Wheeler, 2016b), November to December 2016 (Amec Foster Wheeler, 2017b), June to July 2017 (Amec Foster Wheeler, 2017e), and October to November 2017 (Amec Foster Wheeler, 2018).

Based on the soil gas data collected in November 2017 and in November 2019, the rate at which biodegradation removed petroleum increased at two wells (199-N-171 and 199-N-183), fell at one well (199-N-167) and remained about the same at two wells (199-N-169 and 199-N-172). After several years of biodegradation inactivity at well 199-N-183, biodegradation began returning there starting in July 2017. The biodegradation rate at well 199-N-183 is now greater than that observed at any time since biodegradation rate monitoring began there in January 2014. The third highest biodegradation rate at the site in November 2019 was observed at well 199-N-183. As already discussed, biodegradation rates based upon soil gas evaluation have historically been insignificant at well 199-N-18 and very low at well 199-N-172.

Overall, the vadose zone biodegradation rates exhibit an overall declining trend from the initial rates measured in 2010 (Chart 7).

The biodegradation rates at wells 167, 169 and 172 fell by late 2012 and have remained relatively steady at 30% of initial rate or less since early 2014. The biodegradation rate at well 171 fell by January 2014, but has gyrated upwards and downwards between 18% and 59% of the initial rate since 2014.

Chart 7 – Biodegradation Rate Vs Time as Percent of Initial Biodegradation Rate



A number of variables could be responsible for the decrease in biodegradation indicated. One hypothesis would be that the bio-available hydrocarbon food source in the treatment zone has been degraded to concentrations that no longer support significant biological activity. A second hypothesis would be that the shorter chain hydrocarbons have been expended to leave only the more recalcitrant longer chain hydrocarbons. Changes in subsurface conditions such as temperature, moisture, and/or nutrient availability may also have impacted the rates shown, though one would expect only minor fluctuations in temperature at these depths. The concentration of hydrocarbons in vadose zone soils can most accurately be determined by direct soil sampling.

One ongoing goal of the respirometry tests is to evaluate the potential effect of groundwater elevation variability on the biodegradation rates measured in soil gas. The observed biodegradation rates based upon soil gas at wells 199-N-171 and 199 N 183 were greater in November 2019 than in November 2017 (Table 4), even when groundwater at these locations was higher in 2019 than in 2017 (Table 2). Biodegradation measured in soil gas decreased at wells 199-N-167, 199-N-169 and 199-N-172 from November 2017 to November 2019, and groundwater at these locations also rose. Thus, there is no clear correlation between groundwater elevation change and biodegradation change at these wells when comparing the November 2017 and November 2019 data.

Groundwater Electron Acceptor Interpretation

Oxygen and nitrate have both been depleted in a portion of the TPH-D plume. But oxygen and nitrate are both present in abundance upgradient of the TPH-D plume, as is sulfate, and these compounds are all known to serve as terminal electron acceptors during the biological oxidation of petroleum hydrocarbons. Nitrite, the reduced product of nitrate, is not present as a significant fraction of the total nitrate/nitrite. Therefore, the groundwater in the TPH-D plume appears to be more generally poised at the nitrate reduction stage at present. Hexavalent chromium (Cr6+) is present in groundwater at wells N-96A (10 µg/L), N-183 (7.93 µg/L) and N-377 (11.01 µg/L), again indicating that a relatively oxidized environment exists within the TPH-D plume.

Alkalinity is increasing within the groundwater in the TPH-D plume footprint, suggesting that biodegradation is actively producing carbon dioxide. Carbon dioxide production is certainly observed during respiration tests taking place in the vadose zone, and that carbon dioxide detected in the vadose zone is likely produced in both the vadose and saturated zones.

Summary and Recommendations

The respirometry rates from the November 2019 event remain below literature values for recommending bioventing as a cost effective stand-alone remedial option. However, there is evidence that oxygen in the vadose zone is a limiting factor for microbial degradation in the area of monitoring wells 199-N-169 and 199-N-171 and that bioventing will help maintain this biodegradation, even if the rate is somewhat low.

As is frequently the case with remediation systems, cleanup rates may become asymptotic and efficiencies decrease as target contamination is removed. It appears that asymptotic levels have been achieved with respect to treatment within the unsaturated vadose zone near wells 199-N-167, 199-N-169, and 199-N-172, and that biodegradation continues to show varying levels of activity at well 199-N-171. Because the recent respirometry tests have shown fairly consistent and predictable results, the frequency of respirometry testing has been reduced to a biennial basis. Currently, the next respirometry testing event is planned in 2021.

The concentrations of diesel in groundwater continue to indicate the presence of pockets of NAPL in the saturated or smear zone soil, and high viscosity oily waste sticks to soil. While hydrocarbon biodegradation in the vadose zone is likely continuing in a slow manner, the smear zone has better potential for increased biodegradation rates (petroleum removal) if more oxygen can be delivered to that zone. The bioventing system is not effective in delivering significant oxygen to the smear zone because the higher soil pore water saturation percentage creates a barrier to air flow. The air (oxygen) currently being delivered to the subsurface therefore preferentially remains within the drier, shallower vadose zone. While bioventing will continue to be beneficial as a remedial action, particularly during times of low groundwater, site groundwater and the smear zone will be difficult to treat with the current system.

Biosparging, or injection of atmospheric air into the shallow saturated zone, would provide the oxygen needed to increase microbiological activity below the fluctuating water table, promoting bioremediation of both the shorter and longer-chain petroleum compounds. Biosparging would enhance the current treatment of site hydrocarbons, which consist primarily of the heavier fractions of diesel. If biosparging were to be employed at the site, it is expected to treat petroleum contamination within the capillary fringe, smear zone, saturated zone, and groundwater, and thereby complement the overlying vadose zone bioventing treatment. Biosparging has been identified as a proposed remedy in the 100-NR-1 and 100-NR-2 Operable Units Proposed Plan (CH2MHill Plateau Remediation Company, 2013a). Wood (fka Amec Foster Wheeler) recommends conducting a biosparging pilot test and has submitted conceptual site plans and background information in the “Design Basis for Biosparging Pilot System in Diesel Plume near 166-N Tank Farm Facility at Hanford Site” (Amec Foster Wheeler, 2016b). Amec Foster Wheeler also has prepared a draft pilot study test design (60% design) entitled: “Groundwater Biosparging Treatability Test Plan and 60% Engineering Design for Diesel Plume near 166-N Tank Farm Facility at Hanford Site” (Amec Foster Wheeler, 2017c).

In summary, Wood is recommending the following actions be completed at the site (several of which have already been proposed as part of the biosparging design and treatability test plan documents):

- Continue bioventing with at least one bioventing test every other year. Continue to conduct periodic high and low river bioventing testing events to monitor for changes in overall biological activity to provide updates to biodegradation rates for the site. Groundwater monitoring should be conducted concurrently with the respiration testing so that respirometry testing results can be correlated against dissolved contaminant concentrations and the area of exposed smear zone soil (groundwater elevations).

- When groundwater sampling is scheduled to occur in conjunction with at bioventing test, schedule the collection of groundwater samples for after respirometry soil gas sampling has been completed so as to minimize external disturbances.
- Evaluate converting 199-N-377 to a combined groundwater monitoring and bioventing well, with air injection targeting TPH-diesel contamination in the shallow (Hanford Formation) soils.
- Use a pilot scale test to evaluate the effectiveness of adding a biosparging component to the existing bioventing system, thereby promoting further remediation of zones beneath the water table and accelerating the overall cleanup timeframe. By converting the bioventing system to a combined bioventing/biosparging system, Wood expects to maintain elevated oxygen concentrations in both the saturated and vadose zones. Testing of such a system would be necessary to determine how large the ROI would be within the saturated zone and how quickly the system would reduce contaminant levels in groundwater and the smear zone to cleanup goals. The first step of this process, preparation of the plans and design for the installation and monitoring of the pilot scale system, is currently at the 60% design stage.
- Consider the collection of soil samples within the cleanup area of the site to verify progress toward achievement of cleanup goals for soil. [Note: this sampling might be able to be combined with the installation of new biosparging and monitoring wells].
- Consider the collection of soil and groundwater samples to measure numbers of hydrocarbon-degrading bacteria prior to commencement of a combined bioventing/biosparging pilot test. Other geochemical and nutrient parameters should also be measured in soil and groundwater.
- Consider pulsing of the bioventing system (2 weeks on, 2 weeks off). If coordinated such that system down times are matched up with the regularly-scheduled monthly bioventing well measurements, then the carbon dioxide test results could be used to provide additional respiration data for use in on-going evaluation of system performance.
- Consider using oxygen, nitrate and sulfate concentration distributions, concentration distributions of other electron acceptors (ferric iron : ferrous iron redox pair [or total and dissolved iron] and total and dissolved manganese) and groundwater flow estimates, to make a first approximation of petroleum biodegradation potential under the current conditions.

Figure:

Figure 1 – Wells Utilized for Biovent Respirometry Testing
Figure 2 - Well 199-N-172 – Well Screen Separation Photos
Figure 3 - Interpreted Petroleum Hydrocarbon Plume from Groundwater Samples

Attachments:

Attachment 1 – Daily Field Reports and Field Measurement Tables
Attachment 2 – Instrument Calibration Sheets
Attachment 3 – Design Worksheet for Oxygen Utilization and Biodegradation Rates
Attachment 4 – Groundwater Data Generated during November 2019 Sampling Event (Prepared by Jacobs)
Attachment 5 – Contour Maps for Distribution of Various Parameters in Site Groundwater 2010-2019 (Prepared by S.S. Papadopulos & Associates, Inc. for Jacobs)

References

AMEC Geomatrix, 2010. Technical Memorandum, Results Summary of In-situ Respiration Testing at the N100 Bioremediation Pilot Test Site, March 22.

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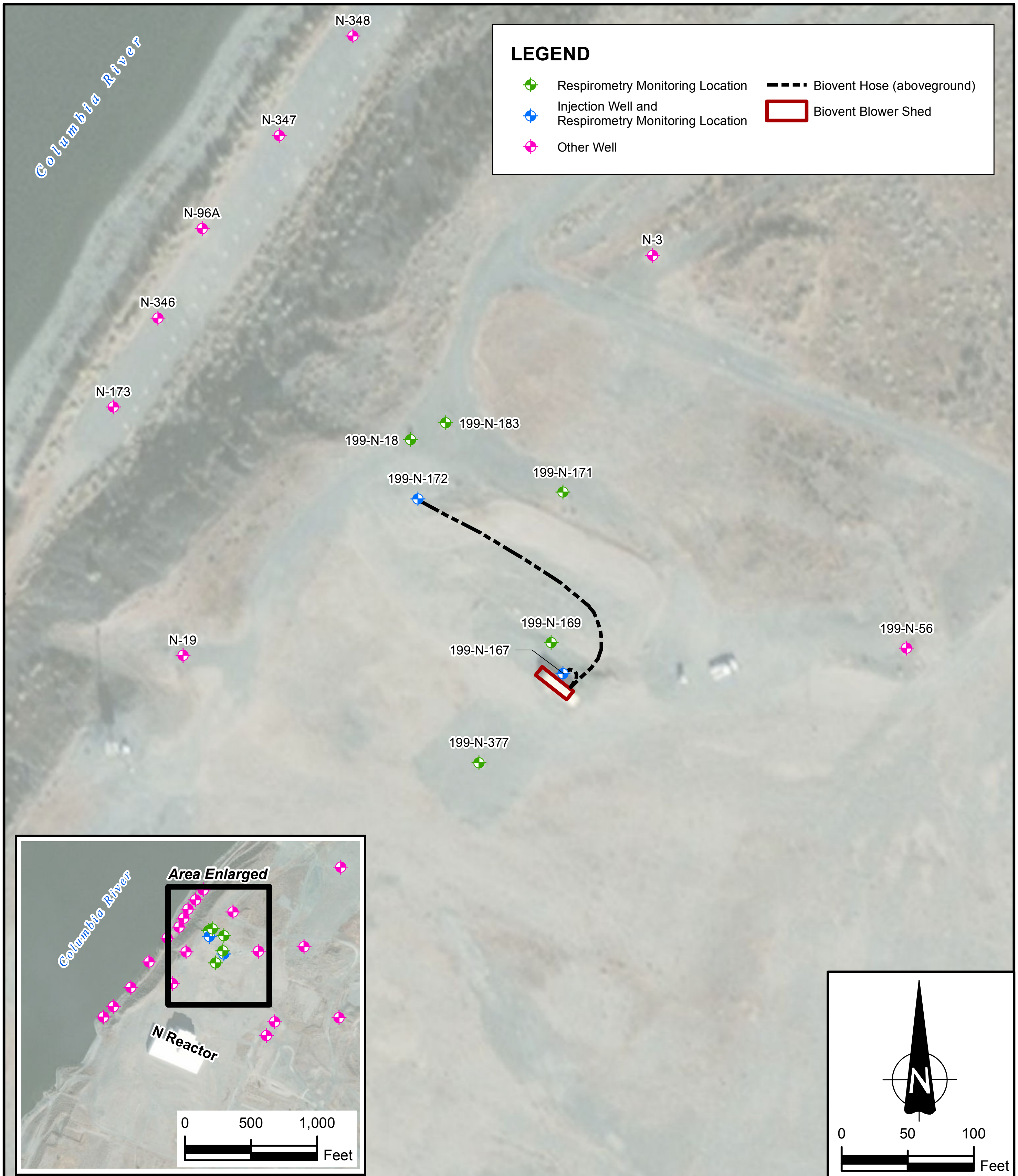
Attachments



CHPRC	100-N AREA BIOVENTING SYSTEM	DATE MAY 2020
		SCALE 1 " = 100 '
Wood Environment & Infrastructure Solutions, Inc. 15862 SW 72nd Ave., Suite 150 Portland, OR 97224	WELLS UTILIZED FOR BIOVENT RESPIROMETRY TESTING	PROJECT NO. 661M120343
		FIGURE 1

wood.

DRAWN BY: PM CHECKED BY: JKH

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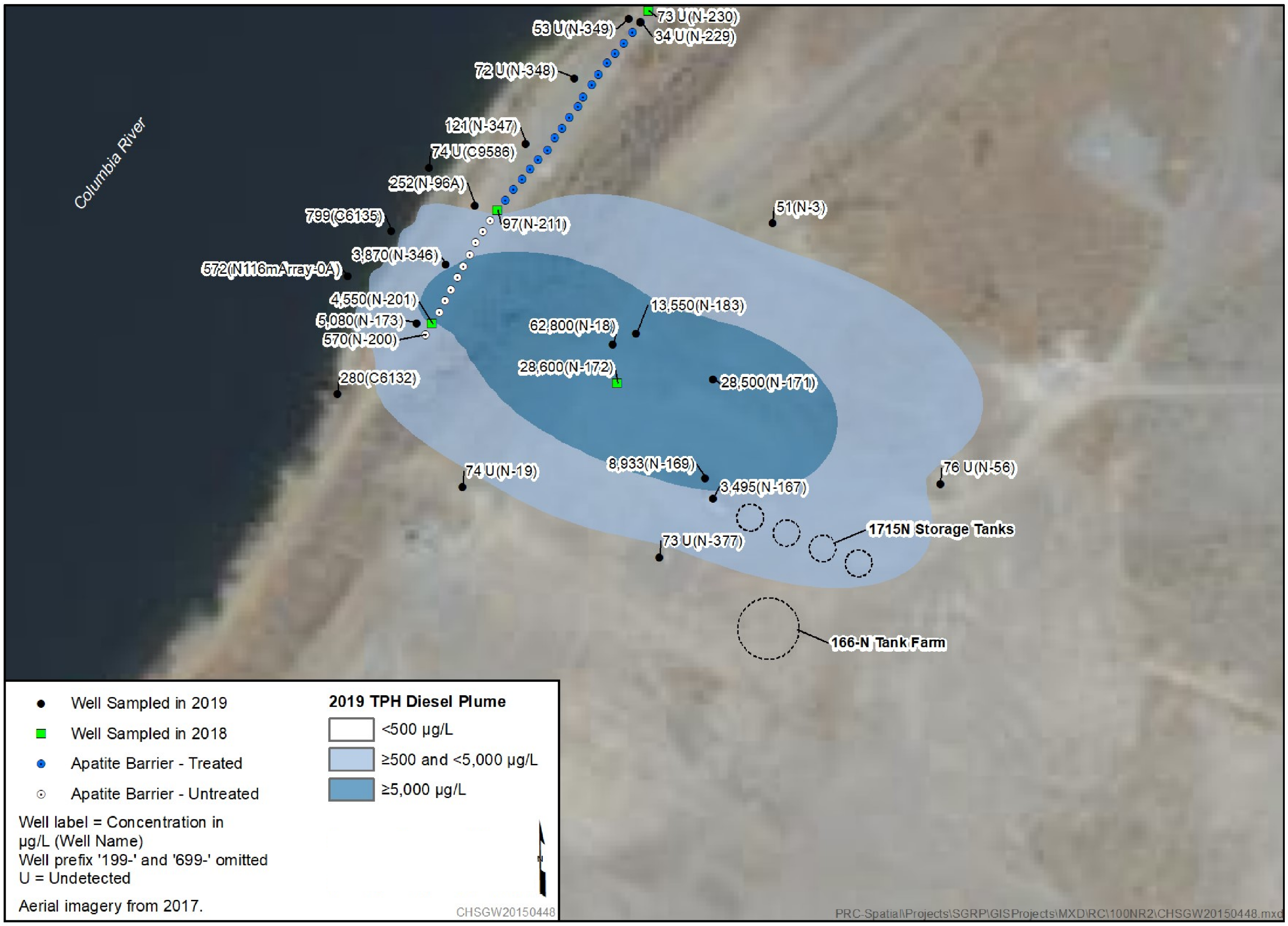
Images obtained from
Art Lee of Jacobs on May 17, 2020.

CHPRC	wood.	100-N AREA BIOVENTING SYSTEM	DATE MAY 2020
			SCALE NOT TO SCALE
Wood Environment & Infrastructure Solutions, Inc. 15862 SW 72nd Ave., Suite 150 Portland, OR 97224		WELL 199-N-172 WELL SCREEN SEPARATION PHOTOS	PROJECT NO. 661M120343
			FIGURE 2

DRAWN BY: PM CHECKED BY: JKH

\\por-fs1\clientdata\12000\12000\12034\120343 - Jacobs FY 2019 & FY 2020\dwg\Respirometry Test Report\2 - Well 199-N-172 – Well Screen Separation Photos.mxd - stephane.descombes - 5/20/2020 - 1:47:57 PM



Images obtained from
Art Lee of Jacobs on May 17, 2020.

CHPRC		100-N AREA BIOVENTING SYSTEM	DATE MAY 2020
			SCALE NOT TO SCALE
Wood Environment & Infrastructure Solutions, Inc. 15862 SW 72nd Ave., Suite 150 Portland, OR 97224		INTERPRETED PETROLEUM HYDROCARBON PLUME FROM GROUNDWATER SAMPLES	PROJECT NO. 661M120343
			FIGURE 3

DRAWN BY: PM CHECKED BY: JKH

\\por-fs1\clientdata\12000\12000\12034\120343 - Jacobs FY 2019 & FY 2020\dwg\Respirometry Test Report\3 - Interpreted Petroleum Hydrocarbon Plume from Groundwater Samples.mxd - stephane.descombes - 5/20/2020 - 1:48:47 PM

Attachment 1
Daily Field Reports and Field Measurement Tables

DAILY FIELD REPORT

PROJECT NAME: HANFORD BIO VENT PROJECT

Project No:	661M120343.02.1	Date:	10/14/2019
Field Report No:		Page:	1
Arrival:		Departure:	
Wood Field Rep.	Jason Gardner	WOOD PLC	John Kuiper
Weather Conditions			

7376 SW Durham Road
Portland, Oregon 97224
Phone: 503-639-3400
Fax: 503-620-7892

FIELD REPORT NOTES

Time: **Field Notes:**

10/14/2019 Monday sampling event

Travel from Portland

06:15 - On site. Performed cal.

07:30 -Kevin, Kathy and Kyle on site for DOE, Art on site for CH2 and IH on site (Randy) and screening wells.

07:58 - DOE operators Kevin and Kathy set up on 169 and we bagan baseline sample collection. After sampling 169 when moved to 18, 183 then 171. Then had facilities shut off blowers.

09:15 - Started 0 hr sampling on 169, then proceded through all other wells. followed by another round 2 hours afetr the start of this round then another 2 hours after that.

14:08 - Finished sampling final round of sampling on 171.

14:30 - Off site.

Contractor's Rep. (Initials) | Continued

DAILY FIELD REPORT

wood.

PROJECT NAME: HANFORD BIO VENT PROJECT

Project No:	661M120343.02.1	Date:	10/15/2019
Field Report No:		Page:	1
Arrival:		Departure:	
Wood Field Rep.	Jason Gardner	WOOD PLC	John Kuiper
Weather Conditions			

7376 SW Durham Road
Portland, Oregon 97224
Phone: 503-639-3400
Fax: 503-620-7892

FIELD REPORT NOTES

Time: **Field Notes:**

10/15/2019 Tuesday sampling event

06:45 - On site. Performed cal.
07:30 -DOE operators Kevin and Kathy on site. IH on site and screening wells.
07:41 - Started sampling on 169.
08:39 - Finished sampling on 171.
09:00 - Off site.

Contractor's Rep. (Initials) | Continued

DAILY FIELD REPORT

PROJECT NAME:	HANFORD BIO VENT PROJECT		
Project No:	661M120343.02.1	Date:	10/16/2019
Field Report No:		Page:	1
Arrival:		Departure:	
Wood Field Rep.	Jason Gardner	WOOD PLC	John Kuiper
Weather Conditions			

wood.
7376 SW Durham Road
Portland, Oregon 97224
Phone: 503-639-3400
Fax: 503-620-7892

FIELD REPORT NOTES

Time: **Field Notes:**

10/16/2019 Tuesday sampling event

05:45 - Cal'd units

07:oo - On site.

07:30 -DOE operators Kevin and Chris on site. IH on site and screening wells.

07:43 - Started sampling on 169. Sampled 169 twice. Switched GEM units due to odd readings.

08:45 - Finished sampling on 171.

09:00 - Off site.

10:00 - Trouble shot GEM unit that had odd readings. Recal'd unit and it had same values as other unit when measuring span gasses.

Contractor's Rep. (Initials) | Continued

DAILY FIELD REPORT

PROJECT NAME:	HANFORD BIO VENT PROJECT		
Project No: 661M120343.02.1		Date: 10/17/2019	
Field Report No:		Page: 1	
Arrival:		Departure:	
Wood Field Rep.	Jason Gardner	WOOD PLC	John Kuiper
Weather Conditions			

wood.
7376 SW Durham Road
Portland, Oregon 97224
Phone: 503-639-3400
Fax: 503-620-7892

FIELD REPORT NOTES

Time: **Field Notes:**

10/17/2019 Tuesday sampling event
05:45 - Cal'd units
07:00 - On site.
07:30 -DOE operators Kevin and Chris on site. IH on site and screening wells.
07:43 - Started sampling on 169. Pulled water . Switinto unit and had to clean and dry lamp and sensor then continued with sampling.
08:48 - Finished sampling on 171.
09:00 - Off site.

Contractor's Rep. (Initials) | Continued

DAILY FIELD REPORT

PROJECT NAME:	HANFORD BIO VENT PROJECT		
Project No:	661M120343.02.1	Date:	10/22/2019
Field Report No:		Page:	1
Arrival:		Departure:	
Wood Field Rep.	Jason Gardner	WOOD PLC	John Kuiper
Weather Conditions			

wood.
7376 SW Durham Road
Portland, Oregon 97224
Phone: 503-639-3400
Fax: 503-620-7892

FIELD REPORT NOTES

Time:	Field Notes:
10/22/2019	Tuesday sampling event
06:20	- On site.
06:35	- Cal'd units
07:20	-DOE operators Kevin and Kathy on site. IH on site and screening wells.
07:38	- Started sampling on 169
08:36	- Finished sampling on 171.
09:00	- Off site.

Contractor's Rep. (Initials)

Continued

DAILY FIELD REPORT

PROJECT NAME:	HANFORD BIO VENT PROJECT		
Project No: 661M120343.02.1		Date: 10/29/2019	
Field Report No:		Page: 1	
Arrival: 7:05		Departure: 9:50	
Wood Field Rep.	Tyler Marley	Wood PLC PM	John Kuiper
Weather Conditions			

7376 SW Durham Road
Portland, Oregon 97224
Phone: 503-639-3400
Fax: 503-620-7892

FIELD REPORT NOTES

Time:	Field Notes:

10/29/2019 Tuesday sampling event

07:05 - On site.

08:15 -DOE operators Malcom and Dan on site. Operators were delayed due to morning meeting. IH on site and screening wells.

08:28 - Started sampling on 169

09:30 - Finished sampling on 171.

09:50 - Off site.

Contractor's Rep. (Initials)	Continued

DAILY FIELD REPORT

PROJECT NAME:	HANFORD BIO VENT PROJECT		
Project No:	661M120343.02.1	Date:	11/5/2019
Field Report No:		Page:	1
Arrival:	7:00	Departure:	9:10
Wood Field Rep.	Tyler Marley	Wood PLC PM	John Kuiper
Weather Conditions			

wood.
7376 SW Durham Road
Portland, Oregon 97224
Phone: 503-639-3400
Fax: 503-620-7892

FIELD REPORT NOTES

Time: **Field Notes:**

11/5/2019 Tuesday sampling event

07:00 - On site.
07:35 -DOE operators Kevin and Kathleen on site. IH on site and screening wells.
07:43 - Started sampling on 169
08:45 - Finished sampling on 171.
09:10 - Off site.

Contractor's Rep. (Initials)

Continued

DAILY FIELD REPORT

PROJECT NAME:	HANFORD BIO VENT PROJECT		
Project No:	661M120343.02.1	Date:	11/12/2019
Field Report No:		Page:	1
Arrival:	7:10	Departure:	8:35
Wood Field Rep.	Tyler Marley	Wood PLC PM	John Kuiper
Weather Conditions			

wood.
7376 SW Durham Road
Portland, Oregon 97224
Phone: 503-639-3400
Fax: 503-620-7892

FIELD REPORT NOTES

Time:	Field Notes:
11/12/2019	Tuesday sampling event
07:10	- On site.
07:15	-DOE operators Kevin and Kathleen on site. IH on site and screening wells.
07:30	- Started sampling on 169
08:25	- Finished sampling on 171.
08:35	- Off site.

Contractor's Rep. (Initials) Continued

DAILY FIELD REPORT

PROJECT NAME:	HANFORD BIO VENT PROJECT		
Project No:	661M120343.02.1	Date:	11/19/2019
Field Report No:		Page:	1
Arrival:	7:05	Departure:	9:05
Wood Field Rep.	Tyler Marley	Wood PLC PM	John Kuiper
Weather Conditions			

7376 SW Durham Road
Portland, Oregon 97224
Phone: 503-639-3400
Fax: 503-620-7892

FIELD REPORT NOTES

Time:	Field Notes:

11/19/2019 Tuesday sampling event

07:05 - On site.

07:35 -DOE operators Malcom and Dan on site. IH on site and screening wells.

07:43 - Started sampling on 169

08:46 - Finished sampling on 171.

09:05 - Off site.

Contractor's Rep. (Initials) | Continued

Field Measurements
October 2019 to November 2019 Respirometry Test
Respirometry Test Results at the Hanford 100-N Site

Monitoring Location	Date	Time	Vac During Extraction (inches H_2O)	Purge Duration (minutes)	Oxygen (%)	Carbon Dioxide (ppm)	Carbon Monoxide (ppm)	TVH (ppm)	Notes
169	10/14/2019	8:04	-250	6	20.5	0	0	4.7	Baseline sampling prior to system shut down. Purge rate at <5 cu ft/sec. Direct read collection was used for sampling. CO reading is likely due to thermal breakdown of contaminate attributed to heat from system.
169	10/14/2019	9:19	-245	4	20.8	0	0	11.5	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
169	10/14/2019	11:19	-248	4	20.1	0	-	6.1	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
169	10/14/2019	13:19	-250	4	20.4	0	-	5.8	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
169	10/15/2019	7:45	-250	4	19.9	0	1,000	1.0	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
169	10/16/2019	7:59	-250	4	19.6	1,000	1,000	12.3	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
169	10/17/2019	7:55	-240	4	19.8	1,000	0	3.6	Pulled in water to lamp and sensor. Had to dry and clean before continuing. Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
169	10/22/2019	7:42	-250	4	19	2,000	0	1.1	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
169	10/29/2019	8:28	-265	44	19.7	2,000	0	0.0	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
169	11/5/2019	7:43	-340	4	17.4	6,000	0	0.0	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
169	11/12/2019	7:30	-262	4	13.3	16,000	0	0.3	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
169	11/19/2019	7:43	-254	4	11.2	22,000	0	0.3	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.

Notes:
cu ft/sec = cubic feet per second
ppm = parts per million
TVH = total volatile hydrocarbons

Well 169

Field Measurements
October 2019 to November 2019 Respirometry Test
Respirometry Test Results at the Hanford 100-N Site

Monitoring Location	Date	Time	Vac During Extraction (inches H_2O)	Purge Duration (minutes)	Oxygen (%)	Carbon Dioxide (ppm)	Carbon Monoxide (ppm)	TVH (ppm)	Notes
167	10/14/2019	n/a	n/a	n/a	n/a	n/a	n/a	n/a	Baseline sampling prior to system shut down. Purge rate at <5 cu ft/sec. Direct read collection was used for sampling. CO reading is likely due to thermal breakdown of contaminate attributed to heat from system.
167	10/14/2019	9:25	-262	4	20.8	0	0	7.0	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
167	10/14/2019	11:25	-260	4	20.2	0	0	5.0	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
167	10/14/2019	13:25	-262	4	20.4	0	0	4.7	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
167	10/15/2019	7:46	-260	4	20.1	0	0	0.8	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
167	10/16/2019	7:54	-269	4	19.7	0	0	0.8	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
167	10/17/2019	7:57	-252	4	20.2	0	0	1.1	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
167	10/22/2019	7:48	-262	4	19.7	0	0	0.8	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
167	10/29/2019	8:34	-275	4	20.7	0	5	0.0	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
167	11/5/2019	7:50	-331	4	19.7	1000	5	0.0	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
167	11/12/2019	7:35	-262	4	17.2	3000	5	0.0	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
167	11/19/2019	7:50	-267	4	15.9	6000	4	0.0	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.

Notes:
cu ft/sec = cubic feet per second
ppm = parts per million
TVH = total volatile hydrocarbons

Well 167

Field Measurements
October 2019 to November 2019 Respirometry Test
Respirometry Test Results at the Hanford 100-N Site

Monitoring Location	Date	Time	Vac During Extraction (inches H_2O)	Purge Duration (minutes)	Oxygen (%)	Carbon Dioxide (ppm)	Carbon Monoxide (ppm)	TVH (ppm)	Notes
171	10/14/2019	9:06	-240	3min	17.8	2,400	0	24.6	Baseline sampling prior to system shut down. Purge rate at <5 cu ft/sec. Direct read collection was used for sampling. CO reading is likely due to thermal breakdown of contaminate attributed to heat from system.
171	10/14/2019	10:08	-239	3min	18.4	1,900	0	18.4	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
171	10/14/2019	12:06	-241	3min	18.2	18,000	0	15.5	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
171	10/14/2019	14:08	-257	3min	18	19,000	0	16.3	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
171	10/15/2019	8:39	-245	3min	17.9	22,000	0	5.7	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
171	10/16/2019	8:45	-243	3min	17.6	22,000	1000	20.1	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
171	10/17/2019	8:47	-238	3min	17.5	22,000	0	4.4	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
171	10/22/2019	8:36	-241	7min	17.8	20,000	1000	7.7	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
171	10/29/2019	9:27	-258	3min	15.8	35,000	0	2.5	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
171	11/5/2019	8:37	-306	3min	13.5	45,000	0	6.2	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
171	11/12/2019	8:19	-244	3min	11.7	48,000	0	5.2	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
171	11/19/2019	8:38	-249	3min	11.2	55,000	0	5.8	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.

Notes:
cu ft/sec = cubic feet per second
ppm = parts per million
TVH = total volatile hydrocarbons

Well 171

Field Measurements
October 2019 to November 2019 Respirometry Test
Respirometry Test Results at the Hanford 100-N Site

Monitoring Location	Date	Time	Vac During Extraction (inches H_2O)	Purge Duration (minutes)	Oxygen (%)	Carbon Dioxide (ppm)	Carbon Monoxide (ppm)	TVH (ppm)	Notes
172	10/14/2019	n/a	n/a	n/a	n/a	n/a	n/a	n/a	Baseline sampling prior to system shut down. Purge rate at <5 cu ft/sec. Direct read collection was used for sampling. CO reading is likely due to thermal breakdown of contaminate attributed to heat from system.
172	10/14/2019	9:36	-274	4	20.7	0	0	4.9	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
172	10/14/2019	11:32	-265	4	20.3	0	0	4.7	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
172	10/14/2019	13:33	-265	4	20.5	0	0	4.8	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
172	10/15/2019	7:59	-260	4	20.2	0	0	0.7	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
172	10/16/2019	8:08	-262	4	20.1	0	0	12.6	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
172	10/17/2019	8:10	-254	4	20.6	0	0	1.3	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
172	10/22/2019	7:56	-268	4	20	0	1000	0.7	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
172	10/29/2019	8:45	-277	4	20.8	1000	0	0.0	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
172	11/5/2019	7:59	-316	4	19.8	2000	0	0.0	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
172	11/12/2019	7:43	-264	4	17.8	3000	0	0.0	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
172	11/19/2019	7:59	-267	4	17.0	6000	0	0.0	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.

Notes:
cu ft/sec = cubic feet per second
ppm = parts per million
TVH = total volatile hydrocarbons

Well 172

Field Measurements
October 2019 to November 2019 Respirometry Test
Respirometry Test Results at the Hanford 100-N Site

Monitoring Location	Date	Time	Vac During Extraction (inches H_2O)	Purge Duration (minutes)	Oxygen (%)	Carbon Dioxide (ppm)	Carbon Monoxide (ppm)	TVH (ppm)	Notes
183	10/14/2019	9:01	-251	15	20.6	2,000	0	19.9	Baseline sampling prior to system shut down. Purge rate at <5 cu ft/sec. Direct read collection was used for sampling. CO reading is likely due to thermal breakdown of contaminate attributed to heat from system.
183	10/14/2019	10:03	-251	15	20.8	2,000	0	17.8	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
183	10/14/2019	12:00	-253	15	20.3	1,000	0	14.8	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
183	10/14/2019	14:02	-264	15	20.3	2,000	0	17.2	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
183	10/15/2019	8:31	-248	15	20	3,000	1000	5.9	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
183	10/16/2019	8:27	-255	15	19.8	4,000	1000	19.4	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
183	10/17/2019	8:38	-247	15	19.9	5,000	1000	4.7	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
183	10/22/2019	8:25	-255	15	18.8	9,000	0	5.8	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
183	10/29/2019	9:06	-268	15	19.4	14,000	0	0.8	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
183	11/5/2019	8:19	-264	15	15.9	30,000	0	5.5	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
183	11/12/2019	8:01	-253	15	15.0	30,000	0	3.0	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
183	11/19/2019	8:18	-258	15	15.0	34,000	0	2.2	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.

Notes:
cu ft/sec = cubic feet per second
ppm = parts per million
TVH = total volatile hydrocarbons

Well 183

Field Measurements
October 2019 to November 2019 Respirometry Test
Respirometry Test Results at the Hanford 100-N Site

Monitoring Location	Date	Time	Vac During Extraction (inches H_2O)	Purge Duration (minutes)	Oxygen (%)	Carbon Dioxide (ppm)	Carbon Monoxide (ppm)	TVH (ppm)	Notes
18	10/14/2019	8:27	-243	15	20.9	0	0	10.9	Baseline sampling prior to system shut down. Purge rate at <5 cu ft/sec. Direct read collection was used for sampling. CO reading is likely due to thermal breakdown of contaminate attributed to heat from system.
18	10/14/2019	9:47	-242	10	20.9	0	0	12.7	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
18	10/14/2019	11:43	-246	10	20.4	0	0	10.4	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
18	10/14/2019	13:45	-252	10	20.5	0	0	9.1	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
18	10/15/2019	8:11	-243	10	20.6	1000	0	1.4	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
18	10/16/2019	8:20	-248	10	20.4	1000	0	14.7	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
18	10/17/2019	8:15	-240	10	20.7	1000	0	1.7	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
18	10/22/2019	8:07	-243	10	20.5	1000	0	1.3	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
18	10/29/2019	8:53	-262	10	22.0	0	0	0.0	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
18	11/5/2019	8:05	-279	10	21.6	1000	0	0.0	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
18	11/12/2019	7:49	-249	10	20.6	1000	0	0.0	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.
18	11/19/2019	8:06	-251	10	21.5	1000	0	0.0	Purge rate at <5 cu ft/sec. Direct read collection was used for sampling.

Notes:
cu ft/sec = cubic feet per second
ppm = parts per million
TVH = total volatile hydrocarbons

Well 18

Attachment 2
Instrument Calibration Sheets

GAS METERS	MODEL AND SERIAL NUMBERS	DATES USED
Pimary O2/CO2 meter	GEM 2000 plus s/n 1109736	Oct 14 thru Nov 19, 2019
Back up O2/CO2 meter	GEM 2000 plus s/n 1117622	not used to date.
Primary VOC meter	Mini Rae- 2000 s/n 110-003625	Oct 14 thru Nov 19, 2019
Back up VOC meter	n/a	not used to date.

Gas detector calibration

Project Name: **Hanford 100N Bio-Vent** Project Number: 661M120343.02.1

Date / Time: 10/16/2019 5:45:00 AM Completed By: Jason Gardner

Instrument name(s) GEM 2000 plus and Mini Rae 2000

Calibration Method: Zero gas (ambient air) readings and then span gases

Equipment owner: ARGUS / HAZCO

Span gas flow control: 0.5 L/min

Instrument	Date	Warm up time	Gas	PID readings	Span Readings	Final readings
GEM 2000 plus s/n 1109736	10/16/2019	30 min	zero air	0.0	20.9%	20.9%
GEM 2000 plus s/n 1109736	10/16/2019	30 min	100 ppm CO	na	100	100
GEM 2000 plus s/n 1109736	10/16/2019	30 min	5000 ppm CO2	na	5000	5000
GEM 2000 plus s/n 1117622	10/16/2019	30 min	zero air	0	20.9%	20.9%
GEM 2000 plus s/n 1117622	10/16/2019	30 min	100 ppm CO	na	100	100
GEM 2000 plus s/n 1117622	10/16/2019	30 min	5000 ppm CO2	n/a	n/a	n/a
Mini Rae 2000 s/n 110-003625	10/16/2019	30 min	100 ppm IsoB	99.6	n/a	n/a
n/a	n/a	n/a	n/a	n/a	n/a	n/a

Notes:
This calibration is for the 10/16/2019 sample event.

Gas detector calibration

Project Name: **Hanford 100N Bio-Vent** Project Number: 661M120343.02.1

Date / Time: 10/17/2019 5:45:00 AM Completed By: Jason Gardner

Instrument name(s) GEM 2000 plus and Mini Rae 2000

Calibration Method: Zero gas (ambient air) readings and then span gases

Equipment owner: ARGUS / HAZCO

Span gas flow control: 0.5 L/min

Instrument	Date	Warm up time	Gas	PID readings	Span Readings	Final readings
GEM 2000 plus s/n 1109736	10/17/2019	30 min	zero air	0.0	20.9%	20.9%
GEM 2000 plus s/n 1109736	10/17/2019	30 min	100 ppm CO	na	100	100
GEM 2000 plus s/n 1109736	10/17/2019	30 min	5000 ppm CO2	na	5000	5000
GEM 2000 plus s/n 1117622	10/17/2019	30 min	zero air	0	20.9%	20.9%
GEM 2000 plus s/n 1117622	10/17/2019	30 min	100 ppm CO	na	100	100
GEM 2000 plus s/n 1117622	10/17/2019	30 min	5000 ppm CO2	n/a	n/a	n/a
Mini Rae 2000 s/n 110-003625	10/17/2019	30 min	100 ppm IsoB	99.9	n/a	n/a
n/a	n/a	n/a	n/a	n/a	n/a	n/a

Notes:
This calibration is for the 10/17/2019 sample event.

Gas detector calibration

Project Name: **Hanford 100N Bio-Vent**

Project Number: 661M120343.02.1

Date / Time: 10/22/2019 6:35:00 AM

Completed By: Jason Gardner

Instrument name(s): GEM 2000 plus and Mini Rae 2000

Calibration Method: Zero gas (ambient air) readings and then span gases

Equipment owner: ARGUS / HAZCO

Span gas flow control: 0.5 L/min

Instrument	Date	Warm up time	Gas	PID readings	Span Readings	Final readings
GEM 2000 plus s/n 1109736	10/22/2019	30 min	zero air	0.0	20.9%	20.9%
GEM 2000 plus s/n 1109736	10/22/2019	30 min	100 ppm CO	na	100	100
GEM 2000 plus s/n 1109736	10/22/2019	30 min	5000 ppm CO2	na	5000	5000
GEM 2000 plus s/n 1117622	10/22/2019	30 min	zero air	0	20.9%	20.9%
GEM 2000 plus s/n 1117622	10/22/2019	30 min	100 ppm CO	na	100	100
GEM 2000 plus s/n 1117622	10/22/2019	30 min	5000 ppm CO2	n/a	n/a	n/a
Mini Rae 2000 s/n 110-003625	10/22/2019	30 min	100 ppm IsoB	99.1	n/a	n/a
n/a	n/a	n/a	n/a	n/a	n/a	n/a

Notes:
This calibration is for the 10/22/2019 sample event.

Gas detector calibration

Project Name: **Hanford 100N Bio-Vent** Project Number: 661M120343.02.1

Date / Time: 10/28/2019 5:05:00 PM Completed By: Tyler Marley

Instrument name(s) GEM 2000 plus and Mini Rae 2000

Calibration Method: Zero gas (ambient air) readings and then span gases

Equipment owner: ARGUS / HAZCO

Span gas flow control: 0.5 L/min

Instrument	Date	Warm up time	Gas	PID readings	Span Readings	Final readings
GEM 2000 plus s/n 1109736	10/28/2019	30 min	zero air	n/a	20.9%	20.9%
GEM 2000 plus s/n 1109736	10/28/2019	30 min	100 ppm CO	n/a	100	100
GEM 2000 plus s/n 1109736	10/28/2019	30 min	5000 ppm CO2	n/a	5000	5000
GEM 2000 plus s/n 1117622	10/28/2019	30 min	zero air	n/a	20.9%	20.9%
GEM 2000 plus s/n 1117622	10/28/2019	30 min	100 ppm CO	n/a	100	100
GEM 2000 plus s/n 1117622	10/28/2019	30 min	5000 ppm CO2	n/a	5000	5000
Mini Rae 2000 s/n 110-003625	10/28/2019	30 min	zero air	0.00	n/a	n/a
Mini Rae 2000 s/n 110-003625	10/28/2019	30 min	100 ppm IsoB	100	n/a	n/a

Notes:
This calibration is for the 10/29/2019 sample event.

Gas detector calibration

Project Name: **Hanford 100N Bio-Vent** Project Number: 661M120343.02.1

Date / Time: 11/4/2019 6:30:00 PM Completed By: Tyler Marley

Instrument name(s) GEM 2000 plus and Mini Rae 2000

Calibration Method: Zero gas (ambient air) readings and then span gases

Equipment owner: ARGUS / HAZCO

Span gas flow control: 0.5 L/min

Instrument	Date	Warm up time	Gas	PID readings	Span Readings	Final readings
GEM 2000 plus s/n 1109736	11/4/2019	30 min	zero air	n/a	20.9%	20.9%
GEM 2000 plus s/n 1109736	11/4/2019	30 min	100 ppm CO	n/a	100	100
GEM 2000 plus s/n 1109736	11/4/2019	30 min	5000 ppm CO2	n/a	5000	5000
GEM 2000 plus s/n 1117622	11/4/2019	30 min	zero air	n/a	20.9%	20.9%
GEM 2000 plus s/n 1117622	11/4/2019	30 min	100 ppm CO	n/a	100	99
GEM 2000 plus s/n 1117622	11/4/2019	30 min	5000 ppm CO2	n/a	5000	5000
Mini Rae 2000 s/n 110-003625	11/4/2019	30 min	zero air	0.00	n/a	n/a
Mini Rae 2000 s/n 110-003625	11/4/2019	30 min	100 ppm IsoB	100	n/a	n/a

Notes:
This calibration is for the 11/5/2019 sample event.

Gas detector calibration

Project Name: **Hanford 100N Bio-Vent** Project Number: 661M120343.02.1

Date / Time: 11/11/2019 10:00:00 PM Completed By: Tyler Marley

Instrument name(s) GEM 2000 plus and Mini Rae 2000

Calibration Method: Zero gas (ambient air) readings and then span gases

Equipment owner: ARGUS / HAZCO

Span gas flow control: 0.5 L/min

Instrument	Date	Warm up time	Gas	PID readings	Span Readings	Final readings
GEM 2000 plus s/n 1109736	11/11/2019	30 min	zero air	n/a	20.9%	20.9%
GEM 2000 plus s/n 1109736	11/11/2019	30 min	100 ppm CO	n/a	100	100
GEM 2000 plus s/n 1109736	11/11/2019	30 min	5000 ppm CO2	n/a	5000	5000
GEM 2000 plus s/n 1117622	11/11/2019	30 min	zero air	n/a	20.9%	20.9%
GEM 2000 plus s/n 1117622	11/11/2019	30 min	100 ppm CO	n/a	100	100
GEM 2000 plus s/n 1117622	11/11/2019	30 min	5000 ppm CO2	n/a	5000	5000
Mini Rae 2000 s/n 110-003625	11/11/2019	30 min	zero air	0.00	n/a	n/a
Mini Rae 2000 s/n 110-003625	11/11/2019	30 min	100 ppm IsoB	101	n/a	n/a

Notes:
This calibration is for the 11/12/2019 sample event.

Gas detector calibration

Project Name: **Hanford 100N Bio-Vent** Project Number: 661M120343.02.1

Date / Time: 11/18/2019 10:00:00 PM Completed By: Tyler Marley

Instrument name(s) GEM 2000 plus and Mini Rae 2000

Calibration Method: Zero gas (ambient air) readings and then span gases

Equipment owner: ARGUS / HAZCO

Span gas flow control: 0.5 L/min

Instrument	Date	Warm up time	Gas	PID readings	Span Readings	Final readings
GEM 2000 plus s/n 1109736	11/18/2019	30 min	zero air	n/a	20.9%	20.9%
GEM 2000 plus s/n 1109736	11/18/2019	30 min	100 ppm CO	n/a	100	100
GEM 2000 plus s/n 1109736	11/18/2019	30 min	5000 ppm CO2	n/a	5000	5000
GEM 2000 plus s/n 1117622	11/18/2019	30 min	zero air	n/a	20.9%	20.9%
GEM 2000 plus s/n 1117622	11/18/2019	30 min	100 ppm CO	n/a	100	100
GEM 2000 plus s/n 1117622	11/18/2019	30 min	5000 ppm CO2	n/a	5000	5000
Mini Rae 2000 s/n 110-003625	11/18/2019	30 min	zero air	0.00	n/a	n/a
Mini Rae 2000 s/n 110-003625	11/18/2019	30 min	100 ppm IsoB	98.9	n/a	n/a

Notes:
This calibration is for the 11/19/2019 sample event.

Attachment 3
Design Worksheet for Oxygen Utilization and Biodegradation Rates

DESIGN WORKSHEET

Client:	CHPRC - JACOBS	Date:	18-May-20
Project:	Hanford 100-N Biovent	Project Number:	661M120343.02.01
Data For:	Oct to Nov 2019 Respiration Test	Prepared by:	J. Spadaro
		Reviewed by:	J. Kuiper

An in-situ respiration test was conducted at the Hanford Site 100-N from June 2017 to July 2017. Data collected from the field test is used to calculate oxygen utilization (k_o) and biodegradation rates (K_b). Calculations and results are presented below.

OXYGEN UTILIZATION RATE CALCULATION

Oxygen utilization rates (%/hour) are derived from the slope of the linear portion of the line when percent oxygen (y-axis) measured in the soil is plotted against time in hours (x-axis). See attached for data plots.

Location	O_2 Utilization (%/hour)	k_o O_2 Utilization (%/day)	R^2 value for linear curve fit
199-N-167	0.0042	0.10	0.721
199-N-169	0.0094	0.23	0.867
199-N-171	0.0085	0.20	0.964
199-N-172	0.0034	0.08	0.740
199-N-183	0.0067	0.16	0.915
199-N-18	--	--	--

Oxygen readings between 19% and 22% represent essentially atmospheric conditions and amount to insignificant oxygen depletion. Biodegradation rates are only calculated for wells with significant oxygen depletion (below 19%); others are marked as --.

DESIGN WORKSHEET

Client:	CHPRC - JACOBS	Date:	18-May-20
Project:	Hanford 100-N Biovent	Project Number:	661M120343.02.01
Data For:	Oct to Nov 2019 Respiration Test	Prepared by:	J. Spadaro
		Reviewed by:	J. Kuiper

BIODEGRADATION RATE CALCULATION

Biodegradation rates (K_b) are calculated for each of the monitoring points.

The Kb values below are calculated using updated site-specific soil bulk density and moisture content soil parameters, based on measured values from samples collected in the screen interval of 199-N-183. The biodegradation calculations for the 2010 and 2012 respiration test data have also been updated with these site-specific soil parameters.

Equation for biodegradation rate calculation:

$$K_b = \frac{-k_o \, \theta_a \, \rho_{o2} \, C \times 0.01}{\rho_k}$$

Equation adapted from Parsons. 2004. Procedures for Conducting Bioventing Pilot Tests and Long-Term Monitoring of Bioventing Systems, prepared for the Air Force Center for Environmental Excellence, Brooks Air Force Base, San Antonio, Texas. May.

Parameters using site-specific measured values from 199-N-183 soil samples

θ_a =	0.32	cm^3 gas/cm^3 soil	Gas-filled pore space (volumetric content at the vapor phase); where $\theta_a = \theta - \theta_w$
ρ_{O2} =	1,378	mg/L	Density of oxygen; assuming 10°C (50°F) soil temperature reference value from United States Environmental Protection Agency. 1995. Manual, Bioventing Principles and Practice, Volume II: Bioventing Design. Office of Research and Development. EPA/625/XXX/001. September.
C =	0.29	---	Mass ratio of hydrocarbons to oxygen required for mineralization; calculated assuming diesel as $C_{10}H_{20}$ and stoichiometric relationship of $C_{10}H_{20} + 15O_2$ => $10CO_2 + 10H_2O$
ρ_k =	1.736	g/cm^3	Soil bulk density; measured value from 199-N-183, average of bulk densities from samples 212 and 215, at depth intervals of 53 to 55 feet and 63 to 65 feet bgs, respectively.
θ =	0.34	cm^3/cm^3	Total porosity; where $\theta = 1 - \rho_k/\rho_T$
θ_w =	0.02	cm^3/cm^3	Water filled porosity; where $\theta_w = M*\rho_k/\rho_T$
ρ_T =	2.65	g/cm^3	Soil mineral density; assumed value
M =	0.0313	g moisture /g soil	3.13% moisture content; measured value from 199-N-183, average of percent moisture from samples 212, 214, and 215

Note: Subsurface soil temperature is assumed to be constant year-round and temperature adjustments of oxygen utilization rates were not conducted. If temperatures are warmer in the summer months then oxygen utilization rates are expected to increase. Temperature changes are extremely unlikely for the deep well locations.

DESIGN WORKSHEET

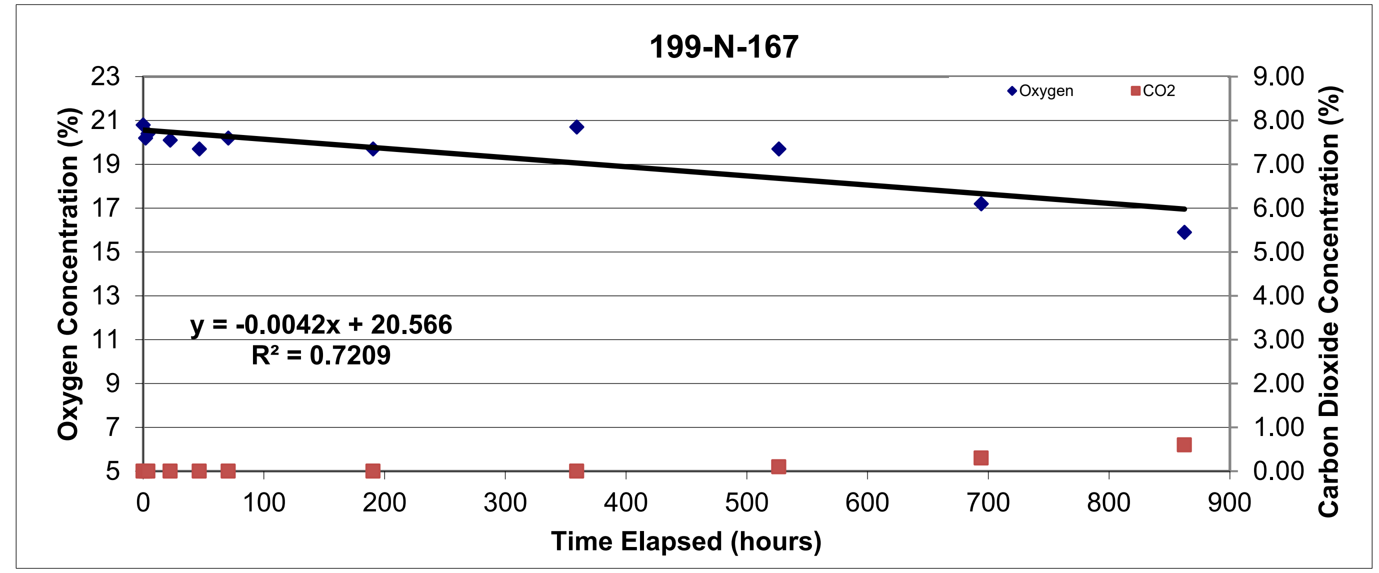
Client: CHPRC - JACOBS
Project: Hanford 100-N Biovent
Data For: Oct to Nov 2019 Respiration Test

Date: 18-May-20
Project Number: 661M120343.02.01
Prepared by: J. Spadaro
Reviewed by: J. Kuiper

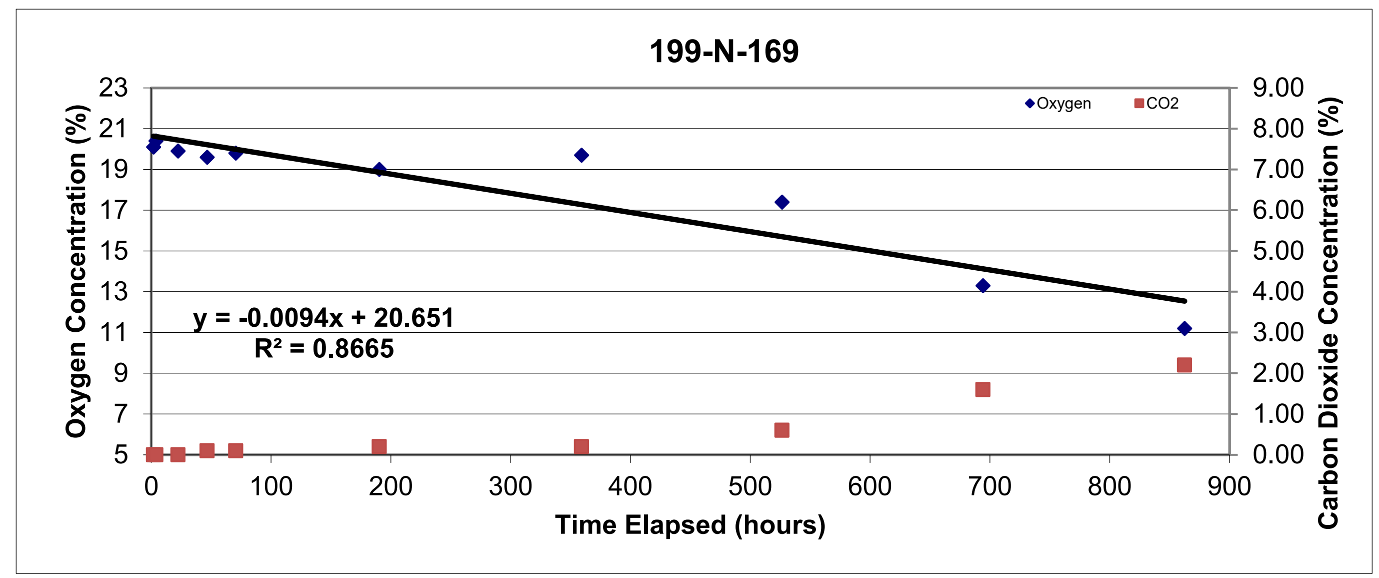
Location	Parameter	Nov-19	Nov-17	Jul-17	Dec-16	Aug-16	Aug-15	Jan-15	Units	Notes
199-N-167	K_o =	0.10	0.18	0.11	0.08	0.09	0.07	0.07	%/day	Oxygen utilization rate; calculated value from respiration test
	K_b =	**-0.08**	**-0.14**	**-0.08**	**-0.06**	**-0.06**	**-0.05**	**-0.05**	mg/Kg-day	Biodegradation rate; calculated value
199-N-169	K_o =	0.23	0.25	0.14	0.18	0.09	0.16	0.3	%/day	Oxygen utilization rate; calculated value from respiration test
	K_b =	**-0.17**	**-0.19**	**-0.11**	**-0.14**	**-0.07**	**-0.12**	**-0.23**	mg/Kg-day	Biodegradation rate; calculated value
199-N-171	K_o =	0.20	0.15	0.09	0.29	0.11	0.18	0.3	%/day	Oxygen utilization rate; calculated value from respiration test
	K_b =	**-0.15**	**-0.11**	**-0.07**	**-0.22**	**-0.08**	**-0.14**	**-0.23**	mg/Kg-day	Biodegradation rate; calculated value
199-N-172	K_o =	0.08	0.09	0.10	0.04	0.03	0.05	0.07	%/day	Oxygen utilization rate; calculated value from respiration test
	K_b =	**-0.06**	**-0.07**	**-0.08**	**-0.03**	**-0.02**	**-0.04**	**-0.05**	mg/Kg-day	Biodegradation rate; calculated value
199-N-183	K_o =	0.16	0.08	0.02	--	--	--	--	%/day	Oxygen utilization rate; calculated value from respiration test
	K_b =	**-0.12**	**-0.06**	**-0.02**	**--**	**--**	**--**	**--**	mg/Kg-day	Biodegradation rate; calculated value
199-N-18	K_o =	--	--	--	--	--	--	--	%/day	Oxygen utilization rate; calculated value from respiration test
	K_b =	**--**	**--**	**--**	**--**	**--**	**--**	**--**	mg/Kg-day	Biodegradation rate; calculated value

Oxygen Utilization and Carbon Dioxide Generation Plots
October to November 2019 Respirometry Test

199-N-167 Air Injection Well (No Baseline)						
Date	Time		Elapsed Time (hr:min:sec)	Elapsed Time (hours)	Oxygen	CO_2
					%	%
10/14/2019	9:25	10/14/2019 9:25	0:00:00	0.00	20.8	0.00
10/14/2019	11:25	10/14/2019 11:25	2:00:00	2.00	20.2	0.00
10/14/2019	13:25	10/14/2019 13:25	4:00:00	4.00	20.4	0.00
10/15/2019	7:46	10/15/2019 7:46	22:21:00	22.35	20.1	0.00
10/16/2019	7:54	10/16/2019 7:54	46:29:00	46.48	19.7	0.00
10/17/2019	7:57	10/17/2019 7:57	70:32:00	70.53	20.2	0.00
10/22/2019	7:48	10/22/2019 7:48	190:23:00	190.38	19.7	0.00
10/29/2019	8:34	10/29/2019 8:34	359:09:00	359.15	20.7	0.00
11/5/2019	7:50	11/5/2019 7:50	526:25:00	526.42	19.7	0.10
11/12/2019	7:35	11/12/2019 7:35	694:10:00	694.17	17.2	0.30
11/19/2019	7:50	11/19/2019 7:50	862:25:00	862.42	15.9	0.60

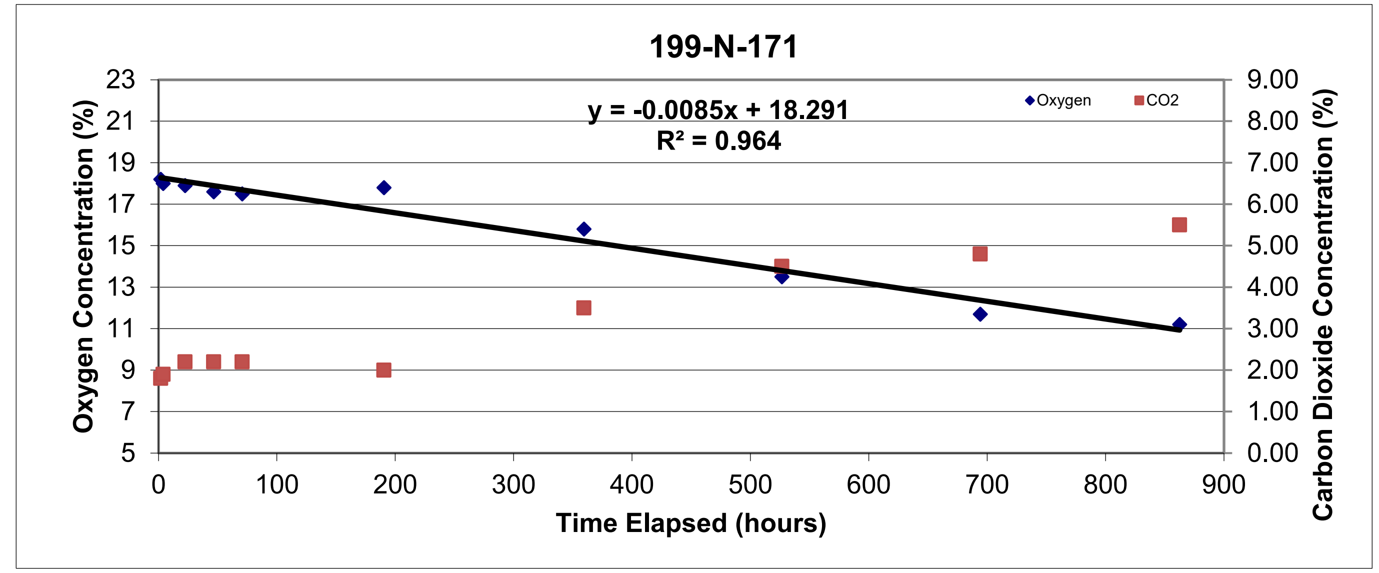


199-N-169						
Date	Time		Elapsed Time (hr:min:sec)	Elapsed Time (hours)	Oxygen	CO_2
					%	%
10/14/2019	8:04	10/14/2019 8:04	Baseline	--	20.5	0.00
10/14/2019	9:19	10/14/2019 9:19	0:00:00	0.00	20.8	0.00
10/14/2019	11:19	10/14/2019 11:19	2:00:00	2.00	20.1	0.00
10/14/2019	13:19	10/14/2019 13:19	4:00:00	4.00	20.4	0.00
10/15/2019	7:45	10/15/2019 7:45	22:26:00	22.43	19.9	0.00
10/16/2019	7:59	10/16/2019 7:59	46:40:00	46.67	19.6	0.10
10/17/2019	7:55	10/17/2019 7:55	70:36:00	70.60	19.8	0.10
10/22/2019	7:42	10/22/2019 7:42	190:23:00	190.38	19	0.20
10/29/2019	8:28	10/29/2019 8:28	359:09:00	359.15	19.7	0.20
11/5/2019	7:43	11/5/2019 7:43	526:24:00	526.40	17.4	0.60
11/12/2019	7:30	11/12/2019 7:30	694:11:00	694.18	13.3	1.60
11/19/2019	7:43	11/19/2019 7:43	862:24:00	862.40	11.2	2.20

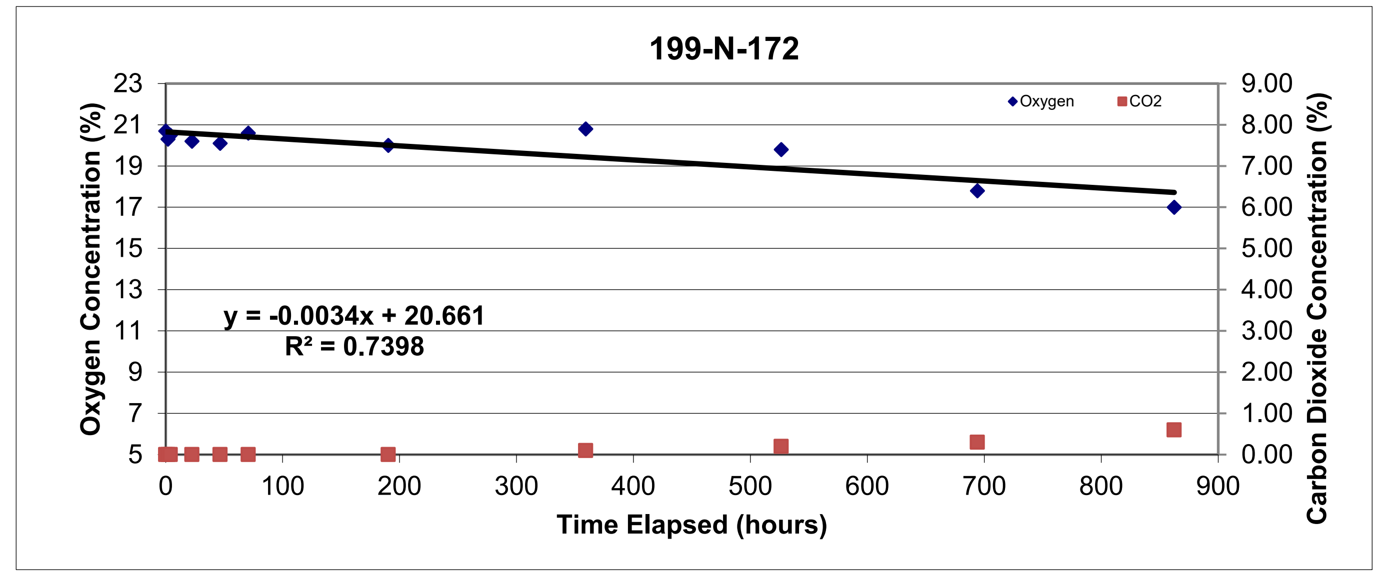


Oxygen Utilization and Carbon Dioxide Generation Plots
October to November 2019 Respirometry Test

199-N-171						
Date	Time		Elapsed Time (hr:min:sec)	Elapsed Time (hours)	Oxygen	CO_2
					%	%
10/14/2019	9:06	10/14/2019 9:06	Baseline	--	17.8	0.24
10/14/2019	10:08	10/14/2019 10:08	0:00:00	0	18.4	0.19
10/14/2019	12:06	10/14/2019 12:06	1:58:00	1.97	18.2	1.80
10/14/2019	14:08	10/14/2019 14:08	4:00:00	4.0	18	1.90
10/15/2019	8:39	10/15/2019 8:39	22:31:00	22.5	17.9	2.20
10/16/2019	8:45	10/16/2019 8:45	46:37:00	46.6	17.6	2.20
10/17/2019	8:47	10/17/2019 8:47	70:39:00	70.6	17.5	2.20
10/22/2019	8:36	10/22/2019 8:36	190:28:00	190.5	17.8	2.00
10/29/2019	9:27	10/29/2019 9:27	359:19:00	359.3	15.8	3.50
11/5/2019	8:37	11/5/2019 8:37	526:29:00	526.5	13.5	4.50
11/12/2019	8:19	11/12/2019 8:19	694:11:00	694.2	11.7	4.80
11/19/2019	8:38	11/19/2019 8:38	862:30:00	862.5	11.2	5.50

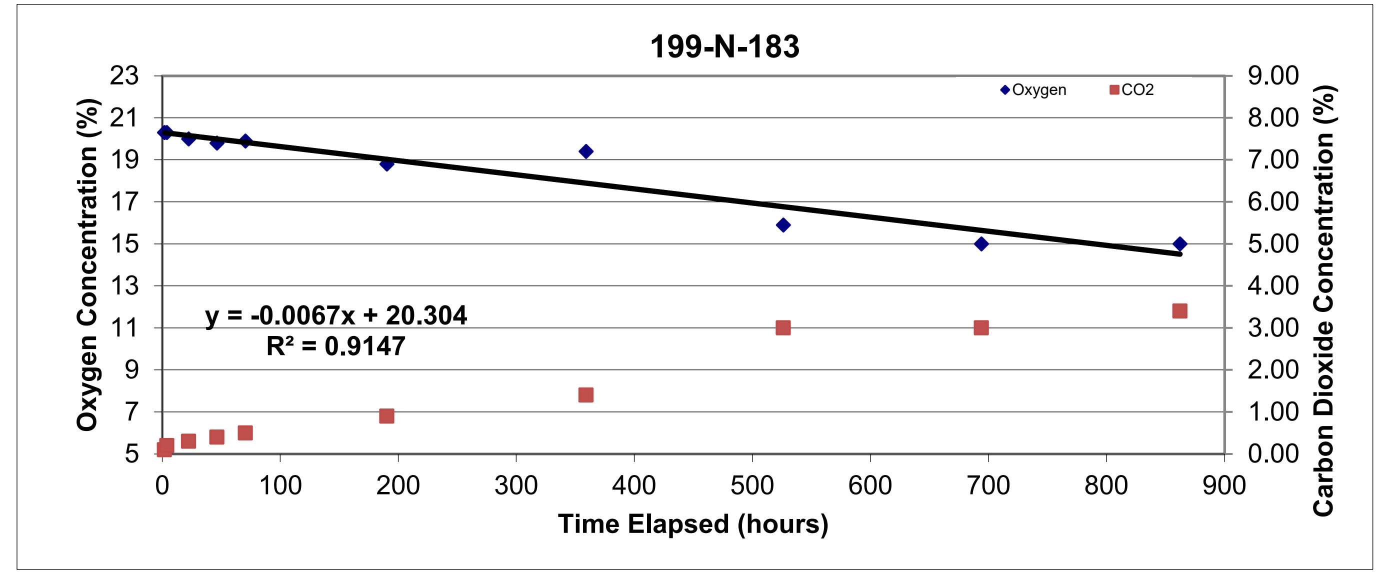


199-N-172 Air Injection Well (No Baseline)						
Date	Time		Elapsed Time (hr:min:sec)	Elapsed Time (hours)	Oxygen	CO_2
					%	%
10/14/2019	9:36	10/14/2019 9:36	0:00:00	0.00	20.7	0.00
10/14/2019	11:32	10/14/2019 11:32	1:56:00	1.93	20.3	0.00
10/14/2019	13:33	10/14/2019 13:33	3:57:00	3.95	20.5	0.00
10/15/2019	7:59	10/15/2019 7:59	22:23:00	22.38	20.2	0.00
10/16/2019	8:08	10/16/2019 8:08	46:32:00	46.53	20.1	0.00
10/17/2019	8:10	10/17/2019 8:10	70:34:00	70.57	20.6	0.00
10/22/2019	7:56	10/22/2019 7:56	190:20:00	190.33	20	0.00
10/29/2019	8:45	10/29/2019 8:45	359:09:00	359.15	20.8	0.10
11/5/2019	7:59	11/5/2019 7:59	526:23:00	526.38	19.8	0.20
11/12/2019	7:43	11/12/2019 7:43	694:07:00	694.12	17.8	0.30
11/19/2019	7:59	11/19/2019 7:59	862:23:00	862.38	17.0	0.60

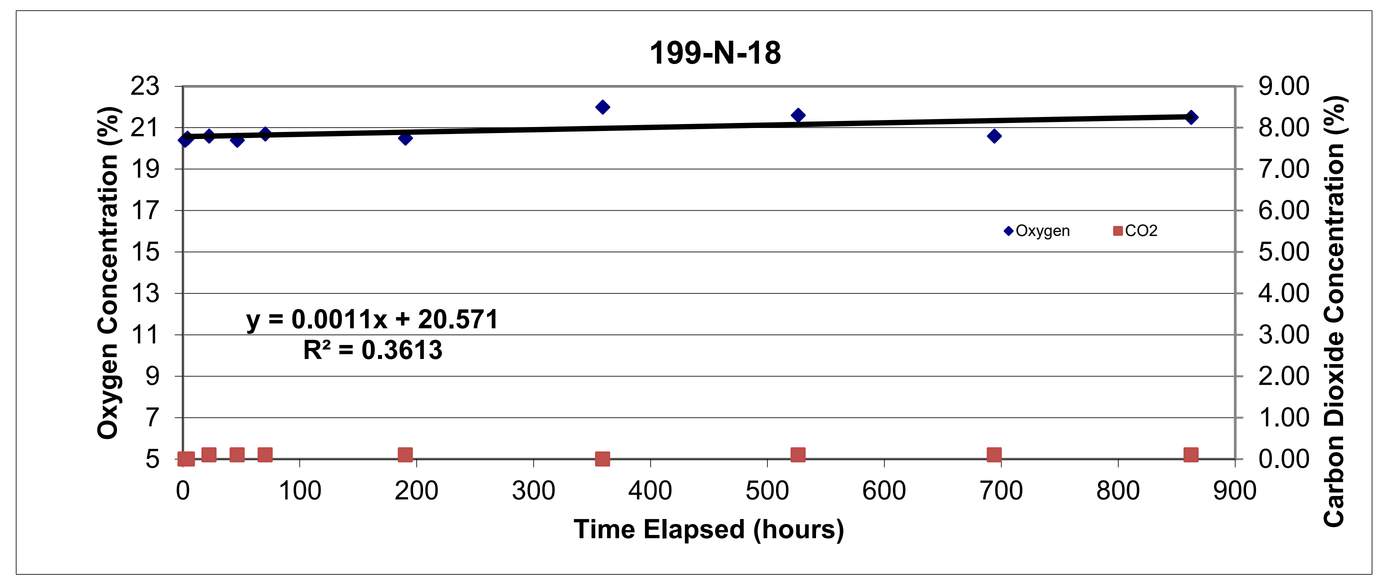


Oxygen Utilization and Carbon Dioxide Generation Plots
October to November 2019 Respirometry Test

199-N-183						
Date	Time		Elapsed Time (hr:min:sec)	Elapsed Time (hours)	Oxygen %	CO_2 %
10/14/2019	9:01	10/14/2019 9:01	Baseline	--	20.6	0.20
10/14/2019	10:03	10/14/2019 10:03	0:00:00	0	20.8	0.20
10/14/2019	12:00	10/14/2019 12:00	1:57:00	1.95	20.3	0.10
10/14/2019	14:02	10/14/2019 14:02	3:59:00	3.98	20.3	0.20
10/15/2019	8:31	10/15/2019 8:31	22:28:00	22.47	20	0.30
10/16/2019	8:27	10/16/2019 8:27	46:24:00	46.40	19.8	0.40
10/17/2019	8:38	10/17/2019 8:38	70:35:00	70.58	19.9	0.50
10/22/2019	8:25	10/22/2019 8:25	190:22:00	190.37	18.8	0.90
10/29/2019	9:06	10/29/2019 9:06	359:03:00	359.05	19.4	1.40
11/5/2019	8:19	11/5/2019 8:19	526:16:00	526.27	15.9	3.00
11/12/2019	8:01	11/12/2019 8:01	693:58:00	693.97	15.0	3.00
11/19/2019	8:18	11/19/2019 8:18	862:15:00	862.25	15.0	3.40



199-N-18						
Date	Time		Elapsed Time (hr:min:sec)	Elapsed Time (hours)	Oxygen %	CO_2 %
10/14/2019	8:27	10/14/2019 8:27	Baseline	--	20.9	0.00
10/14/2019	9:47	10/14/2019 9:47	0:00:00	0	20.9	0.00
10/14/2019	11:43	10/14/2019 11:43	1:56:00	1.93	20.4	0.00
10/14/2019	13:45	10/14/2019 13:45	3:58:00	3.97	20.5	0.00
10/15/2019	8:11	10/15/2019 8:11	22:24:00	22.40	20.6	0.10
10/16/2019	8:20	10/16/2019 8:20	46:33:00	46.55	20.4	0.10
10/17/2019	8:15	10/17/2019 8:15	70:28:00	70.47	20.7	0.10
10/22/2019	8:07	10/22/2019 8:07	190:20:00	190.33	20.5	0.10
10/29/2019	8:53	10/29/2019 8:53	359:06:00	359.10	22.0	0.00
11/5/2019	8:05	11/5/2019 8:05	526:18:00	526.30	21.6	0.10
11/12/2019	7:49	11/12/2019 7:49	694:02:00	694.03	20.6	0.10
11/19/2019	8:06	11/19/2019 8:06	862:19:00	862.32	21.5	0.10



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Attachment 4
Groundwater Data Generated during November 2019 Sampling Event
(Prepared by Jacobs)

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Groundwater Data Generated during November 2019 Sampling Event (Prepared by Jacobs)

Year-Month	(Multiple Items)

Sum of STD_VALUE_RPTD	Column Labels													
Row Labels	**199-N-167**	**199-N-169**	**199-N-171**	**199-N-173**	**199-N-18**	**199-N-183**	**199-N-19**	**199-N-3**	**199-N-377**	**199-N-56**	**199-N-96A**	**C6132**	**C6135**	**N116mArray-0A**
1664A_OILGREASE	**1330**	**1350**	**1940**	**1460**	**5150**	**1810**	**1430**	**2820**	**2640**	**1320**	**1320**			
Oil and grease (ug/L)	1330	1350	1940	1460	5150	1810	1430	2820	2640	1320	1320			
2320_ALKALINITY	**233000**	**287000**	**586000**	**308000**	**747000**	**856000**	**160000**	**481000**	**310000**	**320000**	**163000**			
Alkalinity (ug/L)	233000	287000	586000	308000	747000	856000	160000	481000	310000	320000	163000			
300.0_ANIONS_IC	**369287**							**266938**		**274088**		**234707**		
Bromide (ug/L)	190							310		360				
Chloride (ug/L)	76000							34000		69000		58000		
Fluoride (ug/L)	67							52		52		110		
Nitrate (ug/L)	70800							102000		84100		66400		
Nitrite (ug/L)	1310							46		46		197		
Phosphate (ug/L)	920							530		530				
Sulfate (ug/L)	220000							130000		120000		110000		
360.1_OXYGEN_FLD	**280**	**160**	**60**	**830**	**720**	**50**	**3140**	**33800**	**8800**	**679000**	**6010**	**5060**	**5310**	**3690**
Dissolved oxygen (ug/L)	280	160	60	830	720	50	3140	33800	8800	679000	6010	5060	5310	3690
6010_METALS_ICP	**484669.2**		**471240.1**	**477351.27**	**530731.1**	**1963360.3**	**195510.8**	**529215.59**	**794534.44**	**239467.3**	**187309.3**	**300383.71**	**69865**	**162645.72**
Boron (ug/L)	72		36	30.4	30.5	144	35.5	68.5	68.5	36	72	46.5	50	144
Calcium (ug/L)	320000		350000	319000	333000	1440000	92300	386000	428000	160000	107000	140000	48600	104000
Iron (ug/L)	71		3200	68	58400	24500	58.2	171	146.6	30	130	60	457	6200
Magnesium (ug/L)	56000		55000	56800	76400	246000	19300	67800	84700	25000	21000	28600	7890	22900
Phosphorus (ug/L)	117			120		500			251.7		4200			
Potassium (ug/L)	16400		10000	12830	7590	39200	6410	11770	26250	7400	5900	11370	3170	9200
Sodium (ug/L)	92000		53000	88500	55300	213000	77400	63400	255100	47000	49000	120300	9690	20200
Vanadium (ug/L)	9.2		4.1	2.87	10.6	16.3	7.1	6.09	17.64	1.3	7.3	7.21	8	1.72
6020_METALS_ICPMS	**2633.8531**		**7290.8881**	**8552.84**	**16510.6**	**34914.5054**	**656.22**	**2275.225**	**2804.655**	**814.0261**	**602.7142**	**1108.7**	**7452**	**19566.3451**
Aluminum (ug/L)	20		210	40	100	43	24.4	57.9	83.5	12	79	49.7	40	42
Antimony (ug/L)	0.52		0.14	2	10	0.84	2	3	4	0.12	0.75	4	4	0.48
Arsenic (ug/L)	1.56		3.3	4.25	20	14.2	4	6	11.92	0.39	4.2	8	8	17.1
Barium (ug/L)	129		190	416	308	1270	61.4	390	256	120	82	167.9	68.2	180
Beryllium (ug/L)	0.108		0.054	0.4	1	0.216	0.2	0.6	0.8	0.054	0.108	0.4	0.4	0.216
Cadmium (ug/L)	0.173		0.39	0.6	1	0.566	0.2	0.9	1.2	0.083	0.166	0.4	0.4	0.332
Chromium (ug/L)	3.03		1.2	6	20	3.66	5.9	15.13	30.19	7.9	20.9	15.5	19.8	1.84
Cobalt (ug/L)	2.9		1.6	2.31	24.9	8.9	0.9	0.9	1.505	0.11	0.24	1.8	1.8	4.6
Copper (ug/L)	4.1		11	6.08	24.8	12.07	1.9	4.963	1.613	0.4	2.6	3.8	3.8	1.28
Lead (ug/L)	0.158		2.4	1	5	4.52	1	1.5	2	0.079	0.158	2	2	0.316
Manganese (ug/L)	1280		5600	6200	13700	28200	5	25.9	11.61	1.2	12.36	16	7030	18700
Molybdenum (ug/L)	3.2		3.2	2.54	10	17.1	2	1.702	4.007	0.4	1.95	4	4	3.31
Nickel (ug/L)	4.5		2	28.5	103	15.9	2	8.4	155	1.4	1.88	4	4	3.68
Selenium (ug/L)	2.7		0.99	4	10	3.93	2.1	6	8	1.9	1.45	4.8	4	2.6
Silver (ug/L)	0.058		0.06	0.6	0.9	0.117	0.9	0.9	1.2	0.04	0.058	1.8	1.8	0.116
Strontium (ug/L)	1170		1200	1818	2020	5300	523	1703	2199	660	390	793	238	600
Thallium (ug/L)	0.0141		0.0041	1.2	4.5	0.0164	0.9	1.8	2.4	0.0041	0.0082	1.8	1.8	0.0164
Thorium (ug/L)	0.032		0.04	1.4	4.5	0.1	0.9	2.1	2.8	0.016	0.076	1.8	1.8	0.064
Tin (ug/L)	2.5		0.31	2	6	1.77	1.2	3	4	0.23	0.93	2.4	2.4	2.77
Uranium (ug/L)	6.3		4.2	4.29	4	11.7	8.82	14.57	10.71	6.1	1.08	10.6	0.8	0.0247
Zinc (ug/L)	3		60	11.67	133	5.9	7.5	26.96	13.2	1.6	2.8	15	15	5.6
7196_CR6						**7.93**			**11.01**		**10**			
Hexavalent Chromium (ug/L)						7.93			11.01		10			
8260_VOA_GCMS	**18.19**	**19.45**	**31.52**	**36**	**65.59**	**24.5**	**17.72**	**14.59**	**17.72**	**17.87**	**22.07**			
1,1,1-Trichloroethane (ug/L)	0.3	0.3	0.3	0.3	0.3	0.25	0.3	0.3	0.5	0.3	0.3			
1,1,2-Trichloroethane (ug/L)	0.3	0.3	0.3	0.3	0.3	0.25	0.3	0.3	0.5	0.3	0.3			
1,1-Dichloroethane (ug/L)	0.3	0.3	0.3	0.3	0.3	0.25	0.3	0.3	0.5	0.3	0.3			

Lee, A. 2020a. Email communication from Art Lee at Jacobs, dated 23 January 2020, titled RE: 100-N bioremediation monitoring well groundwater data, received at 3:18pm

Groundwater Data Generated during November 2019 Sampling Event (Prepared by Jacobs)

Sum of STD_VALUE_RPTD	Column Labels													
Row Labels	**199-N-167**	**199-N-169**	**199-N-171**	**199-N-173**	**199-N-18**	**199-N-183**	**199-N-19**	**199-N-3**	**199-N-377**	**199-N-56**	**199-N-96A**	**C6132**	**C6135**	**N116mArray-0A**
1,1-Dichloroethene (ug/L)	0.3	0.3	0.3	0.3	0.3	0.27	0.3	0.3	0.54	0.3	0.3			
1,2-Dichloroethane (ug/L)	0.3	0.3	0.3	0.3	0.3	0.23	0.3	0.15	0.46	0.3	0.3			
2-Butanone (ug/L)	3	3	3	3	5.01	0.72	3	3	1.44	3	3			
4-Methyl-2-pentanone (ug/L)	3	3	3	3	3	0.51	3	3	1.02	3	3			
Acetone (ug/L)	4.04	5.75	17.7	22.3	47.8	18	3.1	3	1.88	3.5	8.37			
Benzene (ug/L)	0.3	0.3	0.3	0.3	0.81	0.26	0.3	0.3	0.52	0.3	0.3			
Carbon disulfide (ug/L)	1.6	1.6	1.6	1.6	3.05	0.4	1.6	0.3	0.8	1.6	1.6			
Carbon tetrachloride (ug/L)	0.3	0.3	0.3	0.3	0.3	0.19	0.3	0.15	0.38	0.3	0.3			
Chlorobenzene (ug/L)	0.3	0.3	0.3	0.3	0.3	0.28	0.3	0.3	0.56	0.3	0.3			
Chloroform (ug/L)	0.75	0.3	0.3	0.3	0.3	0.24	1.22	0.3	3.7	0.97	0.3			
Ethylbenzene (ug/L)	0.3	0.3	0.42	0.3	0.3	0.34	0.3	0.3	0.68	0.3	0.3			
Methylene chloride (ug/L)	1.6	1.6	1.6	1.6	1.6	0.27	1.6	0.34	0.54	1.6	1.6			
Tetrachloroethene (ug/L)	0.3	0.3	0.3	0.3	0.3	0.31	0.3	0.3	0.62	0.3	0.3			
Toluene (ug/L)	0.3	0.3	0.3	0.3	0.3	0.24	0.3	0.3	0.48	0.3	0.3			
Trichloroethene (ug/L)	0.3	0.3	0.3	0.3	0.3	0.31	0.3	0.5	0.62	0.3	0.3			
Vinyl chloride (ug/L)	0.3	0.3	0.3	0.3	0.3	0.19	0.3	0.15	0.38	0.3	0.3			
Xylenes (total) (ug/L)	0.3	0.3	0.3	0.3	0.42	0.99	0.3	1	1.6	0.3	0.3			
8270_SVOA_GCMS	**0.4767**		**5.527**			**1.7532**		**0.9632**	**0.9616**	**0.4864**				
Acenaphthene (ug/L)	0.0275		1.04			0.0323		0.0602	0.0601	0.0304				
Acenaphthylene (ug/L)	0.0275		0.425			0.0323		0.0602	0.0601	0.0304				
Anthracene (ug/L)	0.0275		0.142			0.0323		0.0602	0.0601	0.0304				
Benzo(a)anthracene (ug/L)	0.0275		0.142			0.0323		0.0602	0.0601	0.0304				
Benzo(a)pyrene (ug/L)	0.0275		0.142			0.0323		0.0602	0.0601	0.0304				
Benzo(b)fluoranthene (ug/L)	0.0275		0.142			0.0323		0.0602	0.0601	0.0304				
Benzo(ghi)perylene (ug/L)	0.0275		0.142			0.0323		0.0602	0.0601	0.0304				
Benzo(k)fluoranthene (ug/L)	0.0275		0.142			0.0323		0.0602	0.0601	0.0304				
Chrysene (ug/L)	0.0275		0.142			0.0323		0.0602	0.0601	0.0304				
Dibenz[a,h]anthracene (ug/L)	0.0275		0.142			0.0323		0.0602	0.0601	0.0304				
Fluoranthene (ug/L)	0.0275		0.142			0.0323		0.0602	0.0601	0.0304				
Fluorene (ug/L)	0.0642		1.98			0.903		0.0602	0.0601	0.0304				
Indeno(1,2,3-cd)pyrene (ug/L)	0.0275		0.142			0.0323		0.0602	0.0601	0.0304				
Naphthalene (ug/L)	0.0275		0.142			0.398		0.0602	0.0601	0.0304				
Phenanthrene (ug/L)	0.0275		0.378			0.0323		0.0602	0.0601	0.0304				
Pyrene (ug/L)	0.0275		0.142			0.0323		0.0602	0.0601	0.0304				
8270_SVOA_GCMS_SIM		**0.435**		**0.229**	**8.09**		**0.1975**				**0.1969**			
Acenaphthene (ug/L)		0.01		0.011	1.5		0.011				0.011			
Acenaphthylene (ug/L)		0.0095		0.01	0.19		0.01				0.01			
Anthracene (ug/L)		0.081		0.015	0.27		0.014				0.014			
Benzo(a)anthracene (ug/L)		0.012		0.013	0.24		0.013				0.013			
Benzo(a)pyrene (ug/L)		0.013		0.0053	0.098		0.0058				0.0052			
Benzo(b)fluoranthene (ug/L)		0.014		0.015	0.27		0.015				0.015			
Benzo(ghi)perylene (ug/L)		0.01		0.0084	0.16		0.0083				0.0083			
Benzo(k)fluoranthene (ug/L)		0.011		0.011	0.21		0.011				0.011			
Chrysene (ug/L)		0.012		0.013	0.23		0.012				0.012			
Dibenz[a,h]anthracene (ug/L)		0.0098		0.005	0.092		0.0049				0.0049			
Fluoranthene (ug/L)		0.033		0.036	0.66		0.035				0.035			
Fluorene (ug/L)		0.018		0.019	2.5		0.019				0.019			
Indeno(1,2,3-cd)pyrene (ug/L)		0.014		0.015	0.28		0.015				0.015			
Naphthalene (ug/L)		0.05		0.034	1		0.0054				0.0054			
Phenanthrene (ug/L)		0.13		0.01	0.19		0.0099				0.0099			
Pyrene (ug/L)		0.0077		0.0083	0.2		0.0082				0.0082			
9020_TOX								**16.05**						
Total organic halides (ug/L)								16.05						

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Groundwater Data Generated during November 2019 Sampling Event (Prepared by Jacobs)

Sum of STD_VALUE_RPTD	Column Labels													
Row Labels	**199-N-167**	**199-N-169**	**199-N-171**	**199-N-173**	**199-N-18**	**199-N-183**	**199-N-19**	**199-N-3**	**199-N-377**	**199-N-56**	**199-N-96A**	**C6132**	**C6135**	**N116mArray-0A**
9056_ANIONS_IC		**328347**	**483552**	**317640**	**467092**	**303695**	**304765**	**230259.8**	**618715**		**65302**		**9820**	**59900**
Bromide (ug/L)				297		389	284		647		67			
Chloride (ug/L)		66300	46000	125000	87600	56200	82800	31200	254000		15200		2840	4990
Fluoride (ug/L)		222	93	269	33	33	268	46.8	242		87		146	402
Nitrate (ug/L)		35300	146	2160	146	1760	76100	79700	133200		7440		146	292
Nitrite (ug/L)		5320	108	709	108	108	108	108	216		108		108	216
Phosphate (ug/L)		205	205	205	205	205	205	205	410		6500			
Sulfate (ug/L)		221000	437000	189000	379000	245000	145000	119000	230000		35900		6580	54000
906.0_H3_LSC											**289**			
Tritium (pCi/L)											289			
9060_TOC								**3438**						
Total organic carbon (ug/L)								3438						
9310_ALPHABETA_GPC				**45.897**					**96.4**		**15.85**	**32.94**	**5.48**	**1.471**
Gross alpha (pCi/L)				0.997							4.35	1.44	1.93	0.593
Gross beta (pCi/L)				44.9					96.4		11.5	31.5	3.55	0.878
AMCMISO_EIE_PREC_AEA							**-0.00523**					**0.0156**		
Americium-241 (pCi/L)							-0.00523					0.0156		
C14_LSC							**1.72**					**4.6**		
Carbon-14 (pCi/L)							1.72					4.6		
CONDUCT_FLD	**1171**	**1248**	**1891**	**1208**	**2276**	**2035**	**969**	**3797.14**	**1046**	**1150**	**339**	**799**	**178**	**232**
Specific Conductance (uS/cm)	1171	1248	1891	1208	2276	2035	969	3797.14	1046	1150	339	799	178	232
GAMMA_GS							**16.986**					**-31.901**		
Antimony-125 (pCi/L)							-2.86					3.6		
Cesium-134 (pCi/L)							3.94					2.95		
Cesium-137 (pCi/L)							-1.49					2.29		
Cobalt-60 (pCi/L)							-0.261					-0.644		
Europium-152 (pCi/L)							-2.27					0.823		
Europium-154 (pCi/L)							0.657					-4.16		
Europium-155 (pCi/L)							8.07					-8.16		
Potassium-40 (pCi/L)							11.2					-28.6		
PH_ELECT_FLD	**7.08**	**7.07**	**7.09**	**7.07**	**7.09**	**6.94**	**7.46**	**36.9**	**7.47**	**7.31**	**7.31**	**7.67**	**7.18**	**7.37**
pH Measurement (unitless)	7.08	7.07	7.09	7.07	7.09	6.94	7.46	36.9	7.47	7.31	7.31	7.67	7.18	7.37
PU241_IE_LSC							**15.8**					**10.4**		
Plutonium-241 (pCi/L)							15.8					10.4		
PUISO_PRECIP_AEA							**0.0492**					**-0.0667**		
Plutonium-238 (pCi/L)							-0.0262					-0.0381		
Plutonium-239/240 (pCi/L)							0.0754					-0.0286		
REDOX_PROBE_FLD	**88.7**	**2**	**-100.9**	**169.8**	**25.4**	**-101.1**	**263.5**	**285.2**	**236.3**	**202.4**	**133.2**	**215**	**-13**	**-38**
Oxidation Reduction Potential (RmV)	88.7	2	-100.9	169.8	25.4	-101.1	263.5	285.2	236.3	202.4	133.2	215	-13	-38
SE79_SEP_IE_LSC							**8.9**					**21.8**		
Selenium-79 (pCi/L)							8.9					21.8		
SR90_SEP_LSC						**143**			**36.7**		**1.67**			**2.674**
Strontium-90 (pCi/L)						143			36.7		1.67			2.674
SRISO_SEP_PRECIP_GPC				**19.5**			**14.6**	**552**				**8.97**	**0.392**	
Strontium-90 (pCi/L)				19.5			14.6	552				8.97	0.392	
TC99_EIE_LSC							**-21.8**					**-1.38**		
Technetium-99 (pCi/L)							-21.8					-1.38		
TEMP_FLD	**23.1**	**22.2**	**23.5**	**18.6**	**18.6**	**20.1**	**18.3**	**110**	**19.2**	**18.4**	**19**	**18.2**	**27.2**	**21.8**
Temperature (Deg C)	23.1	22.2	23.5	18.6	18.6	20.1	18.3	110	19.2	18.4	19	18.2	27.2	21.8
TRITIUM_DIST_LSC				**1320**		**1640**	**6680**	**2460**	**2160**			**931**		
Tritium (pCi/L)				1320		1640	6680	2460	2160			931		
TURBIDITY_FLD	**1.35**	**1.45**	**4.45**	**3.84**	**18.3**	**3.72**	**0.58**	**7.42**	**2.81**	**1.29**	**3.22**	**0.55**	**0.87**	**0.33**
Turbidity (NTU)	1.35	1.45	4.45	3.84	18.3	3.72	0.58	7.42	2.81	1.29	3.22	0.55	0.87	0.33

Lee, A. 2020a. Email communication from Art Lee at Jacobs, dated 23 January 2020, titled RE: 100-N bioremediation monitoring well groundwater data, received at 3:18pm

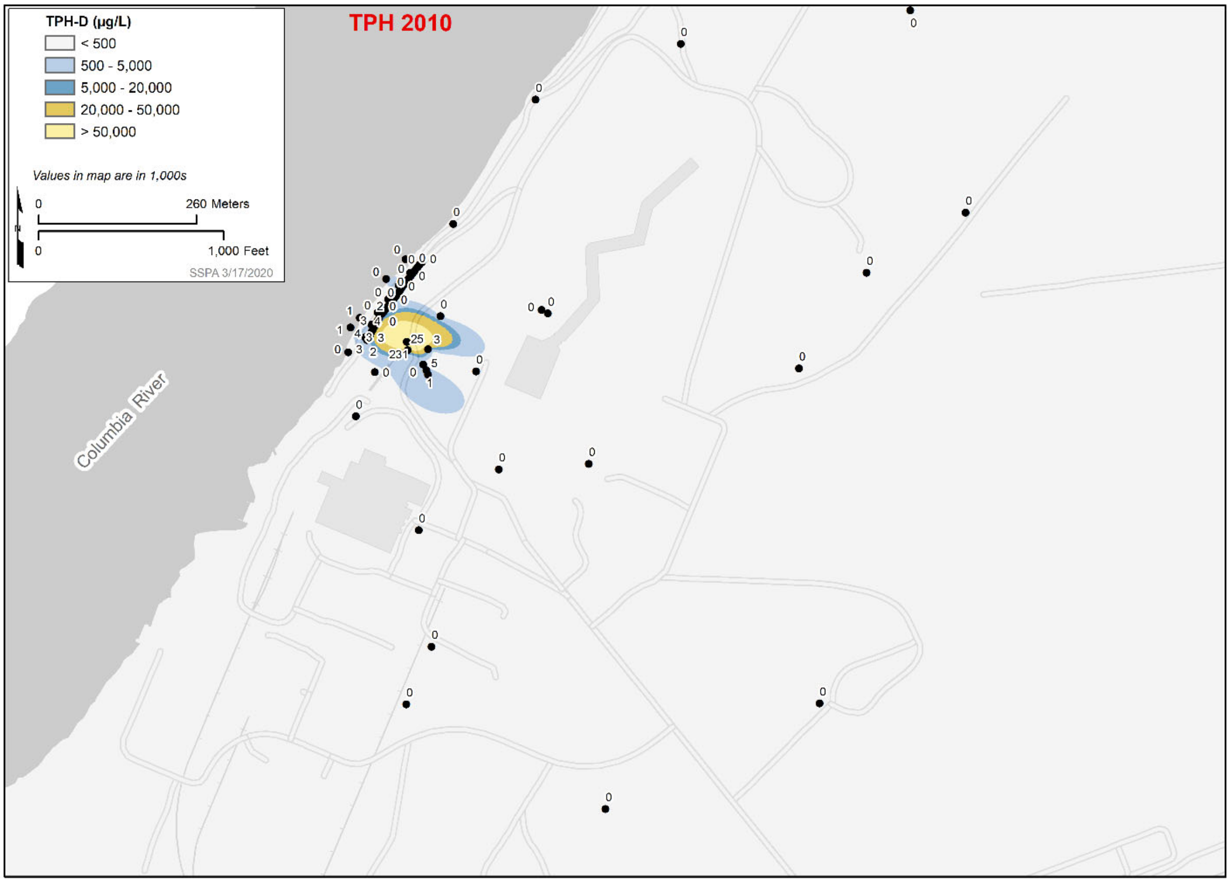
Groundwater Data Generated during November 2019 Sampling Event (Prepared by Jacobs)

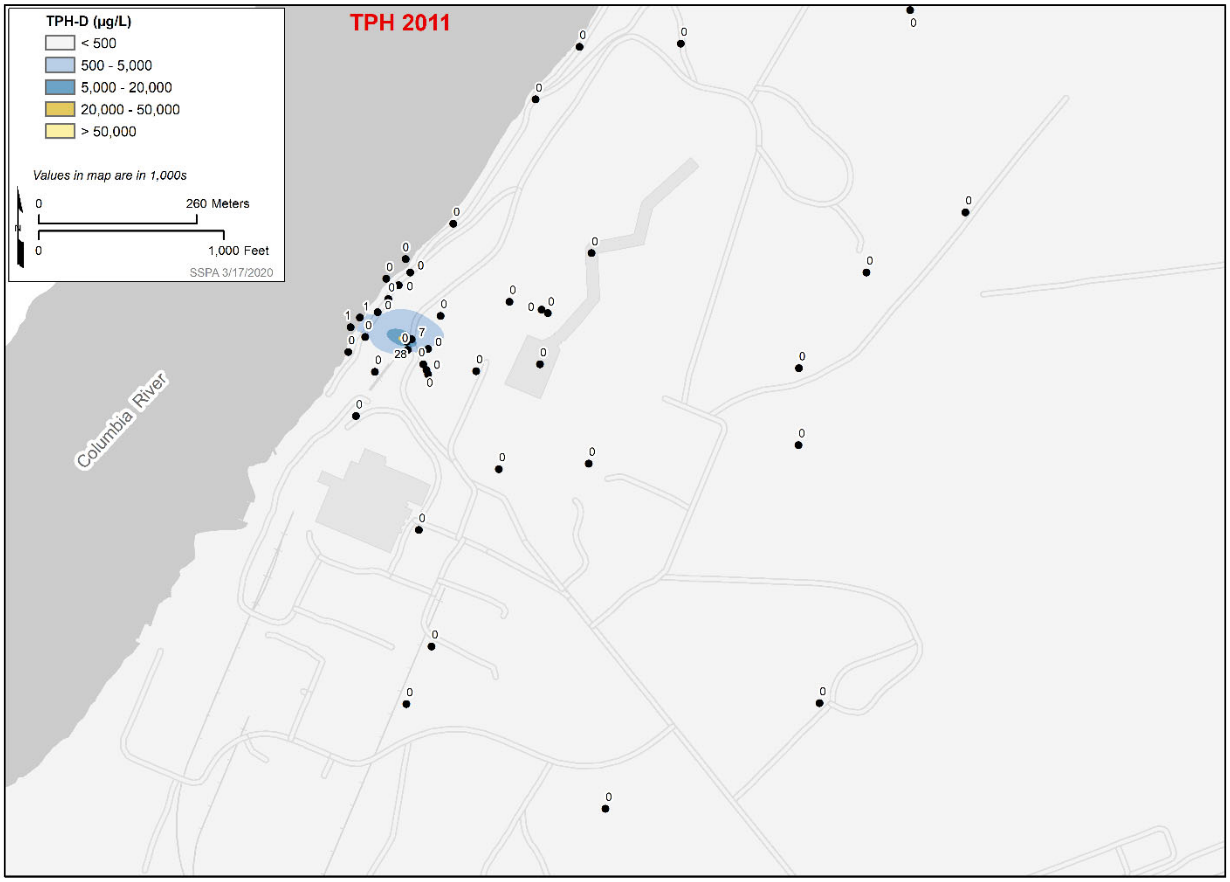
Sum of STD_VALUE_RPTD	Column Labels													
Row Labels	199-N-167	199-N-169	199-N-171	199-N-173	199-N-18	199-N-183	199-N-19	199-N-3	199-N-377	199-N-56	199-N-96A	C6132	C6135	N116mArray-0A
UISO_IE_PRECIP_AEA	**2.3206**	**2.645**	**4.293**	**2.1764**	**2.6832**	**2.1598**	**3.5525**	**4.177**	**1.6827**	**4.3347**	**1.072**	**3.0901**		
Uranium-233/234 (pCi/L)	1.09	1.29	2.1	1.17	1.47	1.11	1.96	2.17	1.18	2.47	0.698	1.72		
Uranium-235 (pCi/L)	0.0506	0.305	0.453	0.0234	0.0932	0.0398	0.0225	0.197	0.0227	0.0547	0.122	0.0401		
Uranium-238 (pCi/L)	1.18	1.05	1.74	0.983	1.12	1.01	1.57	1.81	0.48	1.81	0.252	1.33		
WTPH_DIESEL	**8600**	**15900**	**43000**	**8500**	**97000**	**16700**	**192.4**	**235**	**284.4**	**150.6**	**1110**	**75**	**722**	**871**
Total petroleum hydrocarbons - diesel range (ug/L)	5200	10000	29000	5200	81900	13000	76.4	77	142.2	75.3	610	75	722	871
Total petroleum hydrocarbons - motor oil (high boiling) (ug/L)	3400	5900	14000	3300	15100	3700	116	158	142.2	75.3	500			
WTPH_GASOLINE	**10**	**16.7**	**260**	**12**	**69.4**	**160**	**16.7**	**20**	**20**	**16.7**	**16.7**			
Total petroleum hydrocarbons - gasoline range (ug/L)	10	16.7	260	12	69.4	160	16.7	20	20	16.7	16.7			
Grand Total	**1101122.27**	**634076.95**	**1595209.468**	**1125177.222**	**1866694.853**	**3180473.808**	**673707.68**	**1557286.055**	**1741434.749**	**1516258.717**	**425512.3031**	**543354.298**	**93375.122**	**246900.7101**

Lee, A. 2020a. Email communication from Art Lee at Jacobs, dated 23 January 2020, titled RE: 100-N bioremediation monitoring well groundwater data, received at 3:18pm

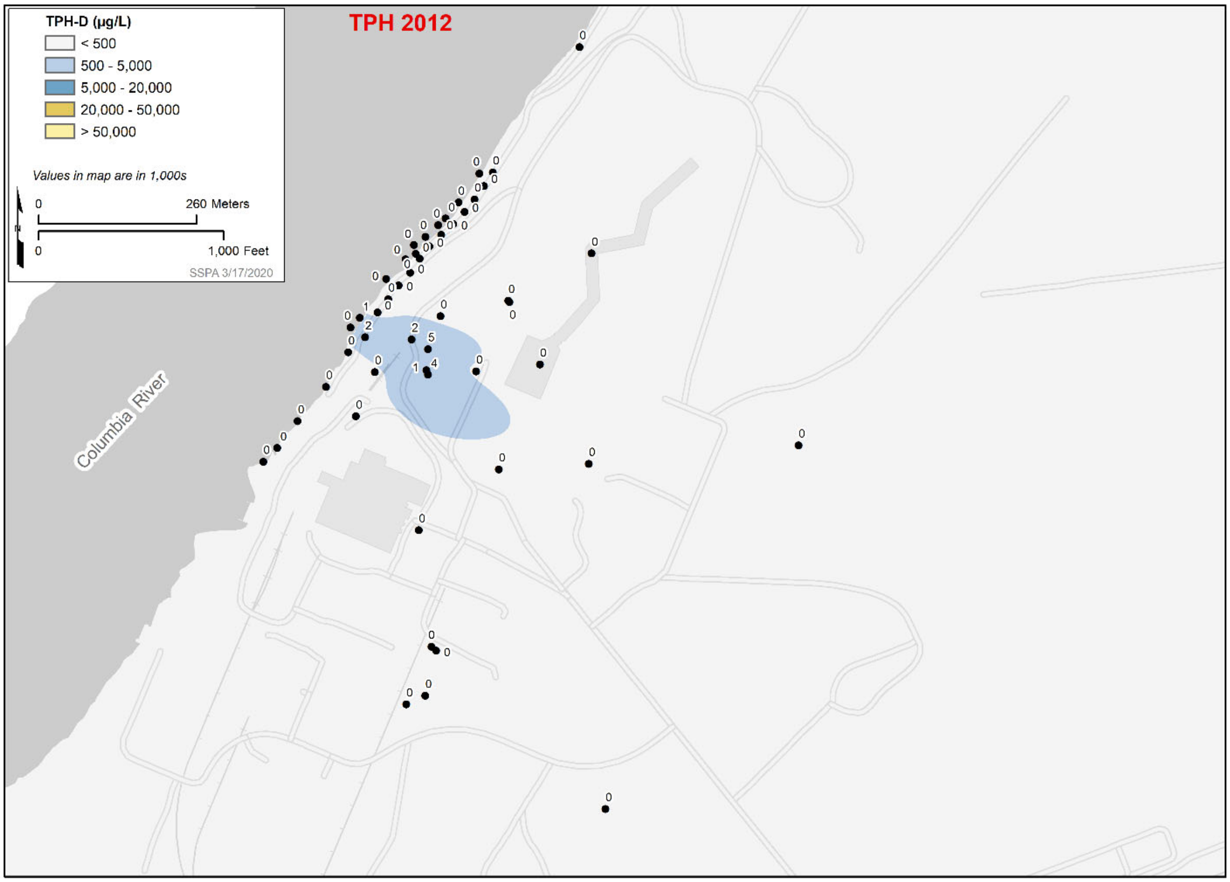
Attachment 5
Contour Maps for Distribution of Various Parameters in Site Groundwater 2010-2019 (Prepared by S.S. Papadopulos & Associates, Inc. for Jacobs)

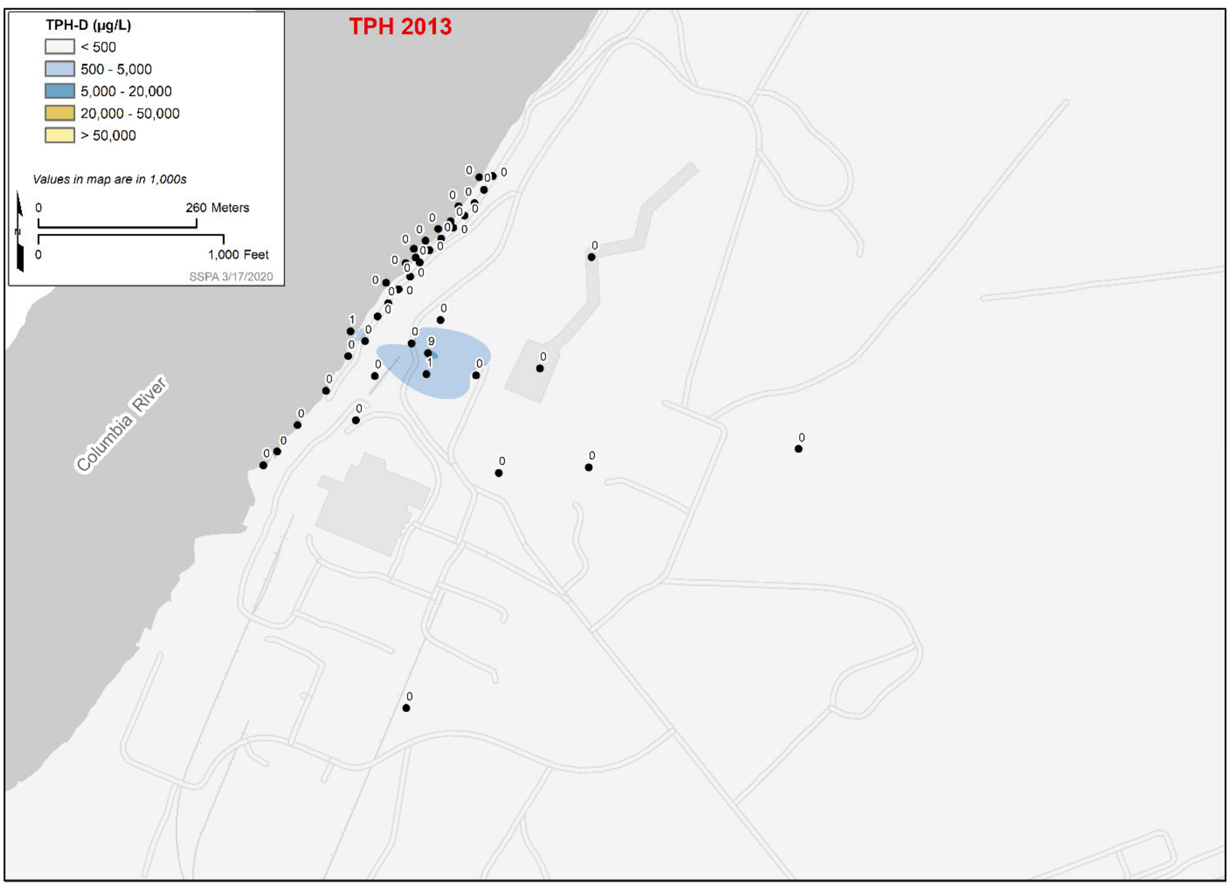
TPH


TPH 2010
TPH-D (µg/L)
< 500
500 - 5,000
5,000 - 20,000
20,000 - 50,000
> 50,000
Values in map are in 1,000s
0
260 Meters
0
1,000 Feet
SSPA 3/17/2020
Columbia River

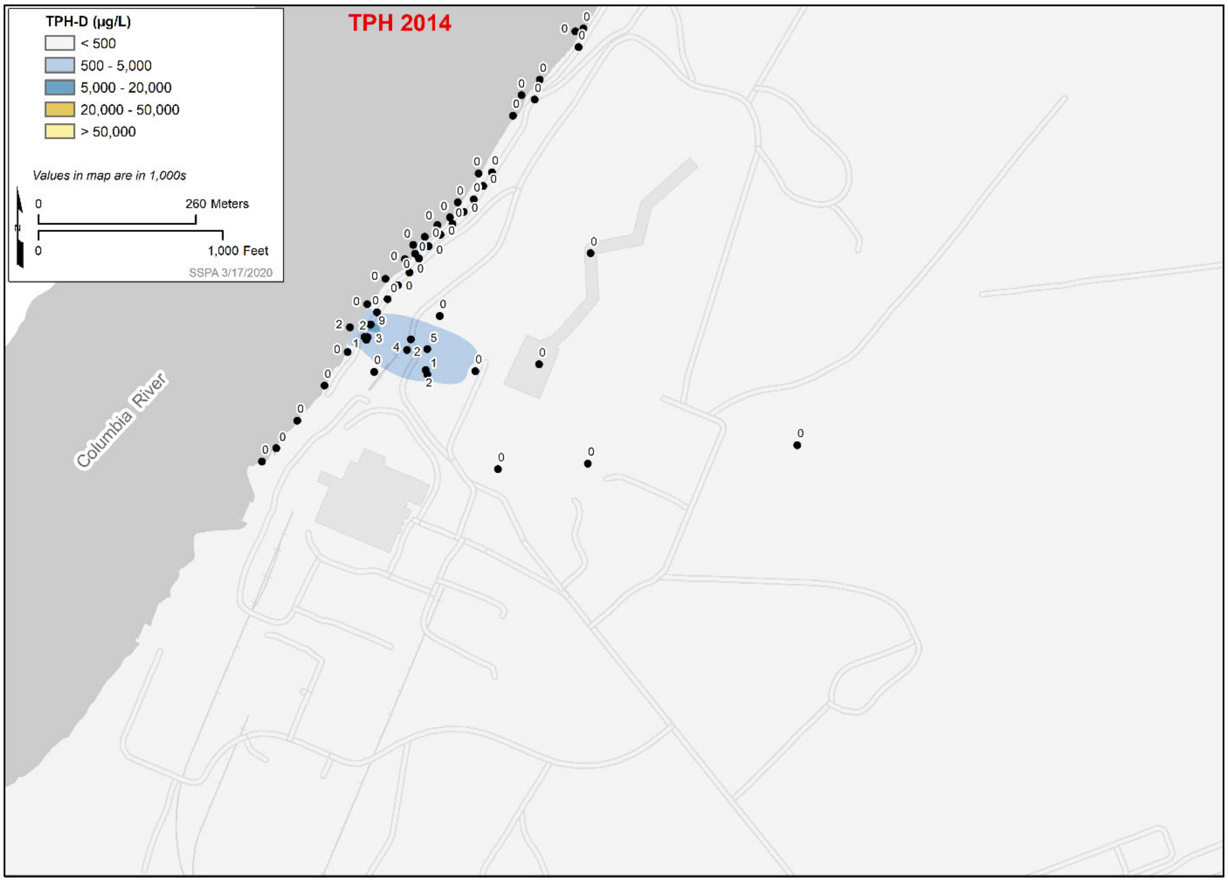

TPH 2011
TPH-D (µg/L)
< 500
500 - 5,000
5,000 - 20,000
20,000 - 50,000
> 50,000
Values in map are in 1,000s
0
260 Meters
0
1,000 Feet
SSPA 3/17/2020
Columbia River

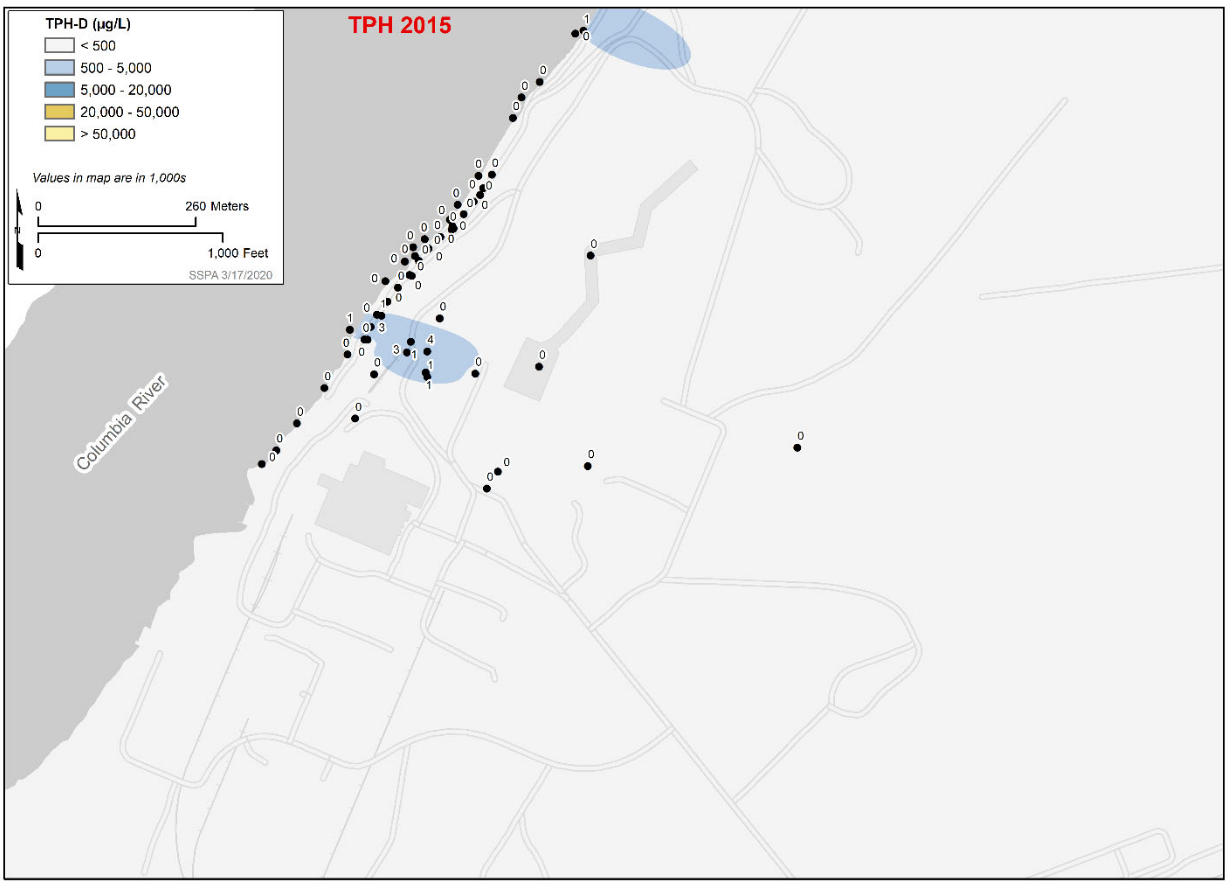
TPH


TPH 2012
TPH-D (µg/L)
< 500
500 - 5,000
5,000 - 20,000
20,000 - 50,000
> 50,000
Values in map are in 1,000s
0
260 Meters
0
1,000 Feet
SSPA 3/17/2020
Columbia River

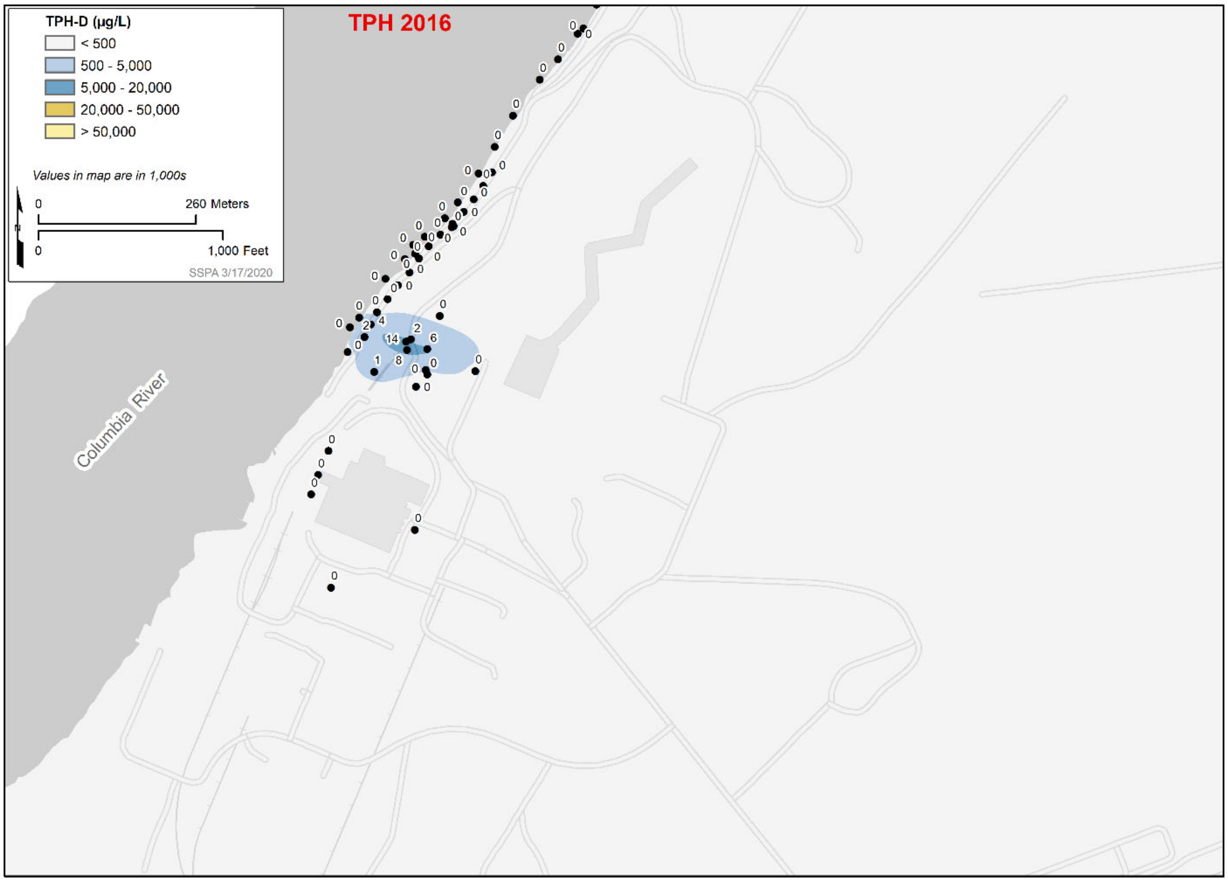

TPH 2013
TPH-D (µg/L)
< 500
500 - 5,000
5,000 - 20,000
20,000 - 50,000
> 50,000
Values in map are in 1,000s
0
260 Meters
0
1,000 Feet
SSPA 3/17/2020
Columbia River

TPH


TPH 2014
TPH-D (µg/L)
< 500
500 - 5,000
5,000 - 20,000
20,000 - 50,000
> 50,000
Values in map are in 1,000s
0
260 Meters
0
1,000 Feet
SSPA 3/17/2020
Columbia River


TPH 2015
TPH-D (µg/L)
< 500
500 - 5,000
5,000 - 20,000
20,000 - 50,000
> 50,000
Values in map are in 1,000s
0
260 Meters
0
1,000 Feet
SSPA 3/17/2020
Columbia River

TPH


TPH-D (µg/L)
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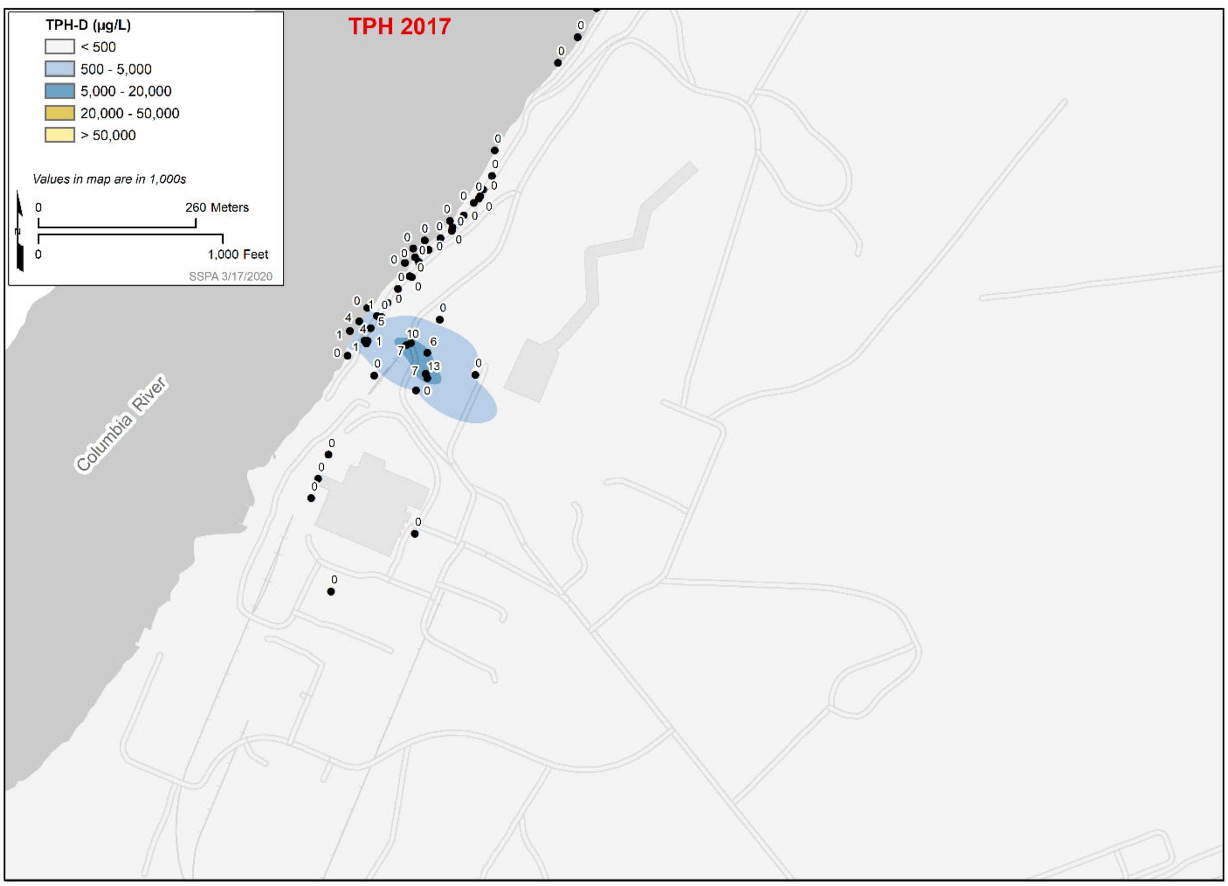
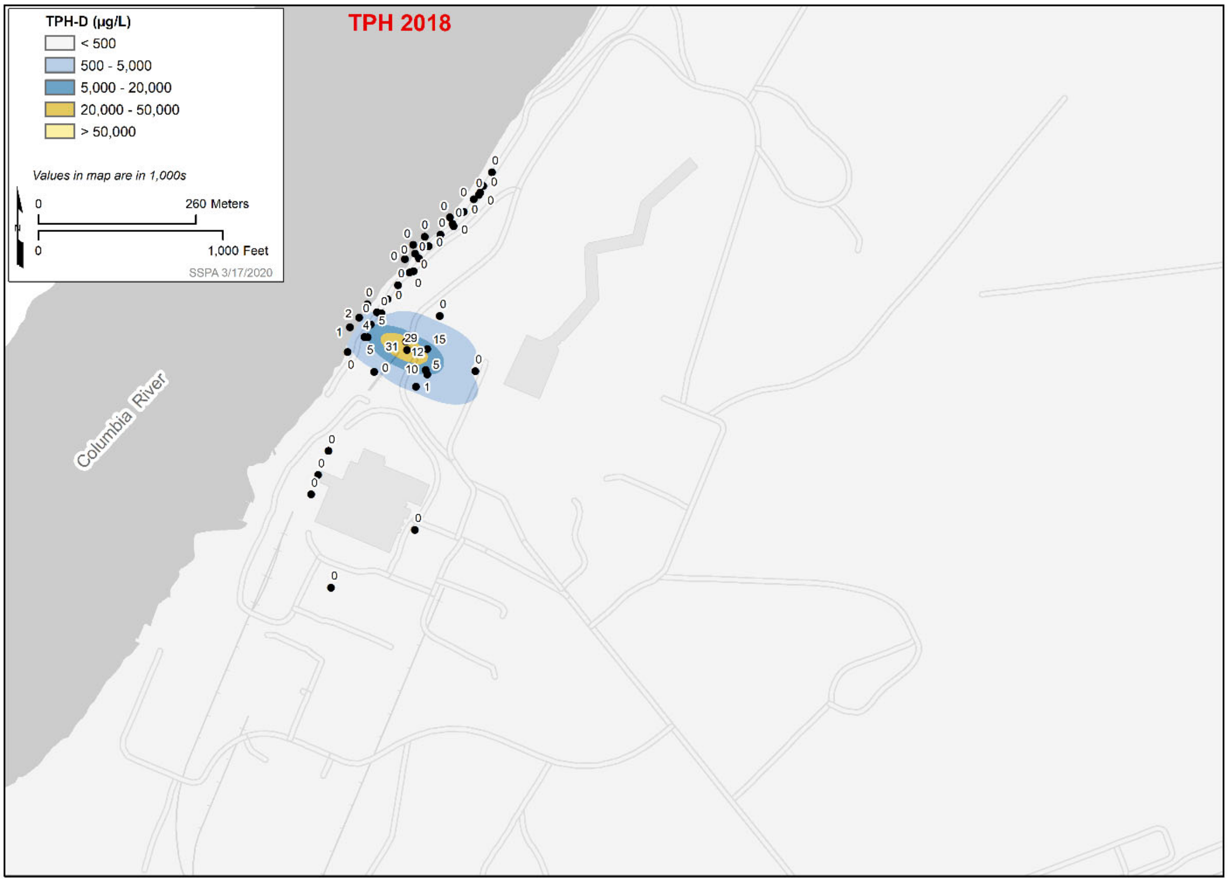
500 - 5,000
5,000 - 20,000
20,000 - 50,000
> 50,000
Values in map are in 1,000s
0
260 Meters
0
1,000 Feet
SSPA 3/17/2020
TPH 2016
Columbia River


TPH-D (µg/L)
< 500
500 - 5,000
5,000 - 20,000
20,000 - 50,000
> 50,000
Values in map are in 1,000s
0
260 Meters
0
1,000 Feet
SSPA 3/17/2020
TPH 2017
Columbia River

TPH


TPH-D (µg/L)
< 500
500 - 5,000
5,000 - 20,000
20,000 - 50,000
> 50,000
Values in map are in 1,000s
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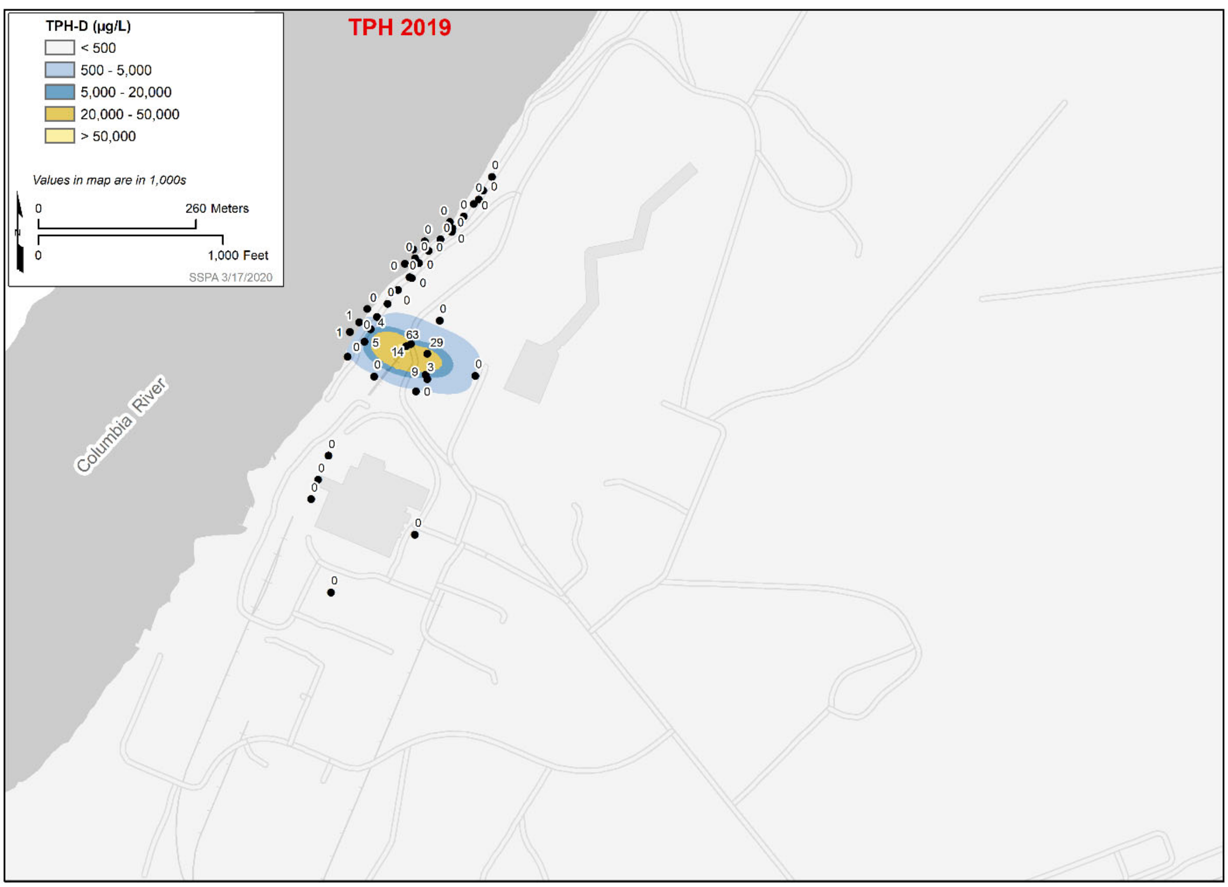
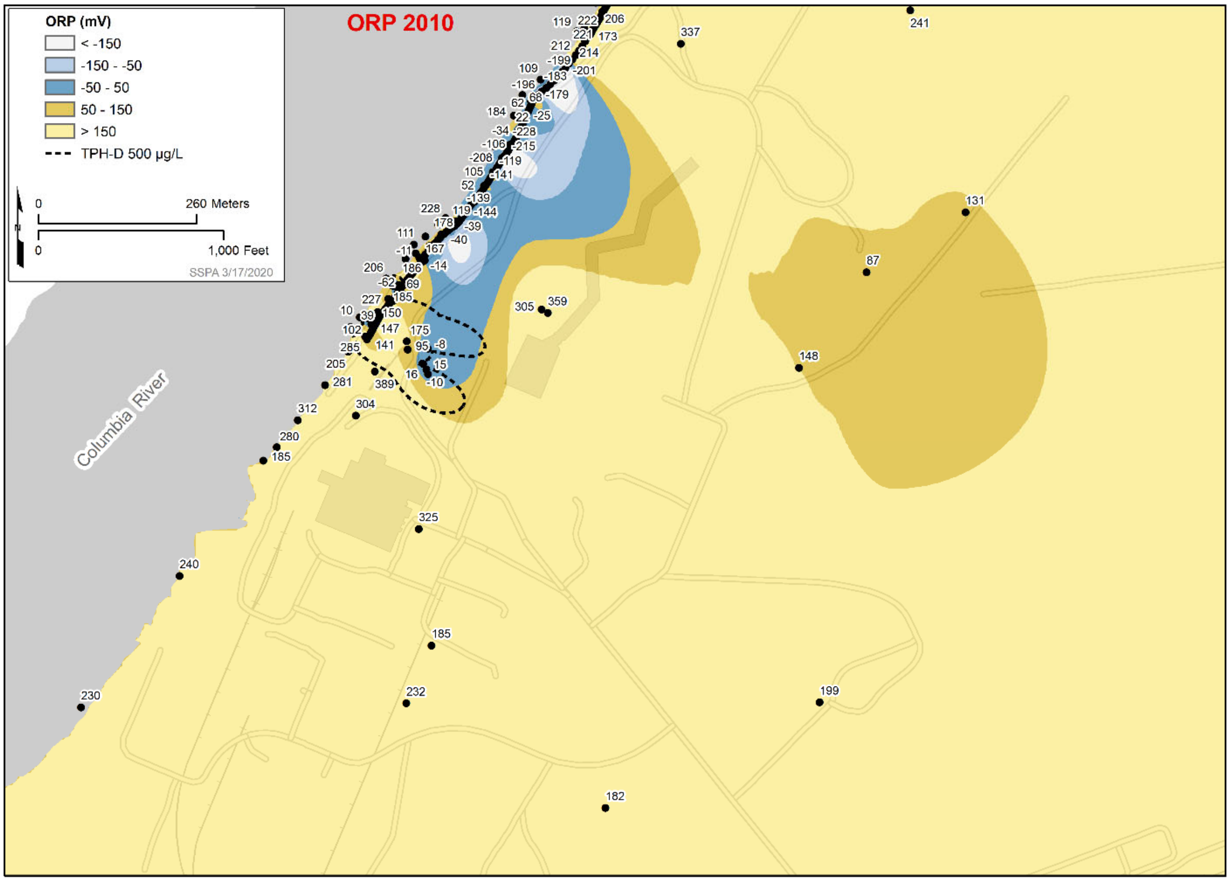
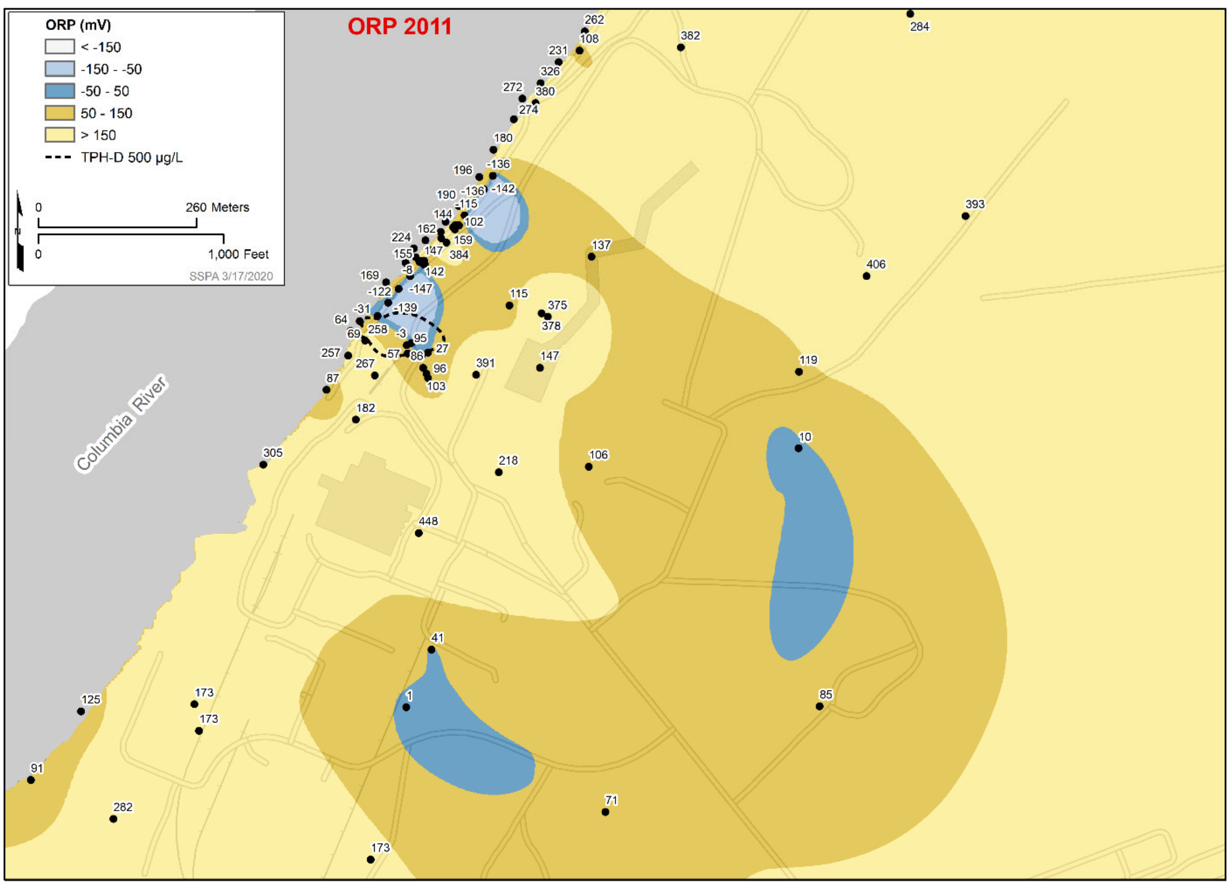
260 Meters
0
1,000 Feet
SSPA 3/17/2020
TPH 2018
Columbia River

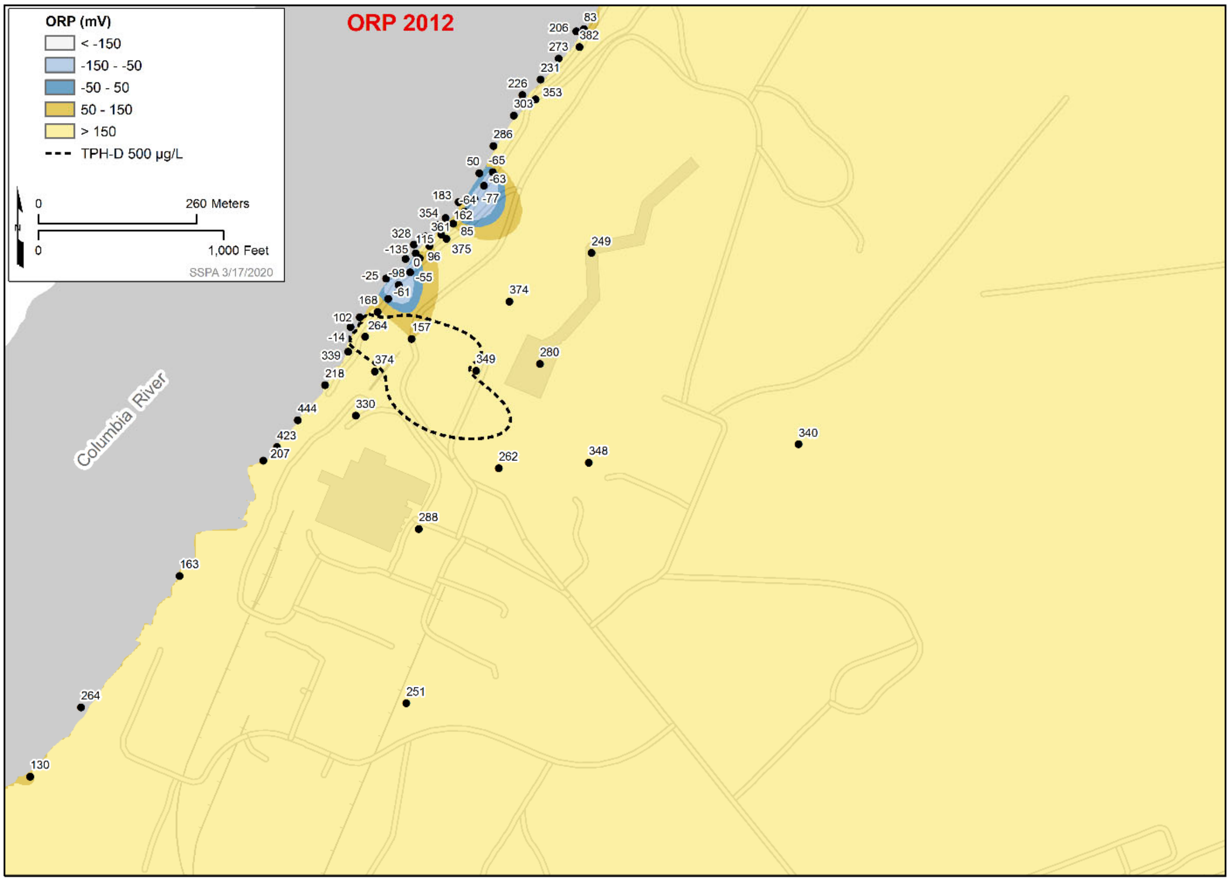

TPH-D (µg/L)
< 500
500 - 5,000
5,000 - 20,000
20,000 - 50,000
> 50,000
Values in map are in 1,000s
0
260 Meters
0
1,000 Feet
SSPA 3/17/2020
TPH 2019
Columbia River

ORP


ORP 2010
ORP (mV)
< -150
-150 - -50
-50 - 50
50 - 150
> 150
TPH-D 500 µg/L
0
260 Meters
0
1,000 Feet
SSPA 3/17/2020
Columbia River
241
337
131
87
148
305
359
325
240
185
230
232
199
182
312
280
185
304


ORP 2011
ORP (mV)
< -150
-150 - -50
-50 - 50
50 - 150
> 150
TPH-D 500 µg/L
0
260 Meters
0
1,000 Feet
SSPA 3/17/2020
Columbia River
284
382
393
406
137
115
375
378
147
391
119
10
106
218
305
182
87
448
41
1
85
125
173
173
91
282
71
173

ORP



ORP 2012
ORP (mV)
< -150
-150 - -50
-50 - 50
50 - 150
> 150
TPH-D 500 µg/L
0
260 Meters
0
1,000 Feet
SSPA 3/17/2020
Columbia River
83
206
382
273
231
226
353
303
286
50
-65
-63
183
-64
-77
354
162
361
85
328
115
375
-135
96
249
0
-25
-98
-55
-61
374
168
102
264
157
-14
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374
349
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340
348
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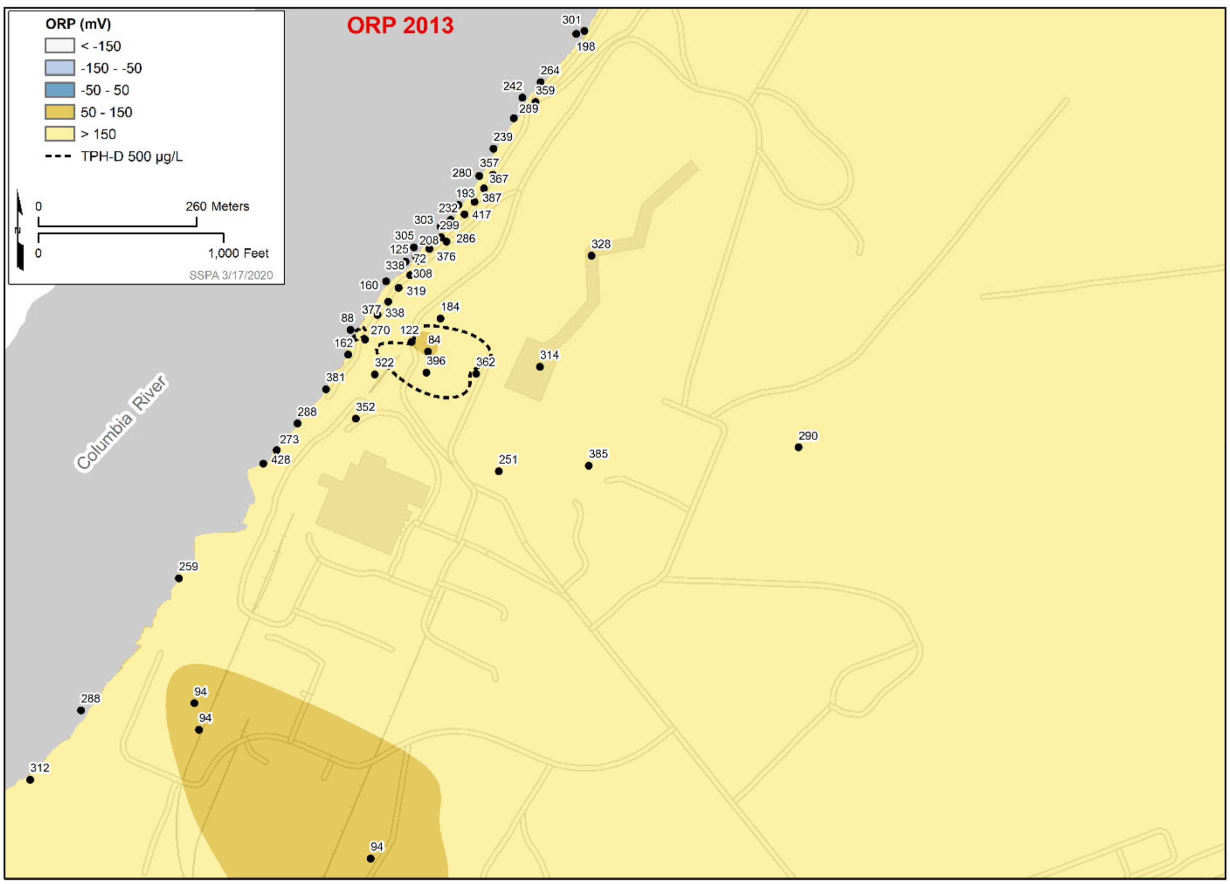
288
163
251
264
130



ORP 2013
ORP (mV)
< -150
-150 - -50
-50 - 50
50 - 150
> 150
TPH-D 500 µg/L
0
260 Meters
0
1,000 Feet
SSPA 3/17/2020
Columbia River
301
198
264
242
359
289
239
357
280
367
193
387
232
417
303
299
305
208
286
125
72
376
338
308
328
160
319
184
377
338
88
270
122
84
162
322
396
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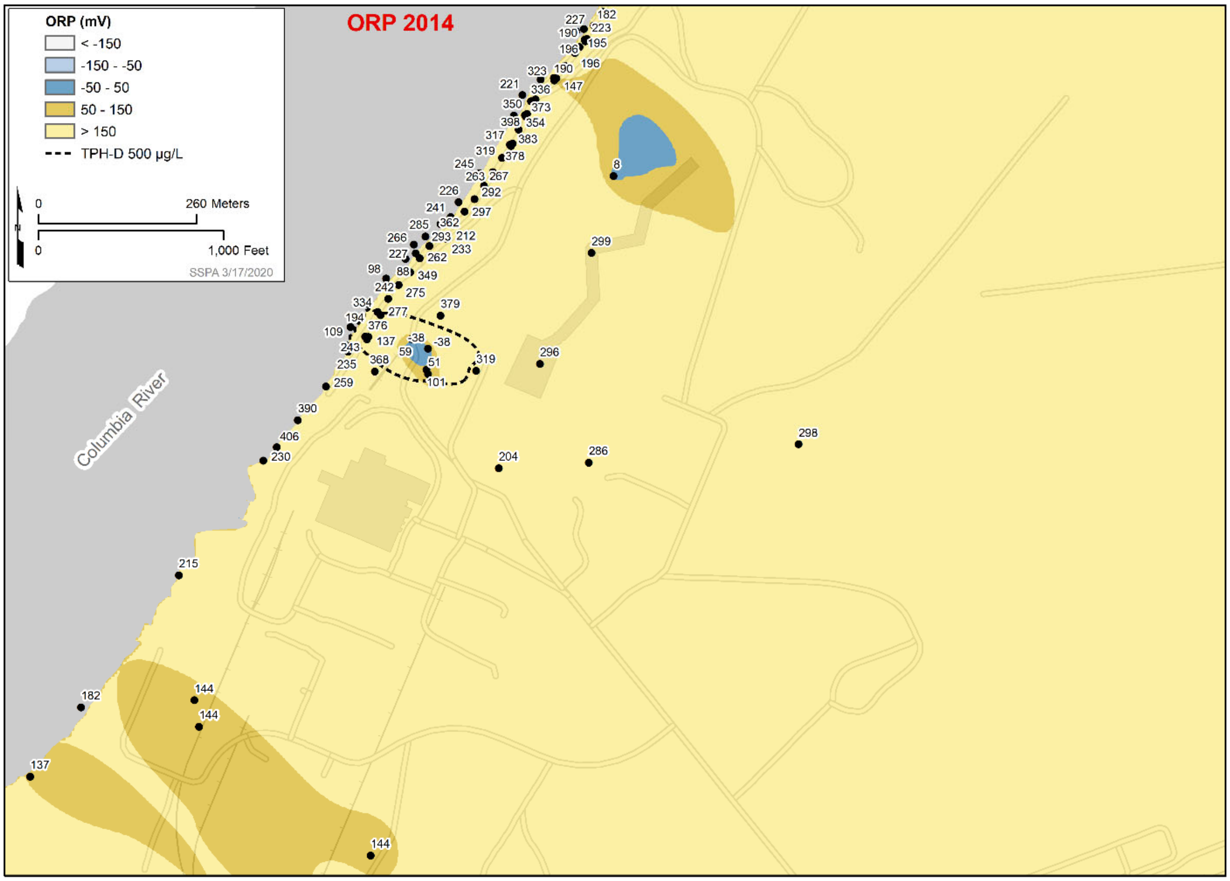
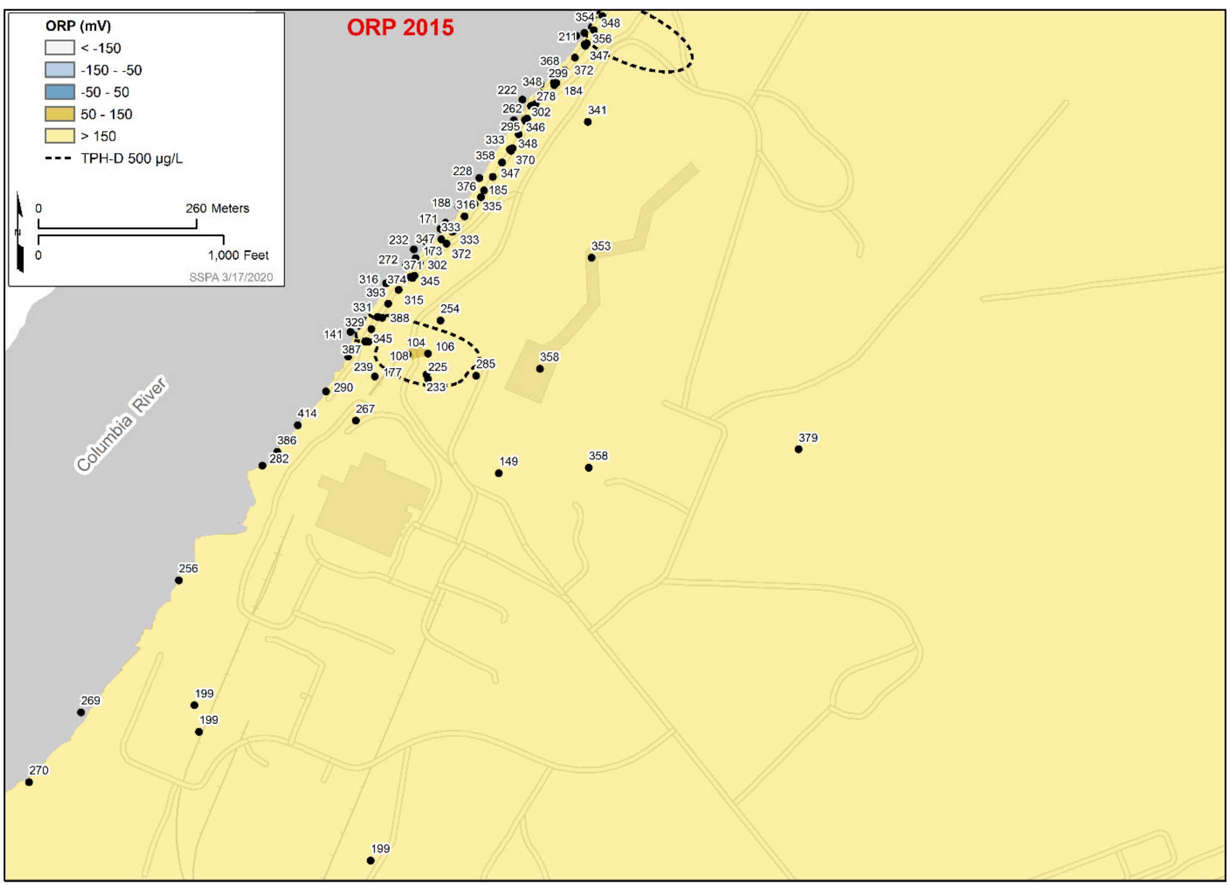
314
381
352
288
273
428
290
385
251
259
288
94
94
312
94

ORP


ORP 2014
ORP (mV)
< -150
-150 - -50
-50 - 50
50 - 150
> 150
TPH-D 500 µg/L
0
260 Meters
0
1,000 Feet
SSPA 3/17/2020
Columbia River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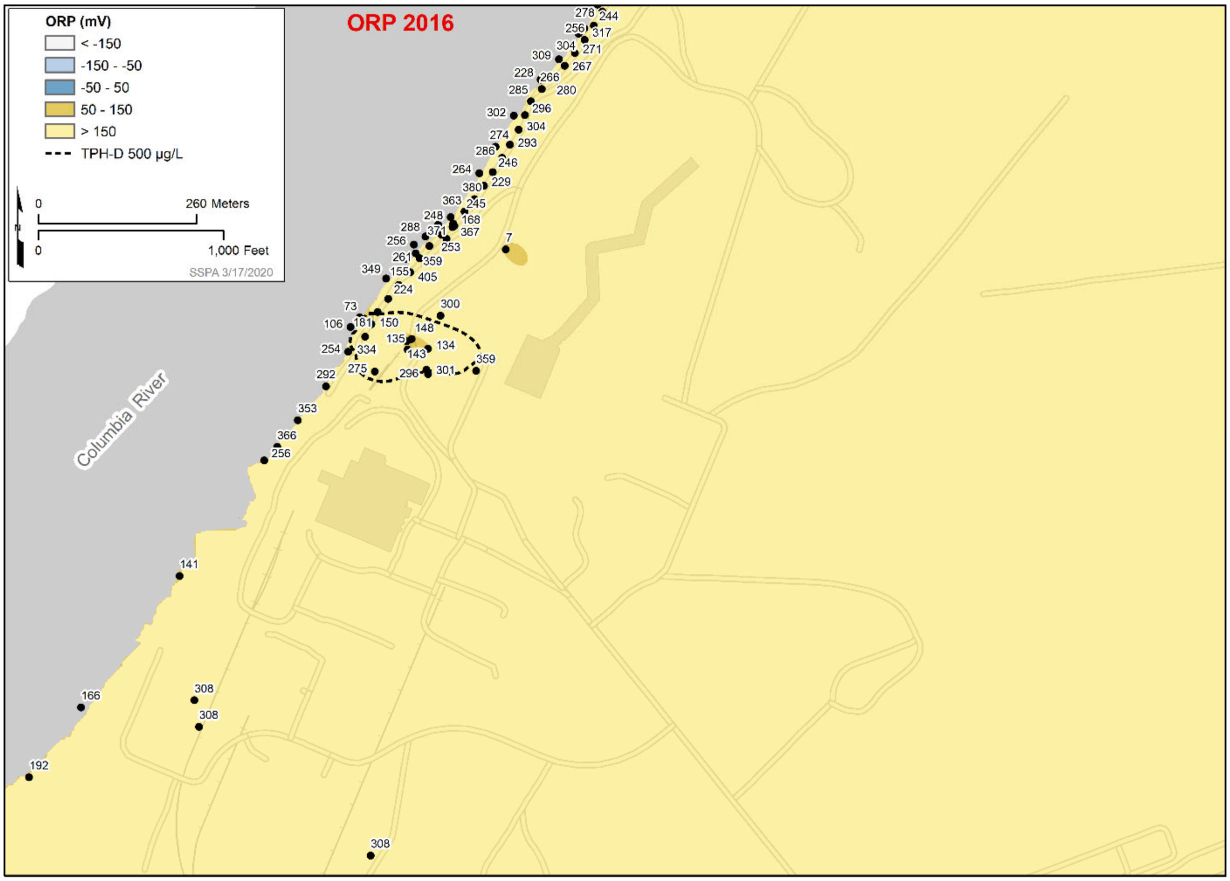
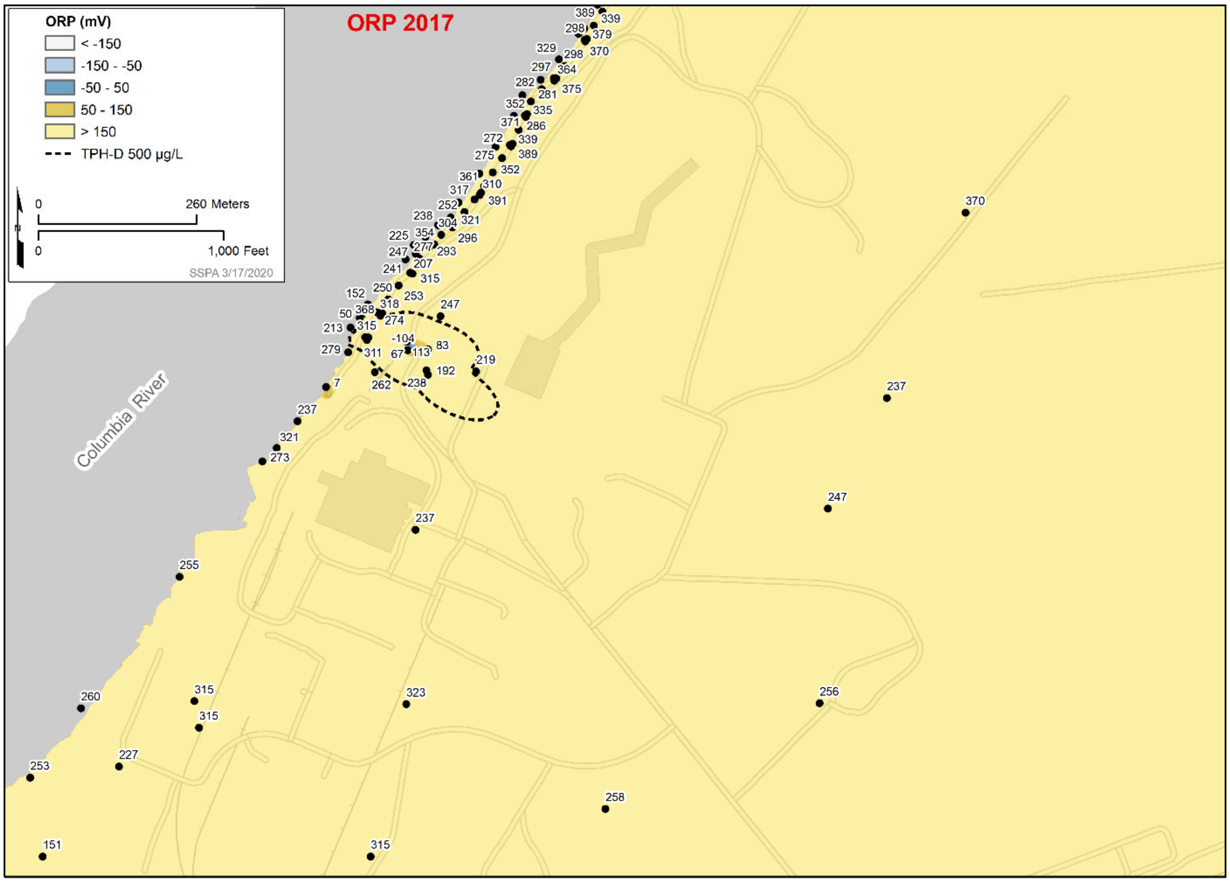
ORP (mV)
< -150
-150 - -50
-50 - 50
50 - 150
> 150
TPH-D 500 µg/L
0
260 Meters
0
1,000 Feet
SSPA 3/17/2020
Columbia River

ORP


ORP 2016
ORP (mV)
< -150
-150 - -50
-50 - 50
50 - 150
> 150
TPH-D 500 µg/L
0
260 Meters
0
1,000 Feet
SSPA 3/17/2020
Columbia River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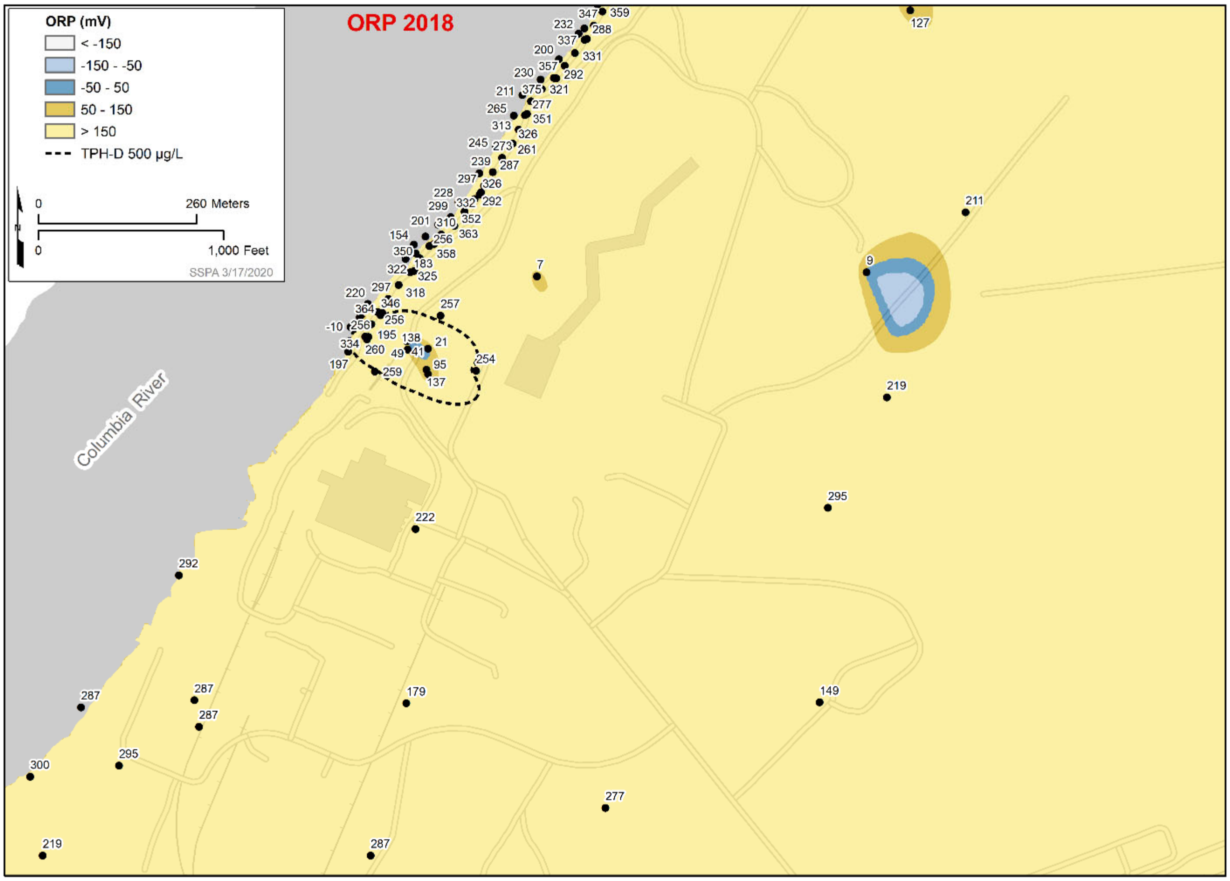
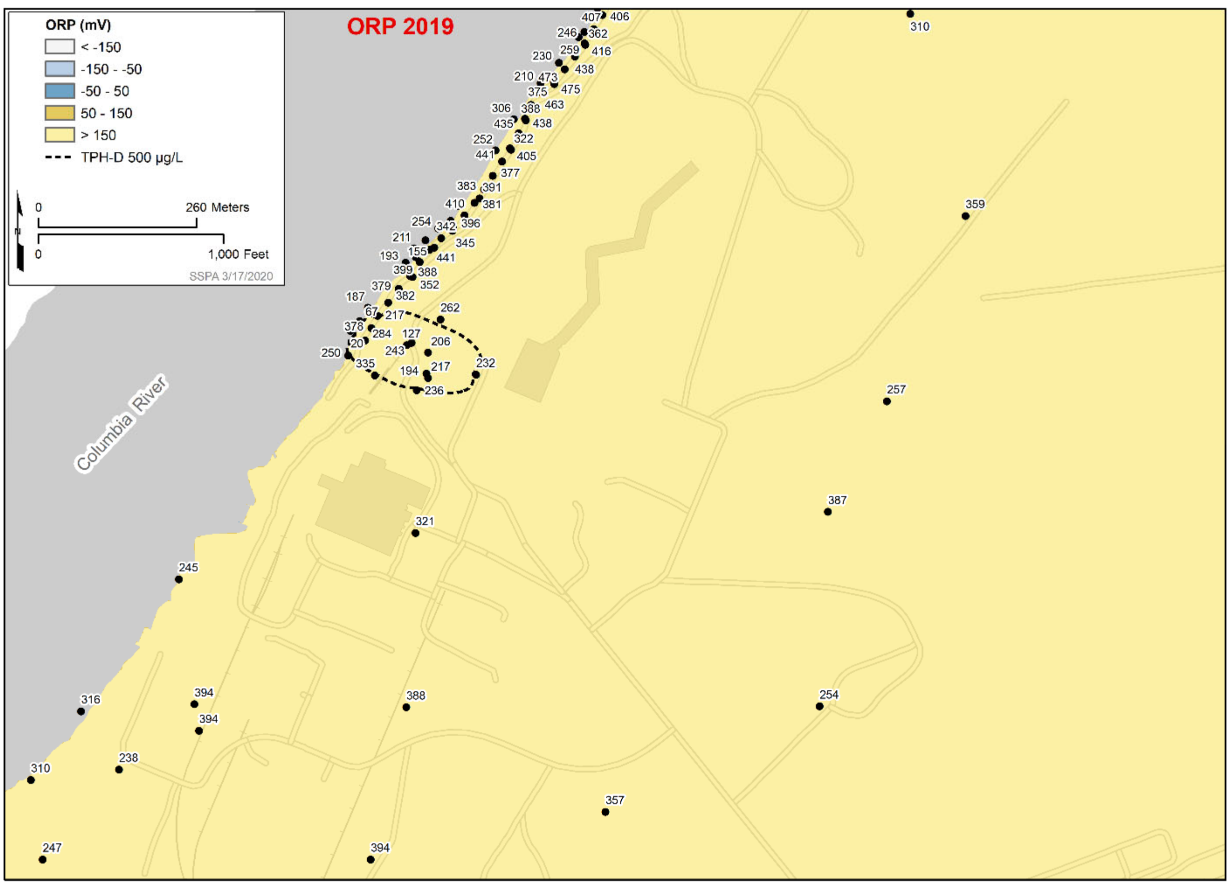
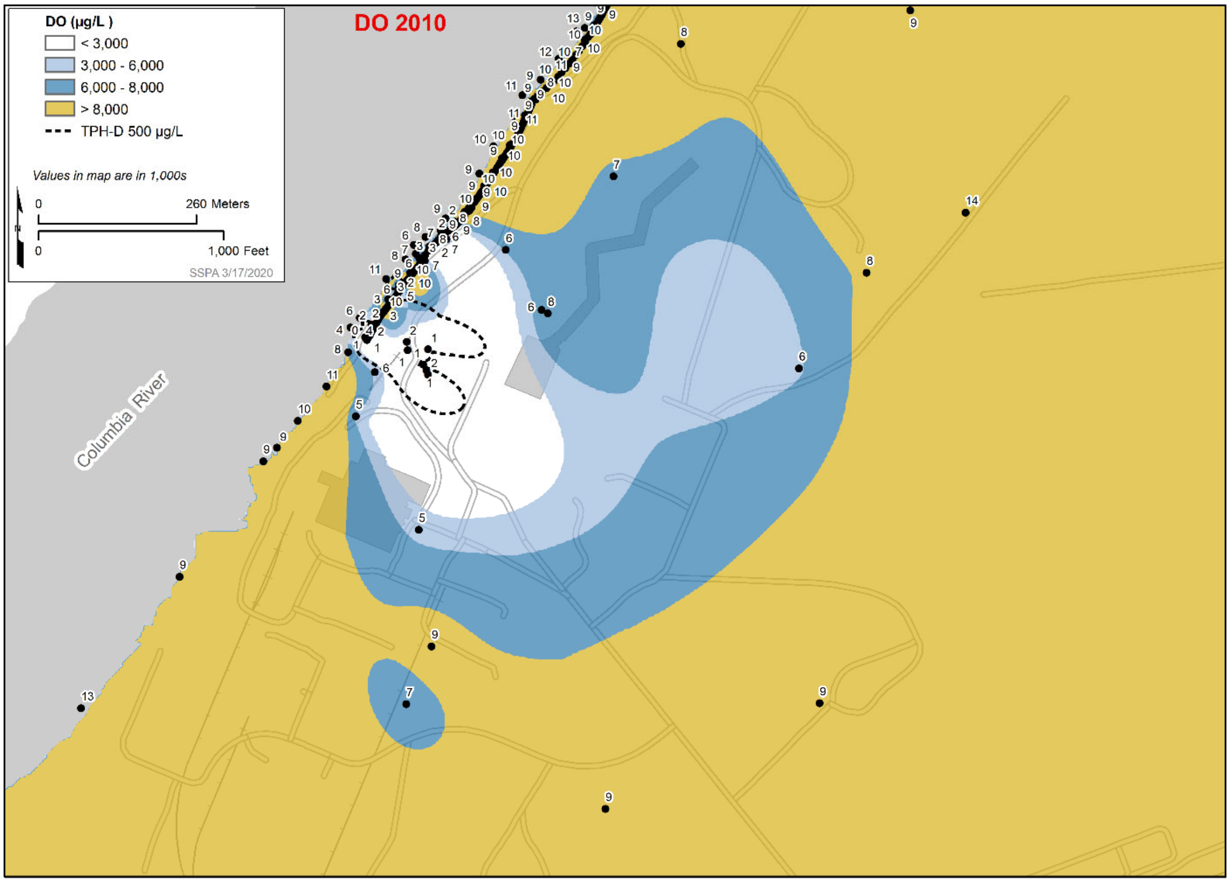
ORP (mV)
< -150
-150 - -50
-50 - 50
50 - 150
> 150
TPH-D 500 µg/L
0
260 Meters
0
1,000 Feet
SSPA 3/17/2020
Columbia River

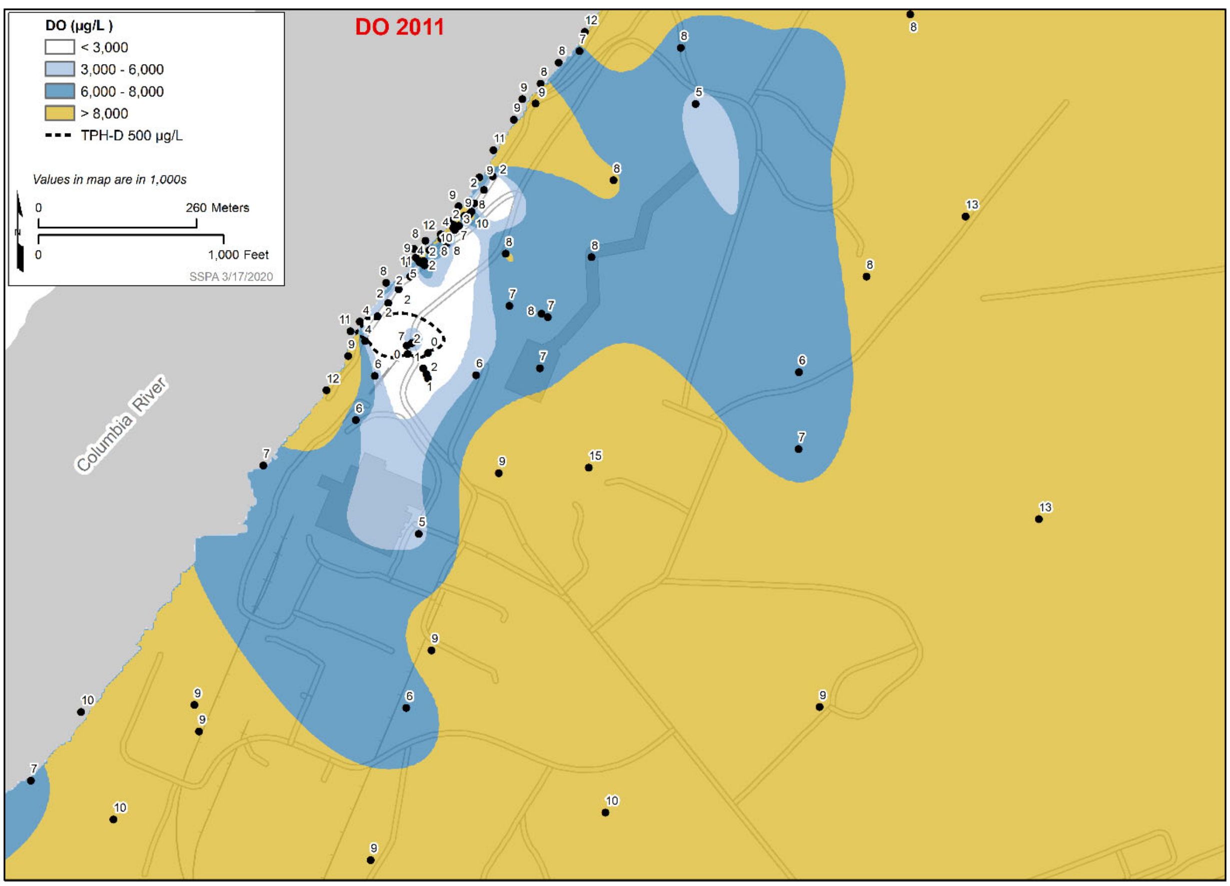
ORP


ORP 2018
ORP (mV)
< -150
-150 - -50
-50 - 50
50 - 150
> 150
TPH-D 500 µg/L
0
260 Meters
0
1,000 Feet
SSPA 3/17/2020
Columbia River

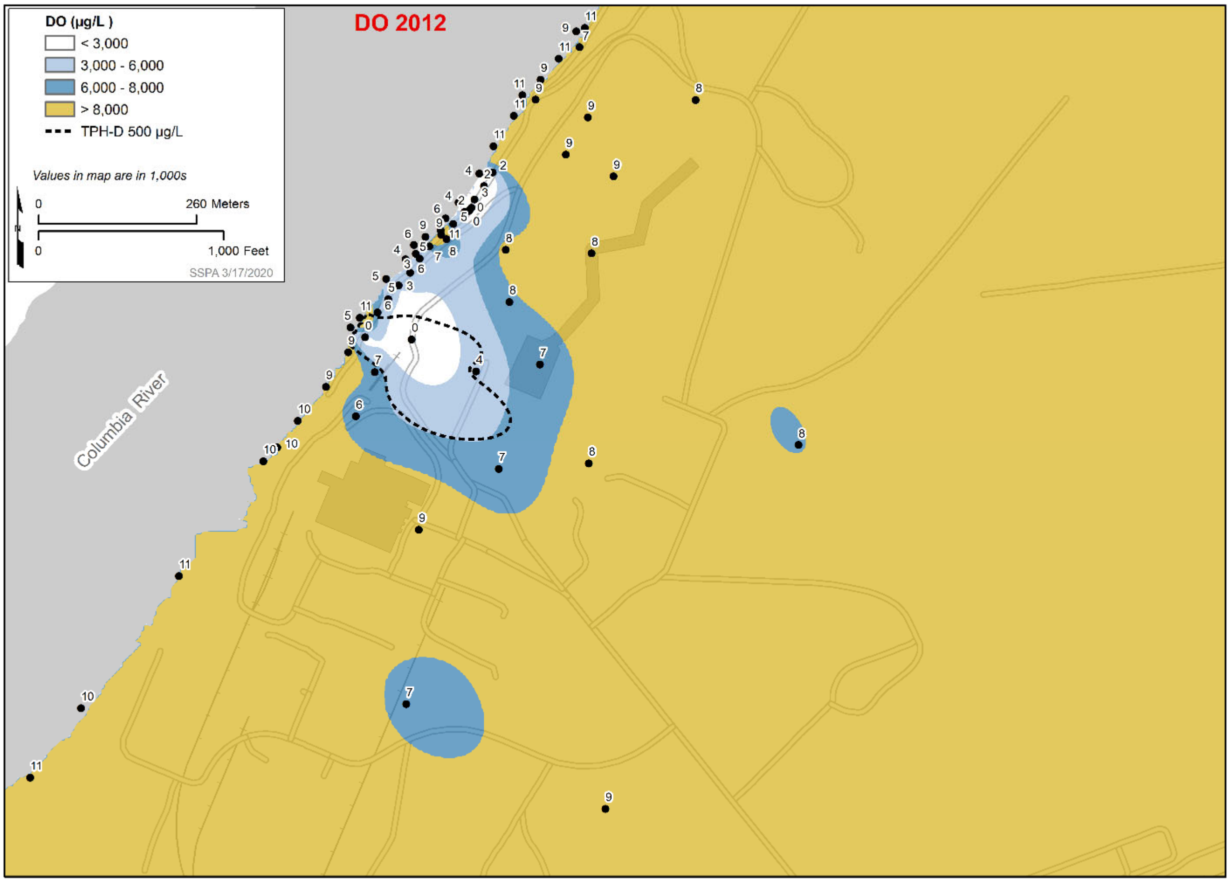

ORP 2019
ORP (mV)
< -150
-150 - -50
-50 - 50
50 - 150
> 150
TPH-D 500 µg/L
0
260 Meters
0
1,000 Feet
SSPA 3/17/2020
Columbia River

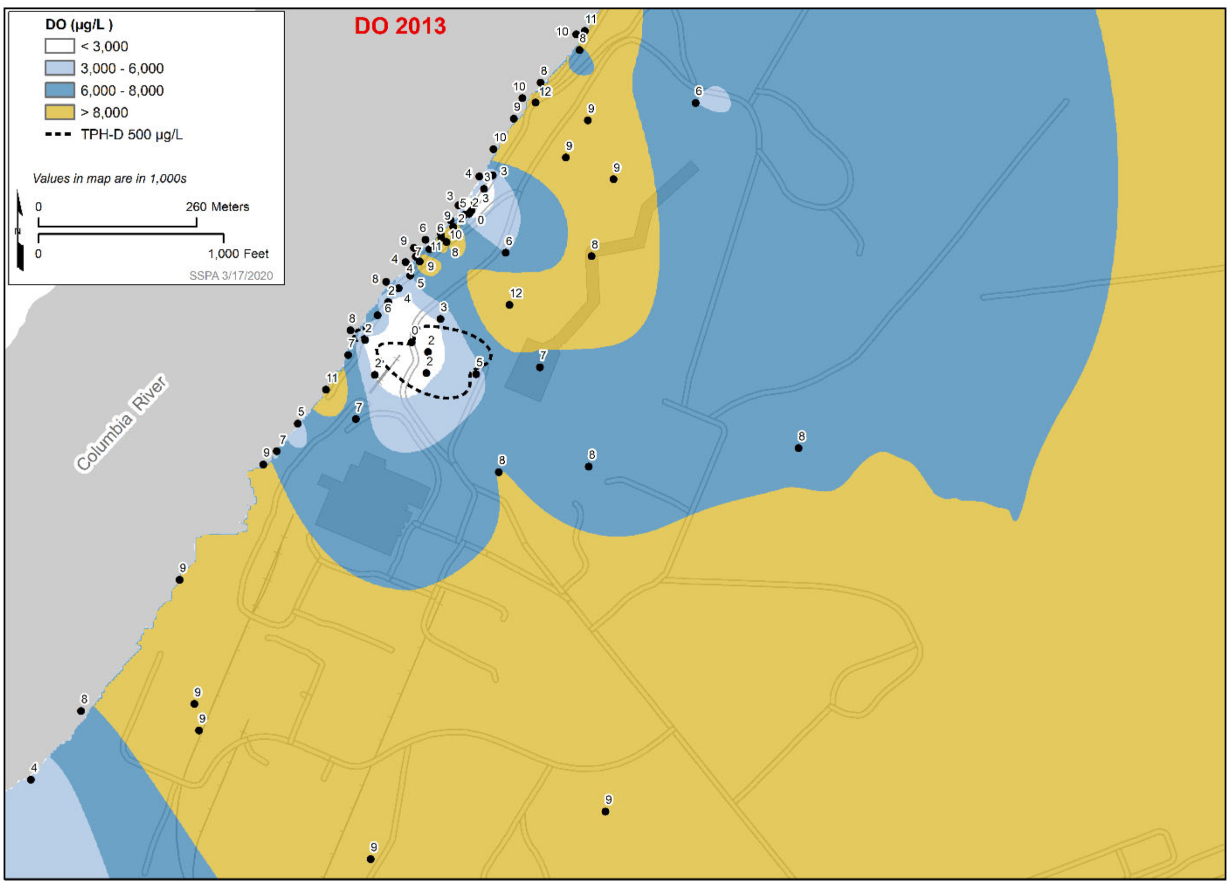
DO


DO 2010
DO (µg/L)
< 3,000
3,000 - 6,000
6,000 - 8,000
> 8,000
TPH-D 500 µg/L
Values in map are in 1,000s
0
260 Meters
0
1,000 Feet
SSPA 3/17/2020
Columbia River

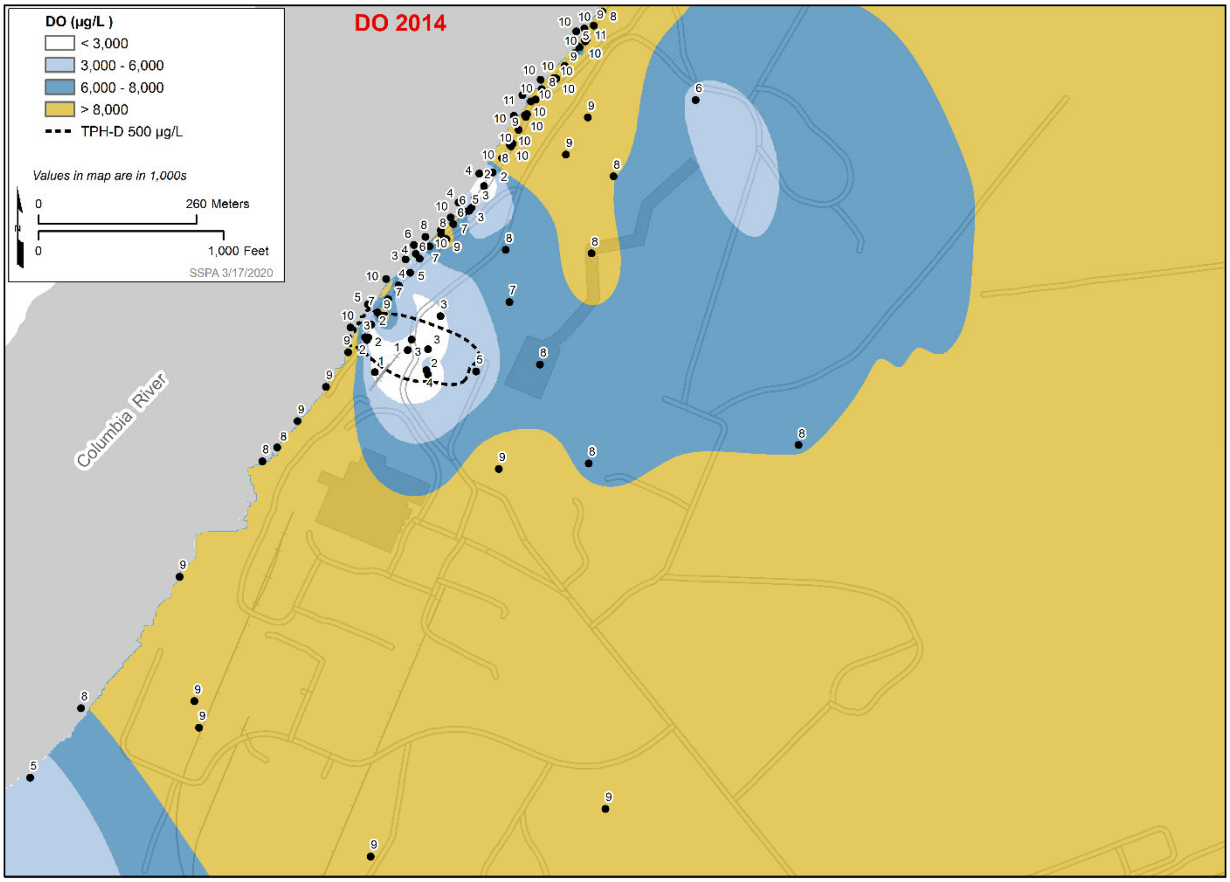

DO 2011
DO (µg/L)
< 3,000
3,000 - 6,000
6,000 - 8,000
> 8,000
TPH-D 500 µg/L
Values in map are in 1,000s
0
260 Meters
0
1,000 Feet
SSPA 3/17/2020
Columbia River

DO


DO 2012
DO (µg/L)
< 3,000
3,000 - 6,000
6,000 - 8,000
> 8,000
TPH-D 500 µg/L
Values in map are in 1,000s
0
260 Meters
0
1,000 Feet
SSPA 3/17/2020
Columbia River


DO 2013
DO (µg/L)
< 3,000
3,000 - 6,000
6,000 - 8,000
> 8,000
TPH-D 500 µg/L
Values in map are in 1,000s
0
260 Meters
0
1,000 Feet
SSPA 3/17/2020
Columbia River

DO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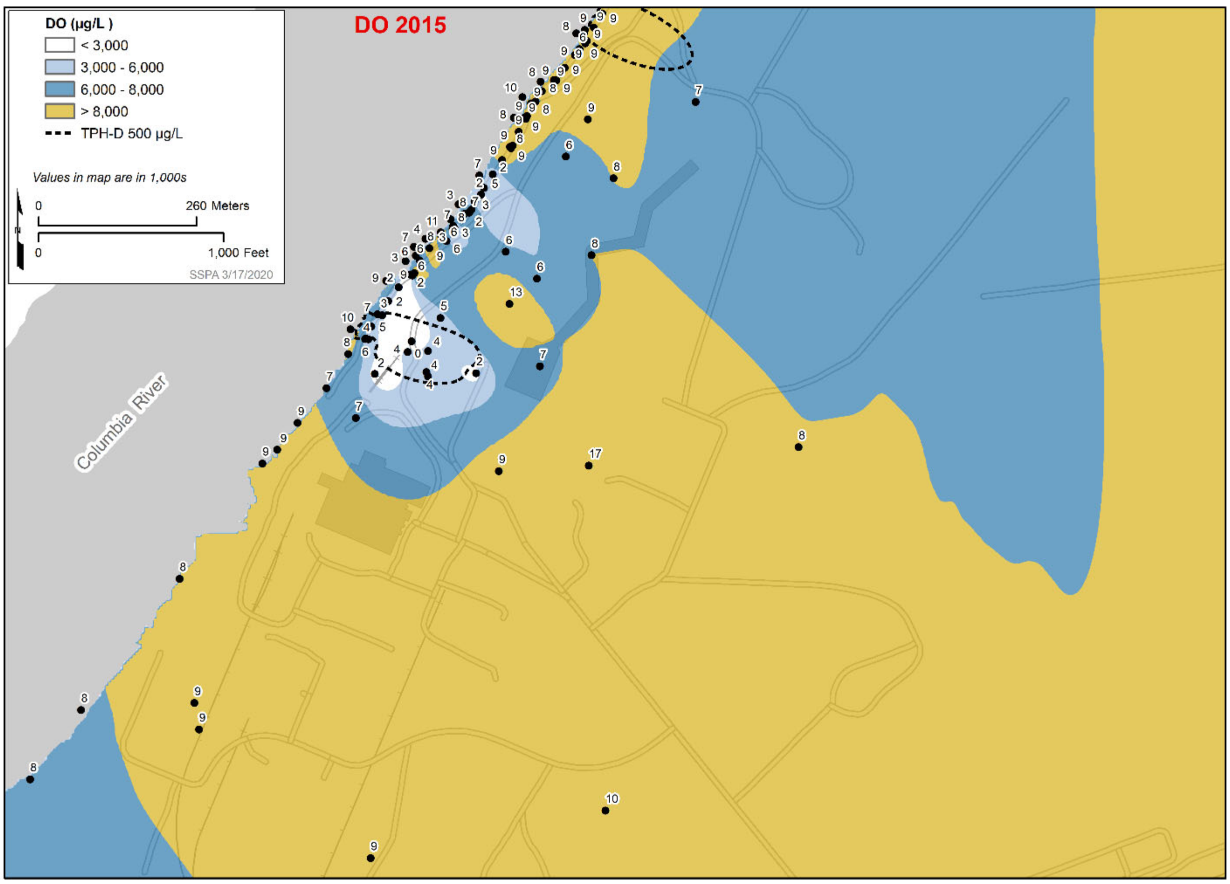
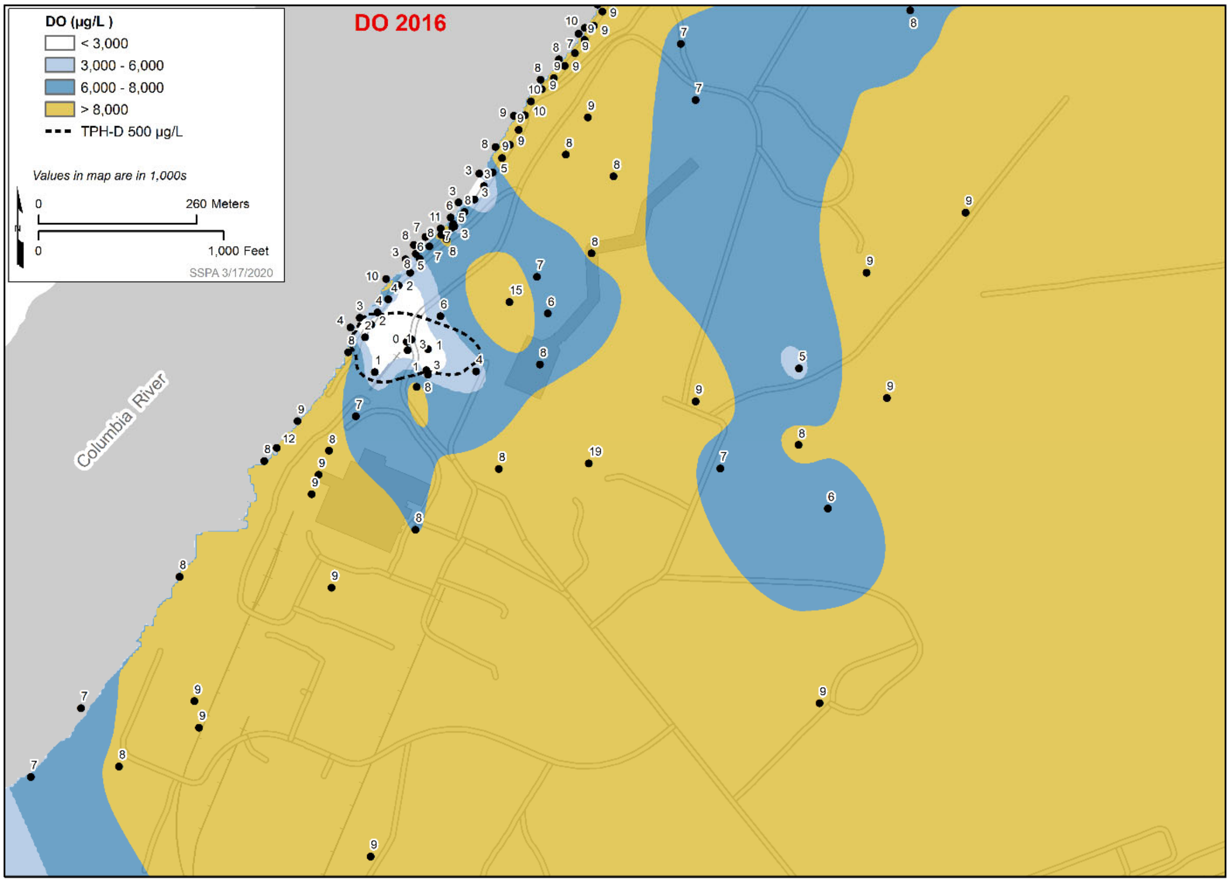
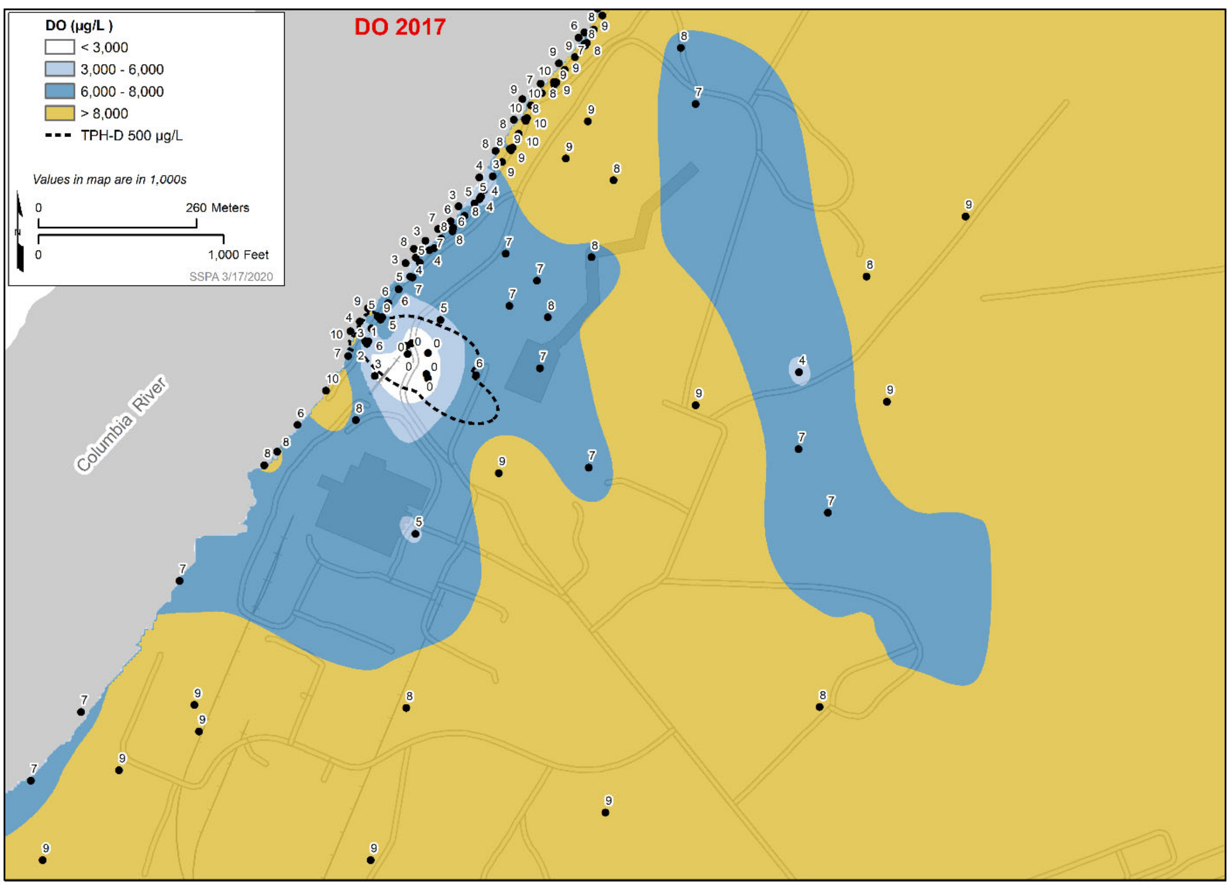
DO (µg/L)
< 3,000
3,000 - 6,000
6,000 - 8,000
> 8,000
TPH-D 500 µg/L
Values in map are in 1,000s
0
260 Meters
0
1,000 Feet
SSPA 3/17/2020
Columbia River

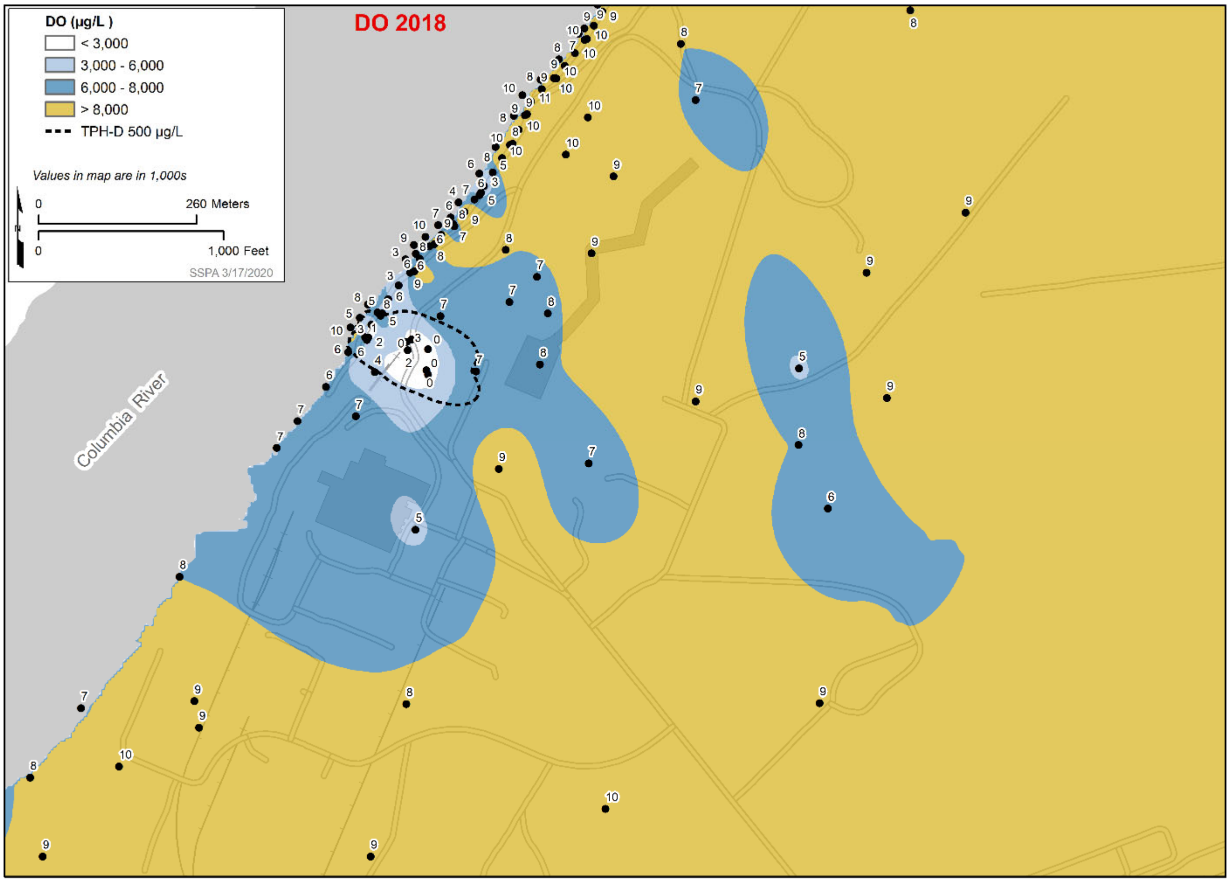

DO 2015
DO (µg/L)
< 3,000
3,000 - 6,000
6,000 - 8,000
> 8,000
TPH-D 500 µg/L
Values in map are in 1,000s
0
260 Meters
0
1,000 Feet
SSPA 3/17/2020
Columbia River

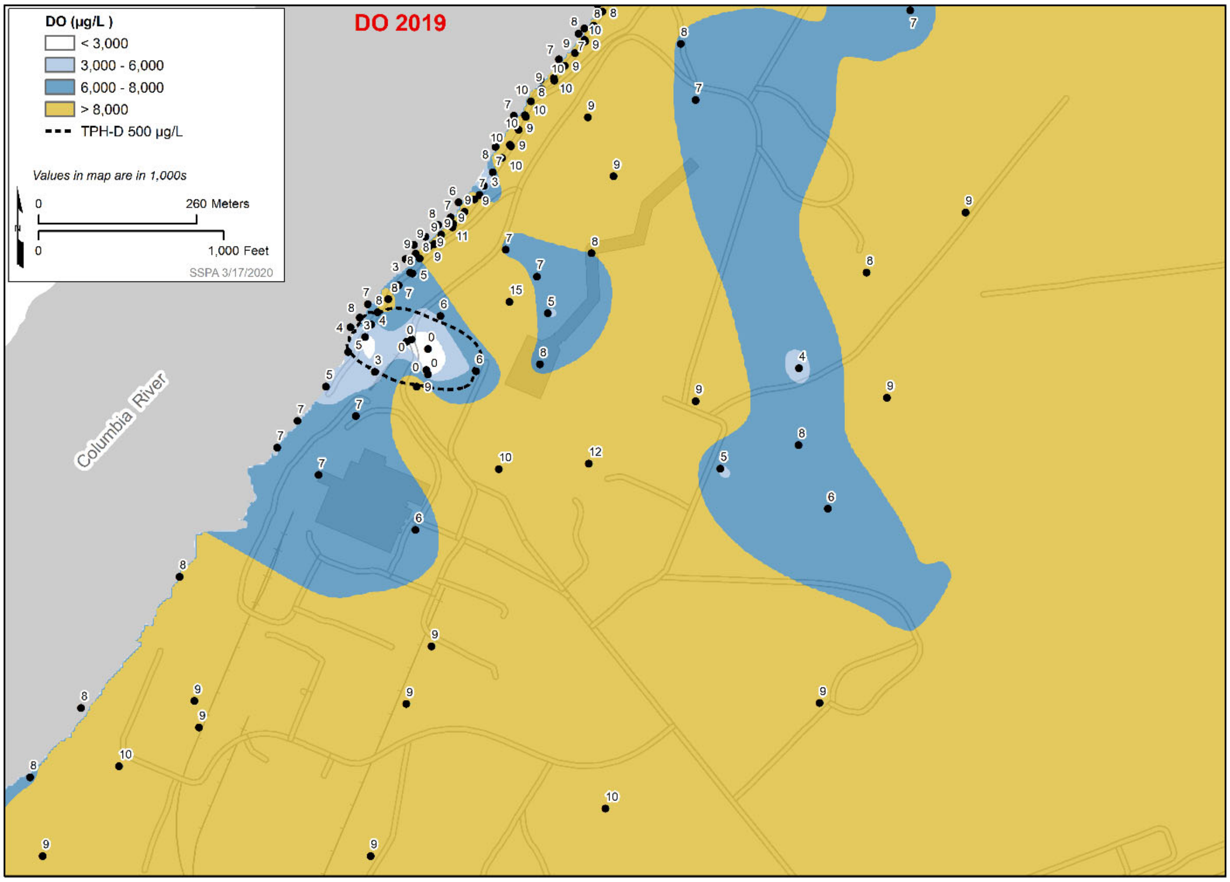
DO


DO 2016
DO (µg/L)
< 3,000
3,000 - 6,000
6,000 - 8,000
> 8,000
TPH-D 500 µg/L
Values in map are in 1,000s
0
260 Meters
0
1,000 Feet
SSPA 3/17/2020
Columbia River

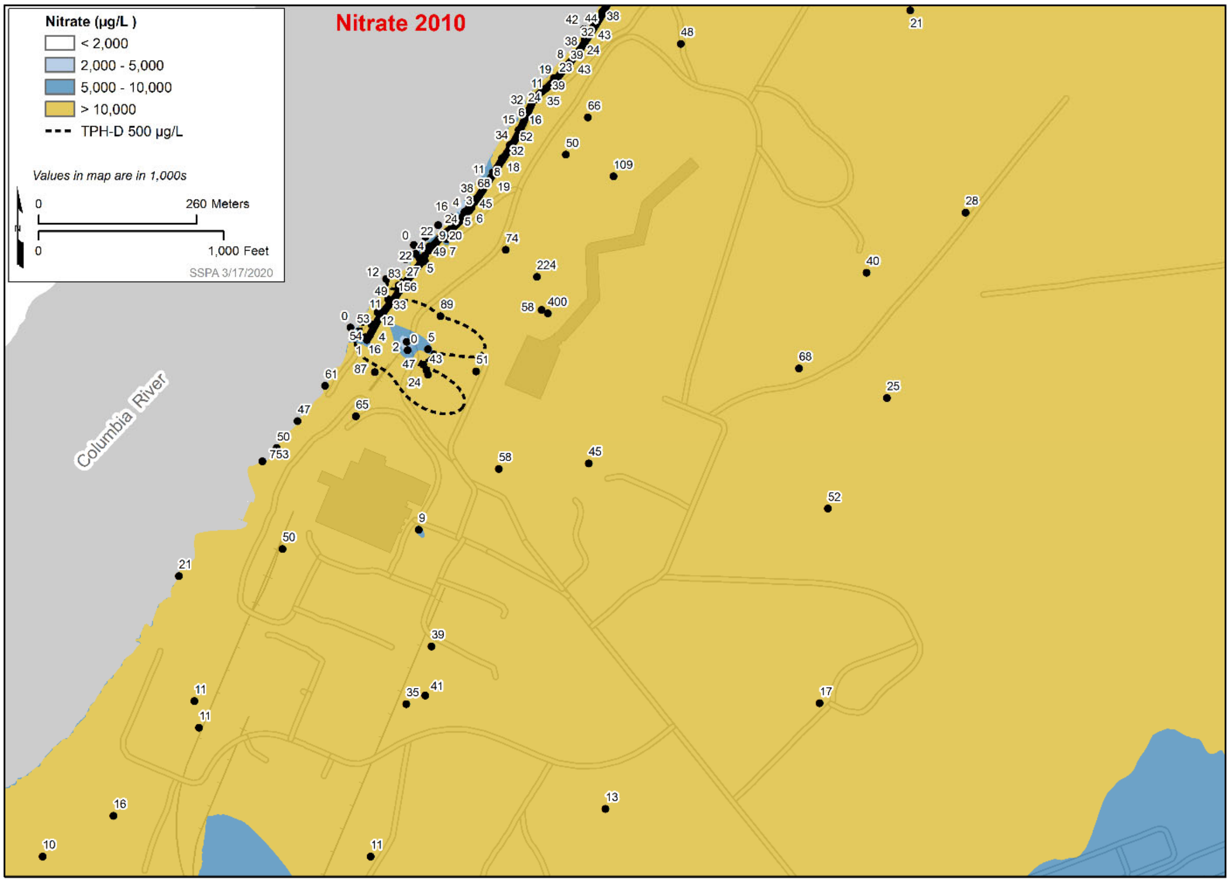

DO 2017
DO (µg/L)
< 3,000
3,000 - 6,000
6,000 - 8,000
> 8,000
TPH-D 500 µg/L
Values in map are in 1,000s
0
260 Meters
0
1,000 Feet
SSPA 3/17/2020
Columbia River

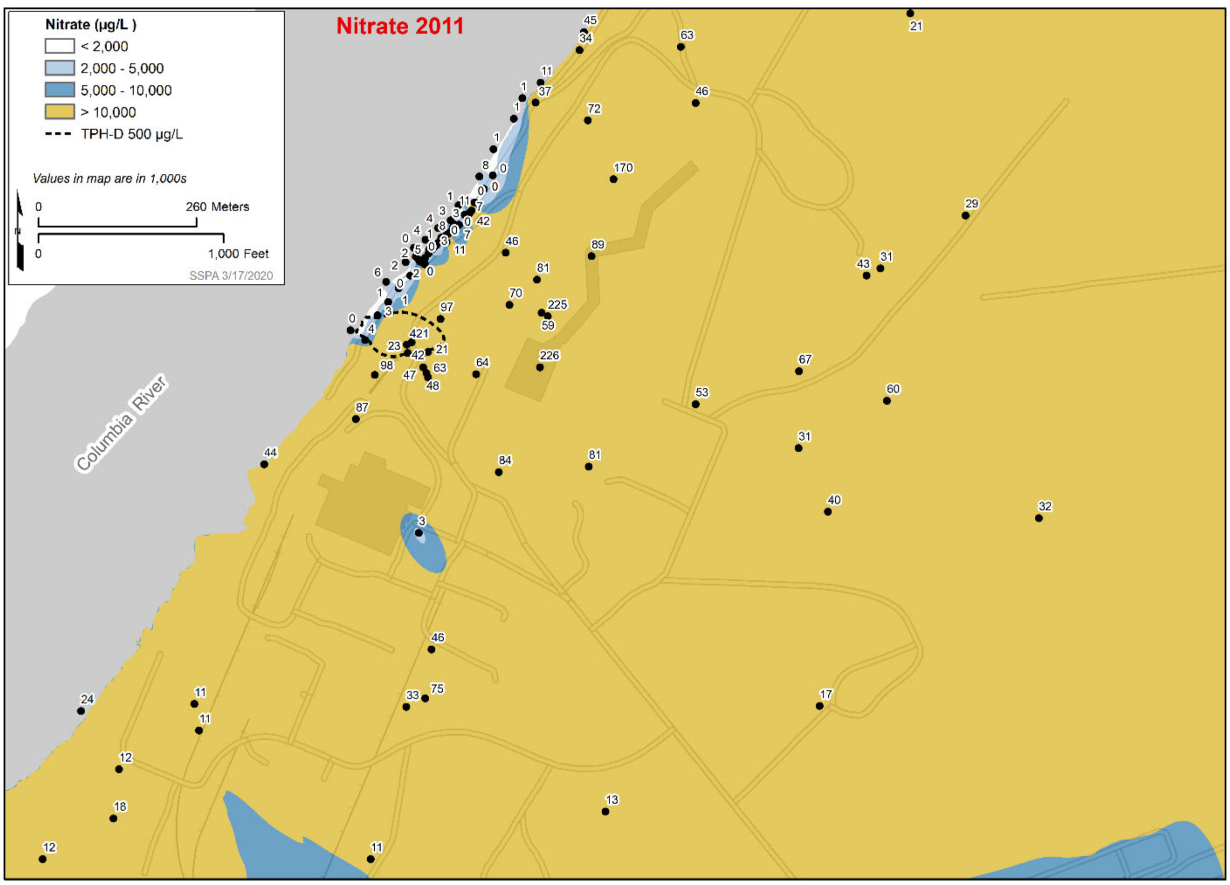
DO


DO 2018
DO (µg/L)
< 3,000
3,000 - 6,000
6,000 - 8,000
> 8,000
TPH-D 500 µg/L
Values in map are in 1,000s
0
260 Meters
0
1,000 Feet
SSPA 3/17/2020
Columbia River

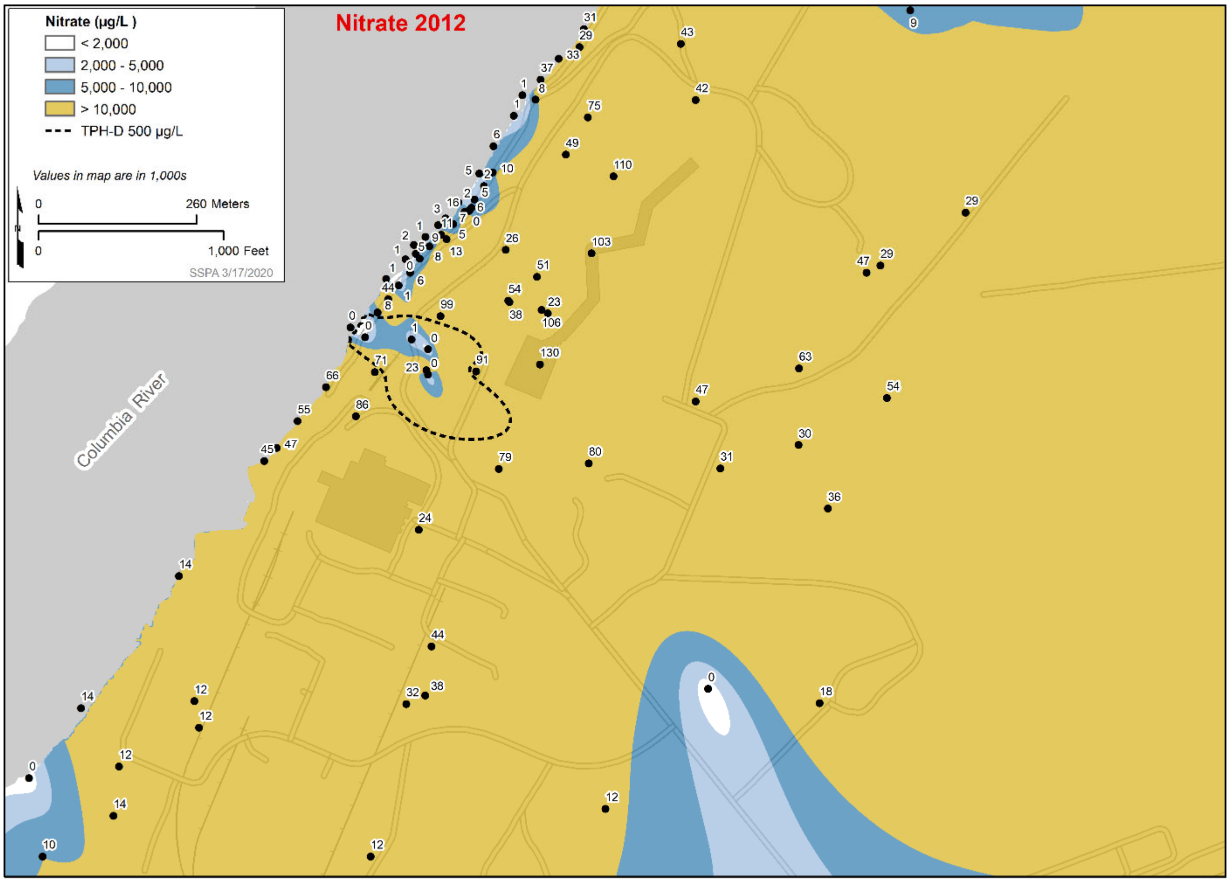

DO 2019
DO (µg/L)
< 3,000
3,000 - 6,000
6,000 - 8,000
> 8,000
TPH-D 500 µg/L
Values in map are in 1,000s
0
260 Meters
0
1,000 Feet
SSPA 3/17/2020
Columbia River

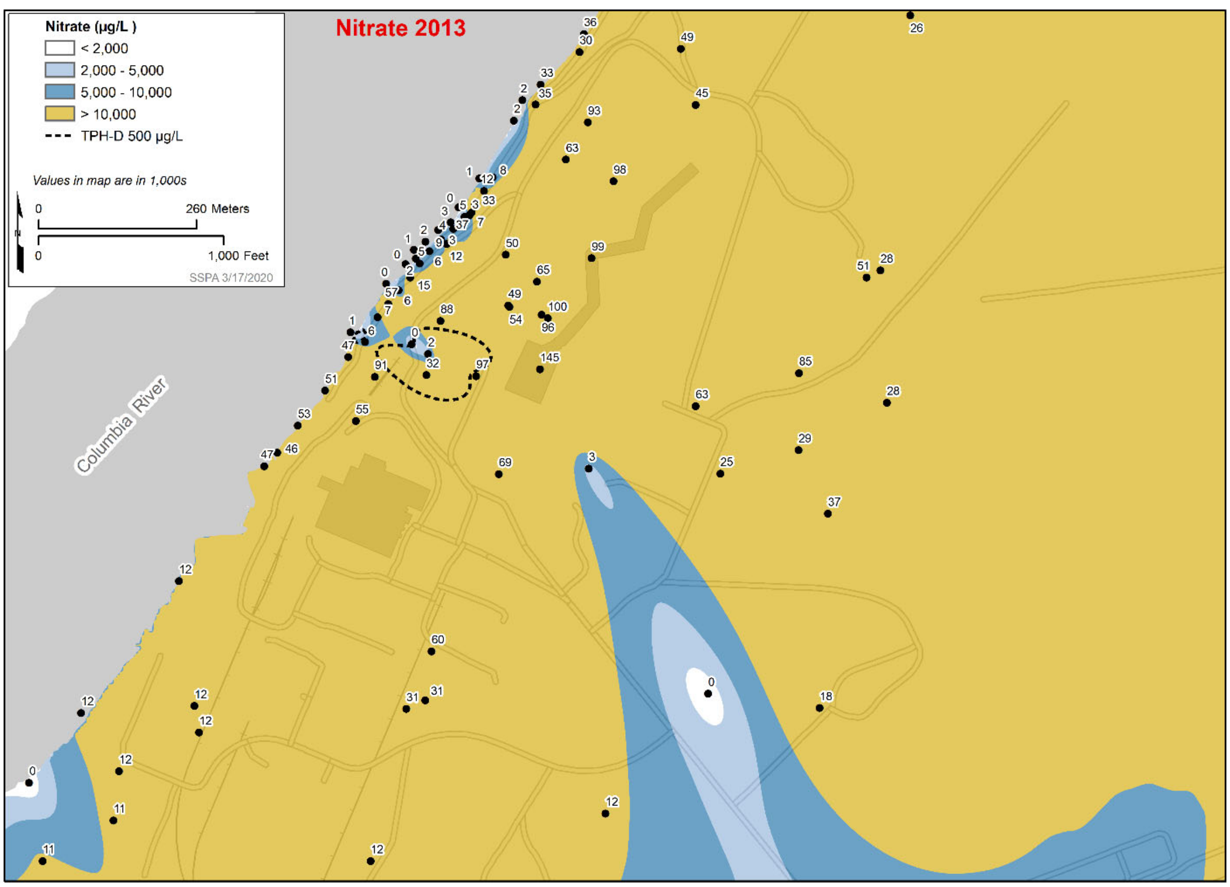
Nitrate


Nitrate 2010
Nitrate (µg/L)
< 2,000
2,000 - 5,000
5,000 - 10,000
> 10,000
TPH-D 500 µg/L
Values in map are in 1,000s
0 260 Meters
0 1,000 Feet
SSPA 3/17/2020
Columbia River

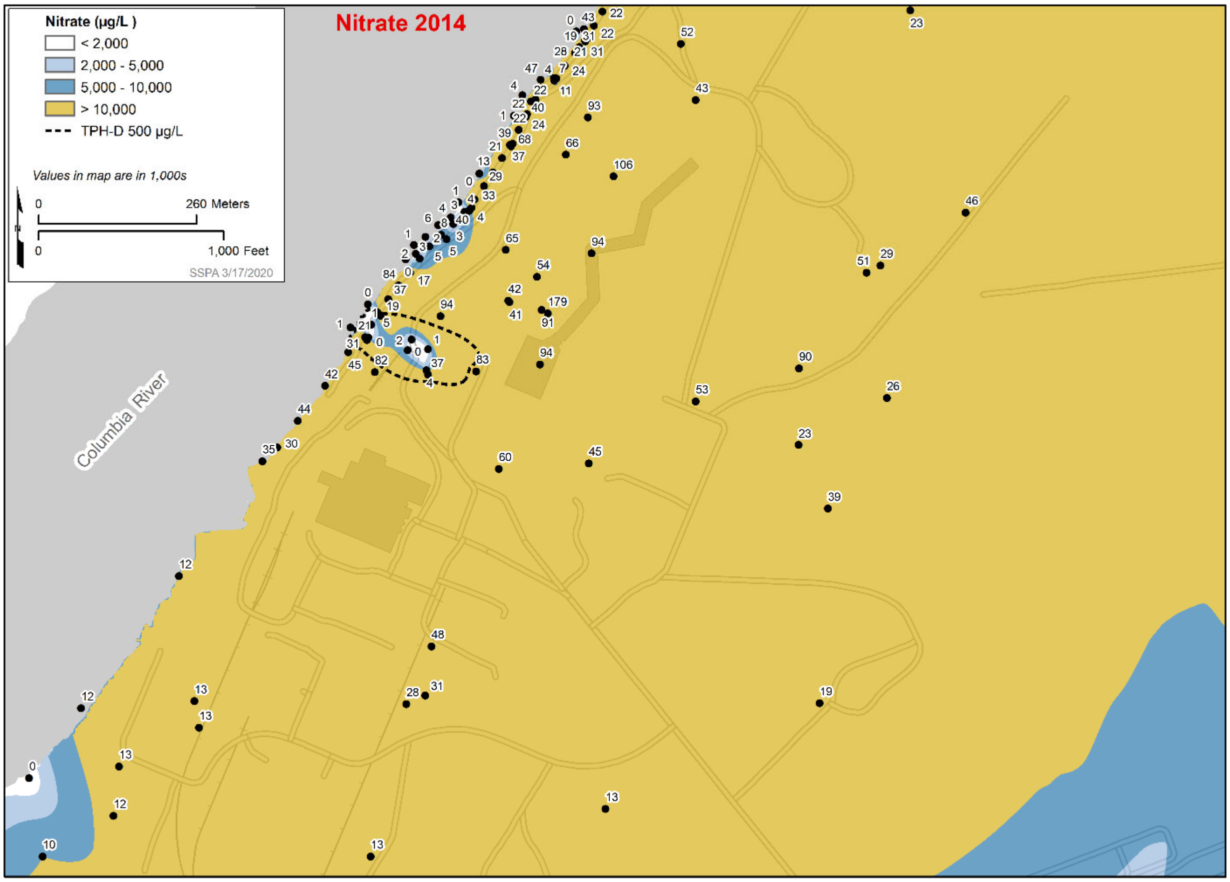

Nitrate 2011
Nitrate (µg/L)
< 2,000
2,000 - 5,000
5,000 - 10,000
> 10,000
TPH-D 500 µg/L
Values in map are in 1,000s
0 260 Meters
0 1,000 Feet
SSPA 3/17/2020
Columbia River

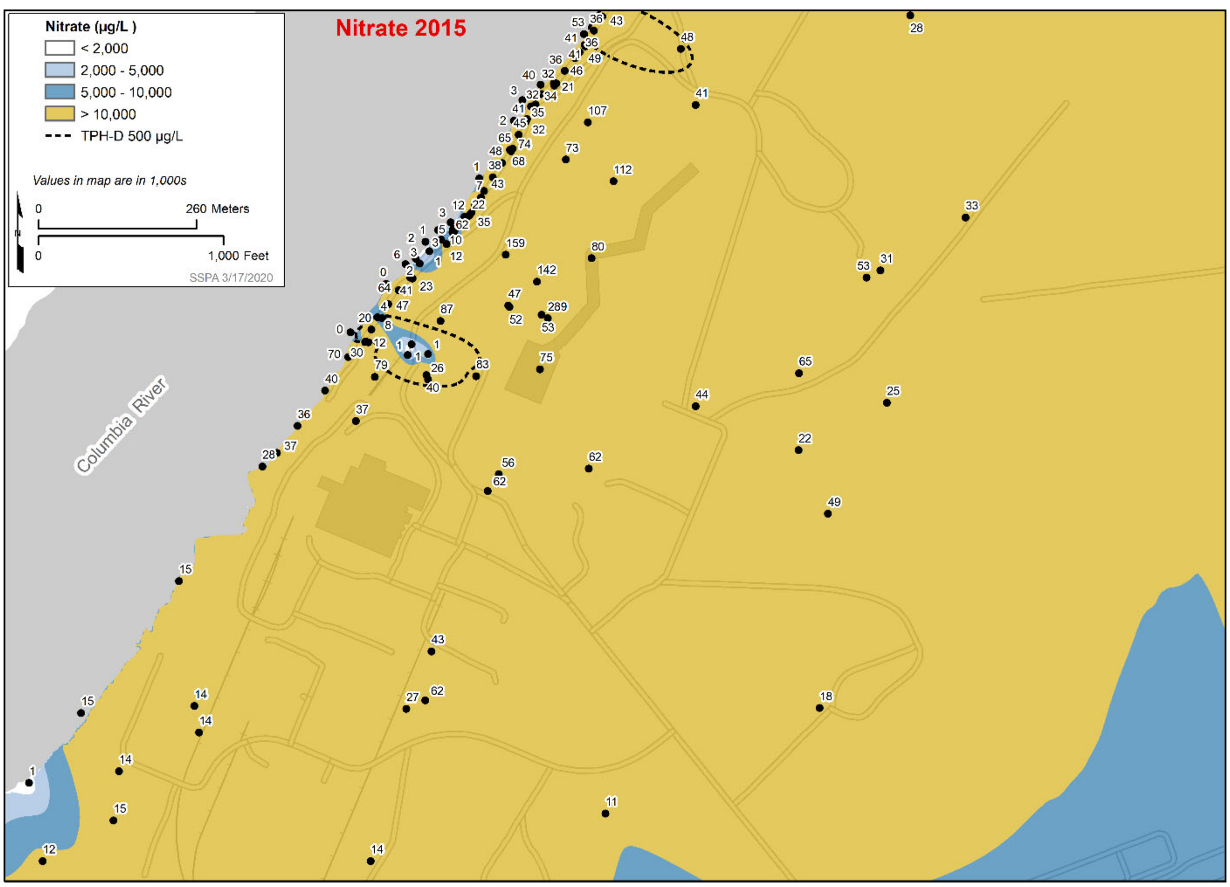
Nitrate


Nitrate 2012
Nitrate (µg/L)
< 2,000
2,000 - 5,000
5,000 - 10,000
> 10,000
TPH-D 500 µg/L
Values in map are in 1,000s
0 260 Meters
0 1,000 Feet
SSPA 3/17/2020
Columbia River

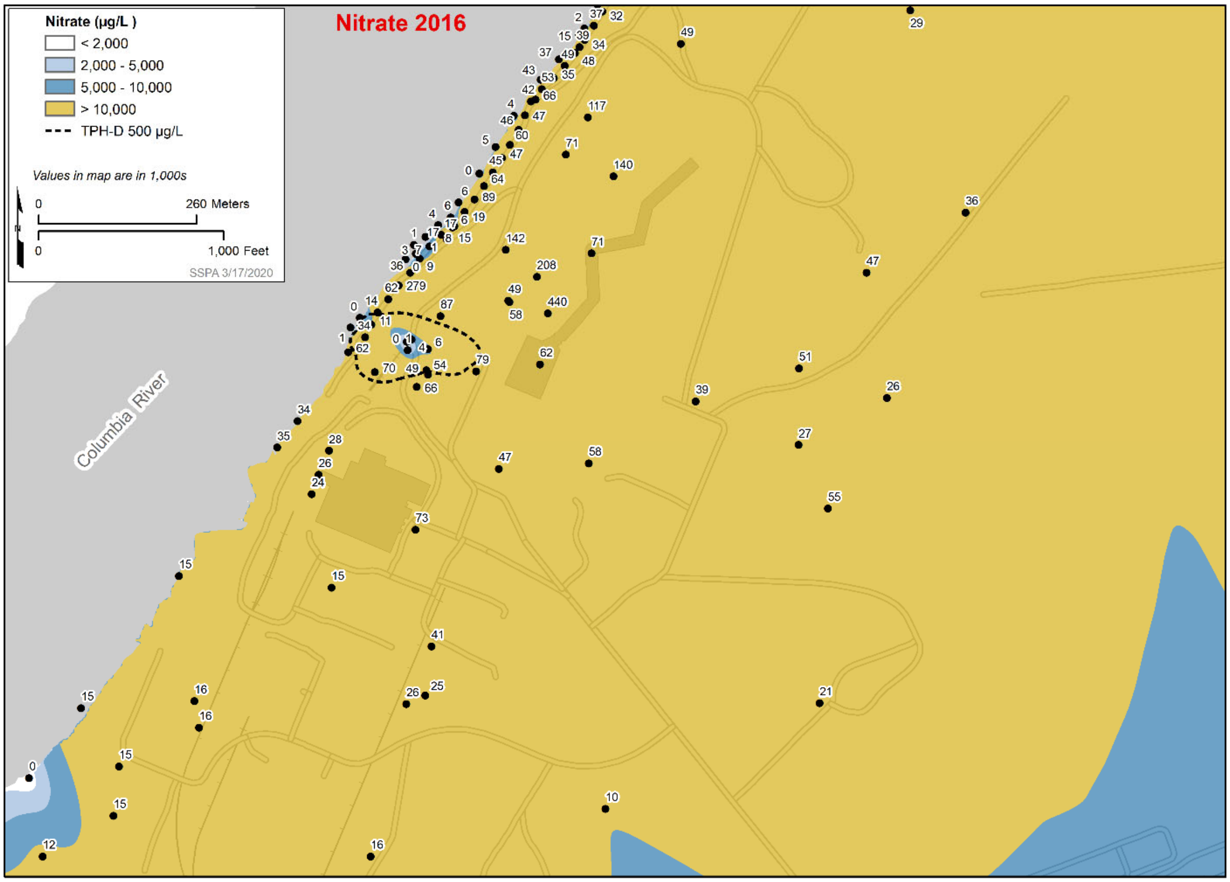

Nitrate 2013
Nitrate (µg/L)
< 2,000
2,000 - 5,000
5,000 - 10,000
> 10,000
TPH-D 500 µg/L
Values in map are in 1,000s
0 260 Meters
0 1,000 Feet
SSPA 3/17/2020
Columbia River

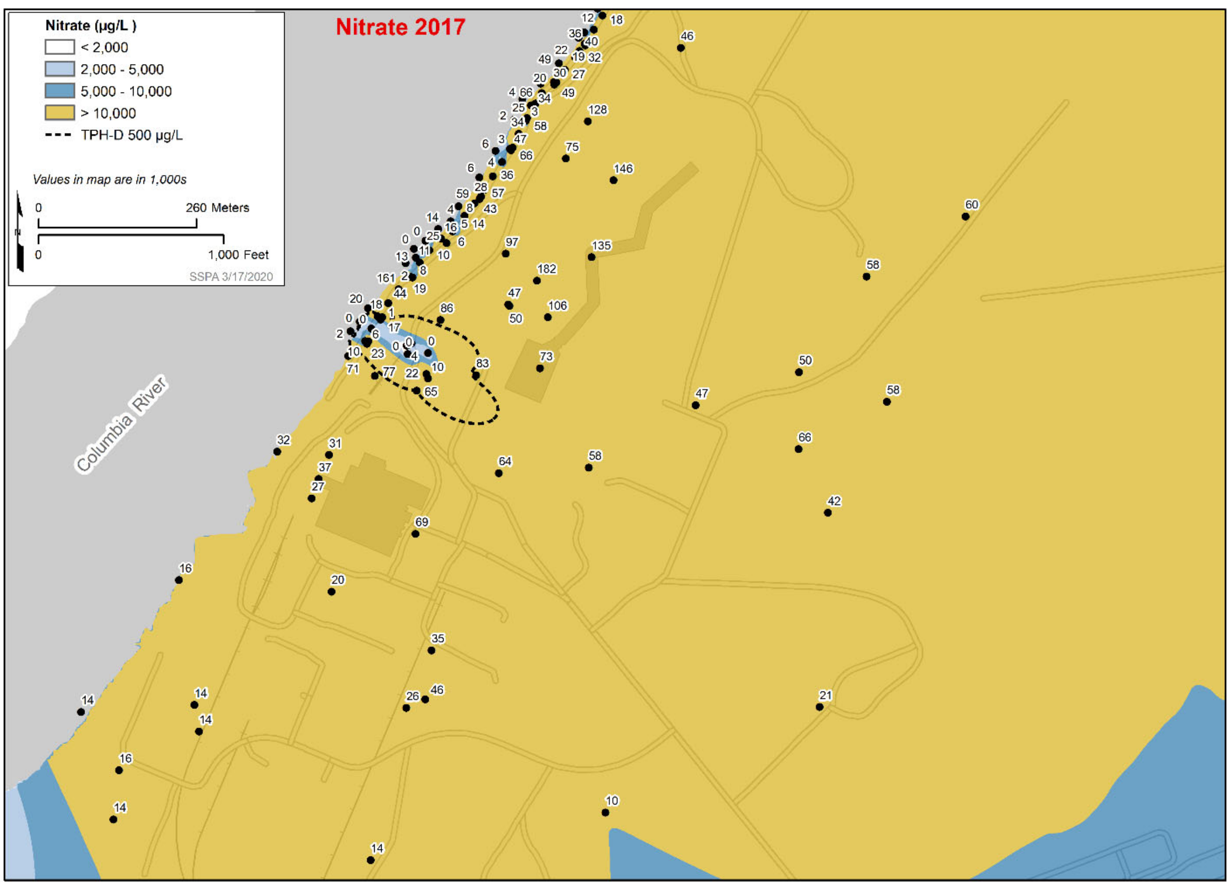
Nitrate


Nitrate 2014
Nitrate (µg/L)
< 2,000
2,000 - 5,000
5,000 - 10,000
> 10,000
TPH-D 500 µg/L
Values in map are in 1,000s
0
260 Meters
0
1,000 Feet
SSPA 3/17/2020
Columbia River

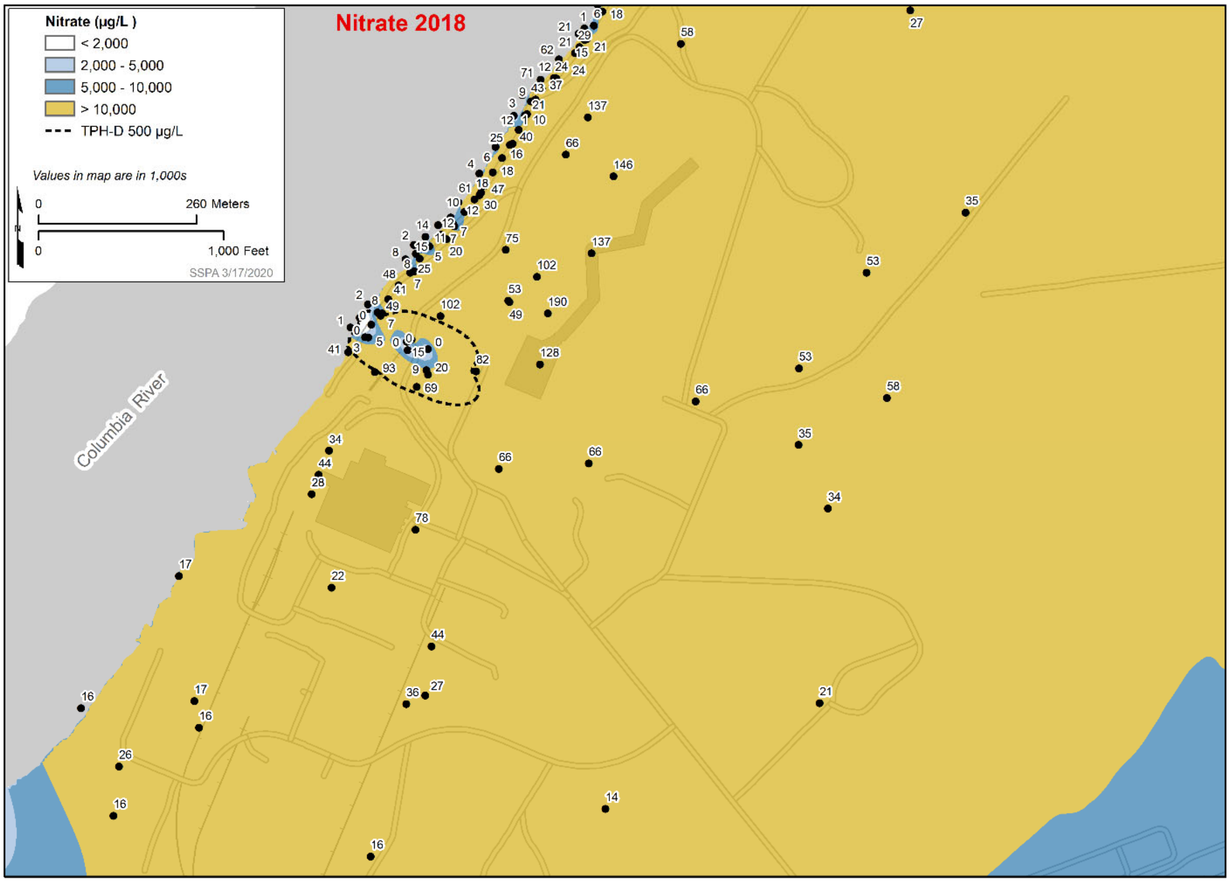

Nitrate 2015
Nitrate (µg/L)
< 2,000
2,000 - 5,000
5,000 - 10,000
> 10,000
TPH-D 500 µg/L
Values in map are in 1,000s
0
260 Meters
0
1,000 Feet
SSPA 3/17/2020
Columbia River

Nitrate


Nitrate 2016
Nitrate (µg/L)
< 2,000
2,000 - 5,000
5,000 - 10,000
> 10,000
TPH-D 500 µg/L
Values in map are in 1,000s
0 260 Meters
0 1,000 Feet
SSPA 3/17/2020
Columbia River


Nitrate 2017
Nitrate (µg/L)
< 2,000
2,000 - 5,000
5,000 - 10,000
> 10,000
TPH-D 500 µg/L
Values in map are in 1,000s
0 260 Meters
0 1,000 Feet
SSPA 3/17/2020
Columbia River

Nitrate


Nitrate 2018
Nitrate (µg/L)
< 2,000
2,000 - 5,000
5,000 - 10,000
> 10,000
TPH-D 500 µg/L
Values in map are in 1,000s
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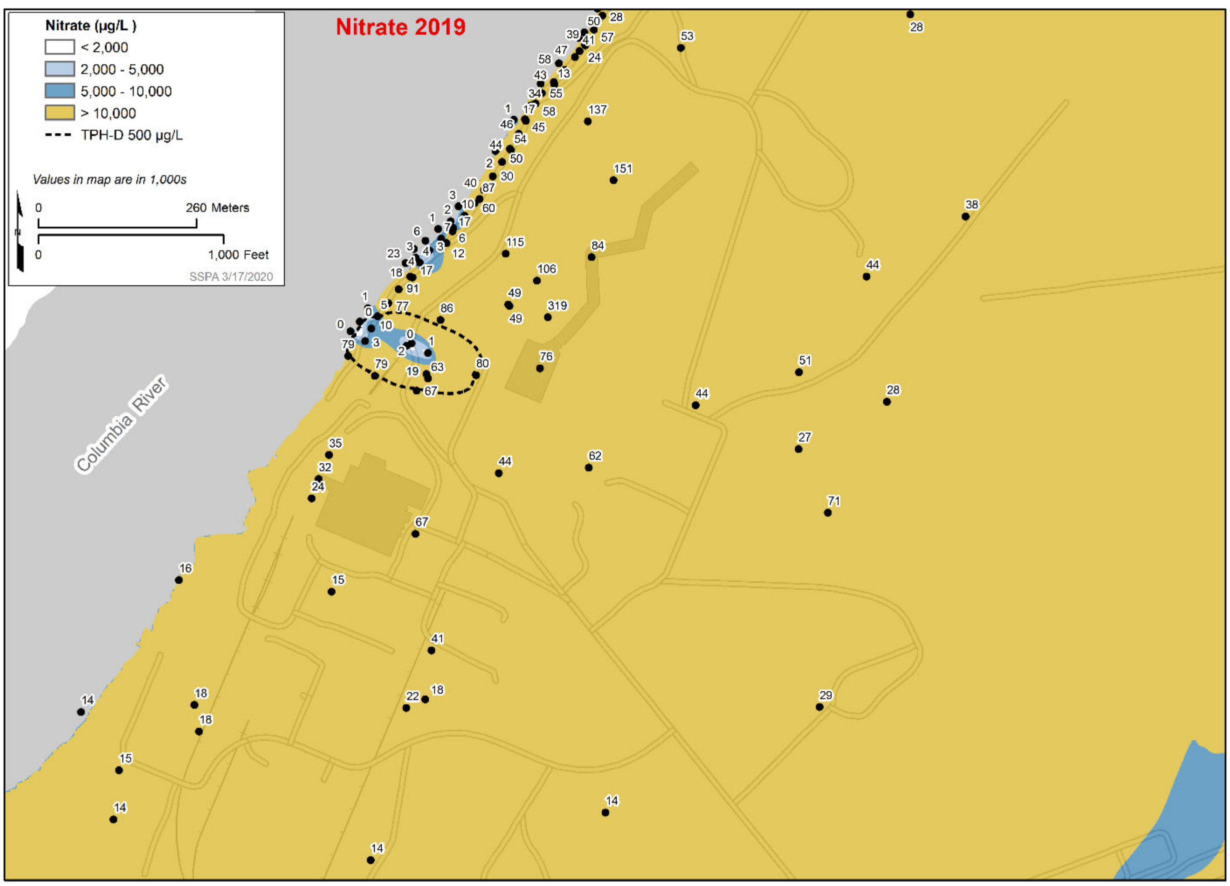
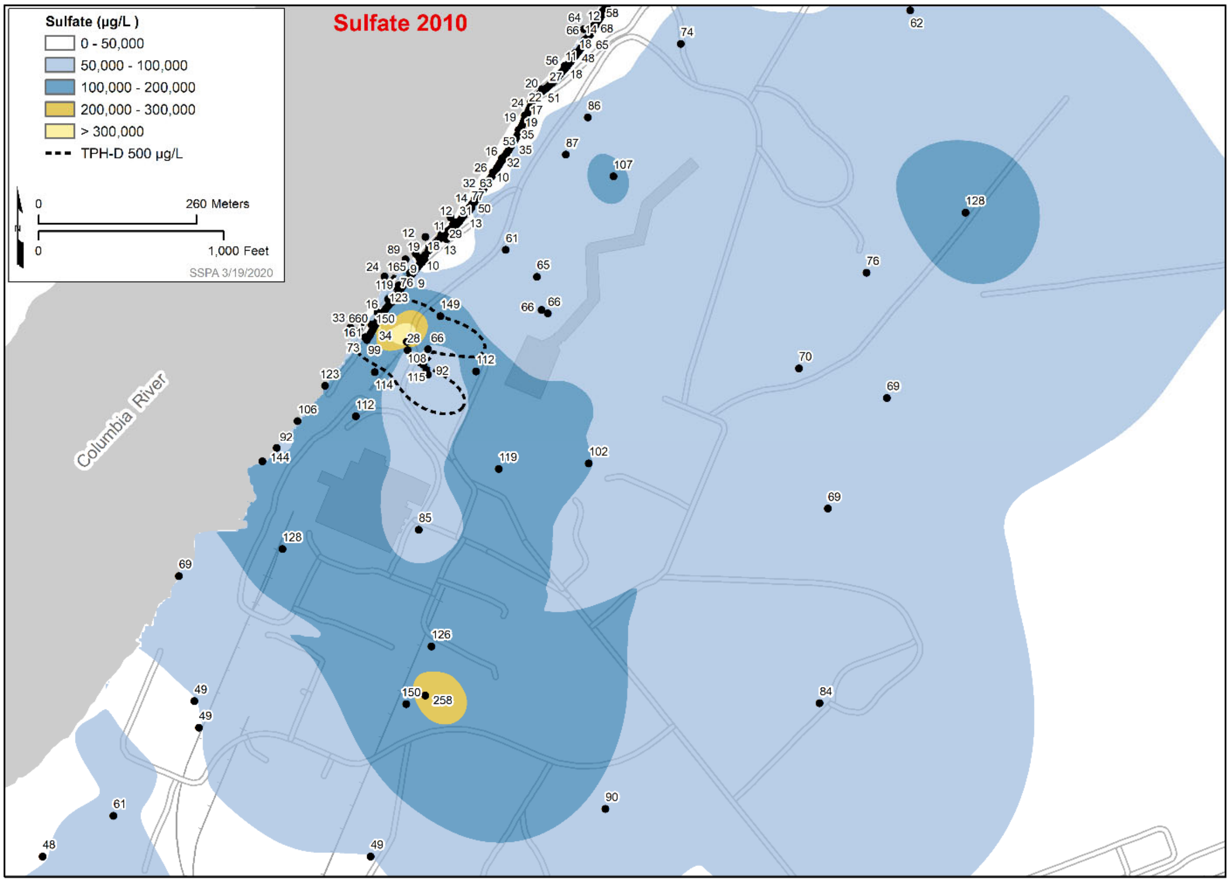
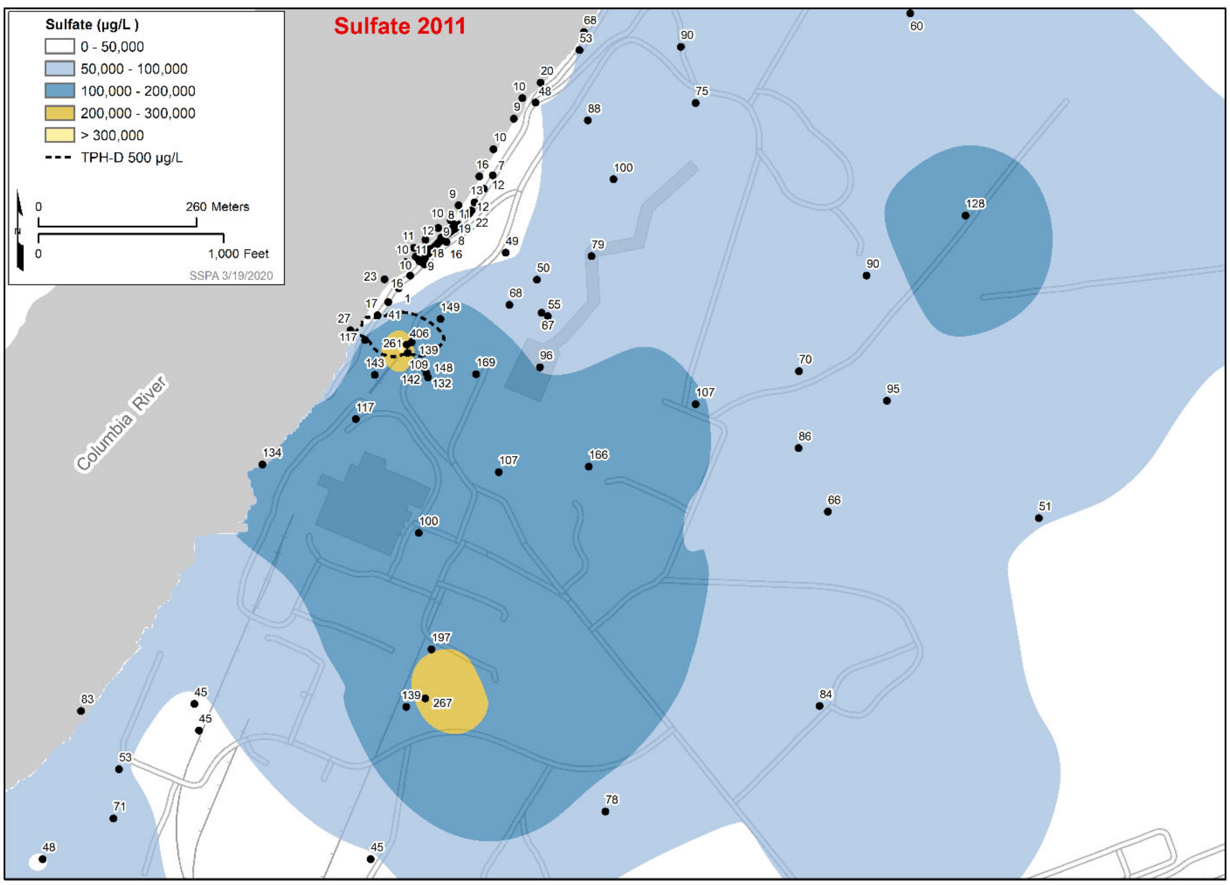
260 Meters
0
1,000 Feet
SSPA 3/17/2020
Columbia River

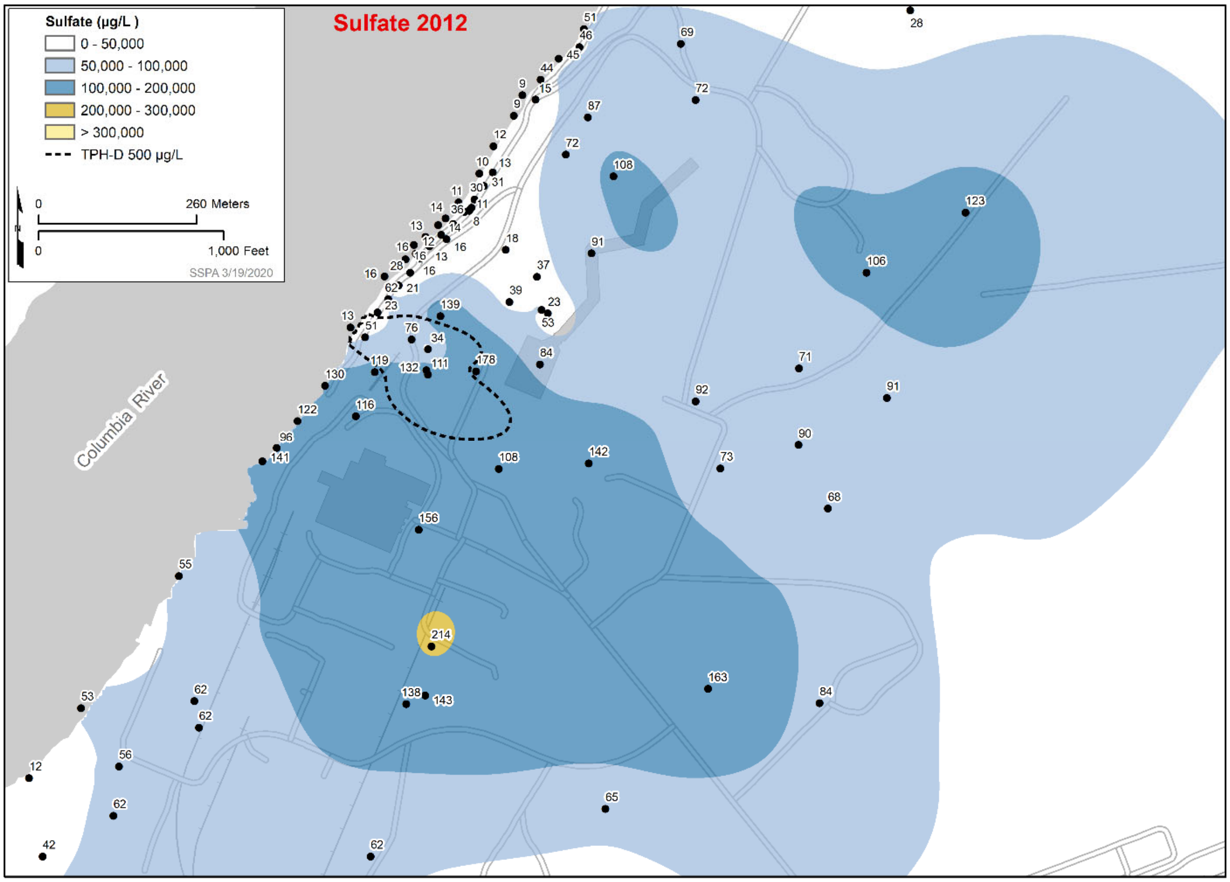

Nitrate 2019
Nitrate (µg/L)
< 2,000
2,000 - 5,000
5,000 - 10,000
> 10,000
TPH-D 500 µg/L
Values in map are in 1,000s
0
260 Meters
0
1,000 Feet
SSPA 3/17/2020
Columbia River

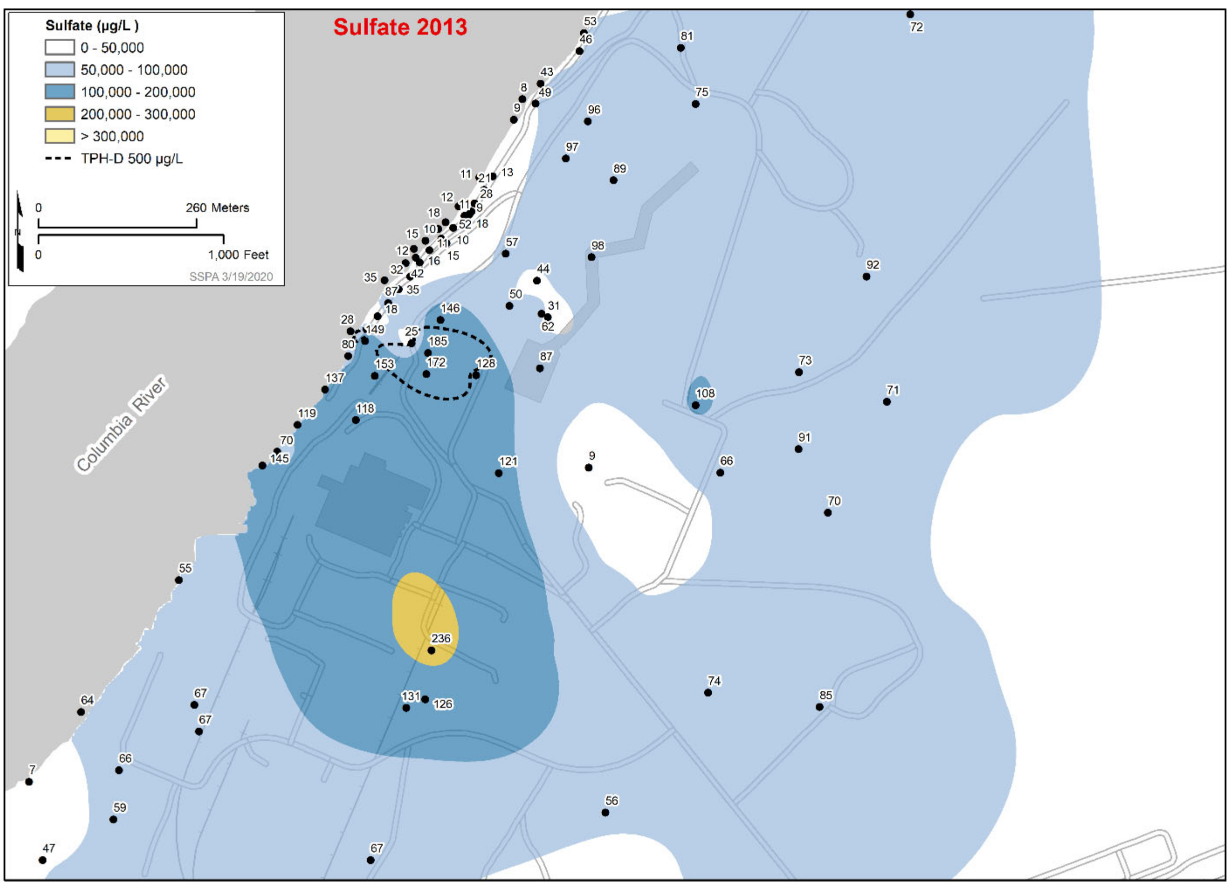
Sulfate


Sulfate (µg/L)
0 - 50,000
50,000 - 100,000
100,000 - 200,000
200,000 - 300,000
> 300,000
TPH-D 500 µg/L
0
260 Meters
0
1,000 Feet
SSPA 3/19/2020
Sulfate 2010
Columbia River


Sulfate (µg/L)
0 - 50,000
50,000 - 100,000
100,000 - 200,000
200,000 - 300,000
> 300,000
TPH-D 500 µg/L
0
260 Meters
0
1,000 Feet
SSPA 3/19/2020
Sulfate 2011
Columbia River

Sulfate


Sulfate 2012
Sulfate (µg/L)
0 - 50,000
50,000 - 100,000
100,000 - 200,000
200,000 - 300,000
> 300,000
TPH-D 500 µg/L
0
260 Meters
0
1,000 Feet
SSPA 3/19/2020
Columbia River


Sulfate 2013
Sulfate (µg/L)
0 - 50,000
50,000 - 100,000
100,000 - 200,000
200,000 - 300,000
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TPH-D 500 µg/L
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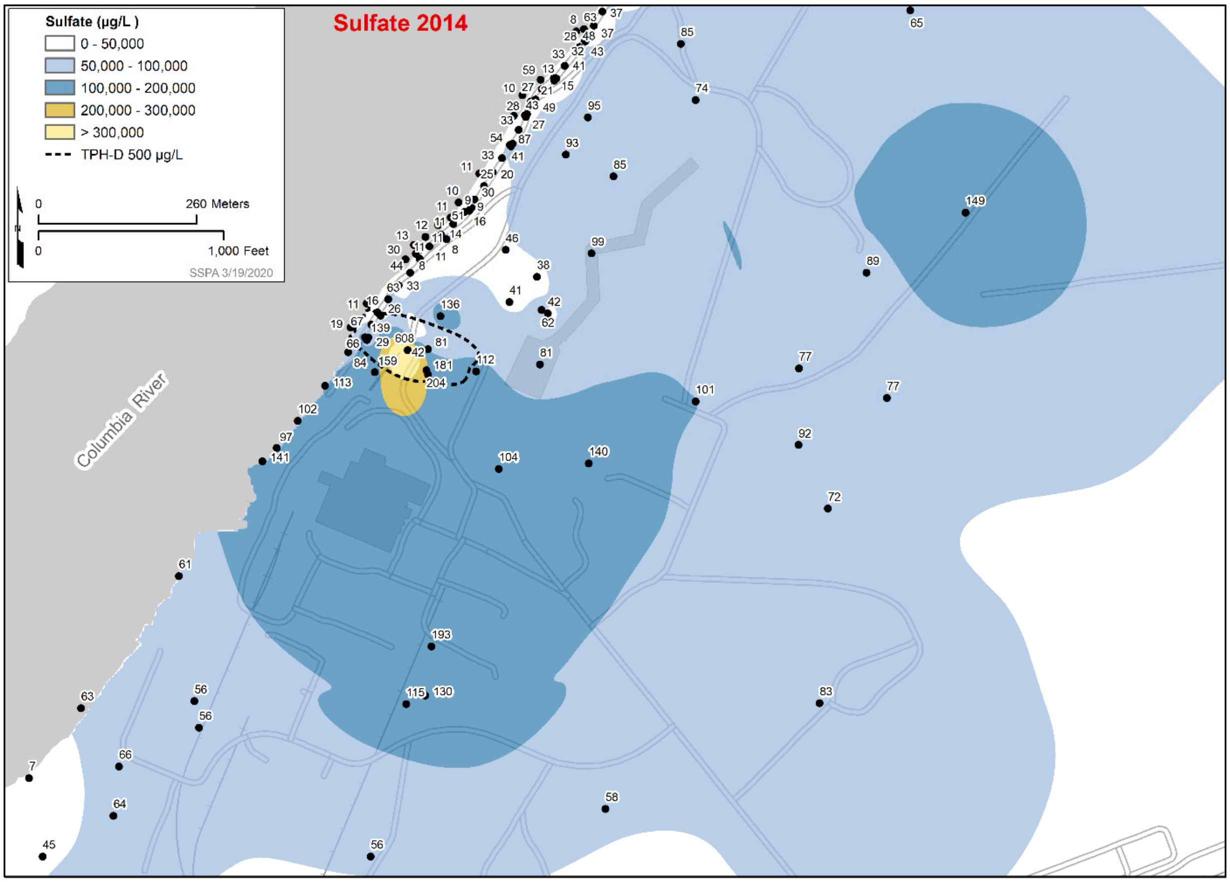
SSPA 3/19/2020
Columbia River

Sulfate


Sulfate 2014
Sulfate (µg/L)
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50,000 - 100,000
100,000 - 200,000
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TPH-D 500 µg/L
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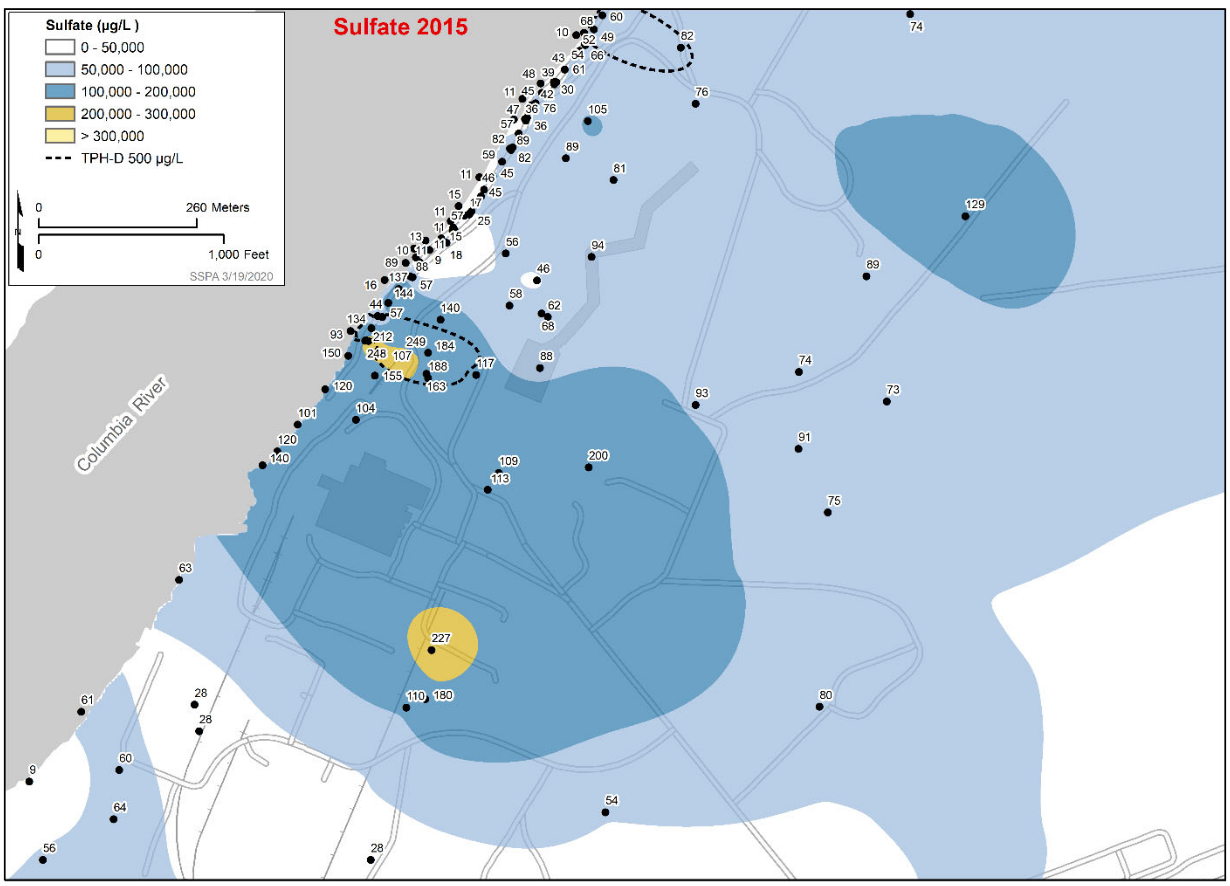
SSPA 3/19/2020
Columbia River


Sulfate 2015
Sulfate (µg/L)
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100,000 - 200,000
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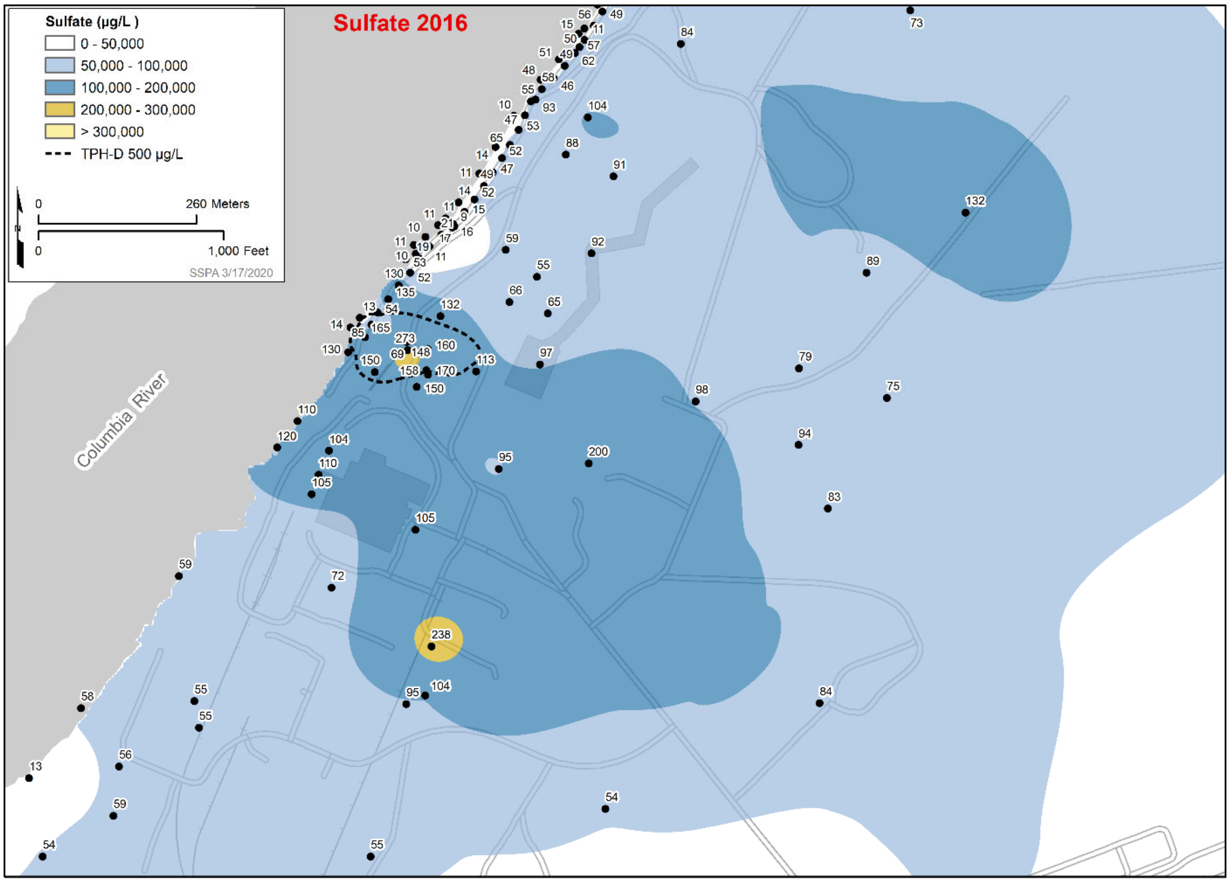
SSPA 3/19/2020
Columbia River

Sulfate


Sulfate 2016
Sulfate (µg/L)
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50,000 - 100,000
100,000 - 200,000
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TPH-D 500 µg/L
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260 Meters
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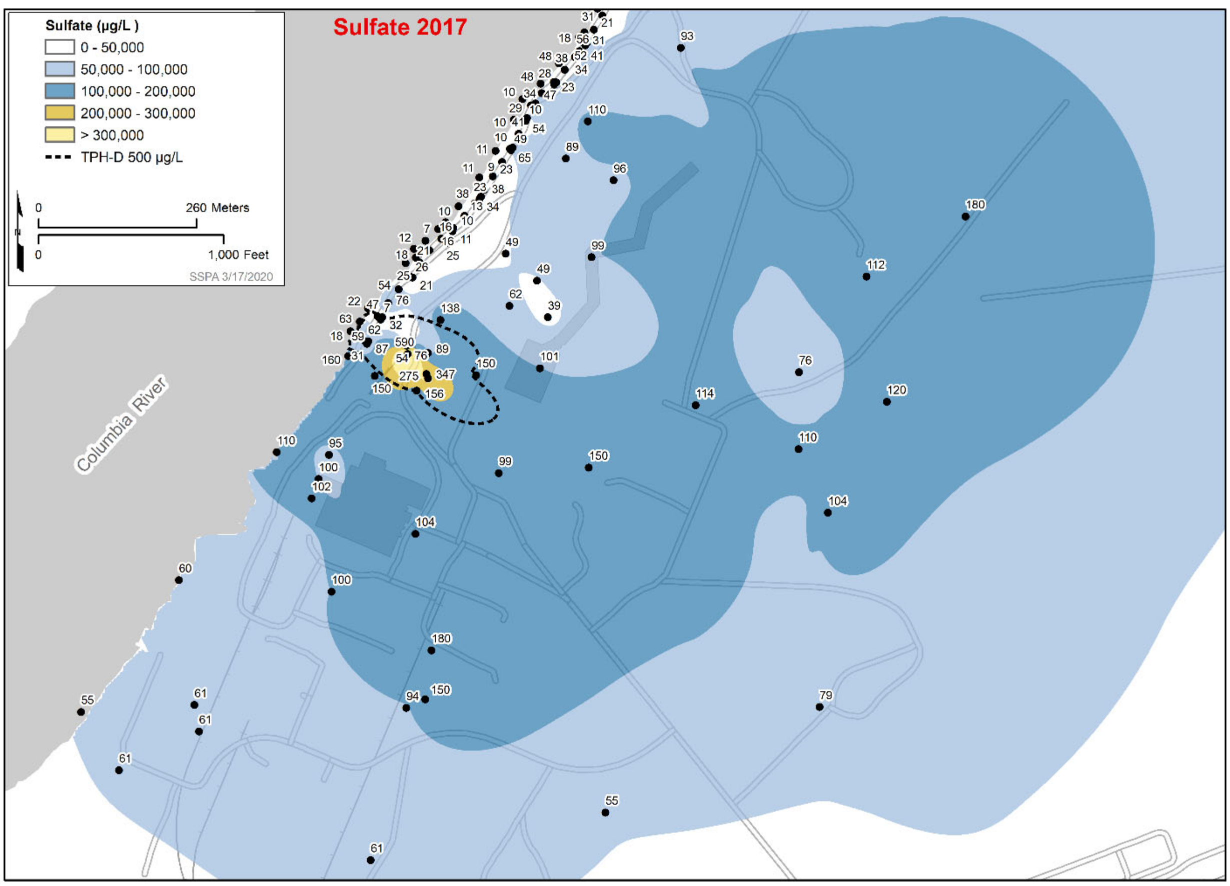
1,000 Feet
SSPA 3/17/2020
Columbia River


Sulfate 2017
Sulfate (µg/L)
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50,000 - 100,000
100,000 - 200,000
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TPH-D 500 µg/L
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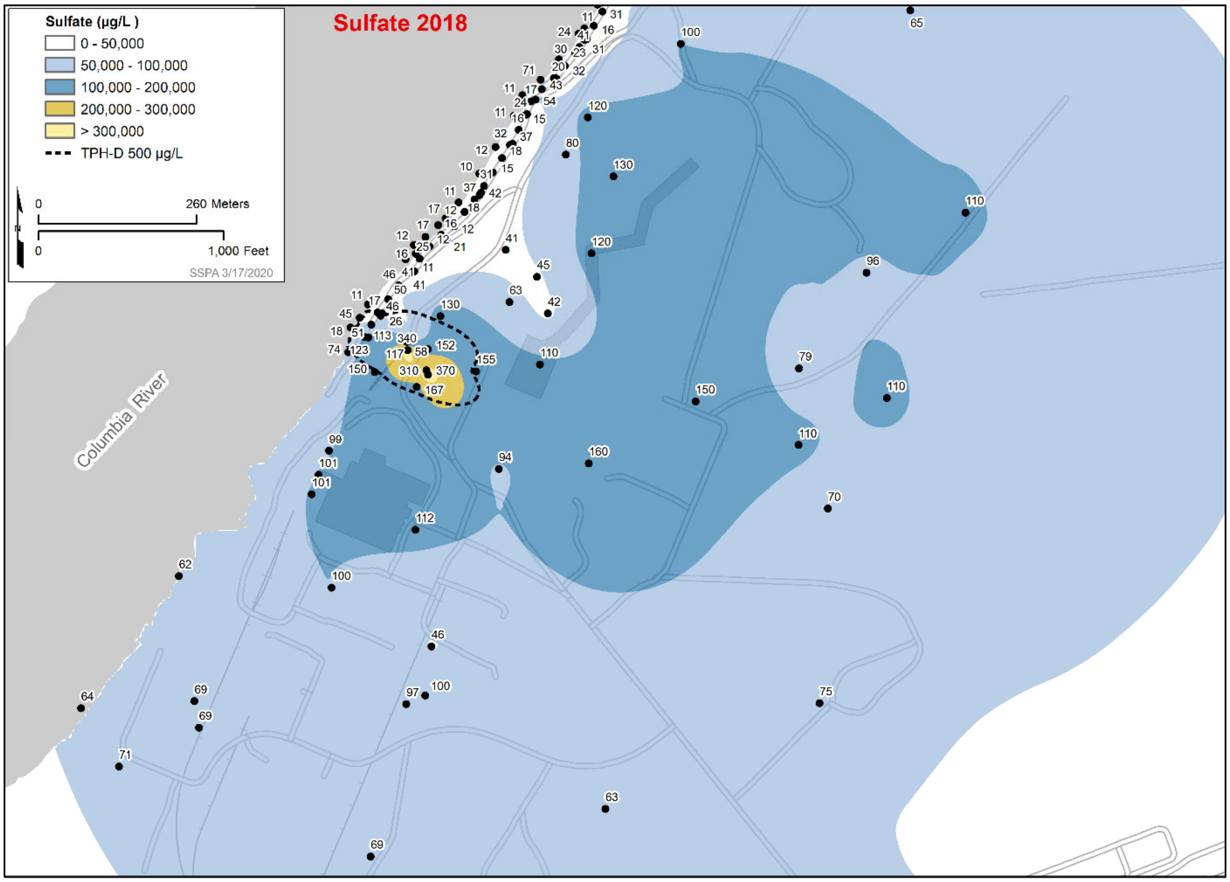
1,000 Feet
SSPA 3/17/2020
Columbia River

Sulfate


Sulfate 2018
Sulfate (µg/L)
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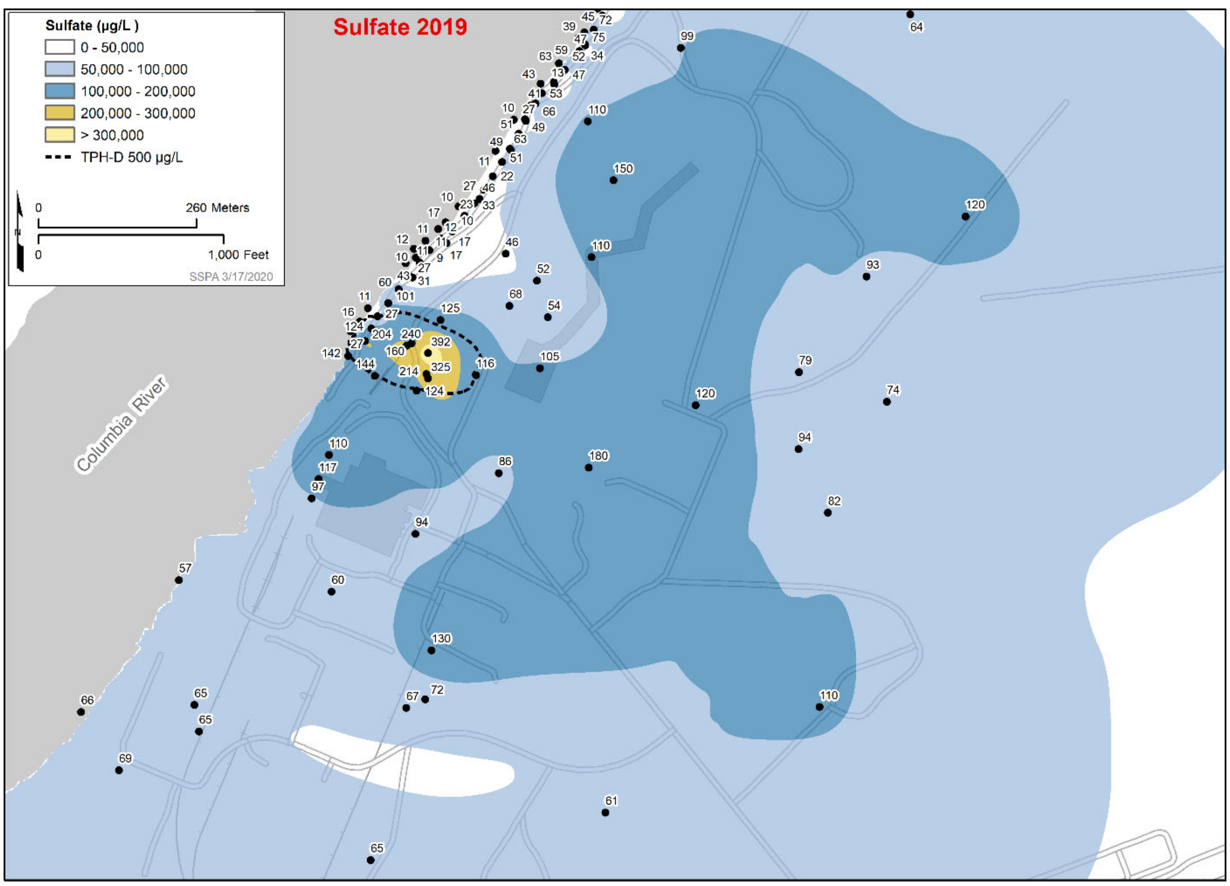
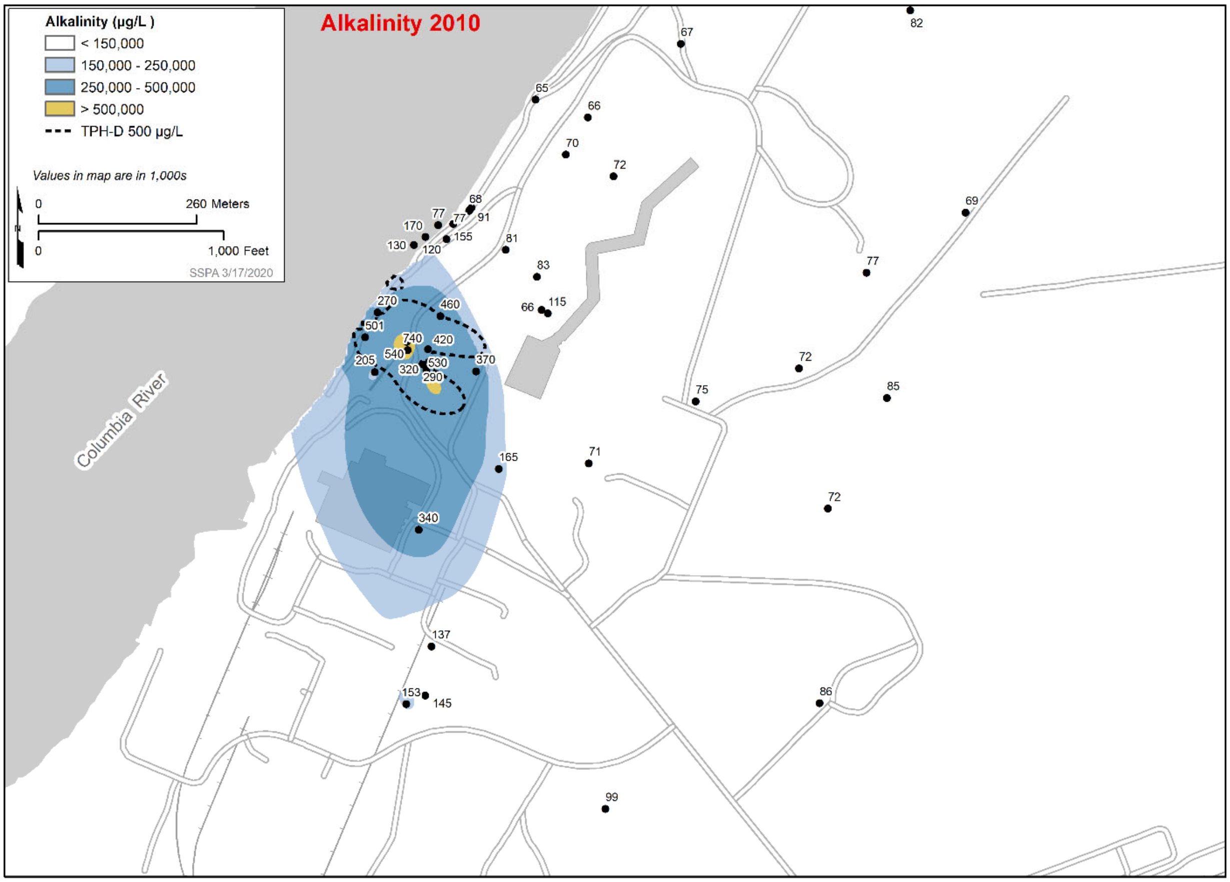
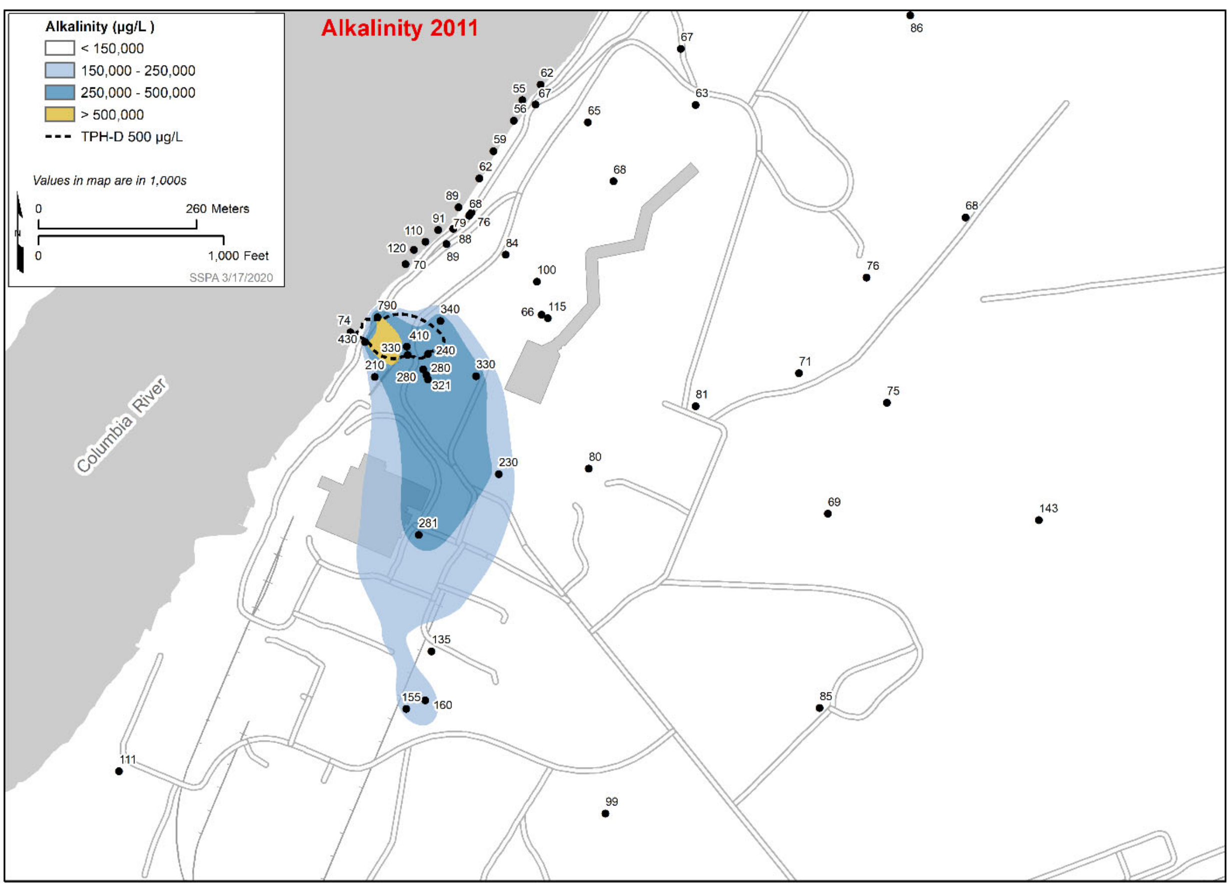
50,000 - 100,000
100,000 - 200,000
200,000 - 300,000
> 300,000
TPH-D 500 µg/L
0
260 Meters
0
1,000 Feet
SSPA 3/17/2020
Columbia River


Sulfate 2019
Sulfate (µg/L)
0 - 50,000
50,000 - 100,000
100,000 - 200,000
200,000 - 300,000
> 300,000
TPH-D 500 µg/L
0
260 Meters
0
1,000 Feet
SSPA 3/17/2020
Columbia River

Alkalinity


Alkalinity 2010
Alkalinity (µg/L)
< 150,000
150,000 - 250,000
250,000 - 500,000
> 500,000
TPH-D 500 µg/L
Values in map are in 1,000s
0
260 Meters
0
1,000 Feet
SSPA 3/17/2020
Columbia River


Alkalinity 2011
Alkalinity (µg/L)
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250,000 - 500,000
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260 Meters
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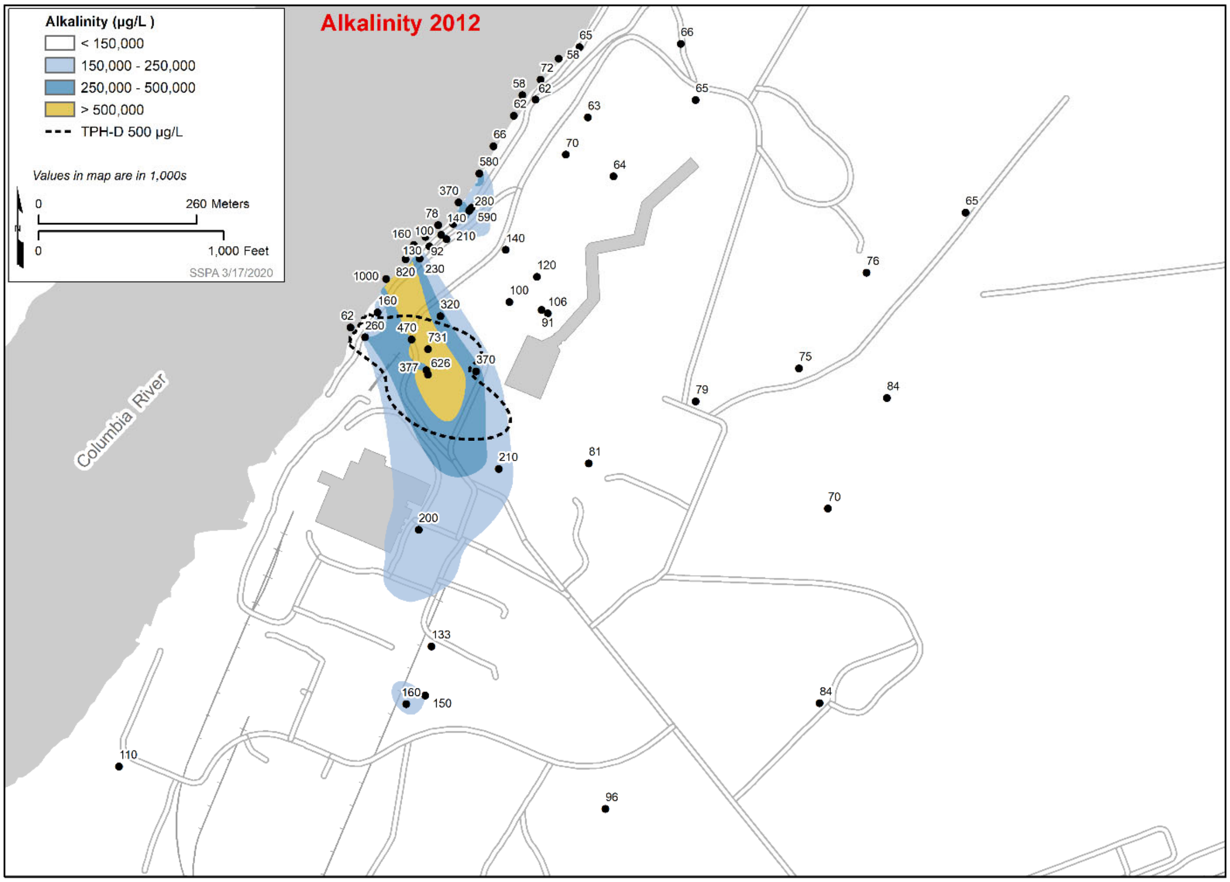
1,000 Feet
SSPA 3/17/2020
Columbia River

Alkalinity


Alkalinity 2012
Alkalinity (µg/L)
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150,000 - 250,000
250,000 - 500,000
> 500,000
TPH-D 500 µg/L
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260 Meters
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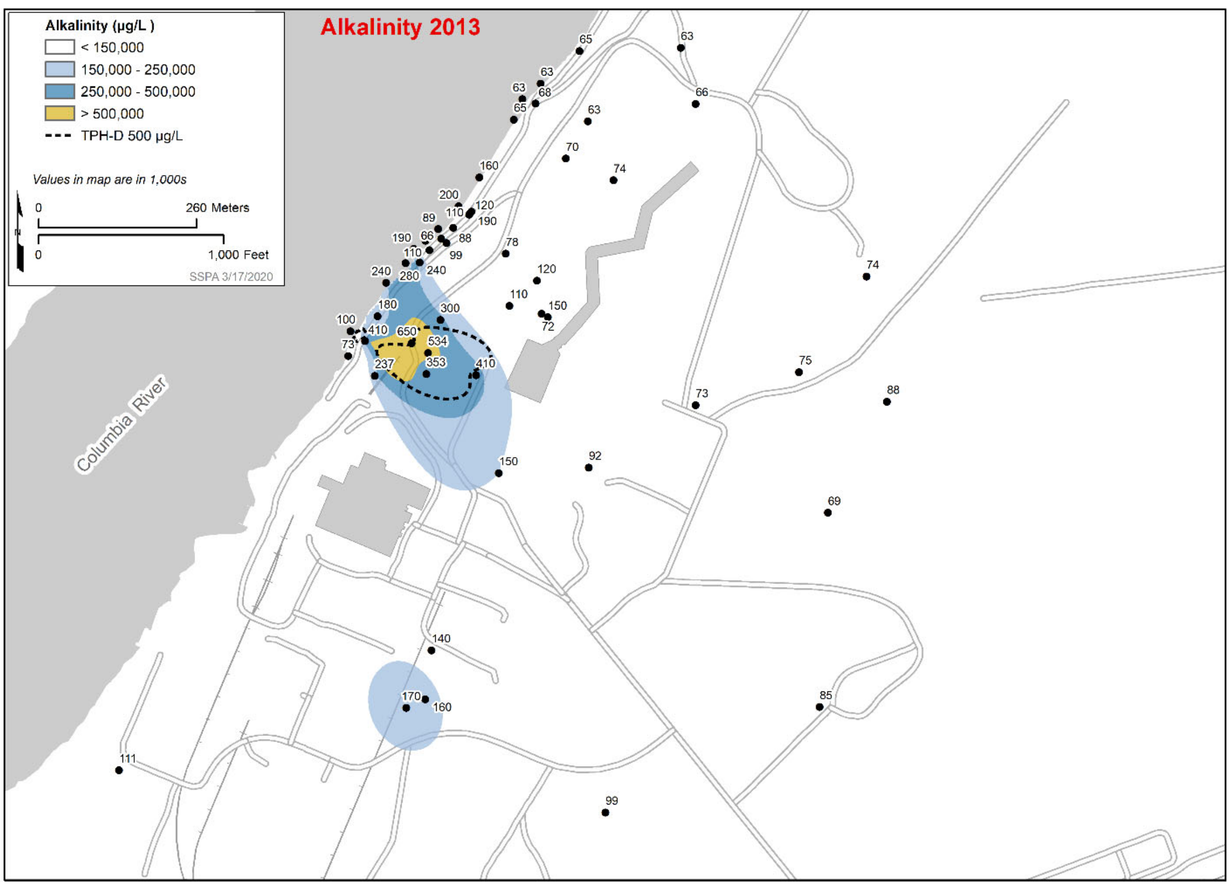
1,000 Feet
SSPA 3/17/2020
Columbia River


Alkalinity 2013
Alkalinity (µg/L)
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150,000 - 250,000
250,000 - 500,000
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260 Meters
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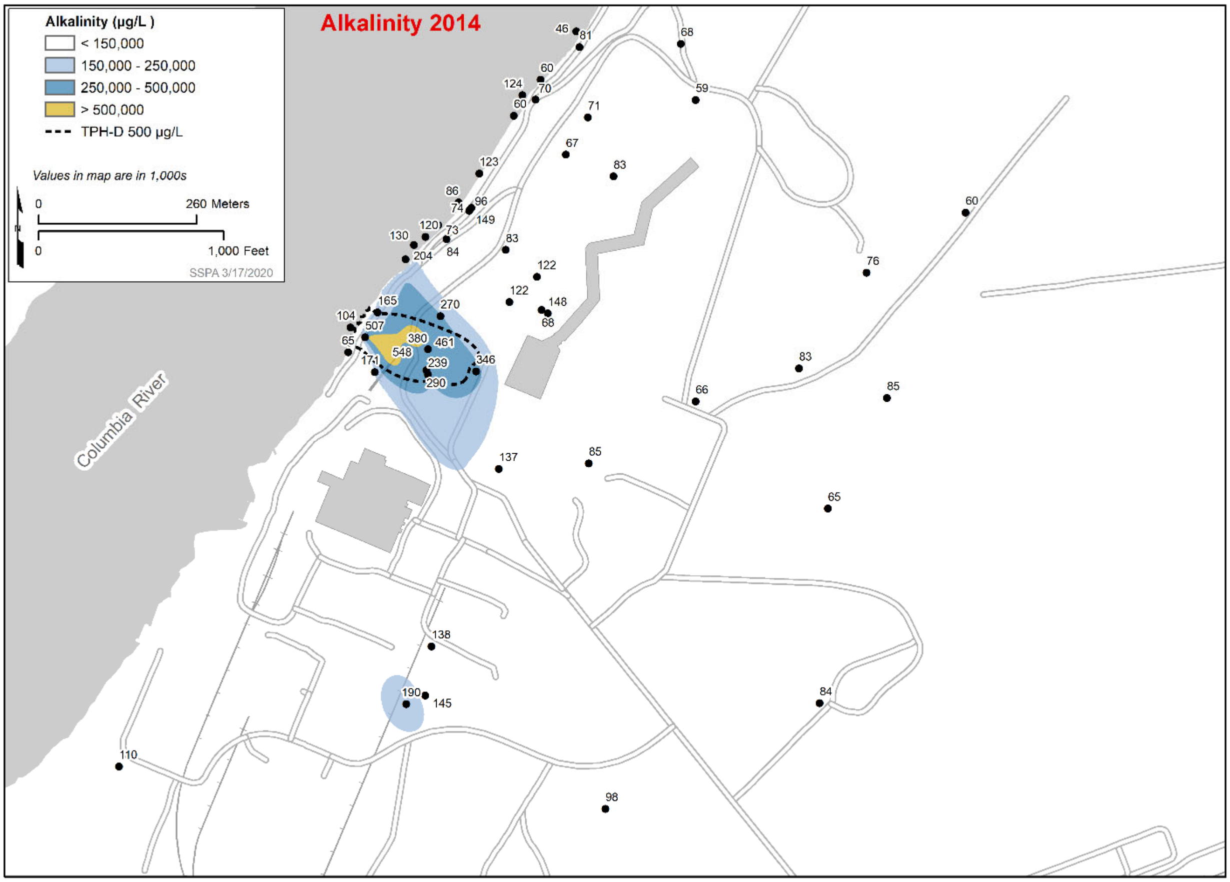
1,000 Feet
SSPA 3/17/2020
Columbia River

Alkalinity


Alkalinity 2014
Alkalinity (µg/L)
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150,000 - 250,000
250,000 - 500,000
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Values in map are in 1,000s
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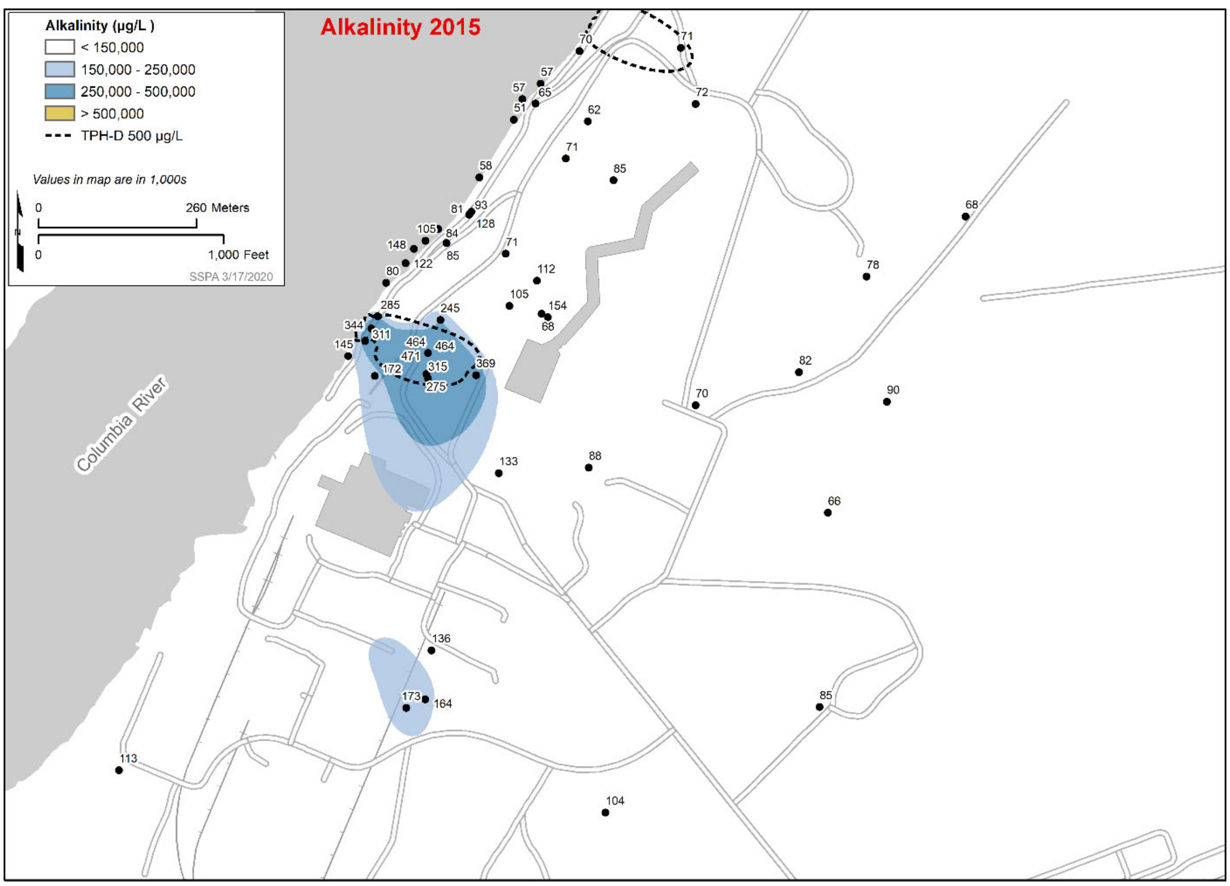
0 1,000 Feet
SSPA 3/17/2020
Columbia River


Alkalinity 2015
Alkalinity (µg/L)
< 150,000
150,000 - 250,000
250,000 - 500,000
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Values in map are in 1,000s
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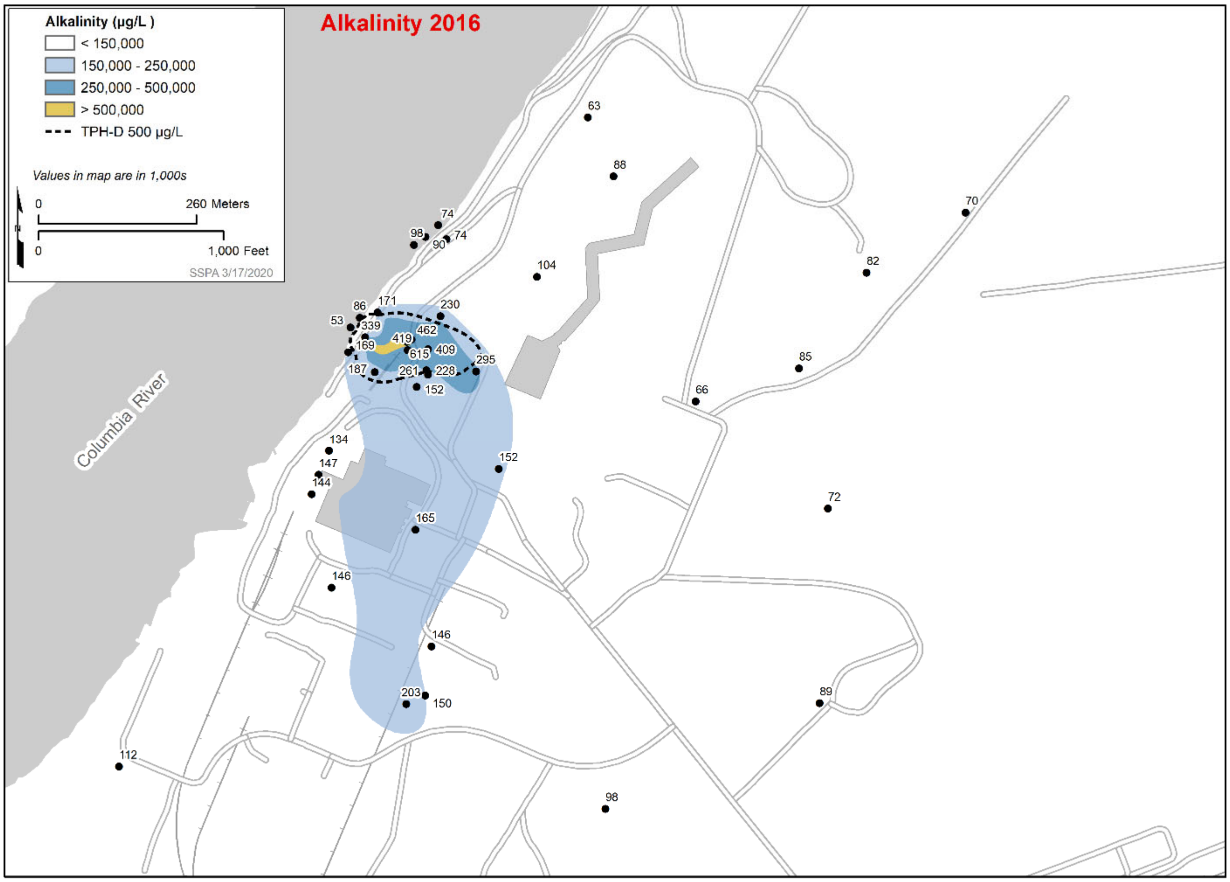
SSPA 3/17/2020
Columbia River

Alkalinity


Alkalinity (µg/L)
< 150,000
150,000 - 250,000
250,000 - 500,000
> 500,000
TPH-D 500 µg/L
Values in map are in 1,000s
0
260 Meters
0
1,000 Feet
SSPA 3/17/2020
Alkalinity 2016
Columbia River
63
88
70
74
98
90
74
104
82
86
171
230
53
339
462
169
419
615
409
187
261
228
295
152
85
66
134
147
144
152
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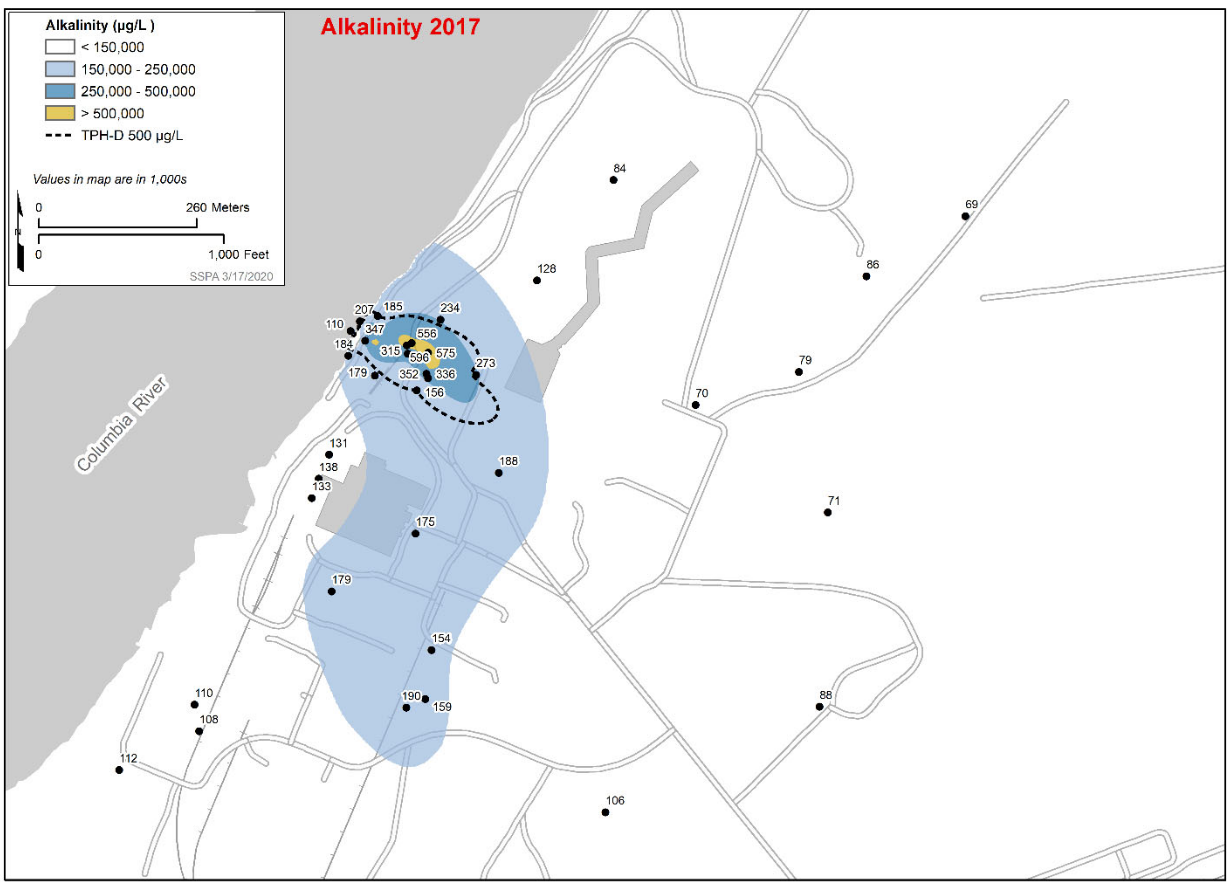
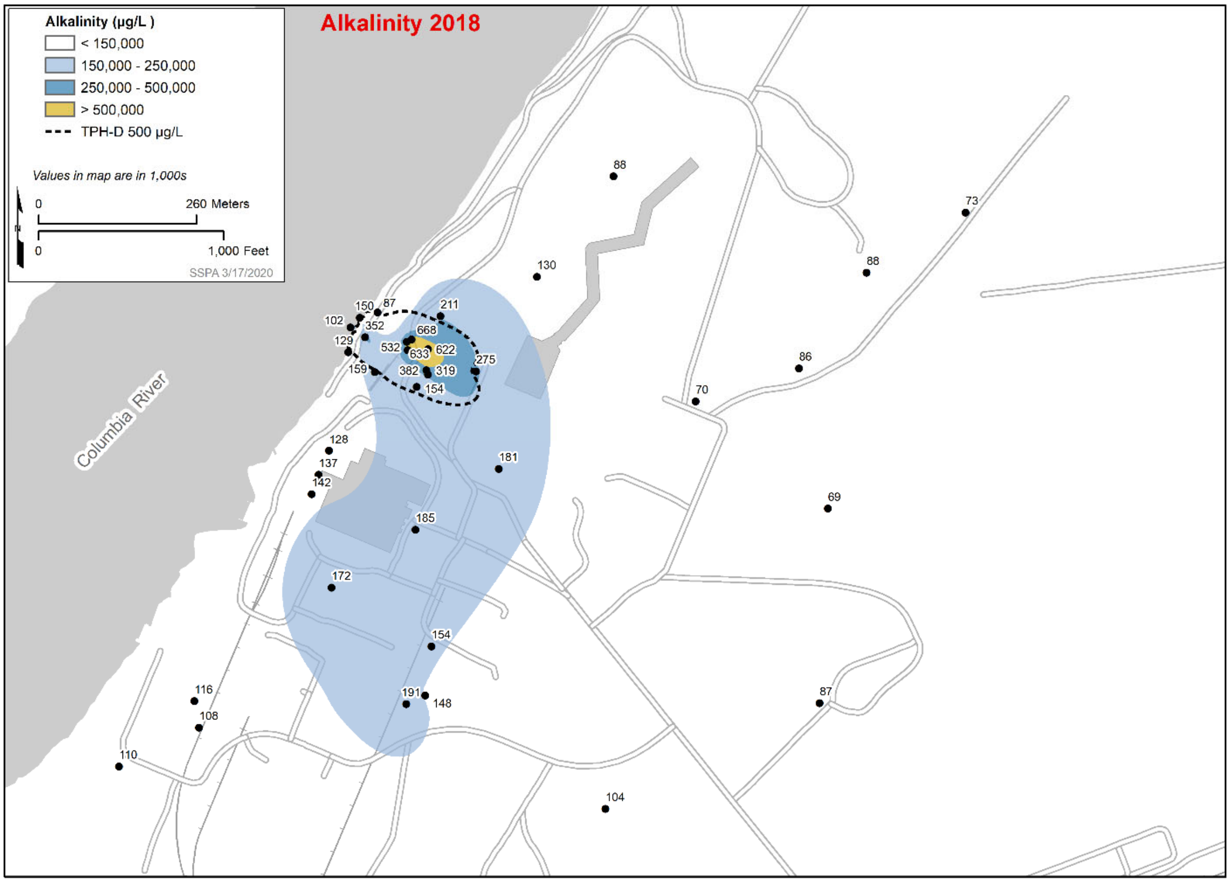
165
146
146
203
150
89
112
98


Alkalinity (µg/L)
< 150,000
150,000 - 250,000
250,000 - 500,000
> 500,000
TPH-D 500 µg/L
Values in map are in 1,000s
0
260 Meters
0
1,000 Feet
SSPA 3/17/2020
Alkalinity 2017
Columbia River
84
69
128
86
207
185
234
110
347
556
184
315
596
575
273
179
352
336
156
79
70
131
138
133
188
71
175
179
154
110
190
159
108
88
112
106

Alkalinity


Alkalinity (µg/L)
< 150,000
150,000 - 250,000
250,000 - 500,000
> 500,000
TPH-D 500 µg/L
Values in map are in 1,000s
0 260 Meters
0 1,000 Feet
SSPA 3/17/2020
Alkalinity 2018
Columbia River
88
73
130
88
150
87
211
102
352
668
129
532
633
622
275
159
382
319
154
86
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87
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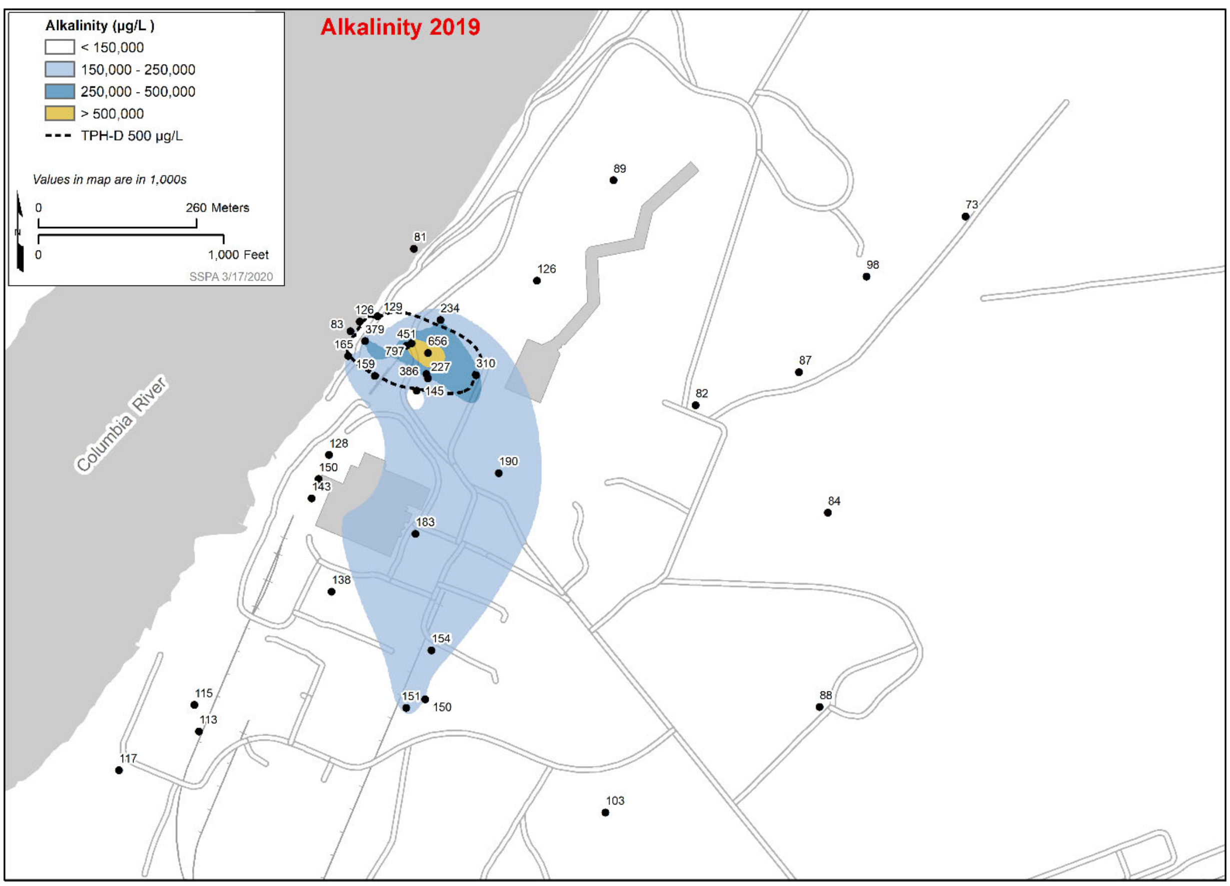
108
110
104


Alkalinity (µg/L)
< 150,000
150,000 - 250,000
250,000 - 500,000
> 500,000
TPH-D 500 µg/L
Values in map are in 1,000s
0 260 Meters
0 1,000 Feet
SSPA 3/17/2020
Alkalinity 2019
Columbia River
89
73
81
126
98
126
129
234
83
379
451
656
165
797
159
386
227
310
145
87
82
128
150
190
143
84
183
138
154
151
150
88
115
113
117
103

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