# Appendices
# Feasibility Study Report – Public Review Draft
# Alexander Avenue Petroleum Tank Facilities Site
# Tacoma, Washington

March 5, 2021

Prepared for

The Port of Tacoma

LANDAU ASSOCIATES

130 2nd Avenue South
Edmonds, WA 98020
(425) 778-0907

APPENDIX A

# Historical Aerial Photographs and Maps

**Table A-1**
**721 Property Historical Site Ownership**
**Alexander Avenue Cleanup Site**
**Port of Tacoma**
**Tacoma, Washington**

# 721 Property

| Time Period | | Owner | Operator | Use | Notes |
|---|---|---|---|---|---|
| 1935 | 1942 | H.D Maxwell and Josephine E. Maxwell | H.D. Maxwell Petroleum Corporation/ Maxwell Petroleum Corporation | Oil and gas distribution facility | "Gasoline Firm to Build Here, Independent Company Leases 4 1/2 Acres on Hylebos Waterway," *Tacoma Sunday Ledger, 1935*. The property was developed as an oil and gasoline distribution plant by H.D. Maxwell. H.D. Maxwell operated two "Maxwell" companies in the same area at the same time, H.D. Maxwell Petroleum Corporation and Maxwell Petroleum Corporation, the connection between the two "Maxwell" companies is still somewhat unclear. |
| 1942 | 1945 | H.D Maxwell and Josephine E. Maxwell | U.S. Government/U.S. Navy | Oil and gas distribution facility | Lease between Maxwell Petroleum Corporation and The United States of America. Lease term from October 1, 1942 to June 30, 1943 with the option to renew until six months after the termination of World War II. |
| 1945 | 1951 | H.D Maxwell and Josephine E. Maxwell | Maxwell Petroleum Corporation & General Petroleum Corporation | Oil and gas distribution facility | In December 1943 General Petroleum Corporation and Maxwell Petroleum Corporation merged "in the Tacoma area," with Maxwell Petroleum acquiring the General stations in Tacoma. General Petroleum Corporation was a subsidiary of Socony (acronym for Standard Oil Company of New York). Socony, through several mergers and successions is now part of Exxon Mobil Corporation. |
| 1951 | 1951 | General Petroleum Corporation | General Petroleum Corporation | Oil and gas distribution facility | General Petroleum Corporation purchases the property from H.D. Maxwell and Josephine E. Maxwell on November 14, 1951, and sold the property the U.S. government a week later. |
| 1951 | 1966 | U.S. Government/ U.S. Air Force (USAF) | New England Tank Industries, Inc. (NETI), Pacific Terminal Company, and Hugh Yates Company | Aviation Gasoline Terminal | Facility operation was contracted with New England Tank Industries (NETI), for "the service and handling of Government-owned petroleum products at [the] installation and the protection of the property." Pacific Terminal Company and Hugh Yates Company were also listed as a fuel service contractor for the Alexander Avenue site. In 1965, USAF transferred 0.71 acres along the Hylebos Watery to the Navy (present-day parcel No. 2275200532). |

**Table A-1**
**721 Property Historical Site Ownership**
**Alexander Avenue Cleanup Site**
**Port of Tacoma**
**Tacoma, Washington**

# 721 Property

| Time Period | | Owner | Operator | Use | Notes |
|---|---|---|---|---|---|
| 1966 | 1969 | Port of Tacoma | Northwest Petroleum? | Diesel and gasoline storage | Old Port of Tacoma Commission meeting notes suggest a company called Northwest Petroleum may have been an early tenant. |
| 1969 | 1982 | Port of Tacoma | Fletcher Oil Company | Diesel and gasoline storage | Fletcher oil Company leased tanks No. 4, 6, 7, and 11 and 4.1-acres of land from the Port of Tacoma. United Independent Oil, a wholly-owned subsidiary of Fletcher Oil. Fletcher sub-leased tank No.4 to Lilyblad Petroleum. In 1973 Tanks 1, 2, and 3 were removed by Don Oline Trucking Co. |
| 1982 | 1983? | Port of Tacoma | PRI Northwest, Inc. (PRN) | Diesel and gasoline storage | PRN is a subsidiary of Pacific Resources Inc. (PRI). PRN assumed control of Fletchers wholesale fuel oil assets and began operating the Fletcher Oil facility at 721 Alexander. PRN may have begun operating the facility as early as 1979. The lease with the Port was not transferred to PRN until 1982. |
| 1983 | 2014 | Port of Tacoma | Property leased to multiple organizations for commercial storage | Commercial storage | ASTs, building, and associated infrastructure were removed from the property in 1983 and the property was paved. |
| 2014? | Today | Port of Tacoma | Puget Sound Energy | Liquefied Natural Gas facility | Development underway for a LNG facility. No new infrastructure is being constructed on the former tank farm parcel, the facility is being built on the adjoining parcels to the south. |

**Table A-2**
**709 Property Historical Site Ownership**
**Alexander Avenue Cleanup Site**
**Port of Tacoma**
**Tacoma, Washington**

## 709 Property

| Time Period | | Owner | Operator | Use | Notes |
|---|---|---|---|---|---|
| 1930? | 1938 | Norton and Mary Clapp | Norton and Mary Clapp | Oil and gas distribution facility | Sometime between 1931 and 1940 the property was developed as a fuel storage and distribution facility. |
| 1938 | 1981 | Fletcher Oil Company | Fletcher Oil Company, Tesoro Petroleum Inc, and United Independent Oil Company, Inc., PRI Northwest | Oil and gas distribution facility | The Fletcher Oil Company (Fletcher) operated a gasoline and diesel-fuel storage and distribution facility at the 709 property. Fletcher operated under several names during its tenure at the site: Fletcher Oil Company, Fletcher Oil Inc., and F.O. Fletcher, Inc. Tenants operated on the property in the 1970s: Tesoro Petroleum, Inc., and United Independent Oil Company, Inc. (CRA 2013). |
| 1981 | 1997 | PRI Northwest, Inc. | PRI Northwest, Inc., Independent Oil Company | Oil and gas distribution facility, leading plant, crude oil distillation plant | PRI Northwest, Inc. (PRI) began leasing the 709 property in 1979 and purchased it in 1981 for use as a storage and distribution facility for unleaded gasoline, leaded gasoline, diesel fuel, and fuel alcohol. Additionally, PRI operated a tetraethyl leading plant for blending lead into gasoline, a process that involves reacting chloroethane with a sodium-lead alloy. Infrastructure removed from the property by 1997. And the United Independent Oil Company operated a crude oil distillation plant (CRA 2013). |
| 1997 | 2001 | OCC Tacoma, Inc. | OCC Tacoma, Inc. | Vacant | |
| 2001 | Today | Mariana Properties, Inc. | Mariana Properties, Inc. | Vacant | The 709 property was used briefly during the winter of 2002–2003 to temporarily stage treated sediments removed by OCC from the Hylebos Waterway (Area 5106 Removal Action) under EPA oversight (EPA 2020). |

1931

# tacomaMAP Print


tacomaMAP



Last Printed: 1/2/2020 4:30 PM

Scale: 1:4,514

0 95 190 380 570 760

ft

N

* This map is not suitable for site-specific analysis or for utility location *

See full disclaimer below:
http://geohub.cityoftacoma.org/pages/disclaimer

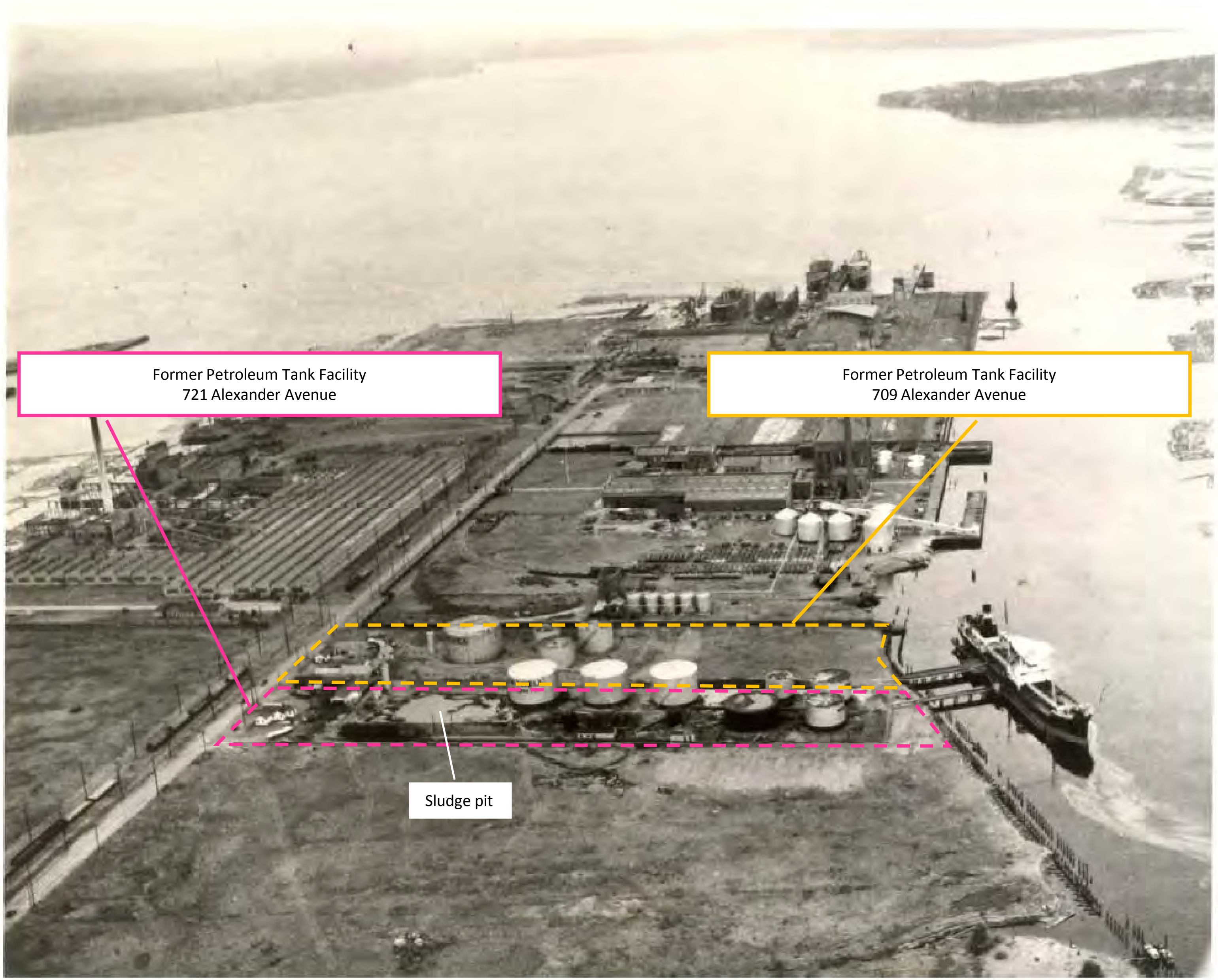



figure 13

AERIAL PHOTOGRAPH - BETWEEN 1936 - 1946

*Occidental Chemical Corporation, Tacoma, Washington*

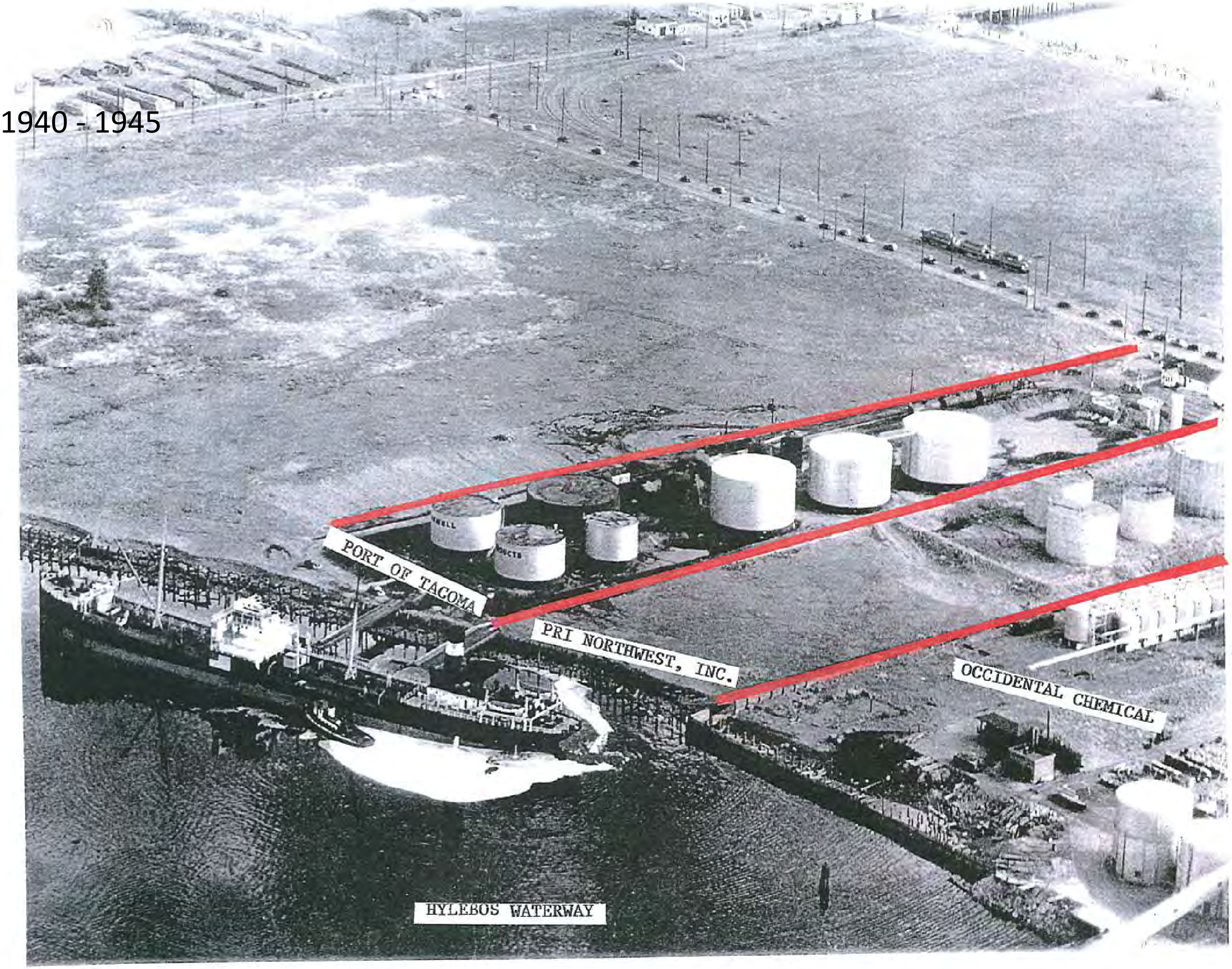
07843-00(083)GN-BU226 MAR 28/2008


figure 14

AERIAL PHOTOGRAPH - BETWEEN 1936 -1946 (2)

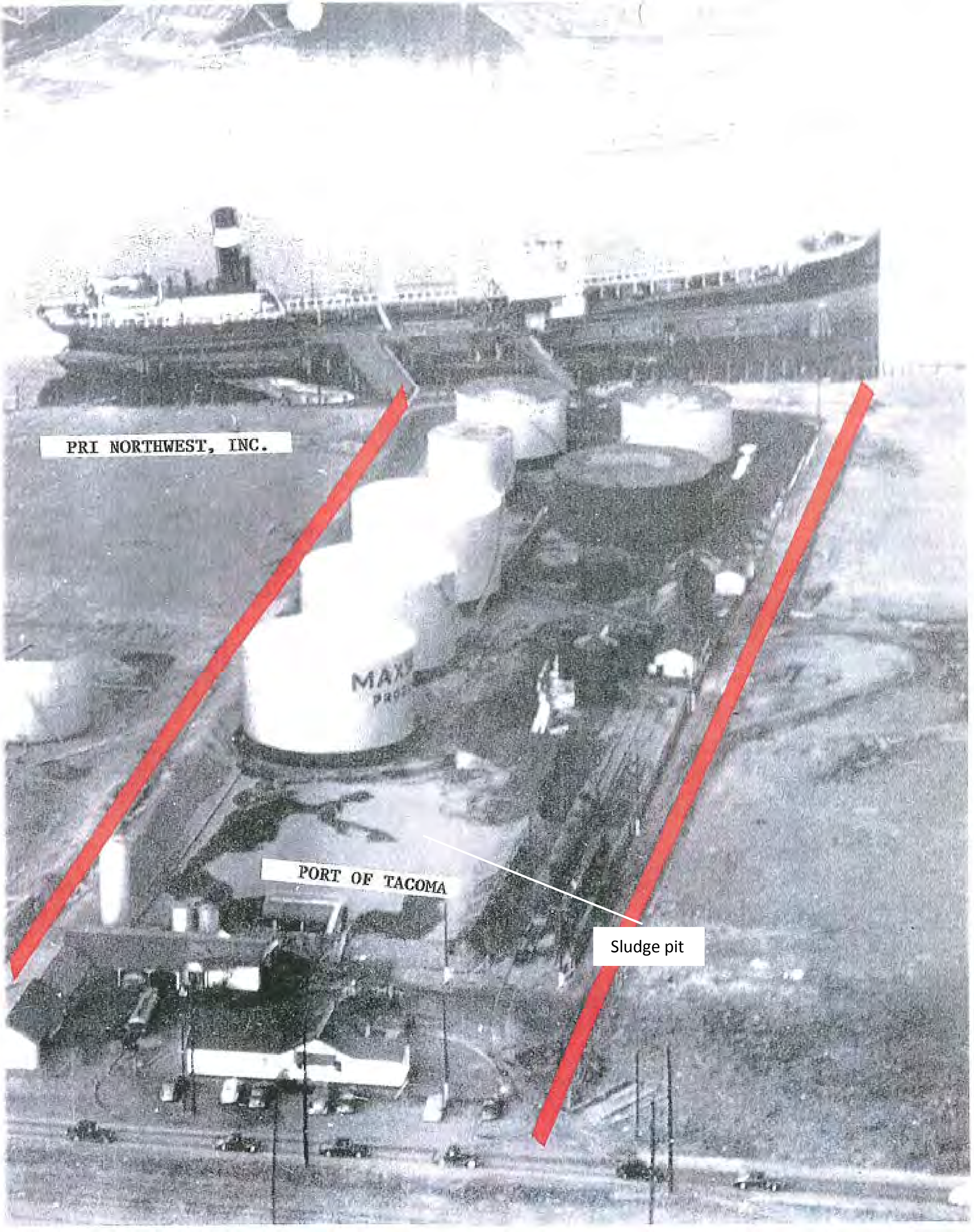
*Occidental Chemical Corporation, Tacoma, Washington*

1940 - 1945

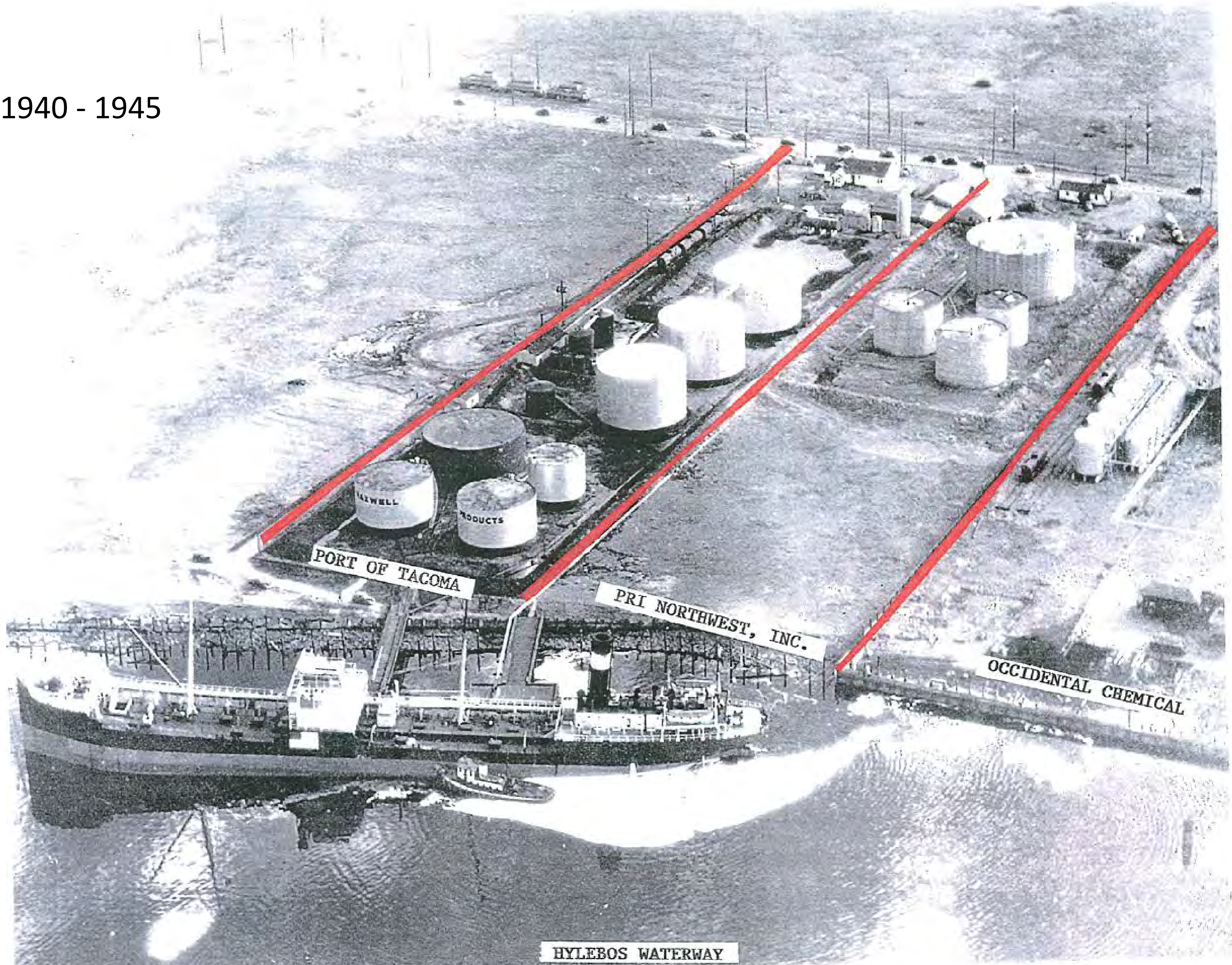


PORT OF TACOMA
PRI NORTHWEST, INC.
OCCIDENTAL CHEMICAL
HYLEBOS WATERWAY

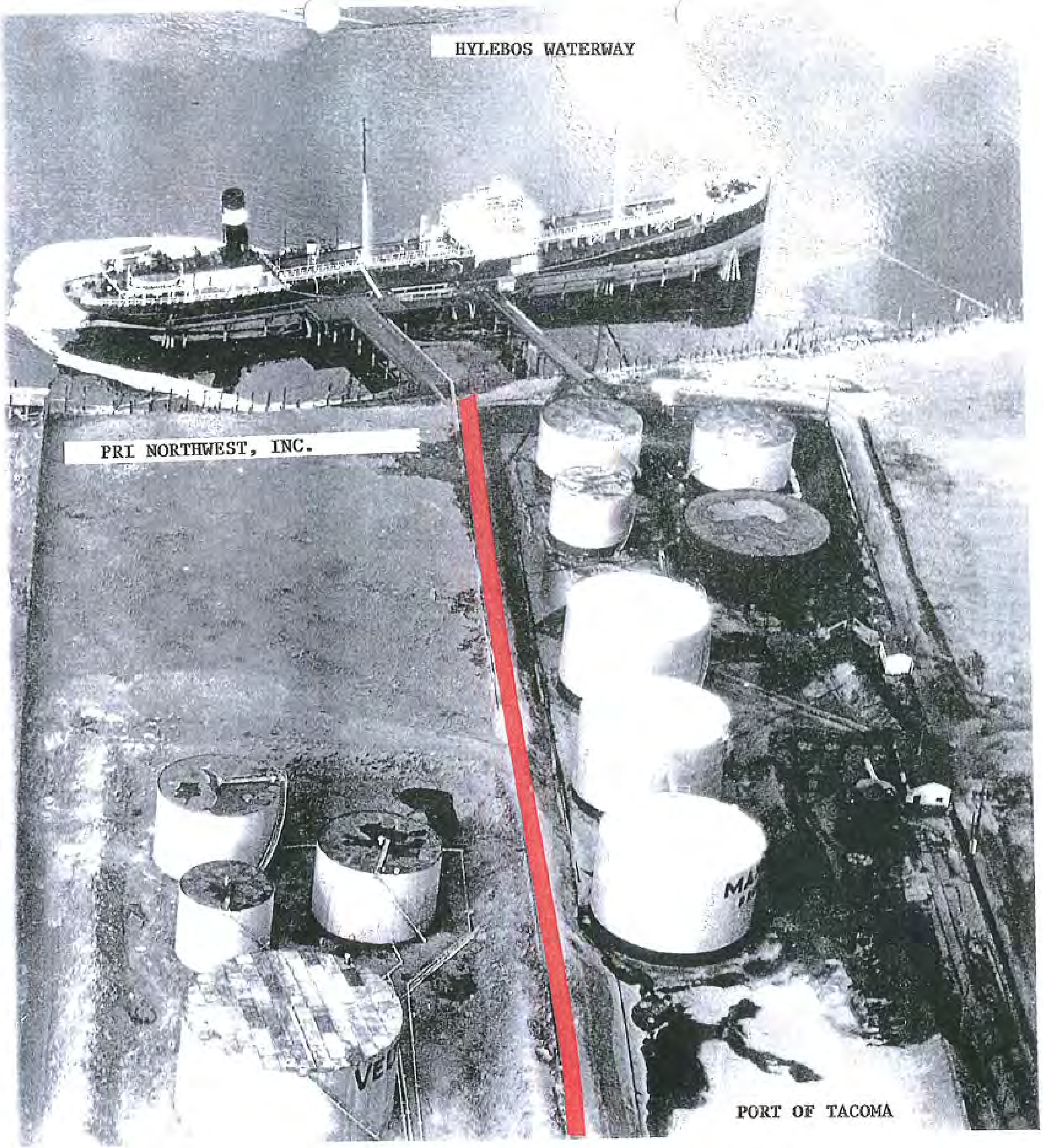
1940 - 1945



1940 - 1945


PORT OF TACOMA
PRI NORTHWEST, INC.
OCCIDENTAL CHEMICAL
HYLEBOS WATERWAY

1940 - 1945



1940

# tacomaMAP Print

Scale: 1:4,514



tacomaMAP



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1944

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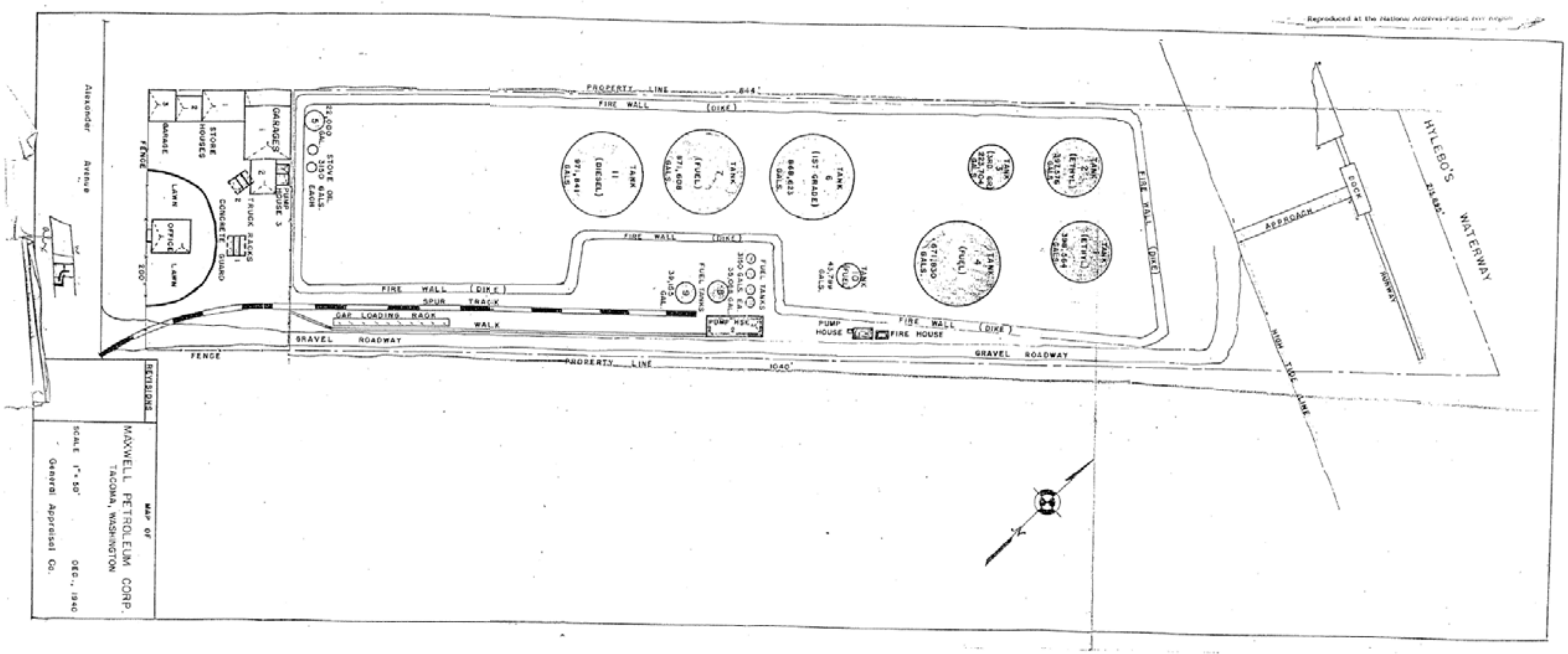
1946

Port of Tacoma Historical Aerial Photo Library:
\\apps.portoftacoma.com\GISHut\Historical\HistoricalAerials

1940



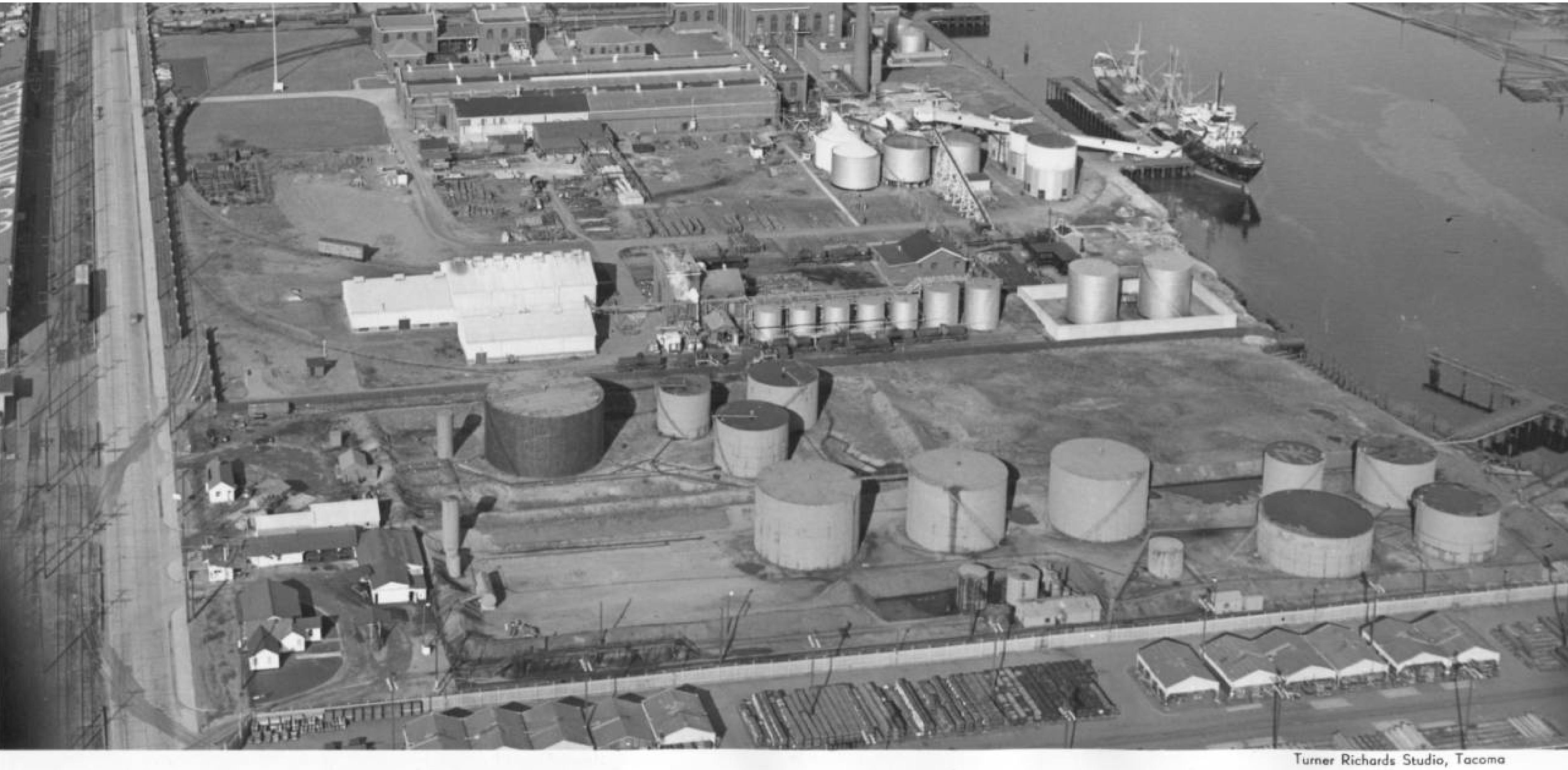

Aspect 2016, Appendix C

1942


In the foreground is the 5,000,000-gal. terminal of the Maxwell Petroleum Corp., Independent oil marketer, on one of tributaries to Puget Sound, at Tacoma, Wash. A tanker from Los Angeles is discharging a load. The 5 vertical tanks immediately in the rear of the Maxwell plant, are the terminal of Fletcher Oil Co., an Independent marketer of Idaho, which supplies its business in eastern Washington from this depot. Log rafts shown on the opposite side of the stream, are a familiar sight in this territory

Guthrie, V.B. 1942. "Home Town Advertising Pulls 'em In For Pacific Northwest Oil Jobber." National Petroleum News. January 21.

1947




Tacoma Public Library, (Richards Studio D25712-8)
http://cdm17061.contentdm.oclc.org/cdm/singleitem/collection/p17061coll21/id/26320/rec/2

1950

# tacomaMAP Print


tacomaMAP



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Scale: 1:2,257

0 45 90 180 270 360

ft

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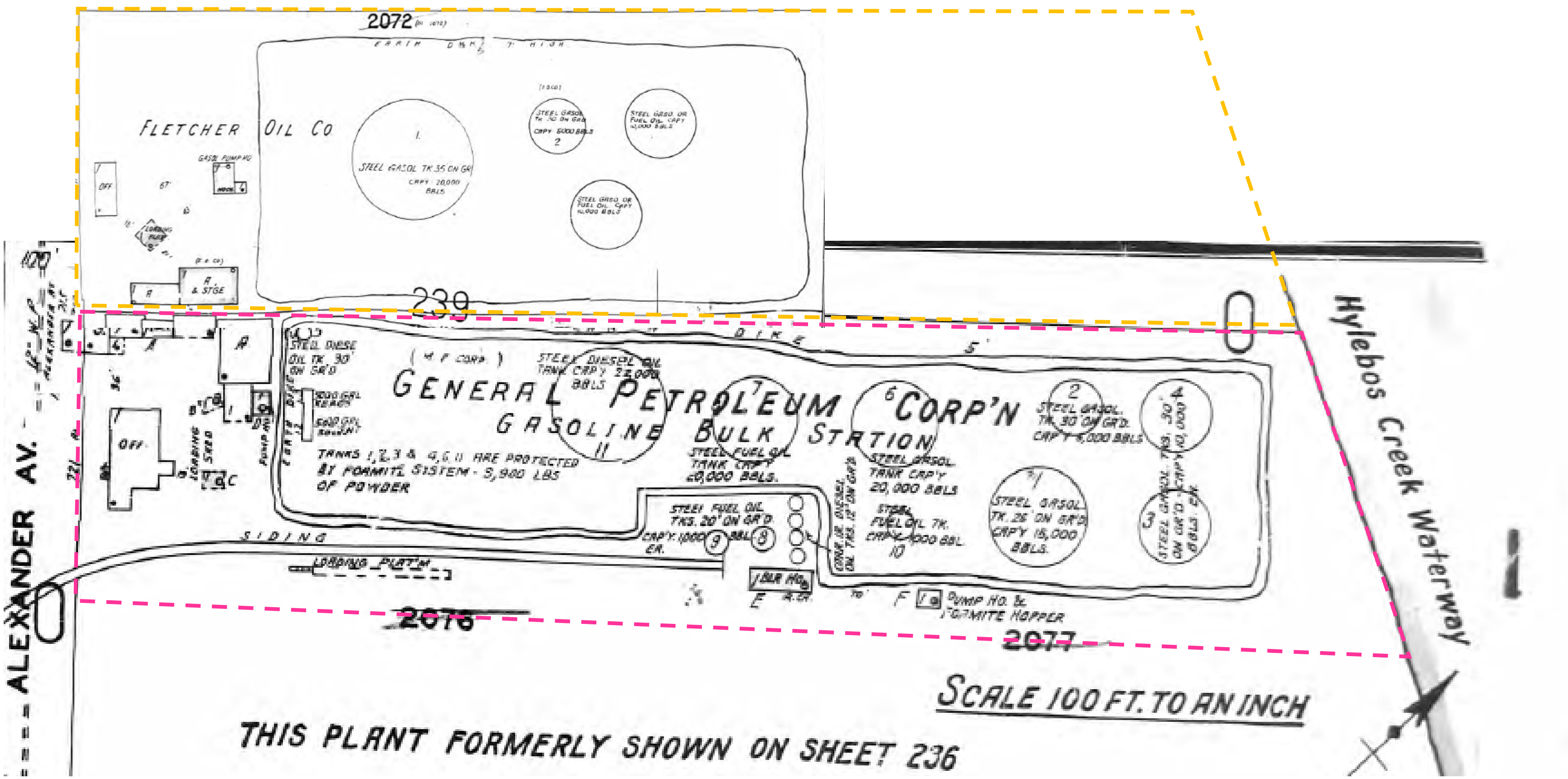
N

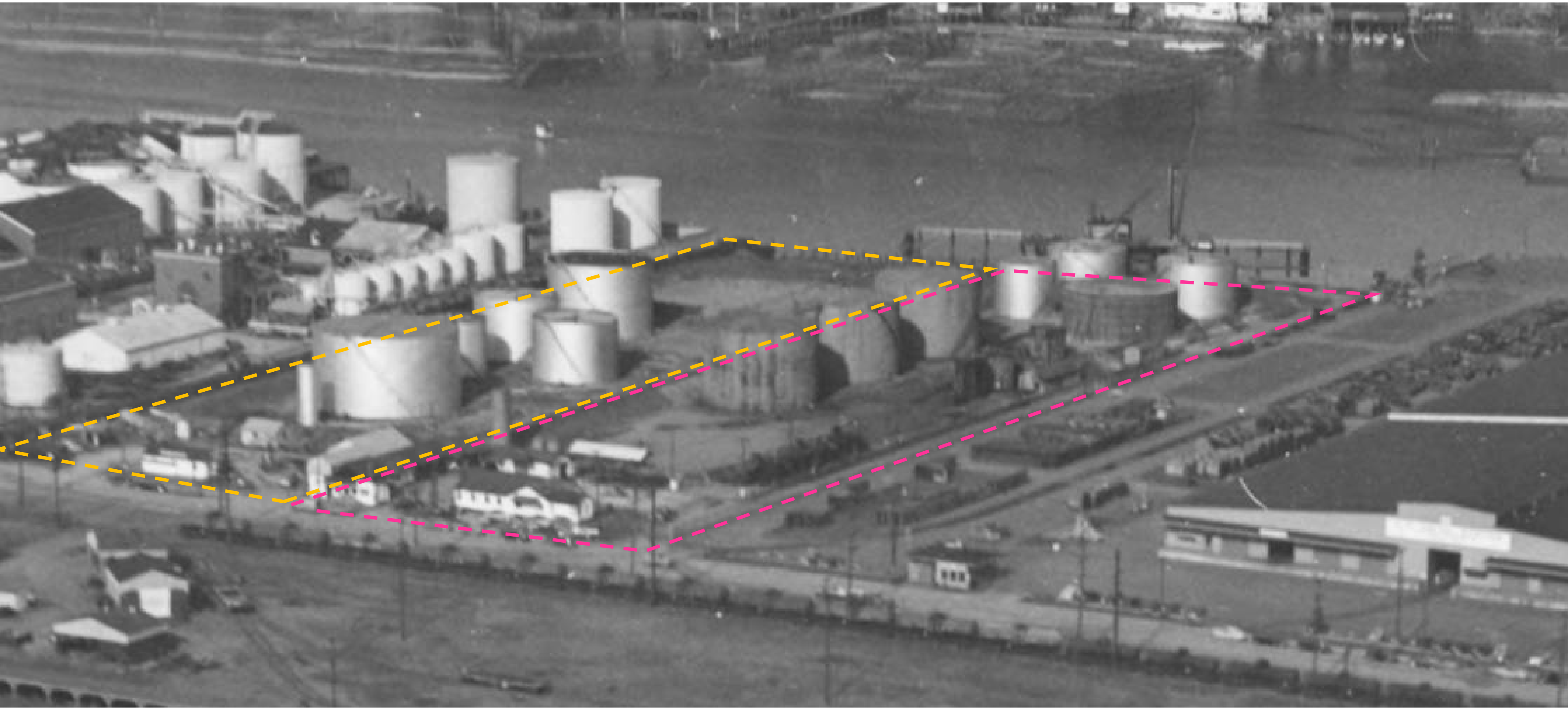
1950

| | |
|---|---|
| Date: | 6/22/2007 11:27:54 AM |
| EDR Inquiry: | 1961558.3s |
| Client: | ENSR Consulting & Engineering |
| Site Name: | Naval and Marine Corps Reserve Center |
| Address: | 1001 Alexander Avenue |
| City, ST, ZIP: | Tacoma WA 98421 |
| Certification # | 3078-4093-98C9 |

Research Associate: TIM Copyright: 1950



1953



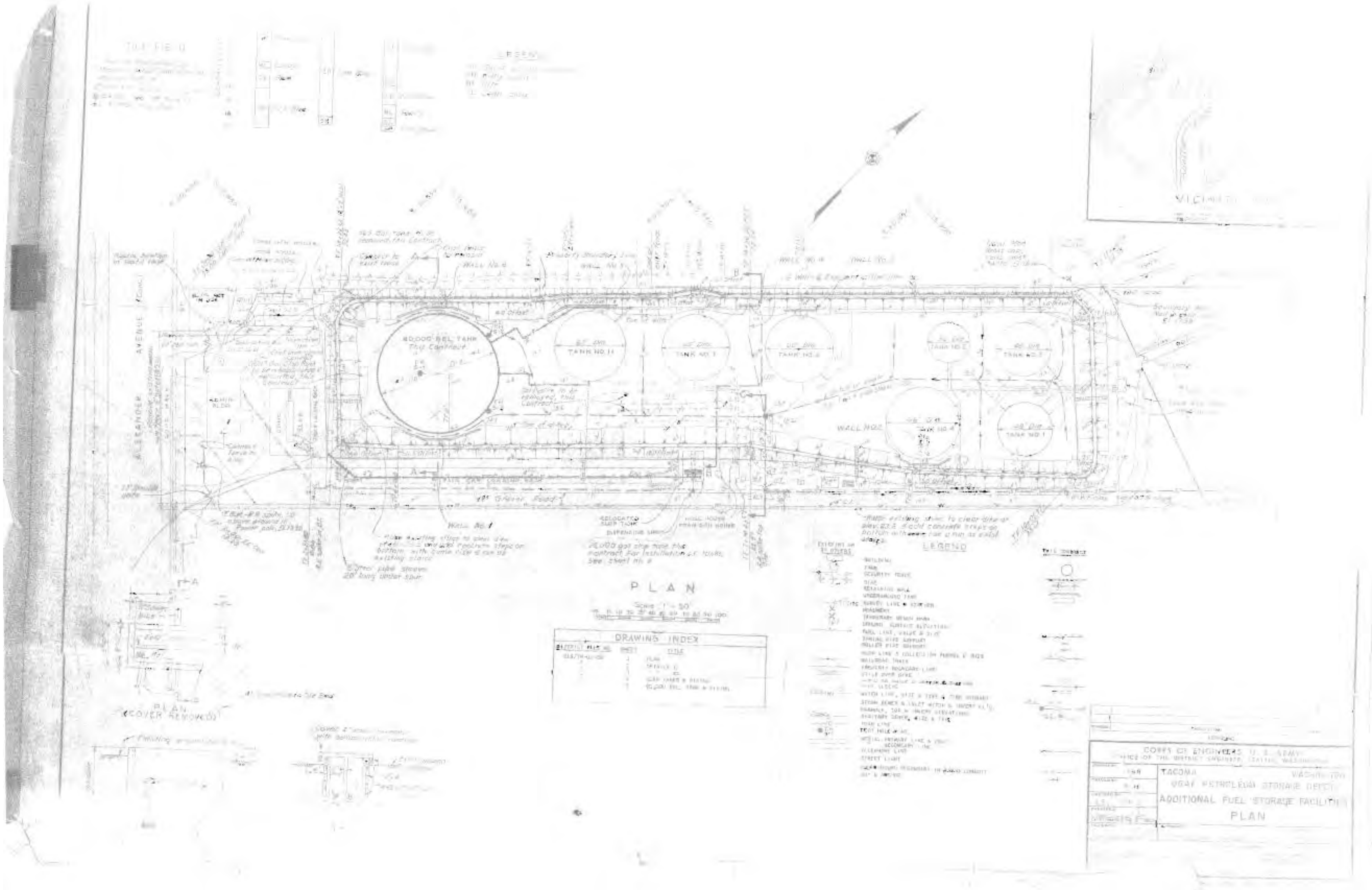
Tacoma Public Library, (Richards Studio WO76034-A)
http://cdm17061.contentdm.oclc.org/cdm/ref/collection/p17061coll21/id/33028/rec/26

# 1953

Tacoma Public Library, (Richards Studio D75943-23), 7/2/53
http://cdm17061.contentdm.oclc.org/cdm/ref/collection/p17061coll21/id/4582/rec/27

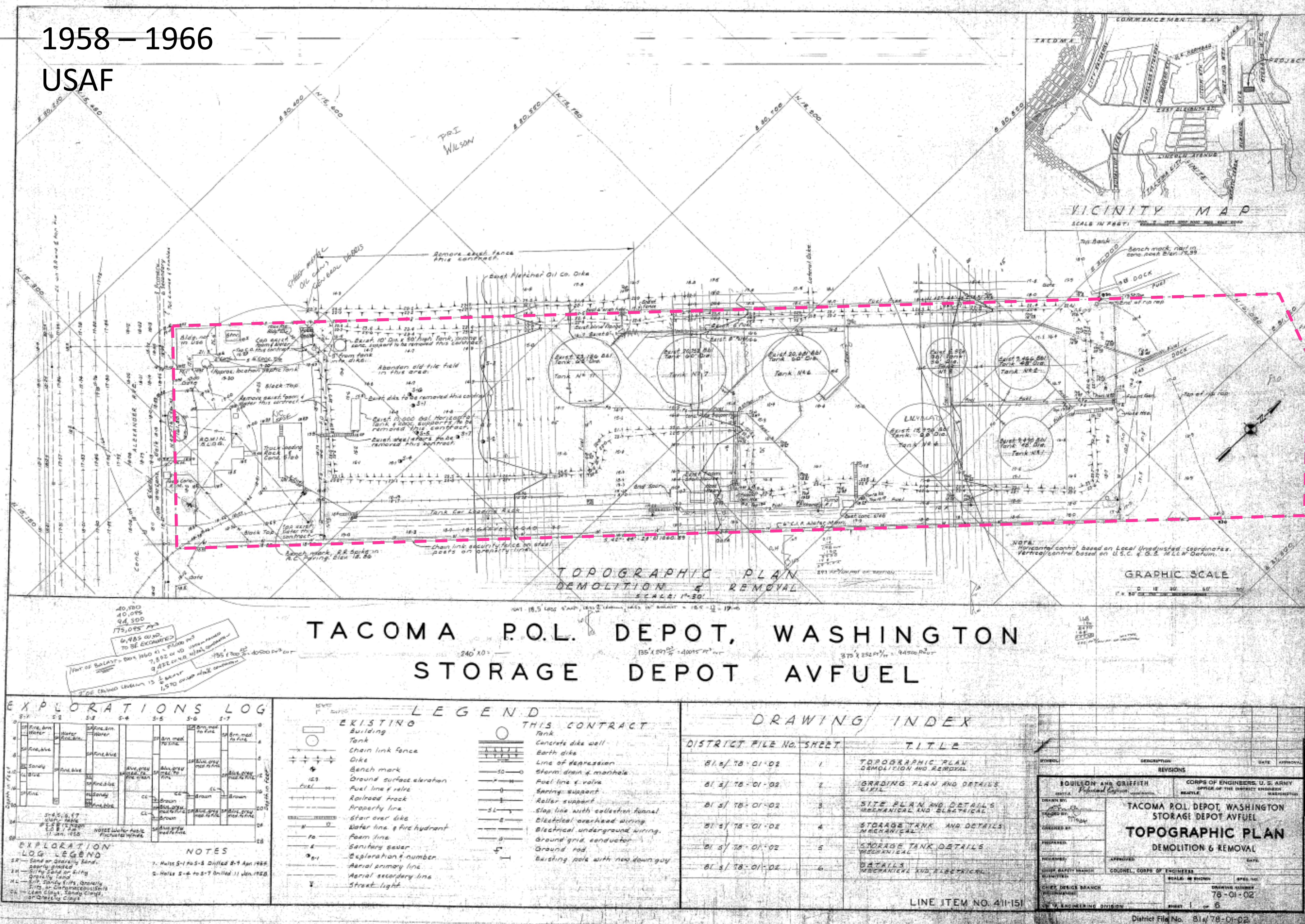
# 1954 -1958

Drawing Date illegible. Drawing date sometime between 1954 (boring S-1, S-2, and S-3 exploration year) and 1958 (year of borings S-4 through S-7 not shown). - SW

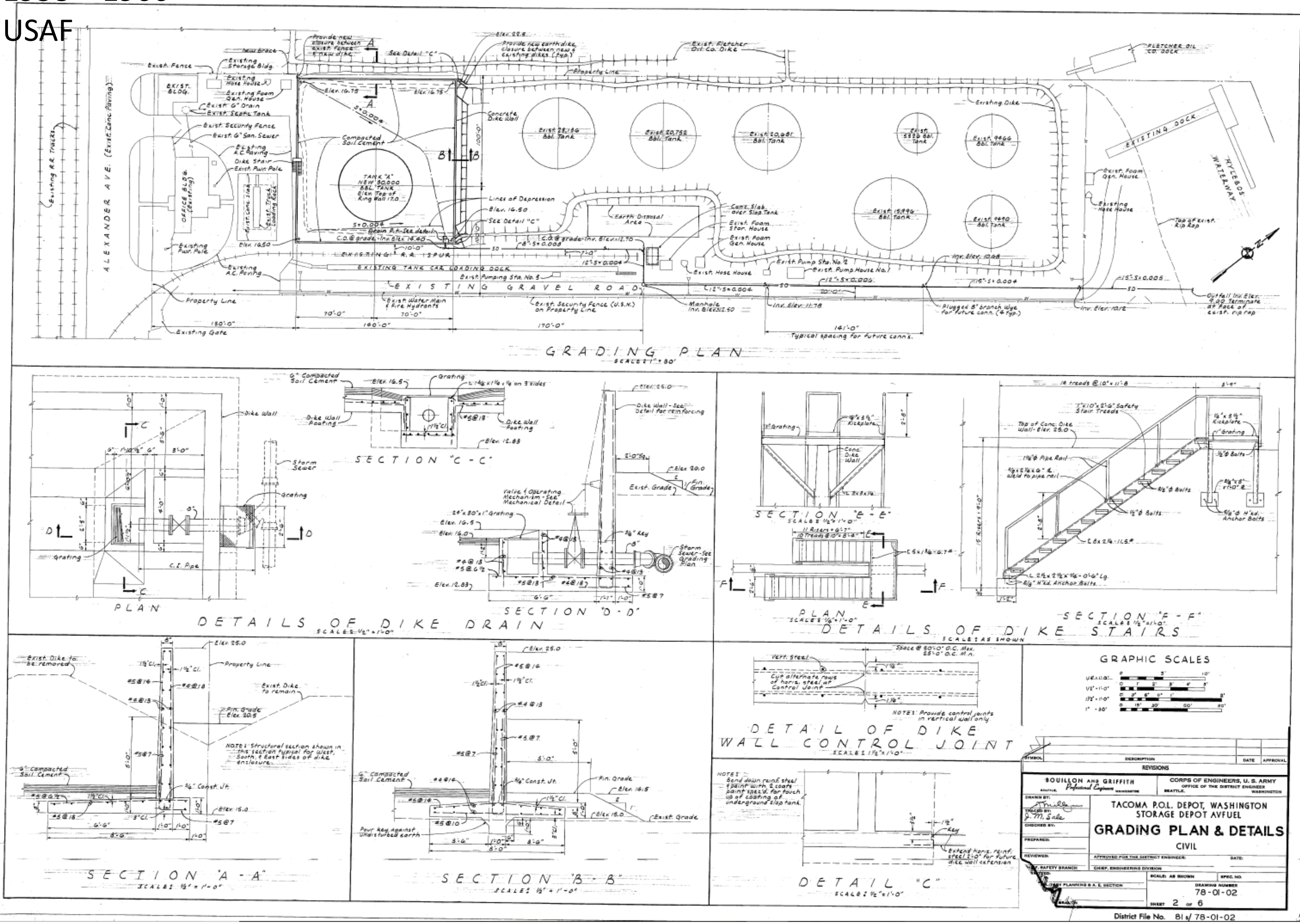


1958 – 1966

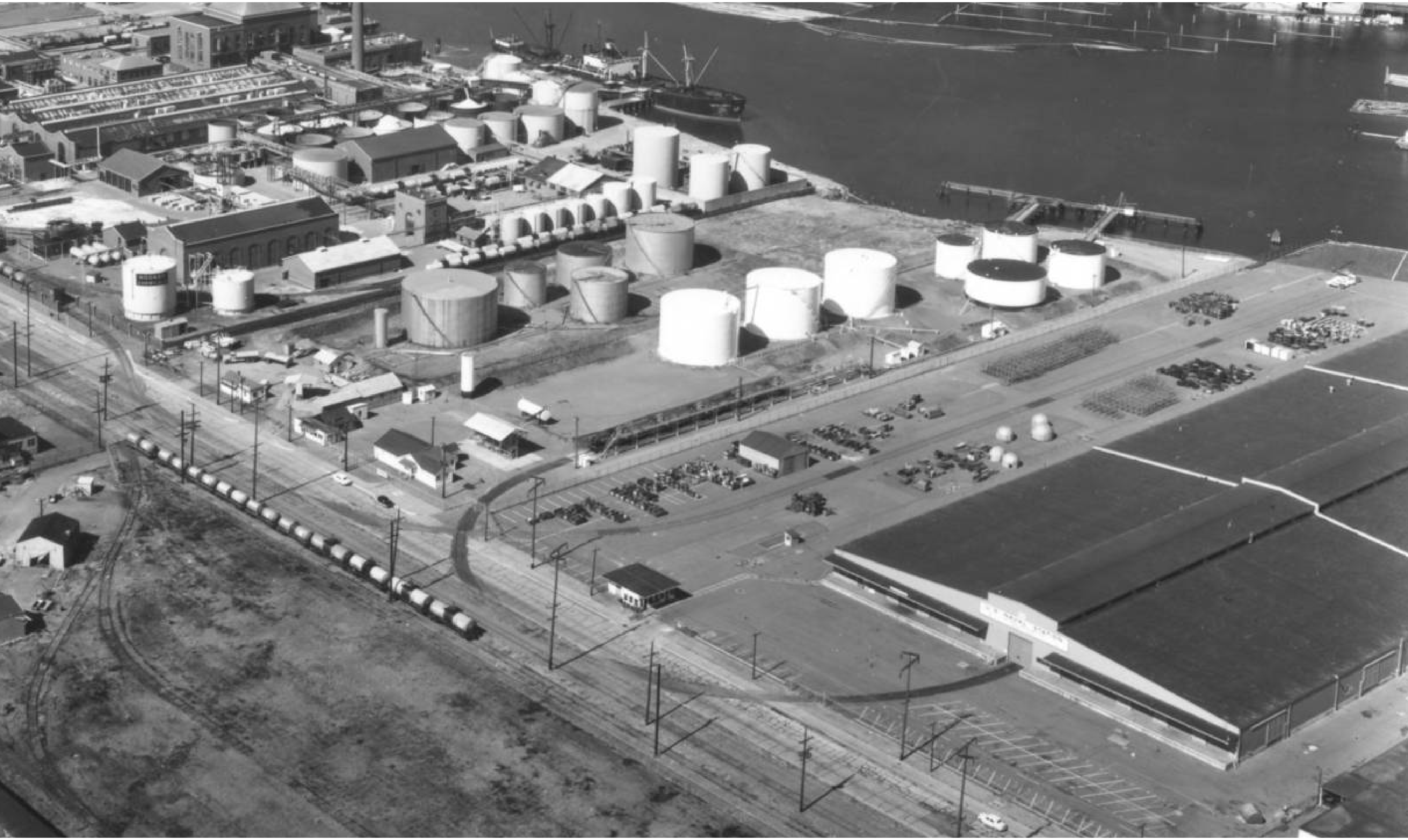
USAF



1958 – 1966
USAF



1960



Tacoma Public Library, (Richards Studio A125600-22)
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1961


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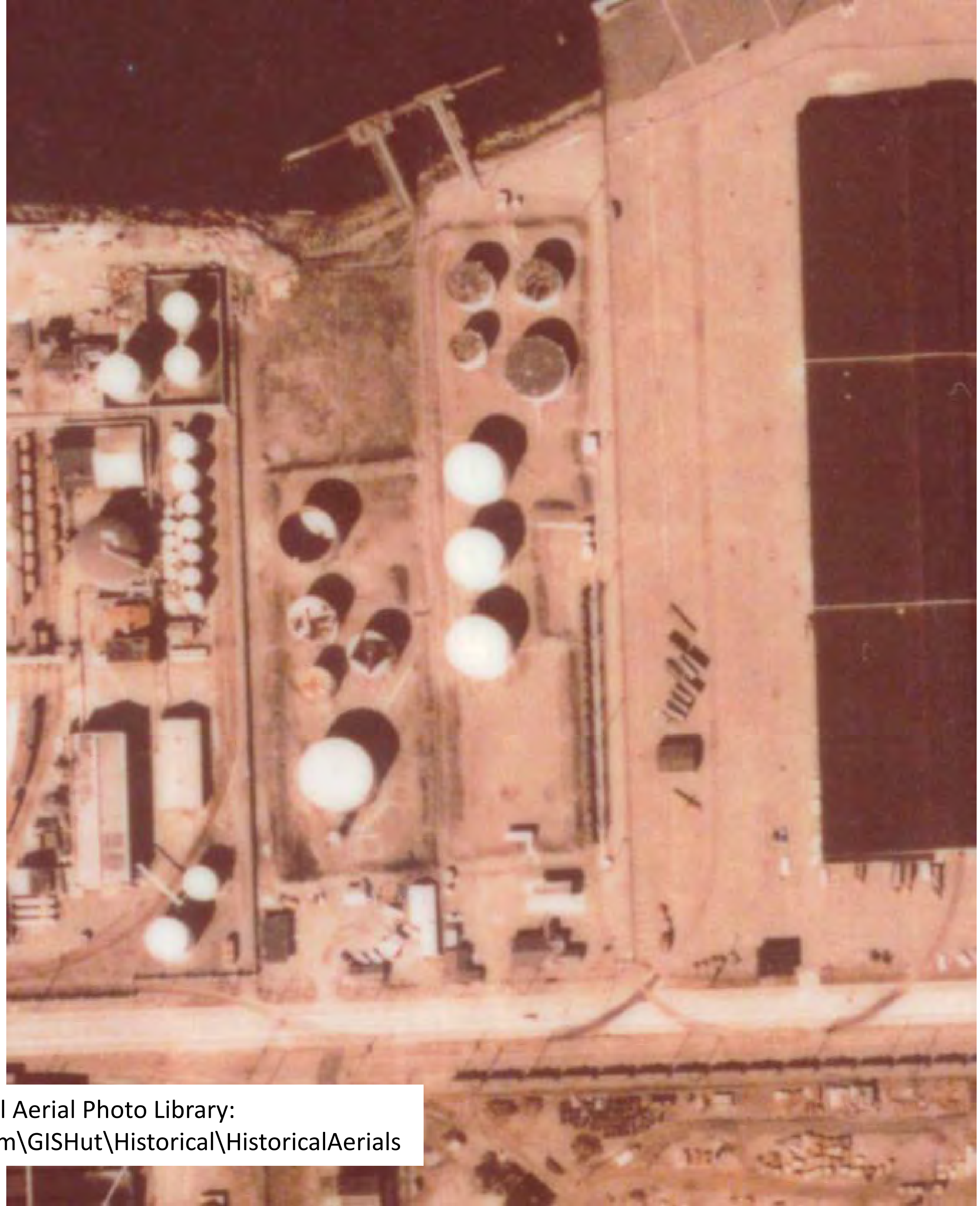
1962



Port of Tacoma Historical Aerial Photo Library:
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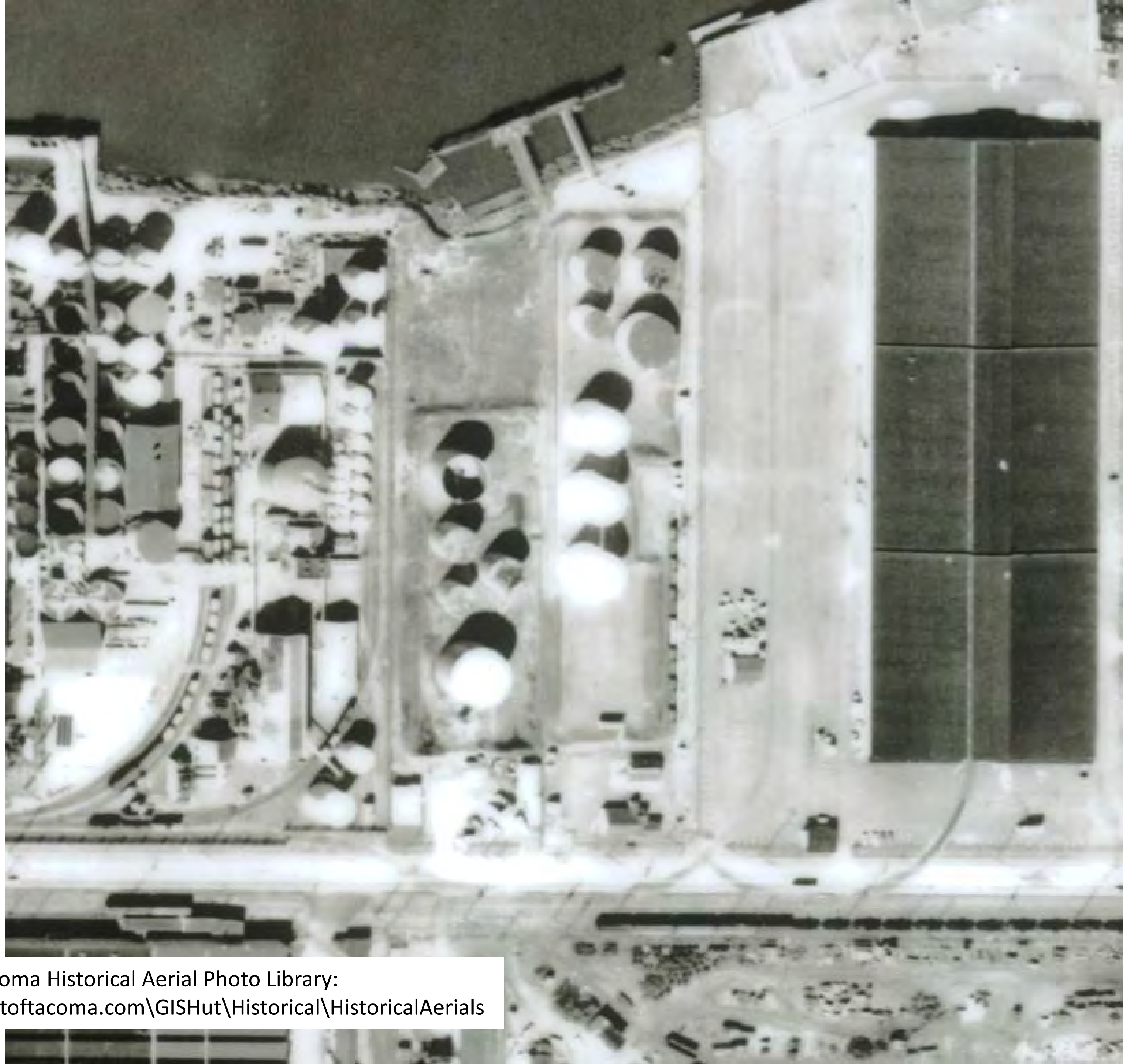
1963



Port of Tacoma Historical Aerial Photo Library:
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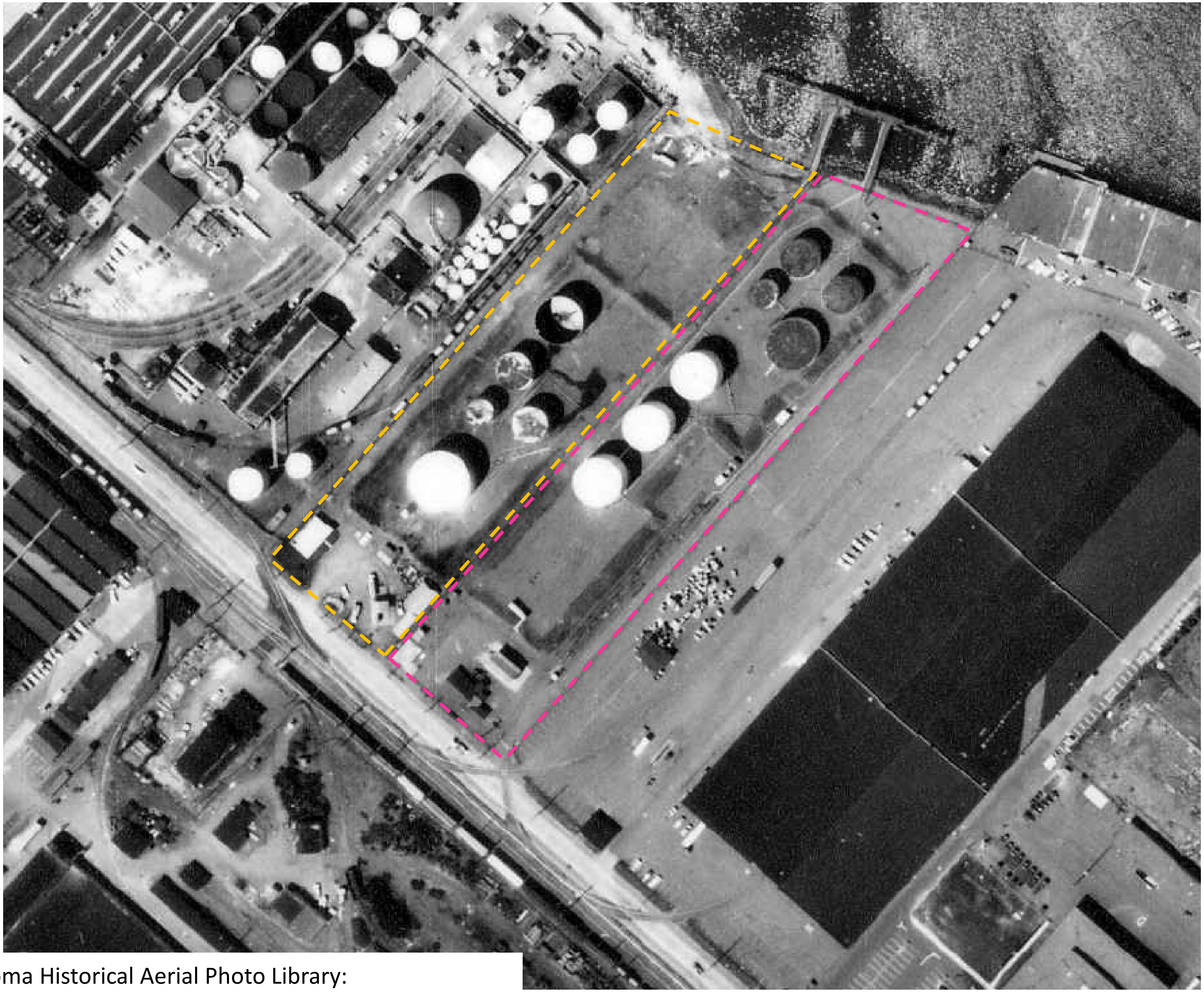
1965



Port of Tacoma Historical Aerial Photo Library:
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1967

Tacoma Public Library, (Richards Studio D150900-406C)
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# 1968


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# 1970

Tacoma Public Library, (Richards Studio D158294-3)
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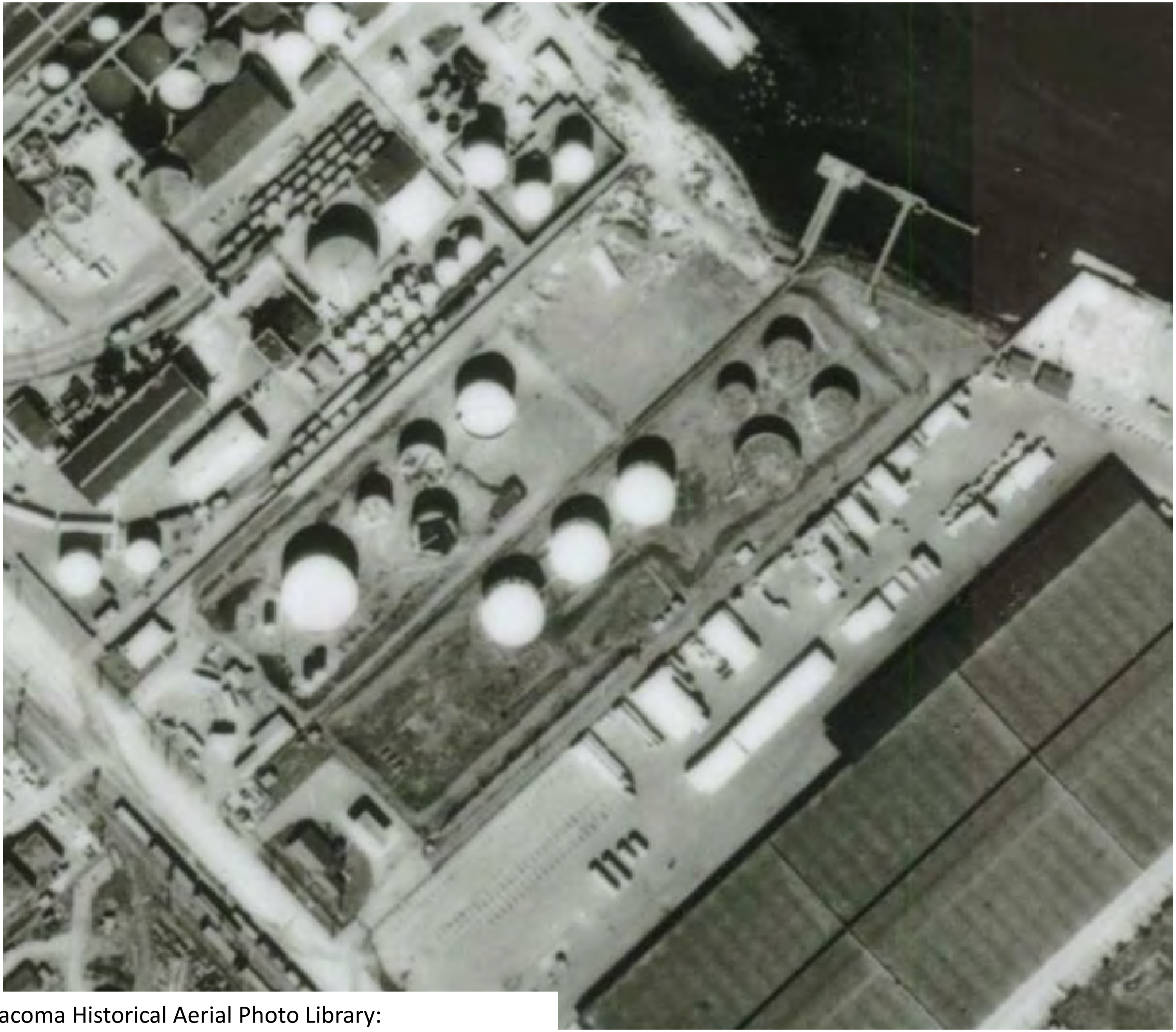
1970



Port of Tacoma Historical Aerial Photo Library:
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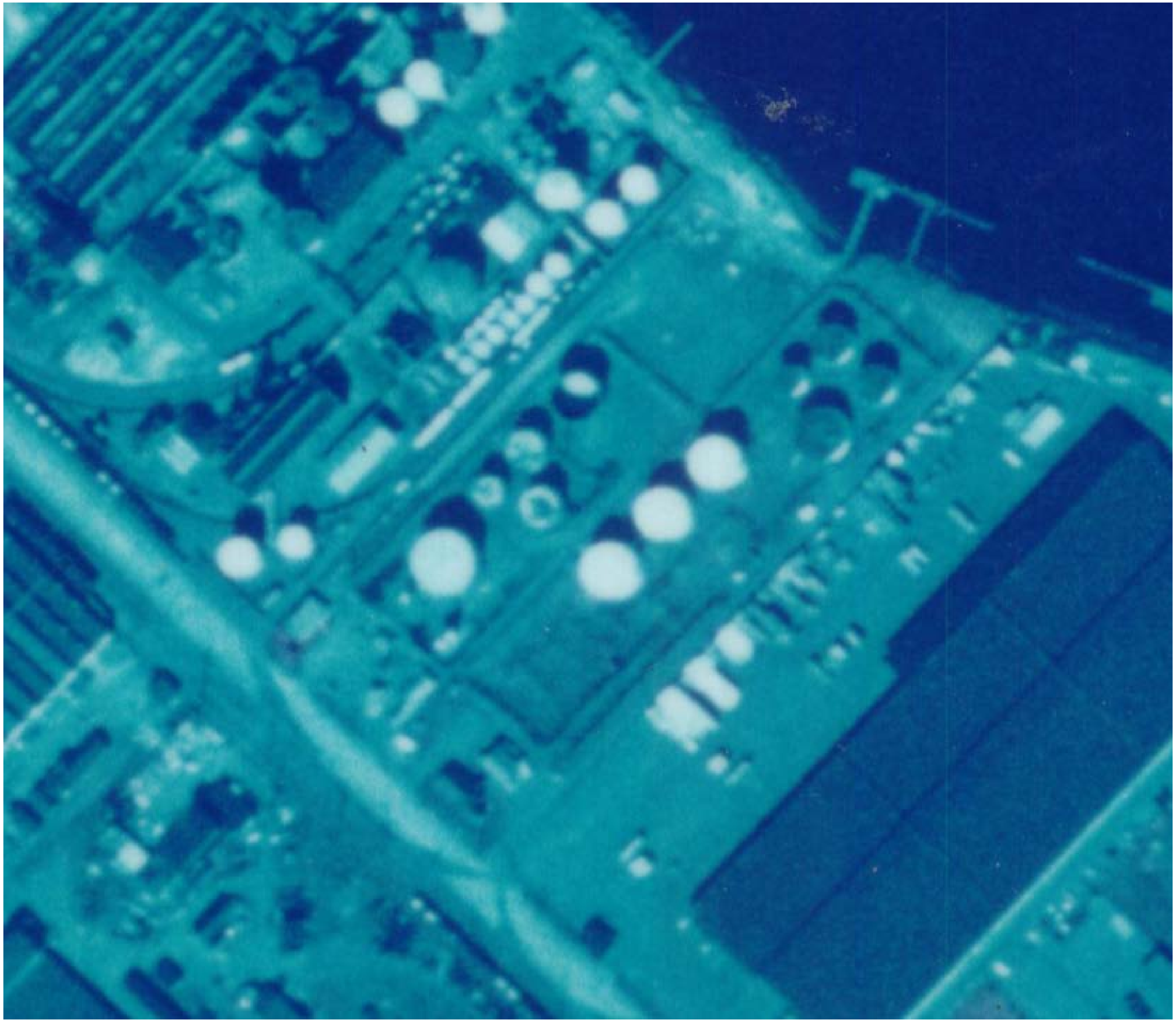
1971



Port of Tacoma Historical Aerial Photo Library:
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1973

Port of Tacoma Historical Aerial Photo Library:
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1978


Port of Tacoma Historical Aerial Photo Library:
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1978

Port of Tacoma Historical Aerial Photo Library:
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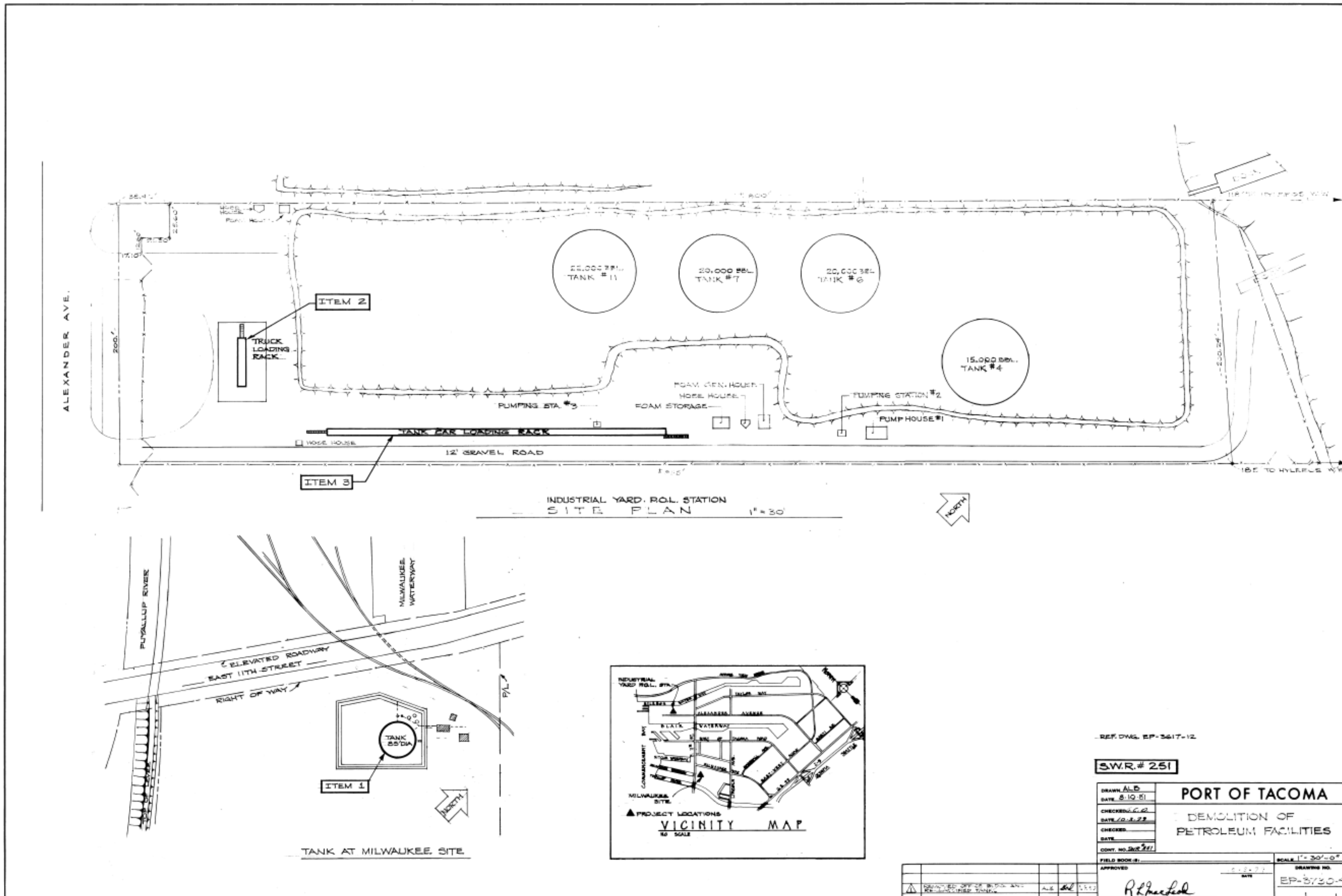
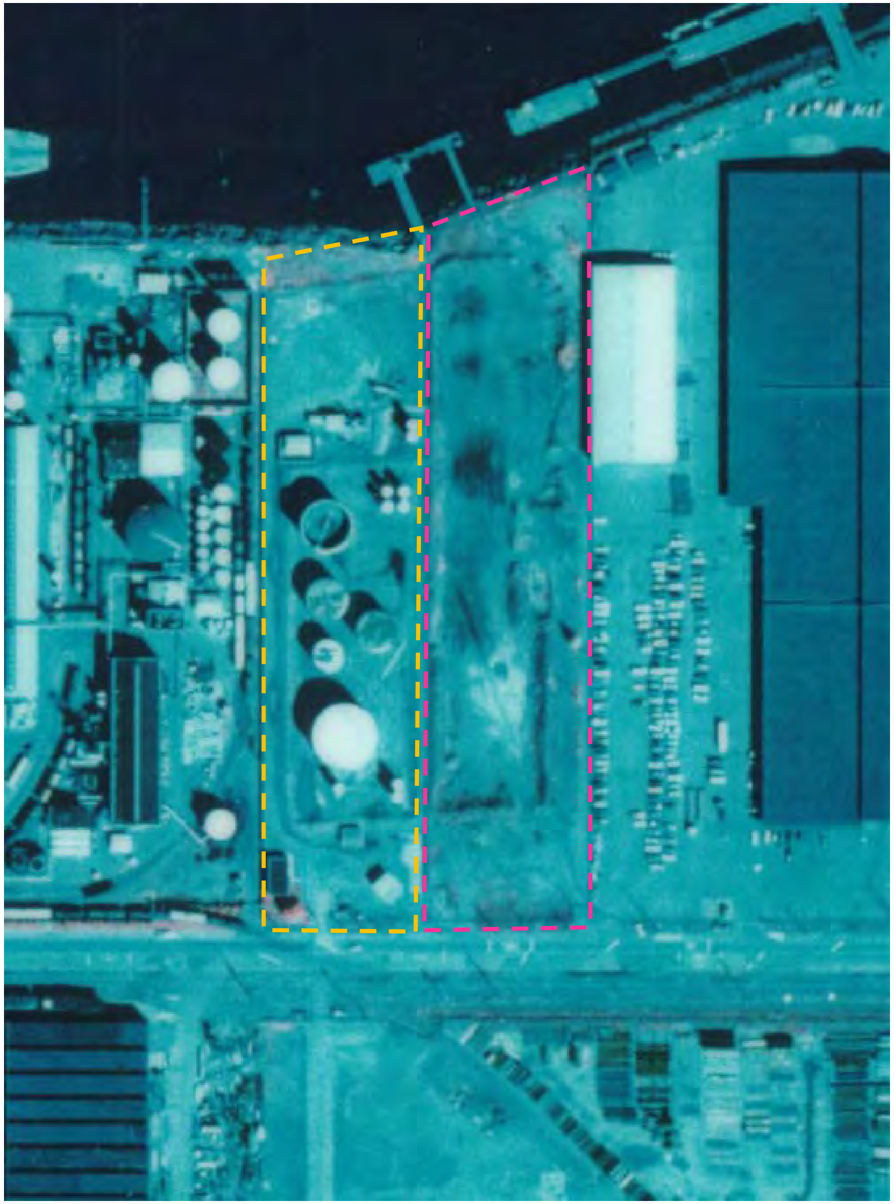
1981


ALEXANDER AVE.
TRUCK LOADING RACK
ITEM 2
22,000 BBL. TANK #11
20,000 BBL. TANK #7
20,000 BBL. TANK #6
15,000 BBL. TANK #4
FOAM GEN. HOUSE
HOSE HOUSE
FOAM STORAGE
PUMPING STA. #3
PUMPING STATION #2
PUMP HOUSE #1
TANK CAR LOADING RACK
HOSE HOUSE
12' GRAVEL ROAD
ITEM 3
INDUSTRIAL YARD P.O.L. STATION
SITE PLAN 1" = 30'
NORTH
PUYALLUP RIVER
MILWAUKEE WATERWAY
ELEVATED ROADWAY
EAST 11TH STREET
RIGHT OF WAY
P/L
TANK 55'DIA
ITEM 1
NORTH
TANK AT MILWAUKEE SITE
INDUSTRIAL YARD P.O.L. STA.
MILWAUKEE SITE
PROJECT LOCATIONS
VICINITY MAP
REF. DWG. EP-3617-12
S.W.R. # 251
PORT OF TACOMA
DEMOLITION OF PETROLEUM FACILITIES
DRAWN ALB
DATE 8-10-81
SCALE 1" = 30'-0"
EP-3730-4
SHEET 1 OF 1
MARK
REVISION
BY
APP.
DATE

1983



Port of Tacoma Historical Aerial Photo Library:
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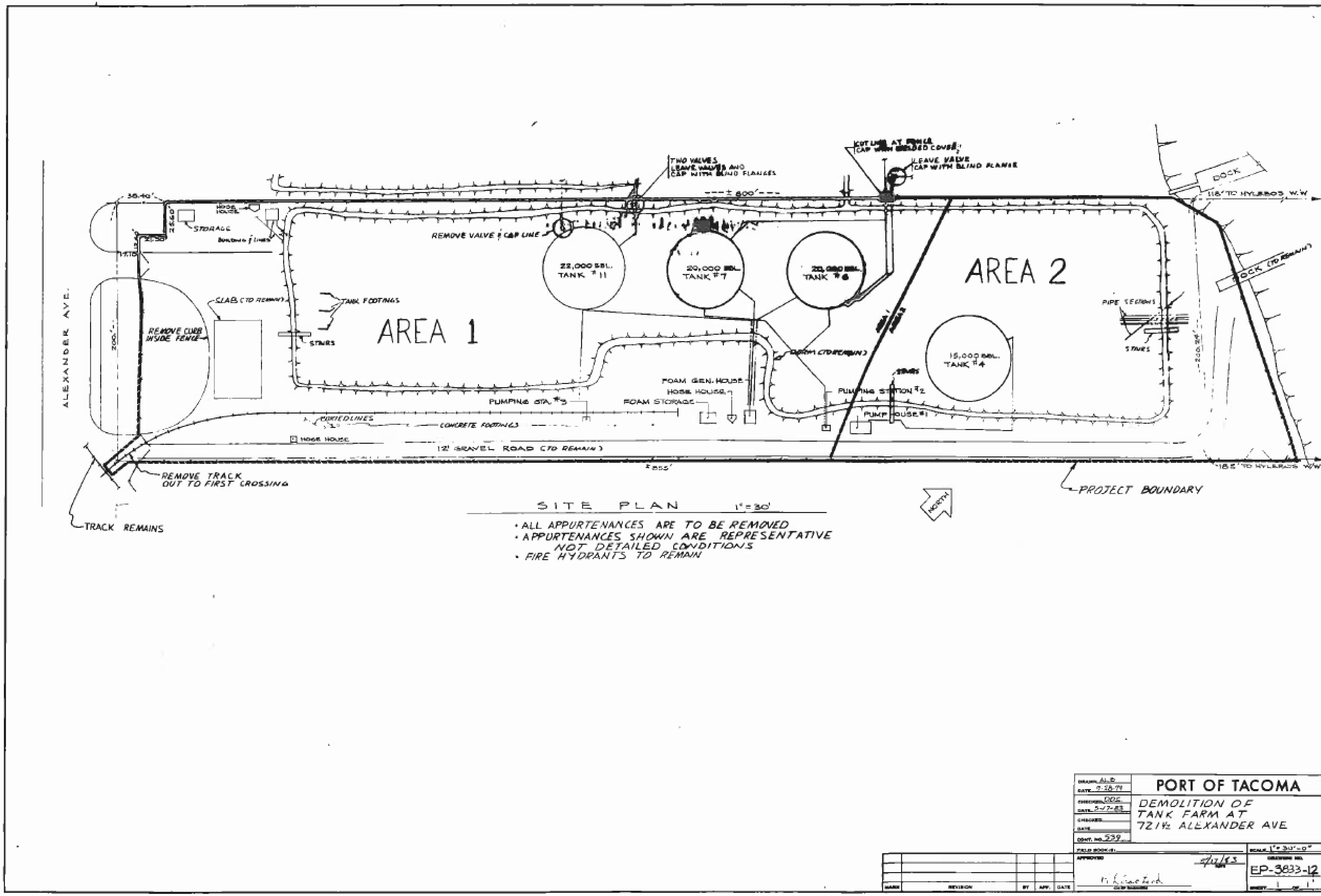
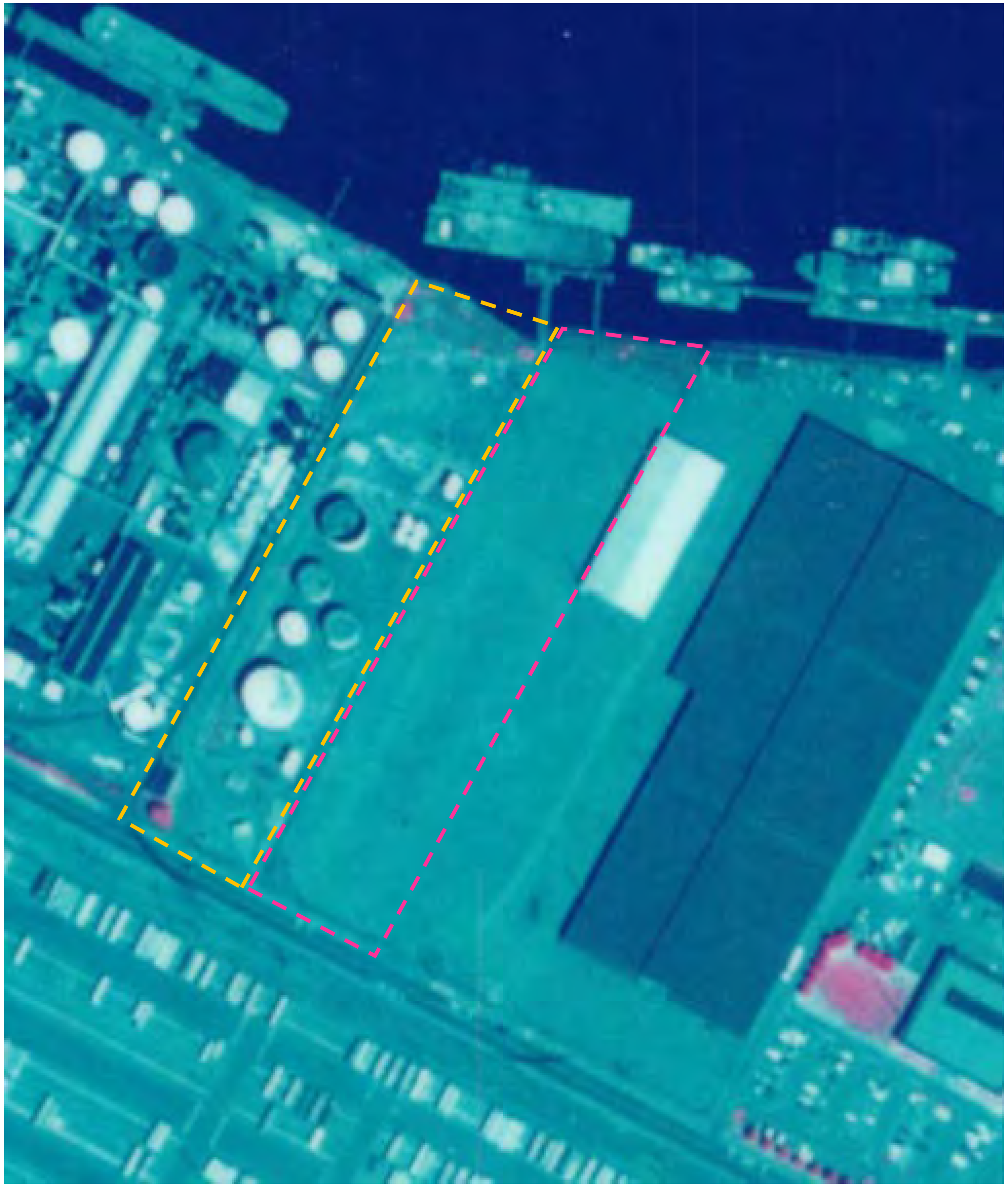
1983


AREA 1
AREA 2
22,000 BBL. TANK #11
20,000 BBL. TANK #7
15,000 BBL. TANK #4
ALEXANDER AVE.
REMOVE VALVE & CAP LINE
TANK FOOTINGS
SLAB (TO REMAIN)
REMOVE CURB INSIDE FENCE
STAIRS
FOAM GEN. HOUSE
HOSE HOUSE
FOAM STORAGE
PUMPING STA. #3
PUMPING STATION #2
PUMP HOUSE #1
CONCRETE FOOTINGS
12' GRAVEL ROAD (TO REMAIN)
REMOVE TRACK OUT TO FIRST CROSSING
TRACK REMAINS
PROJECT BOUNDARY
PIPE SECTIONS
DOCK
NORTH
SITE PLAN 1" = 30'
• ALL APPURTENANCES ARE TO BE REMOVED
• APPURTENANCES SHOWN ARE REPRESENTATIVE NOT DETAILED CONDITIONS
• FIRE HYDRANTS TO REMAIN
PORT OF TACOMA
DEMOLITION OF TANK FARM AT 721½ ALEXANDER AVE
EP-3833-12
1" = 30'-0"

1987



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1989

Port of Tacoma Historical Aerial Photo Library:
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1991

Port of Tacoma Historical Aerial Photo Library:
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1992

Port of Tacoma Historical Aerial Photo Library:
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1996

# tacomaMAP Print


tacomaMAP



Last Printed: 5/29/2020 9:55 AM

Scale: 1:2,257

0 45 90 180 270 360 ft

* This map is not suitable for site-specific analysis or for utility location *

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N

1998

# tacomaMAP Print


Scale: 1:2,257

0 45 90 180 270 360
ft

tacomaMAP



Last Printed: 5/29/2020 10:02 AM



N

2003


Google Earth

2010

Google Earth

2018


Google Earth

2018

Google Earth

APPENDIX B

# Plume Capture Evaluation—Occidental Site Remedy

**From:** Joel Massmann
**To:** Weeks, Sarah
**Subject:** RE: Alexander Ave petroleum capture
**Date:** Tuesday, September 25, 2018 4:37:22 PM
**Attachments:** Captured_benzene_breakthrough.pdf
Escaped_particles.xlsx

Hello Sarah,

I said in our phone call earlier today that I would get back to you with statistics regarding how much of the shallow-zone benzene is captured under Occidental's MSP pumping option. The table below gives the estimated percentage of the benzene mass that is captured. It is about 79%. In terms of the area of the plume area, about 78% is captured. The remaining portion discharges to the Hylebos.

| | Mass | Area |
|---|---|---|
| Captured | 79.4% | 78.3% |
| Escaped | 20.6% | 21.7% |
| Total | 100.0% | 100.0% |

The attached figure shows the estimated arrival times for the 79% that is captured. Most of this mass arrives at the well within about 20 years after pumping is initiated. It should be noted that these estimates do not consider sorption or other retardation processes and it does not consider degradation. It assumes the benzene particles travel with the velocity of the groundwater.

Finally, I have attached an Excel file that gives the coordinates of the particles that are not captured. These particles discharge into the Hylebos.

I understand that you want to check with Joyce Mercuri before I perform a similar evaluation for particles in the deeper groundwater zone on the Alexander Avenue properties. I will wait to hear from you before I do that evaluation. If you have any questions about what I have attached, please let me know.

Thanks.

Joel

**Keta Waters**
1912 33rd Ave S.
Seattle, WA 98144
(206) 236-6225 or (206) 919-1363 (cell)
Joel@KetaWaters.com

**From:** Joel Massmann [mailto:massmann@comcast.net]

**Sent:** Monday, September 24, 2018 3:19 PM
**To:** 'Weeks, Sarah' <sweeks@portoftacoma.com>
**Subject:** RE: Alexander Ave petroleum capture

Hello Sarah,

I have attached a PDF that describes some of the particle tracking results from the Occidental groundwater model. If you think it would be useful for me to share my screen, the link below will allow that access during our call tomorrow.

https://join.me/KetaWaters

I assume you will pass this on to others as you see fit. Could you also send me the call-in information? Thanks.

Joel

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**From:** Joel Massmann [mailto:massmann@comcast.net]
**Sent:** Friday, September 21, 2018 2:49 PM
**To:** 'Weeks, Sarah' <sweeks@portoftacoma.com>
**Subject:** RE: Alexander Ave petroleum capture

Tuesday at 9 works for me. I will send you some PowerPoint slides and a link for the webinar on Monday. I assume you will forward the link to the others who will be on the call/meeting.
Joel

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**From:** Weeks, Sarah [mailto:sweeks@portoftacoma.com]
**Sent:** Friday, September 21, 2018 2:38 PM
**To:** Joel Massmann <massmann@comcast.net>
**Subject:** RE: Alexander Ave petroleum capture

Hi Joel –

Great! A webinar would be great. We already have a project meeting set up on Tuesday the 25th at 9am. Would that work for you?

Sarah

**Sarah Weeks |** Environmental Project Manager **|** Port of Tacoma **|** 253.383.9450 **|**
www.portoftacoma.com

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**From:** Joel Massmann [mailto:massmann@comcast.net]
**Sent:** Thursday, September 20, 2018 9:07 AM

**To:** Weeks, Sarah <sweeks@portoftacoma.com>
**Subject:** RE: Alexander Ave petroleum capture

Hello Sarah,

I have incorporated the benzene and GRO plumes that Charles provided into the groundwater flow model and have run particle tracking algorithms to evaluate plume capture. I have looked at particle tracks for both the “no-action” alternative and for Occidental’s preferred alternative.

How would you like those results presented? I could send you a brief memo that describes the results or we could set up a webinar to go over the results. If there are other simulations that you know you want to consider, please let me know.

Thanks.

Joel

**Keta Waters**
**1912 33rd Ave S.**
**Seattle, WA 98144**
**(206) 236-6225 or (206) 919-1363 (cell)**
**Joel@KetaWaters.com**

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**From:** Weeks, Sarah [mailto:sweeks@portoftacoma.com]
**Sent:** Tuesday, September 11, 2018 11:52 AM
**To:** Joel Massmann <massmann@comcast.net>
**Subject:** Alexander Ave petroleum capture

Hi Joel –

Checking in on the capture analysis for the petroleum contaminant plume at Alexander Avenue. Were you able to connect with Charles and get what you needed to run the analysis?

Sarah

**Sarah Weeks** | Environmental Project Manager | Port of Tacoma | 253.383.9450 |
www.portoftacoma.com

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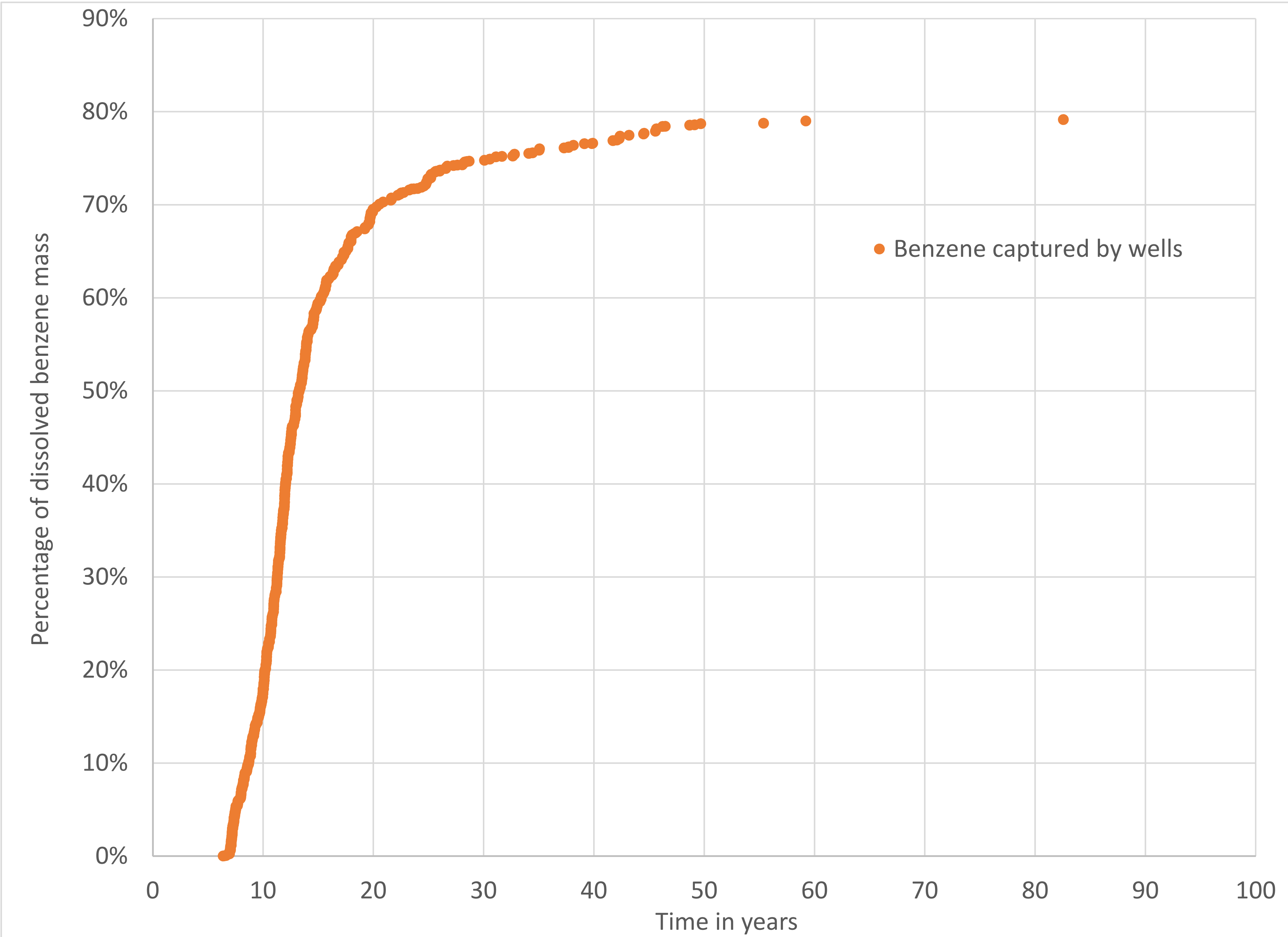


90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percentage of dissolved benzene mass
0
10
20
30
40
50
60
70
80
90
100
Time in years
Benzene captured by wells

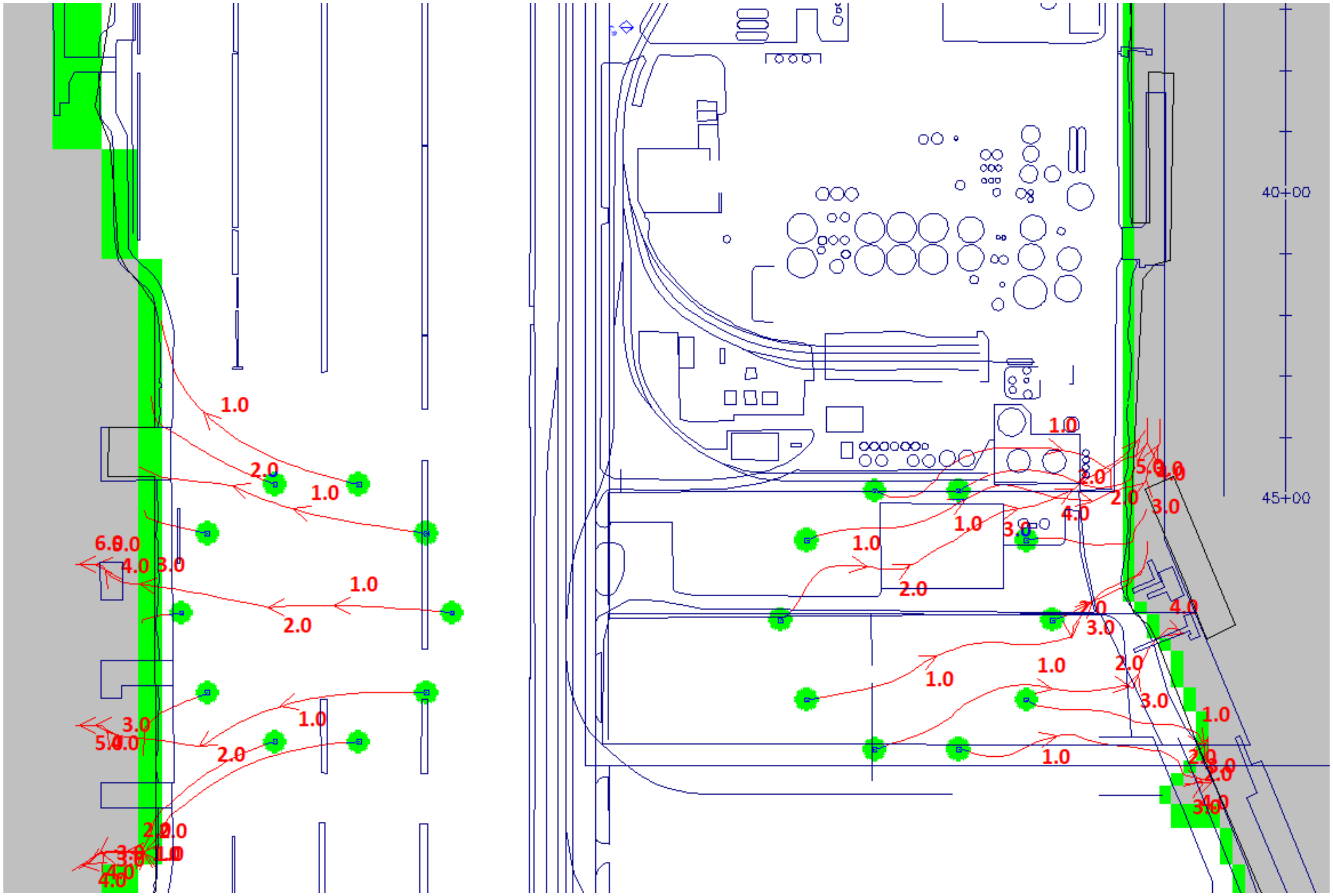



**Figure 1.** Particle tracks for the OCC "No Action" alternative. Arrow heads give the locations at yearly intervals. Particles are placed in layer 1 (elevation +12 to -1.75 ft NGVD). All particles discharge to the Hylebos or Blair Waterway. Travel times are on the order of 2 to 4 years. This travel time does not consider the effects of sorption or other retardation processes. Particle tracks for the existing system are essentially the same as those shown above.

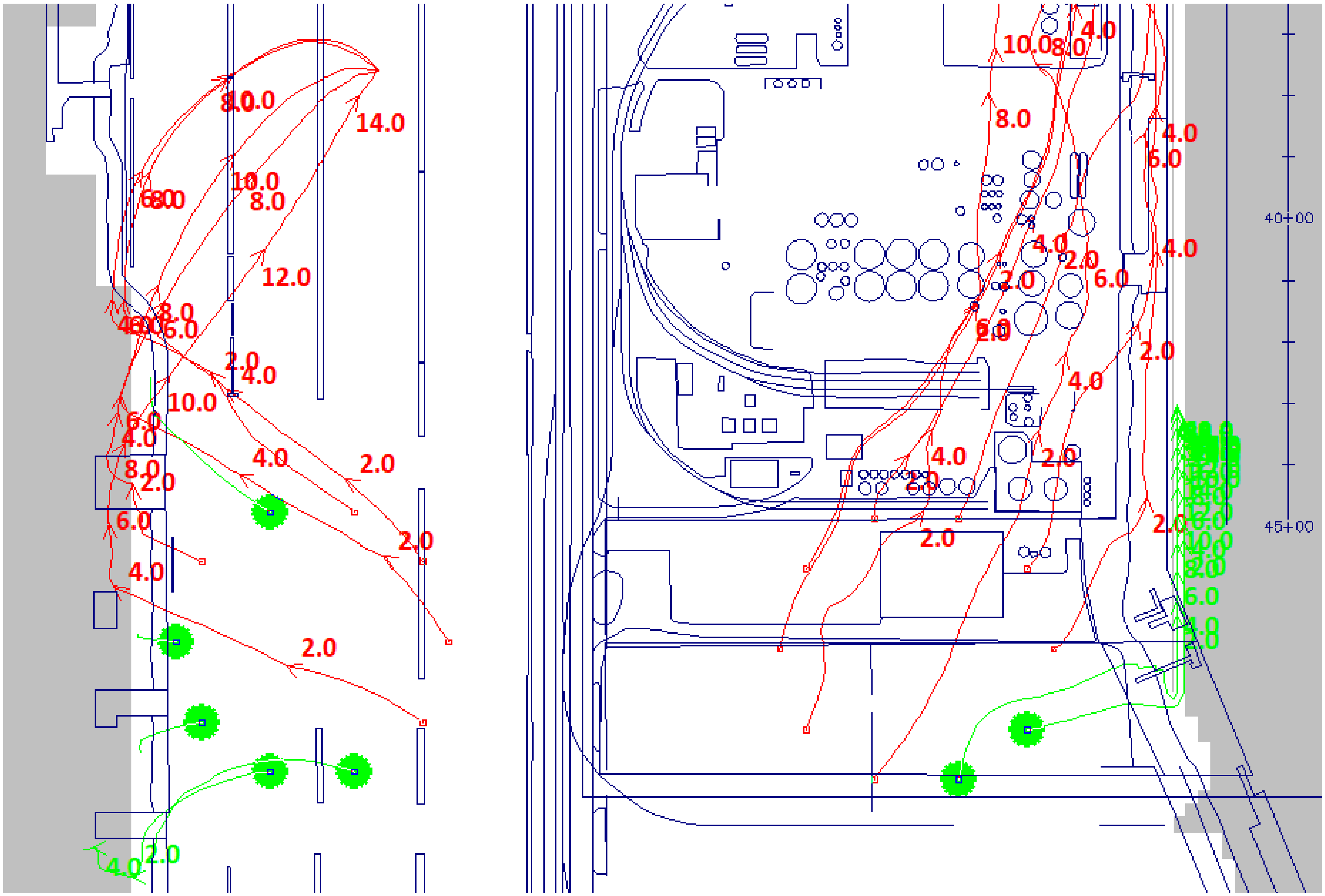


**Figure 2.** Particle tracks for the OCC "MSP" alternative. Green circles and lines denote particles that discharge to either the Hylebos or Blair waterways. Red squares and lines denote particles captured by the MSP extraction system. The average travel time to the extraction system is approximately 10 to 20 years.

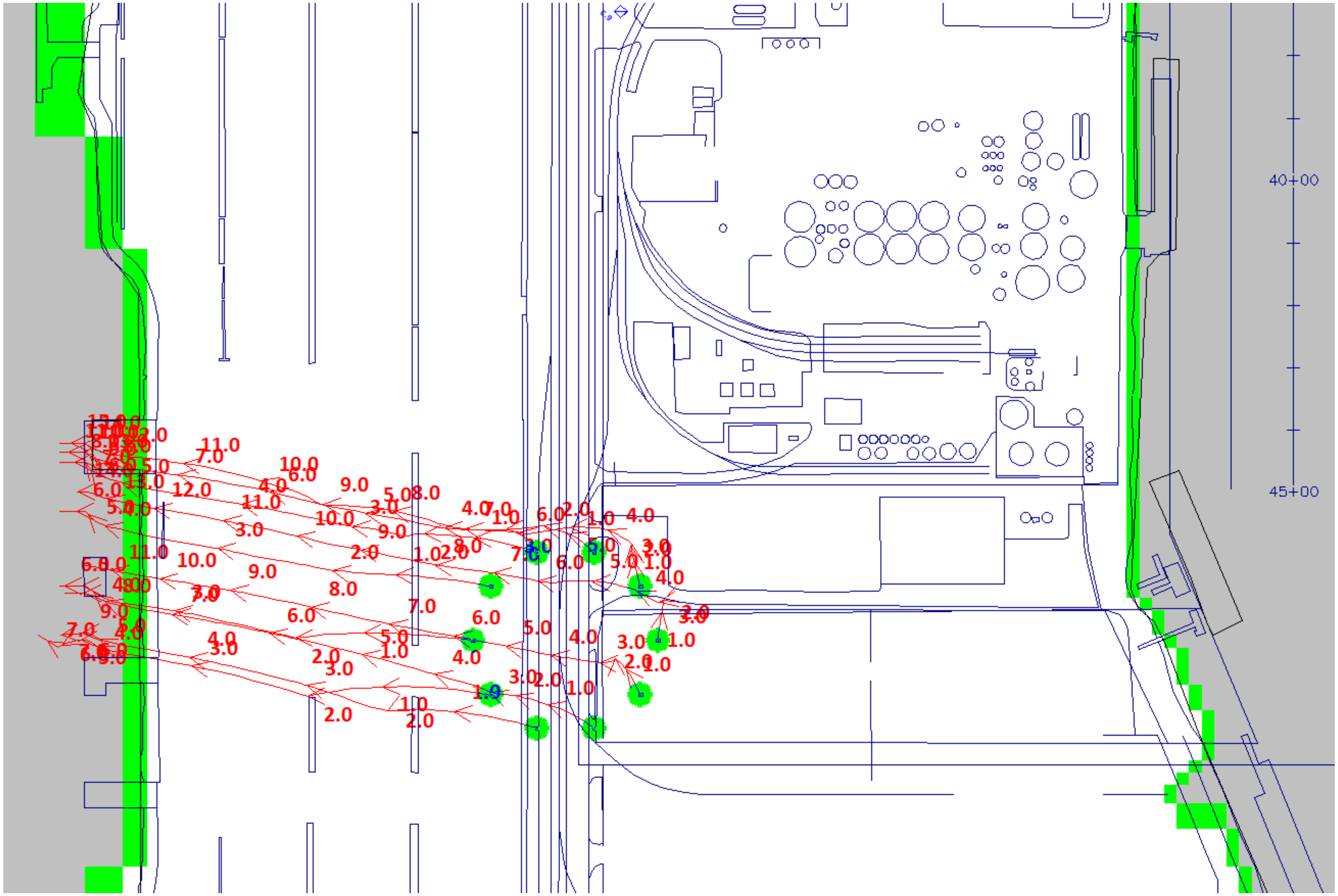



**Figure 1.** Particle tracks for the OCC "No Action" alternative. Arrow heads give the locations at yearly intervals. Particles are placed in layer 1 (elevation +12 to -1.75 ft NGVD). All particles discharge to the Blair Waterway. Travel times are on the order of 5 to 10 years. This travel time does not consider the effects of sorption or other retardation processes.

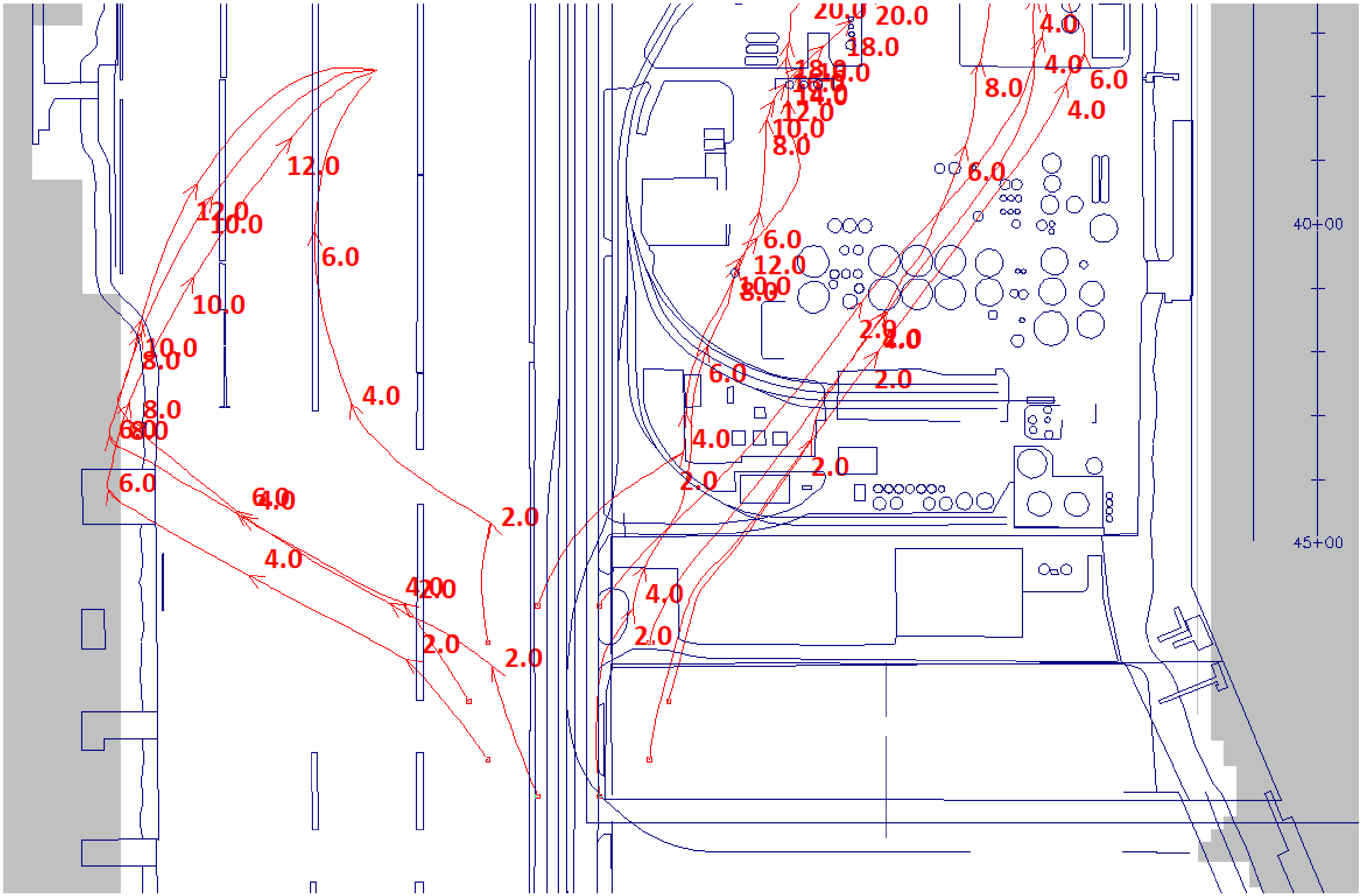



**Figure 2.** Particle tracks for the OCC "MSP" alternative. Ten particles were released in the vicinity of Alexander Avenue. Red squares and lines denote that all particles are captured by the MSP extraction system. The average travel time to the extraction system is approximately 10 to 20 years.


**Figure 1.** Particle tracks for benzene in the shallow aquifer with the "MSP" pumping system. Concentration information provided by C. San Juan, Ecology. Plume contour shown in black corresponds to 24 ug/L benzene and and contours shown in white corresponds to 800 ug/L GRO. Blue tracks discharge to Hylebos Waterway; red tracks are captured by pumping system.

**Figure 2.** Particle tracks for benzene in the shallow aquifer with the "No Action" alternative. Concentration information provided by C. San Juan, Ecology. Plume contour shown in black corresponds to 24 ug/L benzene and and contours shown in white corresponds to 800 ug/L GRO. Blue tracks discharge to Hylebos Waterway.

APPENDIX C

# Petroleum Hot Spot Analyses

DEPARTMENT OF ECOLOGY
State of Washington

# Alexander Ave. Petroleum

SOIL MASS, VOLUME AND AREA

# Alexander Ave. Petroleum

- How much soil needs to be removed / treated?
- What is a reasonable and permanent remedy?
- What will it cost?

# Methods

- Assemble historical soil TPH data.
- Derive target concentrations. Map soil TPH footprints at target concentrations.
- **Use contouring and polygon methods to calculate soil TPH mass, volume and area from target concentrations.**
- Compare results.

# Plume Stability Method

***Use the plume stability method to calculate concentration, mass, volume and area…***

**J.A. Ricker/ Ground Water Monitoring & Remediation 28, no. 4: 85–94**

Ground Water Monitoring&Remediation

## A Practical Method to Evaluate Ground Water Contaminant Plume Stability

*by Joseph A. Ricker*


### Abstract

Evaluating plume stability is important for the evaluation of natural attenuation of dissolved chemicals in ground water. When characterizing ground water contaminant plumes, there are numerous methods for evaluating concentration data. Typically, the data are tabulated and ground water concentrations presented on a site figure. Contaminant concentration isopleth maps are typically developed to evaluate temporal changes in the plume boundaries, and plume stability is often assessed by conducting trend analyses for individual monitoring wells. However, it is becoming more important to understand and effectively communicate the nature of the entire plume in terms of its stability (i.e., is the plume growing, shrinking, or stable?). This article presents a method for evaluating plume stability using innovative techniques to calculate and assess historical trends in various plume characteristics, including area, average concentration, contaminant mass, and center of mass. Contaminant distribution isopleths are developed for several sampling events, and the characteristics mentioned previously are calculated for each event using numerical methods and engineering principles. A statistical trend analysis is then performed on the calculated values to assess the plume stability. The methodology presented here has been used at various contaminated sites to effectively evaluate the stability of contaminant plumes comprising tetrachloroethene, carbon tetrachloride, pentachlorophenol, creosote, naphthalene, benzene, and chlordane. Although other methods for assessing contaminant plume stability exist, this method has been shown to be efficient, reliable, and applicable to any site with an established monitoring well network and multiple years of analytical data.


### Introduction

Evaluating plume stability is important for the evaluation of natural attenuation of dissolved chemicals in ground water. U.S. EPA (1998) states that the primary line of evidence in evaluating natural attenuation is historical ground water chemistry data that demonstrate a clear and meaningful trend of decreasing contaminant mass and/or concentration over time at appropriate monitoring or sampling points. When characterizing ground water contaminant plumes, there are numerous methods for evaluating concentration data.

Wiedemeier et al. (2000) discussed common approaches for evaluating plume stability using both graphical and statistical techniques. Graphical methods include the following: (1) the preparation of contaminant concentration isopleth maps; (2) plotting concentration data vs. time for individual monitoring wells; and (3) plotting concentration data vs. distance downgradient for several monitoring wells. Common statistical methods for evaluation of temporal and spatial trends include regression analysis (U.S. EPA 2006), the Mann-Whitney *U*-test (Mann and Whitney 1947), and the Mann-Kendall test (U.S. EPA 2006; Gilbert 1987).

Graphical plume stability analysis by comparing isopleth maps over time can provide compelling visual evidence for natural attenuation. However, a comparison of apparent plume size over time does not always provide a complete analysis. Consider, for example, the case of a plume that discharges to a surface water body, or a plume geometry that is persistent over time. In this case, the plume area would remain relatively unchanged, whereas the overall plume average concentration and mass may be decreasing. The change in plume mass would not be necessarily reflected in the visual analysis of isopleth maps. However, a quantitative analysis of changes in overall plume concentration and mass would provide a better understanding of the plume stability.

A common approach for evaluating plume stability is the use of statistical analysis techniques for single-well data. However, chemical concentration trends at individual monitoring wells may show different trends. For example, at a given site, there may be wells exhibiting decreasing



Ground Water Monitoring & Remediation 28, no. 4/Fall 2008/pages 85–94 85

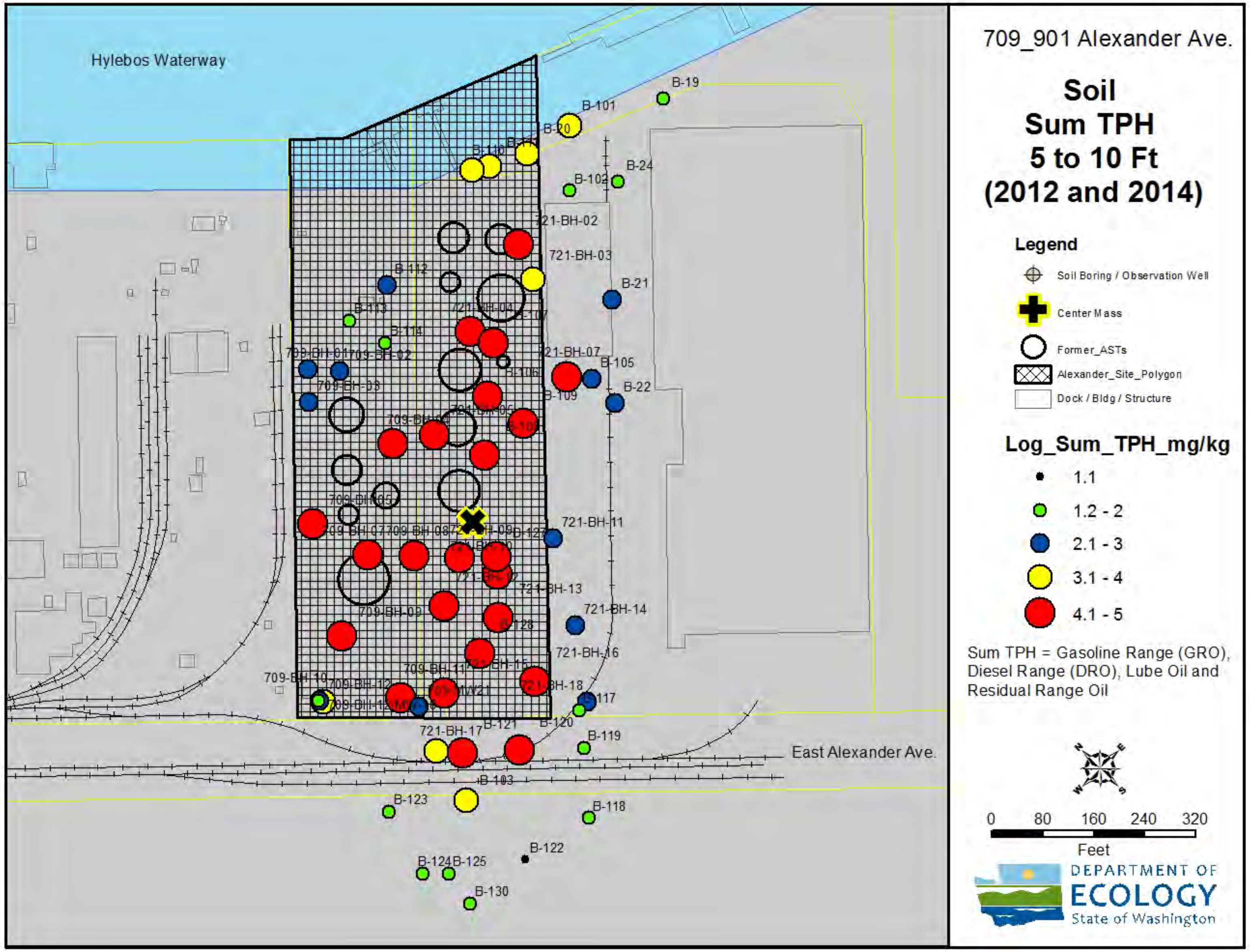
# Baseline Data Assembly (Soil TPH)

- Assemble historical soil TPH data (gasoline, diesel, lube oil and residual range; Ecology EIM; Occidental GHD e-dat database). Filter the data to the 709, 721 and 901 parcels (omit 605 parcel / Occidental). Result = 1,003 records (1989-2014). Soil sampling depths @ < 1 to 75 feet.

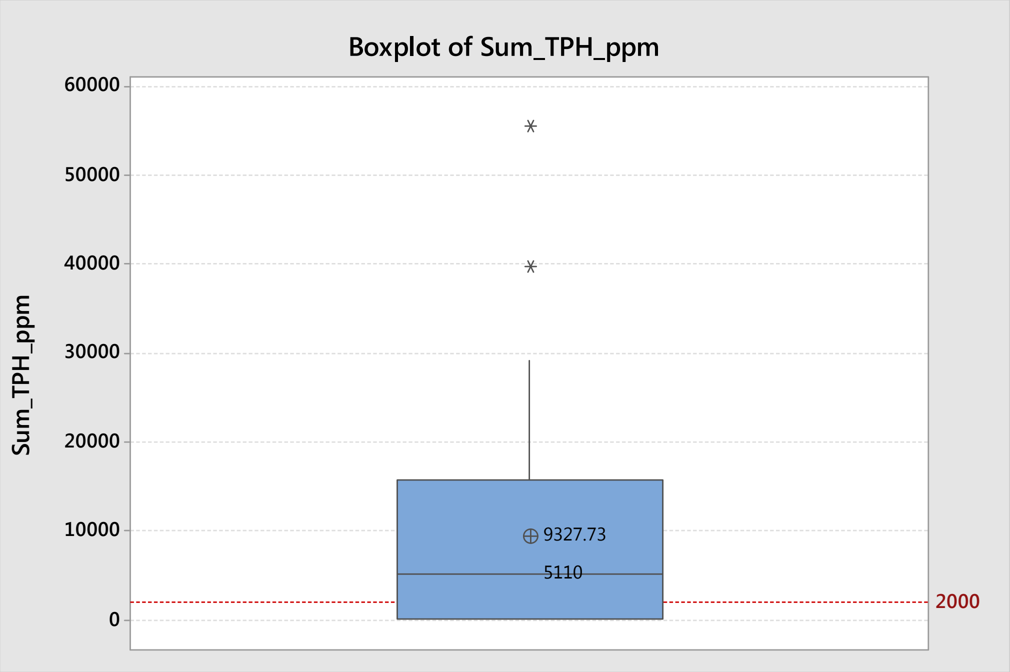
- Re-filter the data to: 1) date collected (2012 and 2014) and 2) depth (5 to 10 ft). Filter and omit the "B-XX" (e.g. B-10) series data (LNG plant), except for B-19, 20, 21, 22 and 24. Result = 173 records.

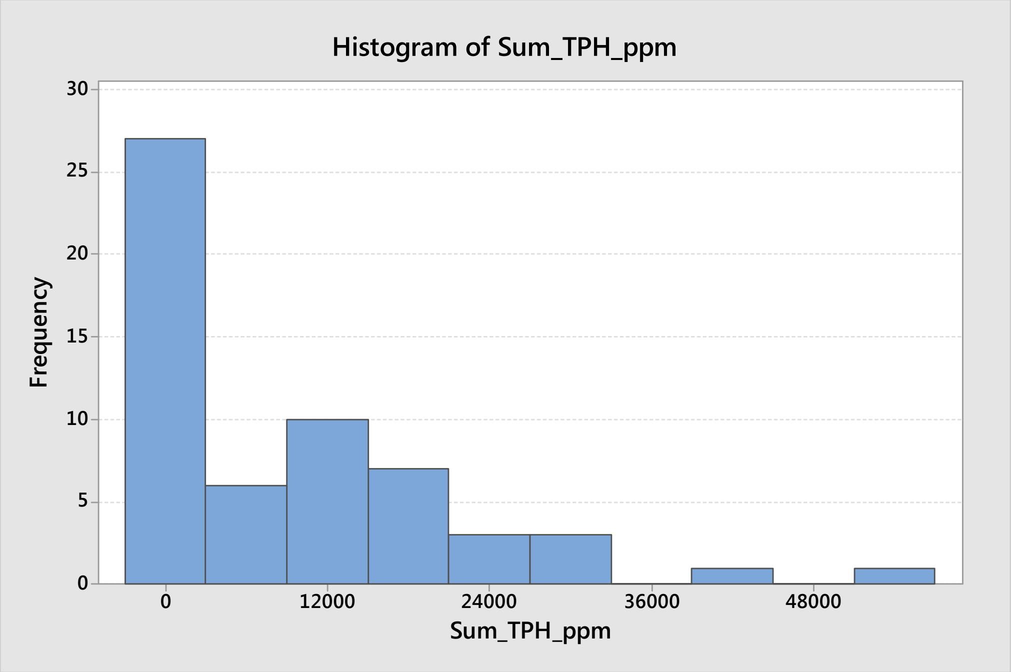
- Sum the TPH result for each location (sum = gasoline, diesel and lube oil). If more than one result per location, then select the higher value. **Result = 58 records.**

Baseline Soil Sum TPH Data Alexander Petroleum



# Soil Sum TPH Box Plot and Histogram

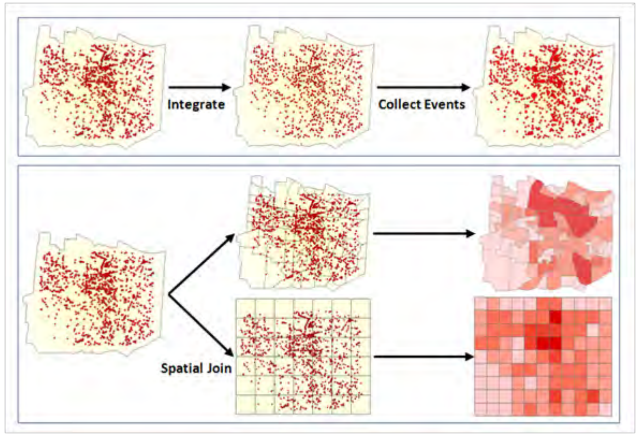


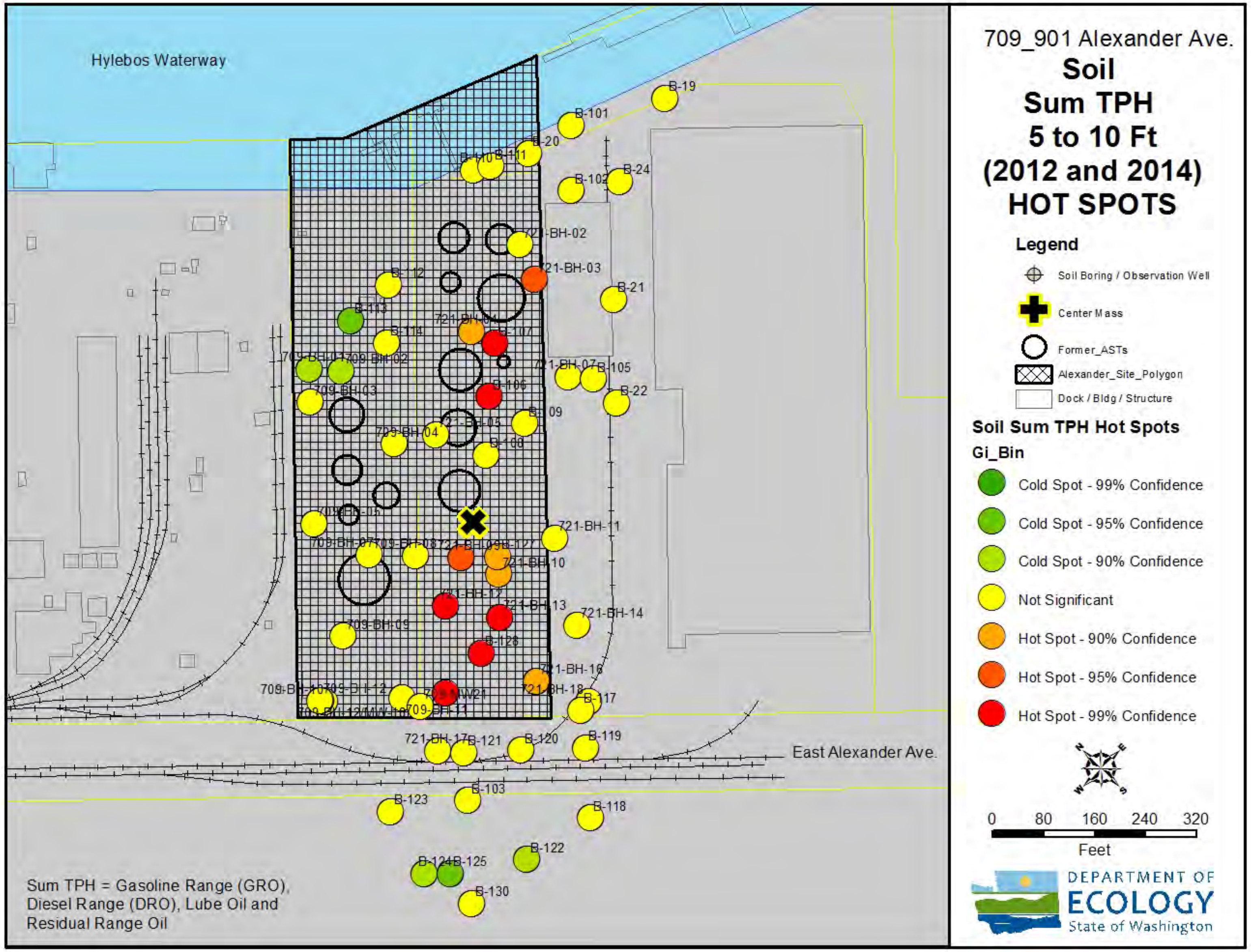



# Soil TPH HOT SPOTs

- Use ArcMap geostat analyst to define soil TPH hot spots.
- Calculate mass, volume and area from hot spot target concentration.

The Hot Spot Analysis tool calculates the Getis-Ord Gi* statistic (pronounced G-i-star) for each feature in a dataset. The resultant z-scores and p-values tell you where features with either high or low values cluster spatially.






## Soil Sum TPH Hot Spots (n = 12)

| Location | Sum_TPH_ppm |
|---|---|
| 721-BH-03 | 6,860 |
| 721-BH-04 | 55,490 |
| 721-BH-09 | 15,670 |
| 721-BH-10 | 20,080 |
| 721-BH-12 | 25,310 |
| 721-BH-13 | 29,210 |
| 721-BH-15 | 20,050 |
| 721-BH-16 | 27,390 |
| B-106 | 10,480 |
| B-107 | 20,900 |
| B-127 | 13,267 |
| B-128 | 25,420 |

# Target Soil Concentrations

- **What is an appropriate target concentration?** You need target levels for mass, volume and area.
- Use two methods: 1) arbitrary, and 2) hot spot.
- Use Method A soil diesel range target of 2,000 ppm as the baseline.
- Arbitrary (best professional judgement) – target soil sum TPH concentrations @ 2,000 ppm, 5,000 ppm, 10,000 ppm, 15,000 ppm and 30,000 ppm selected.
- Hot spot – target concentration is derived from ArcMap hot spot statistical analysis.

# Soil TPH Volume and Area

- Use the Surfer contouring software to grid the data. Use both **regular scale** and **log-transformed** concentration data to determine the area footprints.

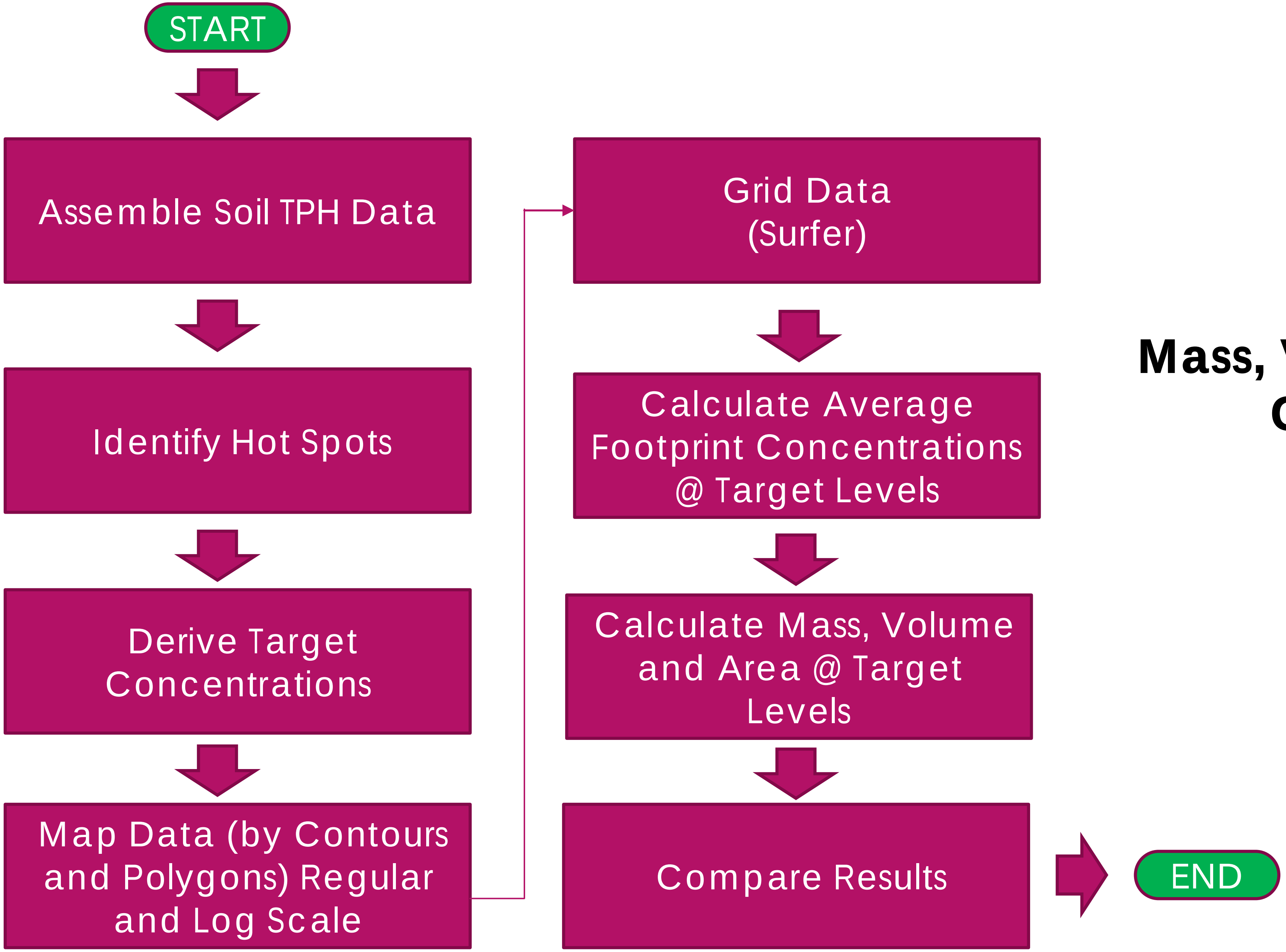
- Calculate mass, volume and area from the target concentrations. Use the Surfer (Golden Software) contouring software to grid the data. Calculate the grid volume @ target concentrations (X and Y = ft units; Z = concentration = mg/kg). **Divide the grid volume (ft2*mg/kg) by area (ft2) for average sum-TPH soil concentration (mg/kg).**

- Note – average footprint concentration is target level + average footprint concentration. For example, if target is 2,000 ppm, then final average concentration = 2,000 ppm + (average footprint concentration). Why? It's because you are calculating the average concentration above some target.

# Soil TPH Mass

- **Mass = Soil Concentration * UCF * Soil Bulk Density * Soil Volume**
- Soil Concentration = average sum-TPH (mg/kg)
- UCF = unit conversion (1 kg = 1x10^6 mg)
- Soil bulk density = 42.5 (kg/ft3)
- Soil Volume = (ft3) = area above target (ft2)*thickness (5-ft)*soil porosity (0.3)

# Mass, Volume and Area Calculations Process



# Soil Sum TPH Average Concentrations
## (Regular Scale Concentration Contours)

| Target_ Soil | Positive Volume (Cut) | Positive Planar Area (Cut) | Average Sum TPH |
|---|---|---|---|
| mg/kg | mg/kg*ft2 | ft2 | mg/kg |
| | | | |
| 2,000 | 4,504,275,682 | 366,635 | 14,285 |
| 5,000 | 3,462,126,624 | 318,506 | 15,870 |
| 10,000 | 2,015,044,497 | 251,480 | 18,013 |
| 15,000 | 1,044,901,976 | 140,037 | 22,462 |
| 19,000 | 589,337,947 | 90,737 | 25,495 |
| 30,000 | 75,377,940 | 14,078 | 35,354 |

# Soil Sum TPH Average Concentrations
## (Log Scale Concentration Contours)

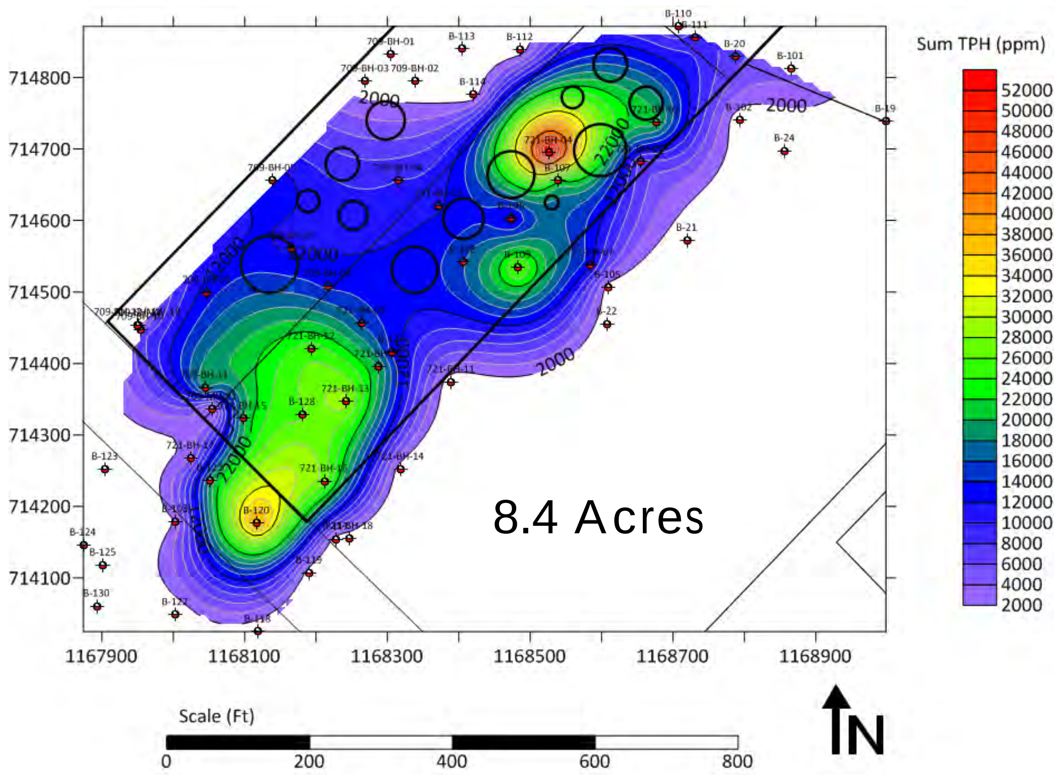
| Target_ Soil | Positive Volume (Cut) | Positive Planar Area (Cut) | Average Sum TPH |
|---|---|---|---|
| mg/kg | mg/kg*ft2 | ft2 | mg/kg |
| | | | |
| 2,000 | 4,504,275,682 | 262,537 | 19,157 |
| 5,000 | 3,462,126,624 | 215,831 | 21,041 |
| 10,000 | 2,015,044,497 | 162,965 | 22,365 |
| 15,000 | 1,044,901,976 | 97,032 | 25,769 |
| 19,000 | 589,337,947 | 63,727 | 28,248 |
| 30,000 | 75,377,940 | 14,175 | 35,318 |

# HOT SPOT Soil Sum TPH Average Concentration

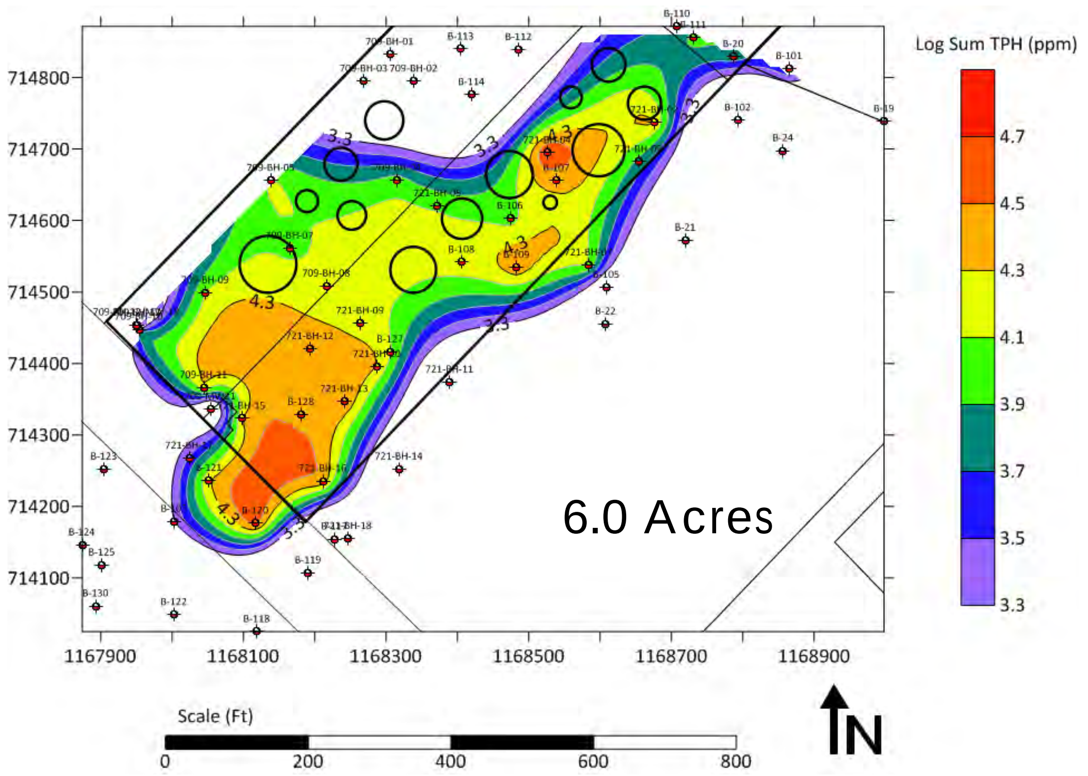
| Substance | Positive Volume (Cut) | Positive Planar Area (Cut) | *Average Sum TPH | Target__Log_Soil |
|---|---|---|---|---|
| | mg/kg*ft2 | ft2 | mg/kg | mg/kg |
| | | | | |
| Sum_TPH | 1,305,057,544 | 68,764 | 18,979 | 4.3 |

*Note – this is the average concentration for the hot spot footprint (12 data points).

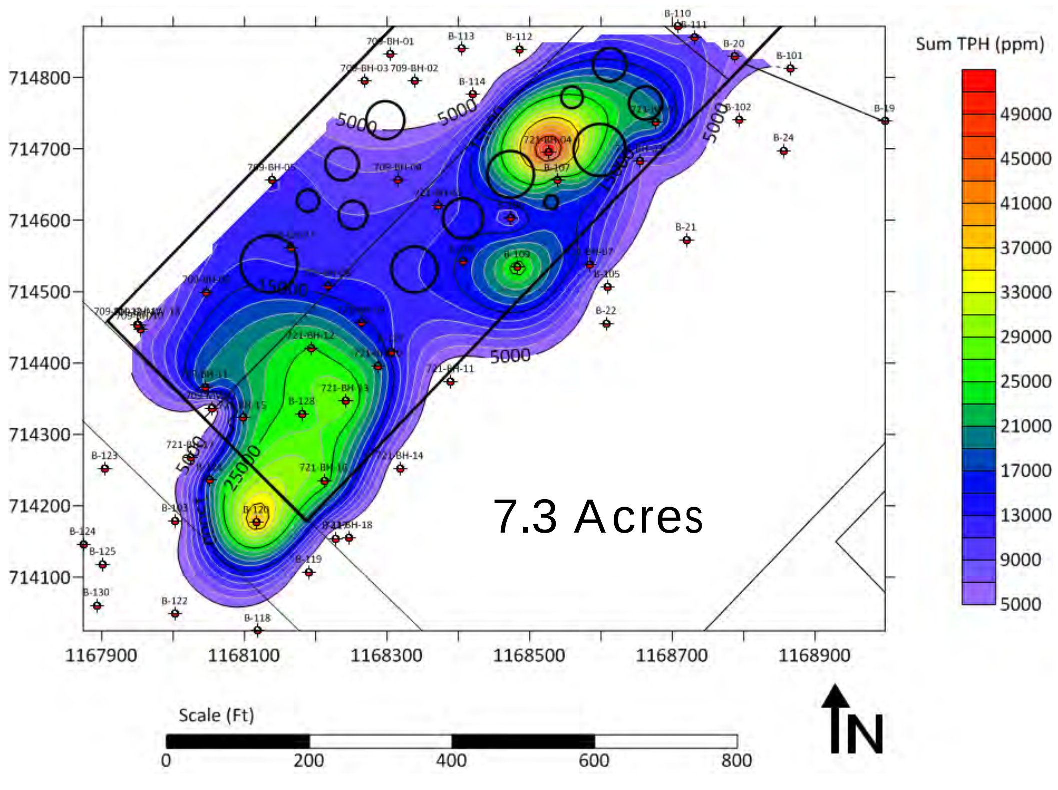
## Soil Sum TPH Footprint @ Target = 2,000 ppm



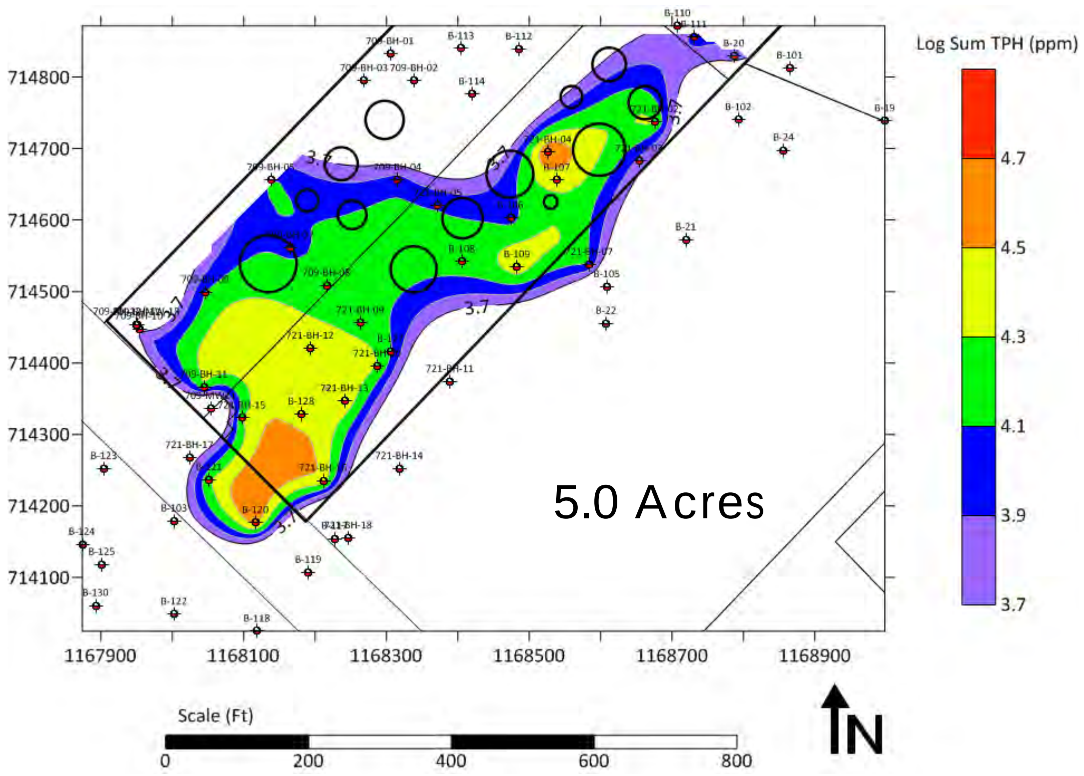

## Same Data and Same Target By Log Concentration Contours



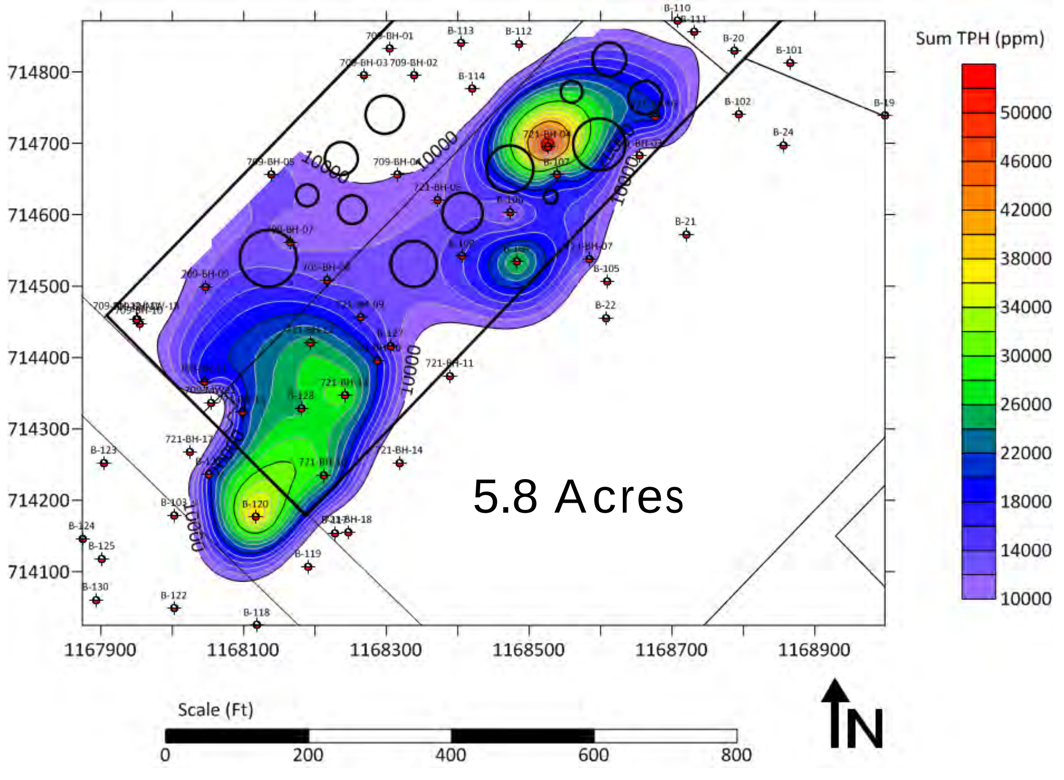
## Soil Sum TPH Footprint @ Target = 5,000 ppm



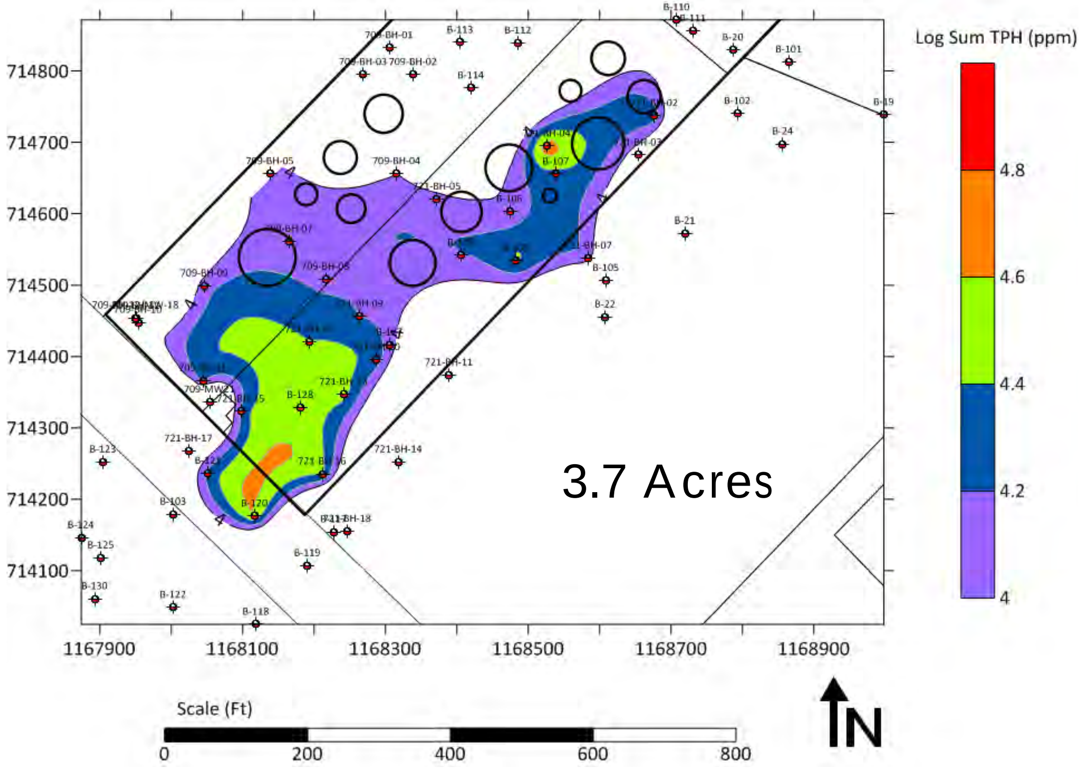

## Same Data and Same Target By Log Concentration Contours



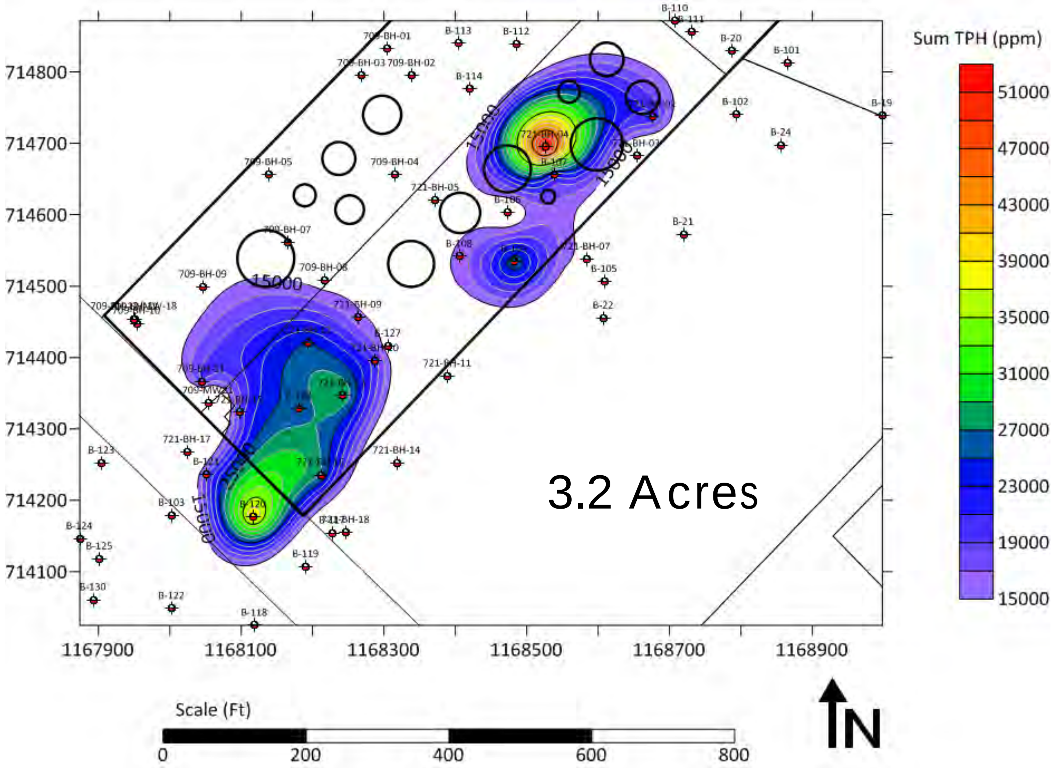
Soil Sum TPH Footprint @ Target = 10,000 ppm



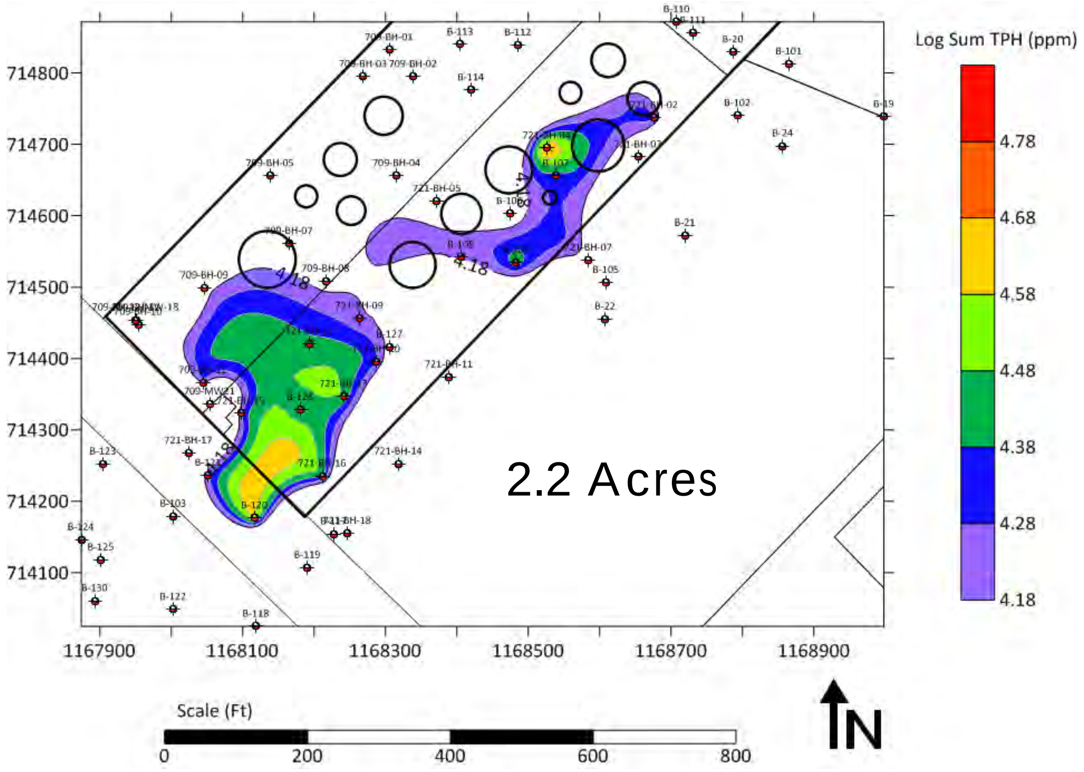

Same Data and Same Target
By Log Concentration Contours



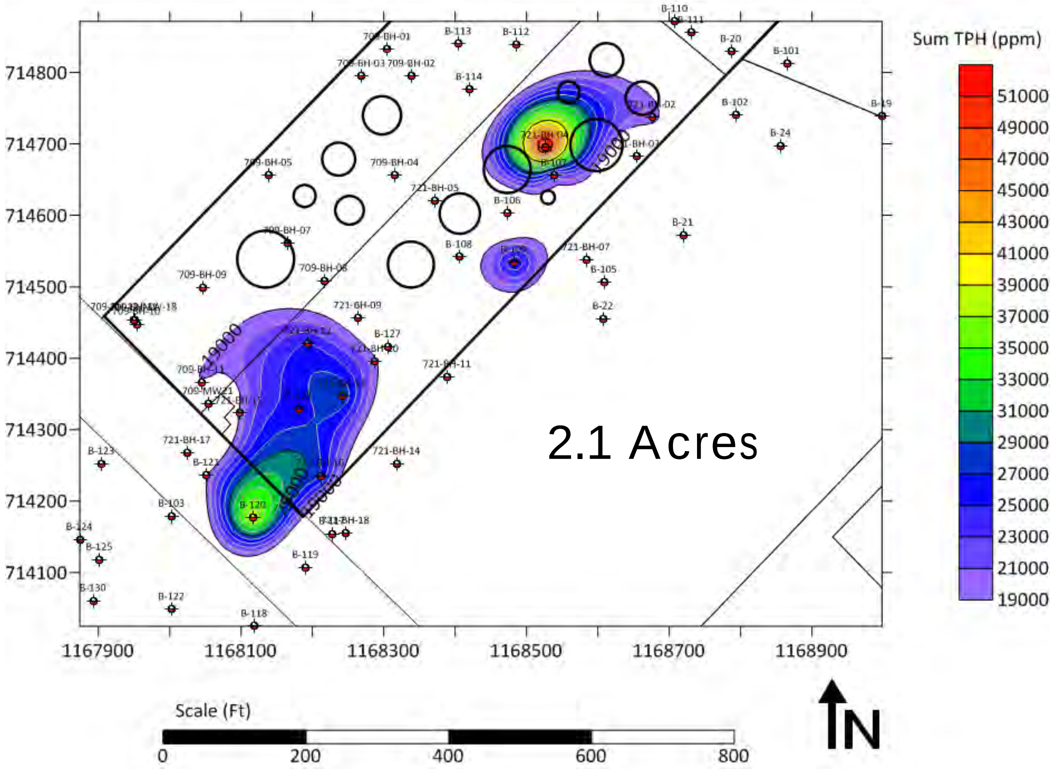
## Soil Sum TPH Footprint @ Target = 15,000 ppm



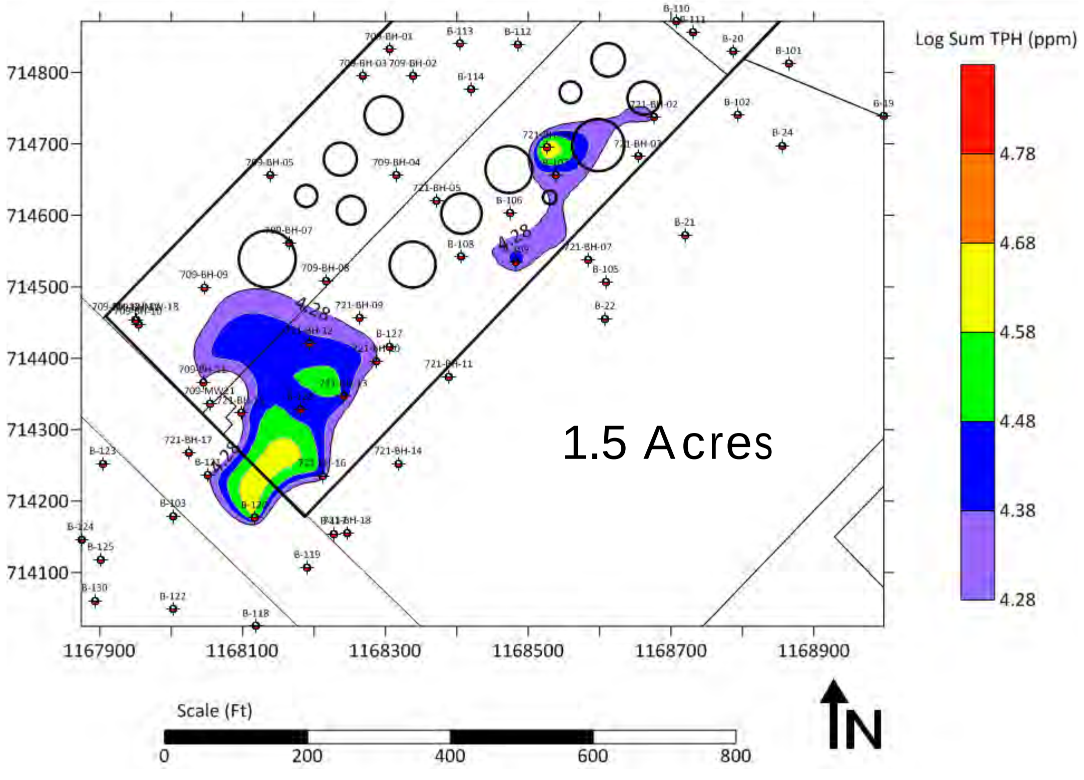

## Same Data and Same Target By Log Concentration Contours



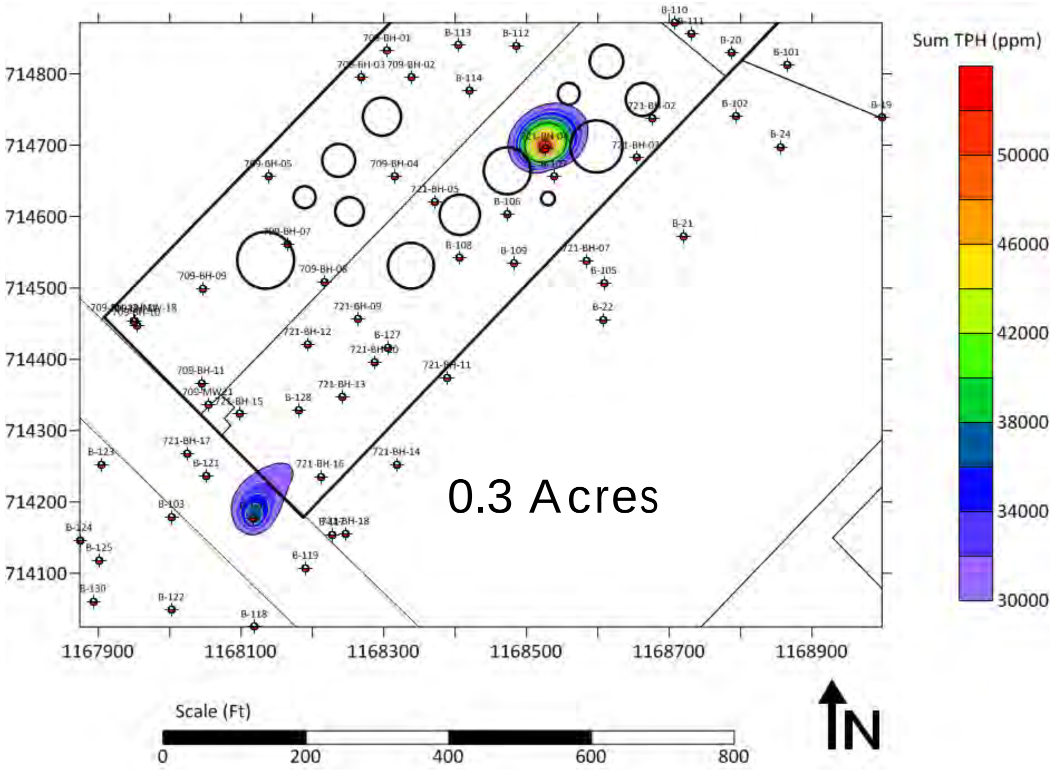
## Soil Sum TPH Footprint @ Target = 19,000 ppm
**HOT SPOT**



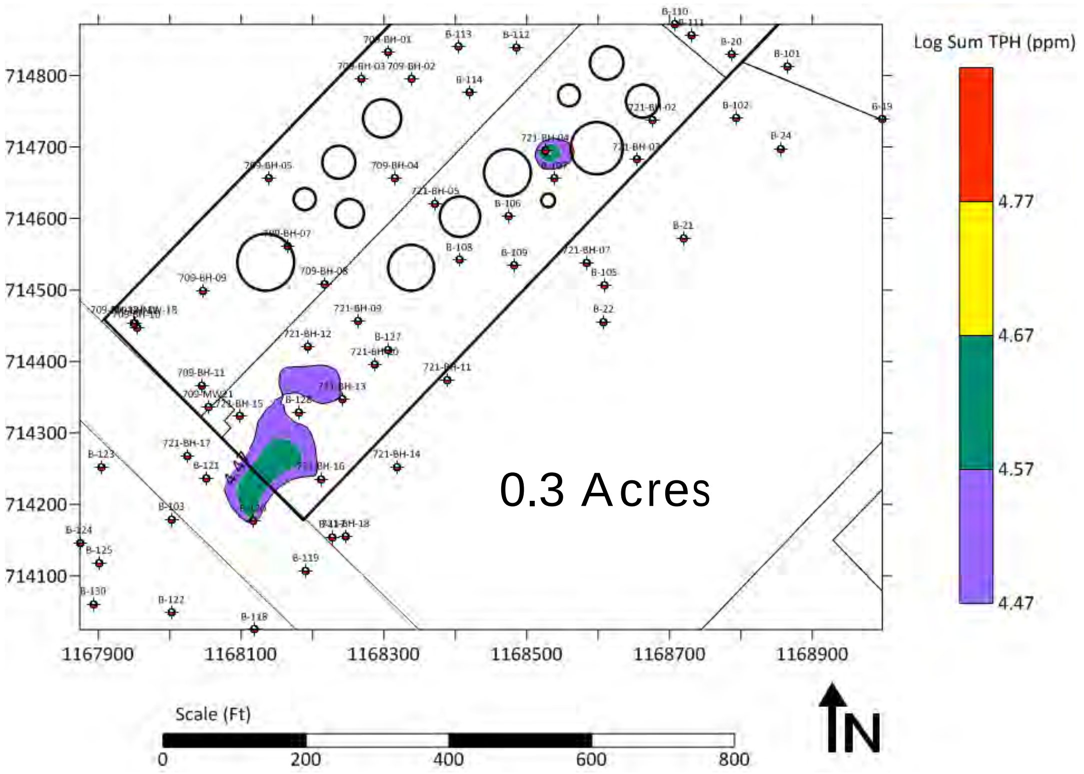

## Same Data and Same Target By Log Concentration Contours



## Soil Sum TPH Footprint @ Target = 30,000 ppm




## Same Data and Same Target By Log Concentration Contours



# Mass / Volume Results
# Regular Scale Concentration Contours

| Target Concentration | Mass | Affected Soil Volume | Affected Soil Area |
|---|---|---|---|
| (mg/kg) | (Lbs) | (CY) | (Acres) |
| 2,000 | 735,679 | 20,369 | 8.4 |
| 5,000 | 709,991 | 17,695 | 7.3 |
| 10,000 | 636,274 | 13,971 | 5.8 |
| 15,000 | 441,820 | 7,780 | 3.2 |
| 19,000 | 324,937 | 5,041 | 2.1 |
| 30,000 | 69,912 | 782 | 0.3 |

# Mass / Volume Results (%)
# Regular Scale Concentration Contours

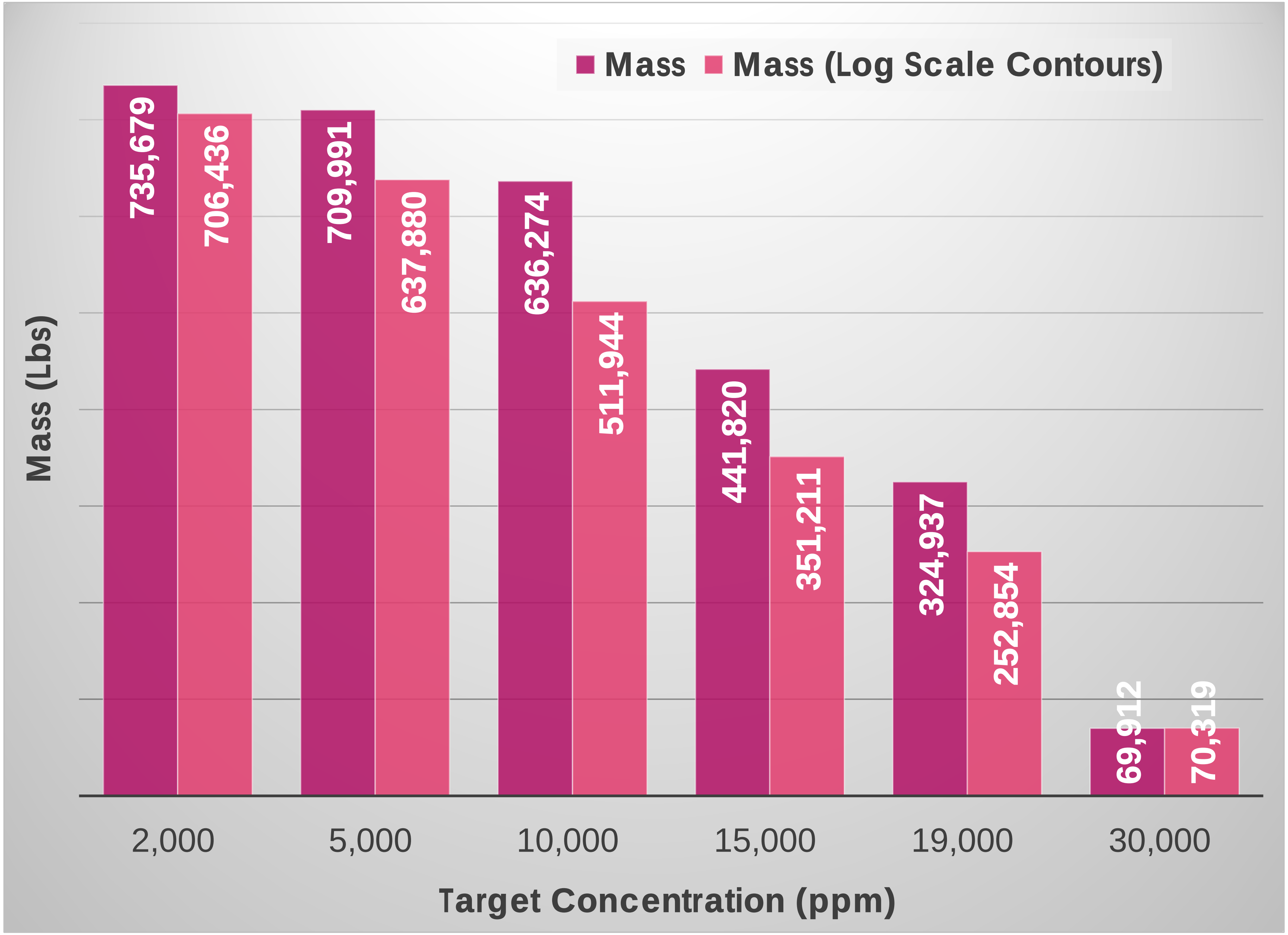
| Target Concentration | Mass | Affected Soil Volume | Affected Soil Area |
|---|---|---|---|
| (mg/kg) | (%) | (%) | (%) |
| 2,000 | 100% | 100% | 100% |
| 5,000 | 97% | 87% | 87% |
| 10,000 | 86% | 69% | 69% |
| 15,000 | 60% | 38% | 38% |
| 19,000 | 44% | 25% | 25% |
| 30,000 | 10% | 4% | 4% |

# Mass / Volume Results
# Log Scale Concentration Contours

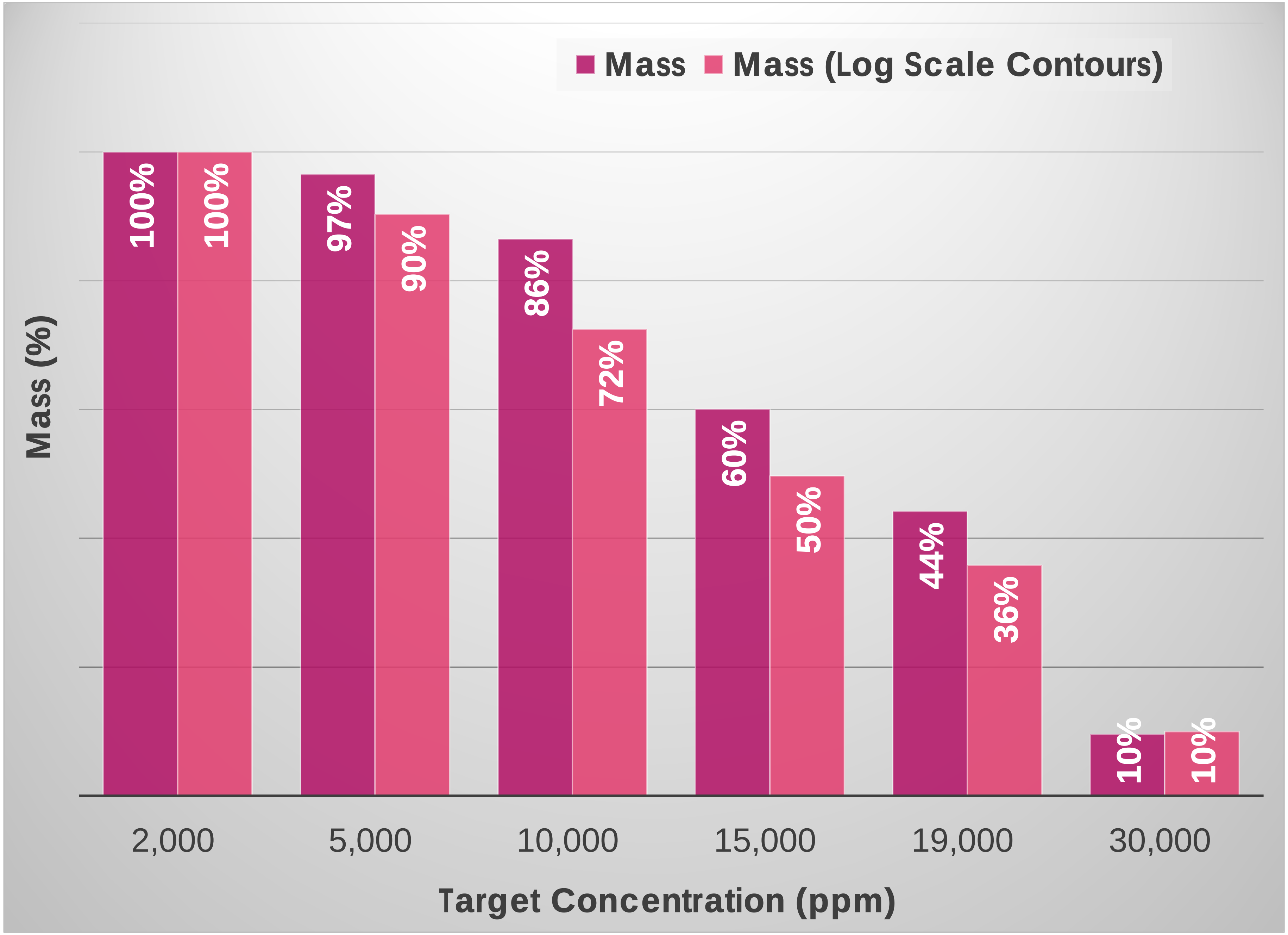
| Target Concentration | Mass | Affected Soil Volume | Affected Soil Area |
|---|---|---|---|
| (mg/kg) | (Lbs) | (CY) | (Acres) |
| 2,000 | 706,436 | 20,369 | 8.4 |
| 5,000 | 637,880 | 17,695 | 7.3 |
| 10,000 | 511,944 | 13,971 | 5.8 |
| 15,000 | 351,211 | 7,780 | 3.2 |
| 19,000 | 252,854 | 5,041 | 2.1 |
| 30,000 | 70,319 | 782 | 0.3 |

# Mass / Volume Results (%)
# Log Scale Concentration Contours

| Target Concentration | Mass | Affected Soil Volume | Affected Soil Area |
|---|---|---|---|
| (mg/kg) | (%) | (%) | (%) |
| 2,000 | 100% | 100% | 100% |
| 5,000 | 90% | 82% | 82% |
| 10,000 | 72% | 62% | 62% |
| 15,000 | 50% | 37% | 37% |
| 19,000 | 36% | 24% | 24% |
| 30,000 | 10% | 5% | 5% |

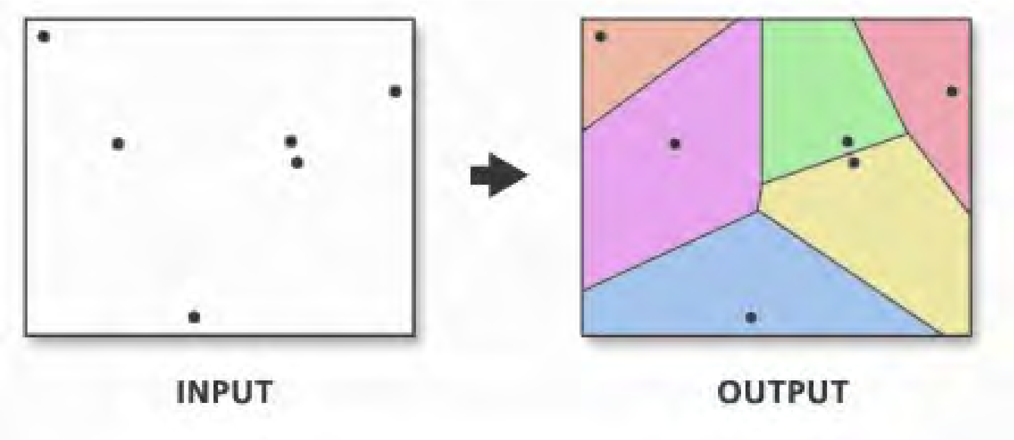


Mass
Mass (Log Scale Contours)
Mass (Lbs)
735,679
706,436
709,991
637,880
636,274
511,944
441,820
351,211
324,937
252,854
69,912
70,319
2,000
5,000
10,000
15,000
19,000
30,000
Target Concentration (ppm)

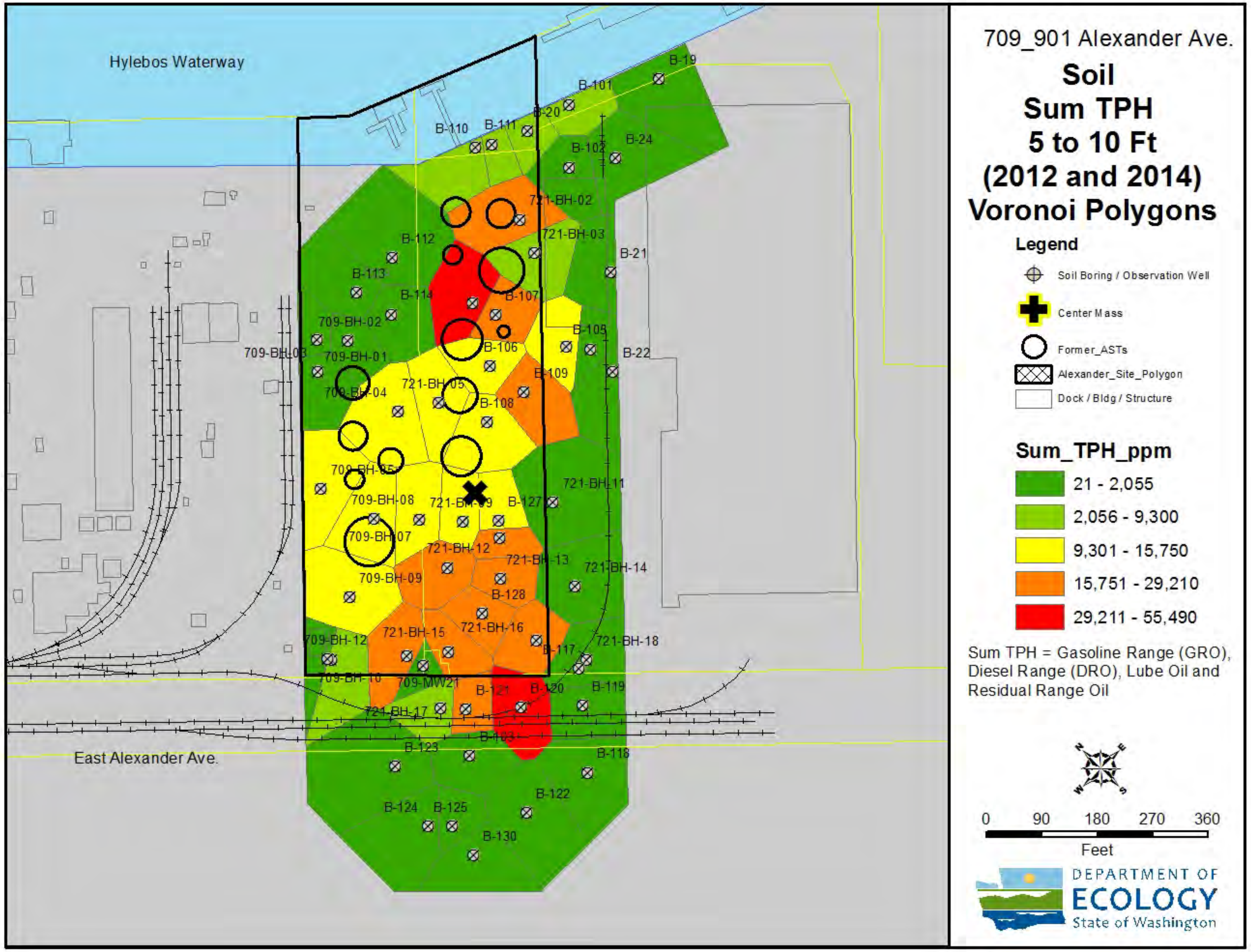

Mass
Mass (Log Scale Contours)
Mass (%)
100%
100%
97%
90%
86%
72%
60%
50%
44%
36%
10%
10%
2,000
5,000
10,000
15,000
19,000
30,000
Target Concentration (ppm)

# TPH Mass Volume by Voronoi Polygons

- Voronoi Diagram (aka Thiessen polygons) can be used to create polygons from spatial data.
- The partitioning of a plane with points into convex polygons such that each polygon contains exactly one generating point and every point in a given polygon is closer to its generating point than to any other.



Soil Sum TPH Voronoi Polygons

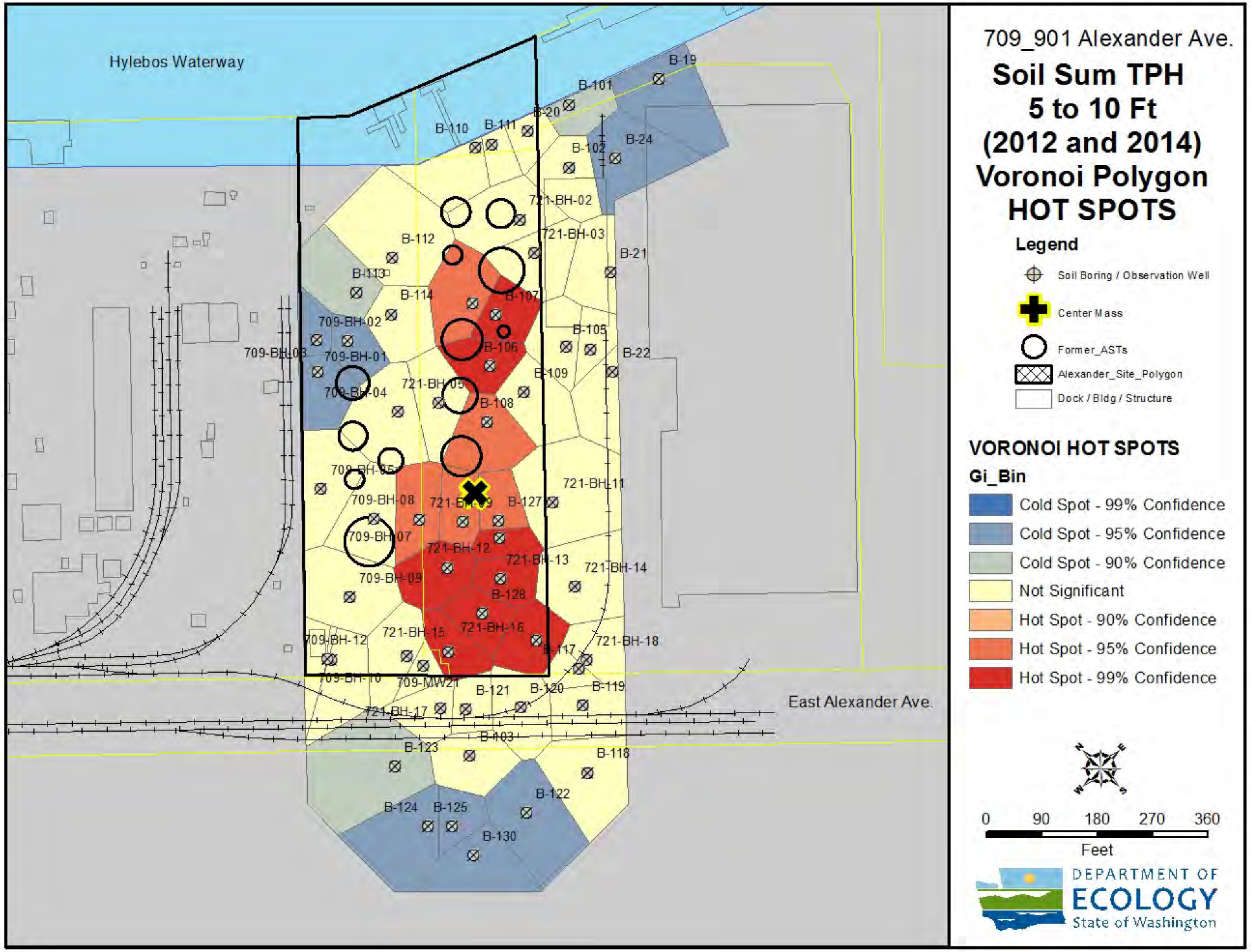


# Soil Sum TPH Mass, Volume and Area by Voronoi Polygons

| *Total Mass | Volume | Area |
|---|---|---|
| (Lbs) | (CY) | (Acres) |
| 845,418 | 35,311 | 14.6 |

*This is the total mass above the data limits (TPH gasoline and diesel range detection limits of 3 – 30 ppm).

Soil Sum TPH Voronoi Polygon HOT SPOTS



# Soil Sum TPH **HOT SPOT** Mass, Volume and Area by Voronoi Polygons

| Mass | Volume | Area |
|---|---|---|
| (Lbs) | (CY) | (Acres) |
| 287,396 | 6,327 | 2.6 |

# Total Mass Comparison

| Method | Mass |
|---|---|
| | (lbs) |
| Contouring | *735,679 |
| Log Contouring | *706,436 |
| Polygon | **845,418 |

* Mass above target concentration = 2,000 ppm (Method A)
** Mass above data limits (detection limit of 3 – 30 ppm for gasoline / diesel range)

# Hot Spot Mass Comparison

| Method | Mass |
|---|---|
| | (lbs) |
| Contouring | 324,937 |
| Log Contouring | 252,854 |
| Polygon | 287,396 |

# Alexander Avenue Petroleum Tank Farm--Benzene Mass, Volume, and Area

Goal: Use the Gi-Ord Hot Spot method to derive a target benzene concentration and resulting mass, volume, and area

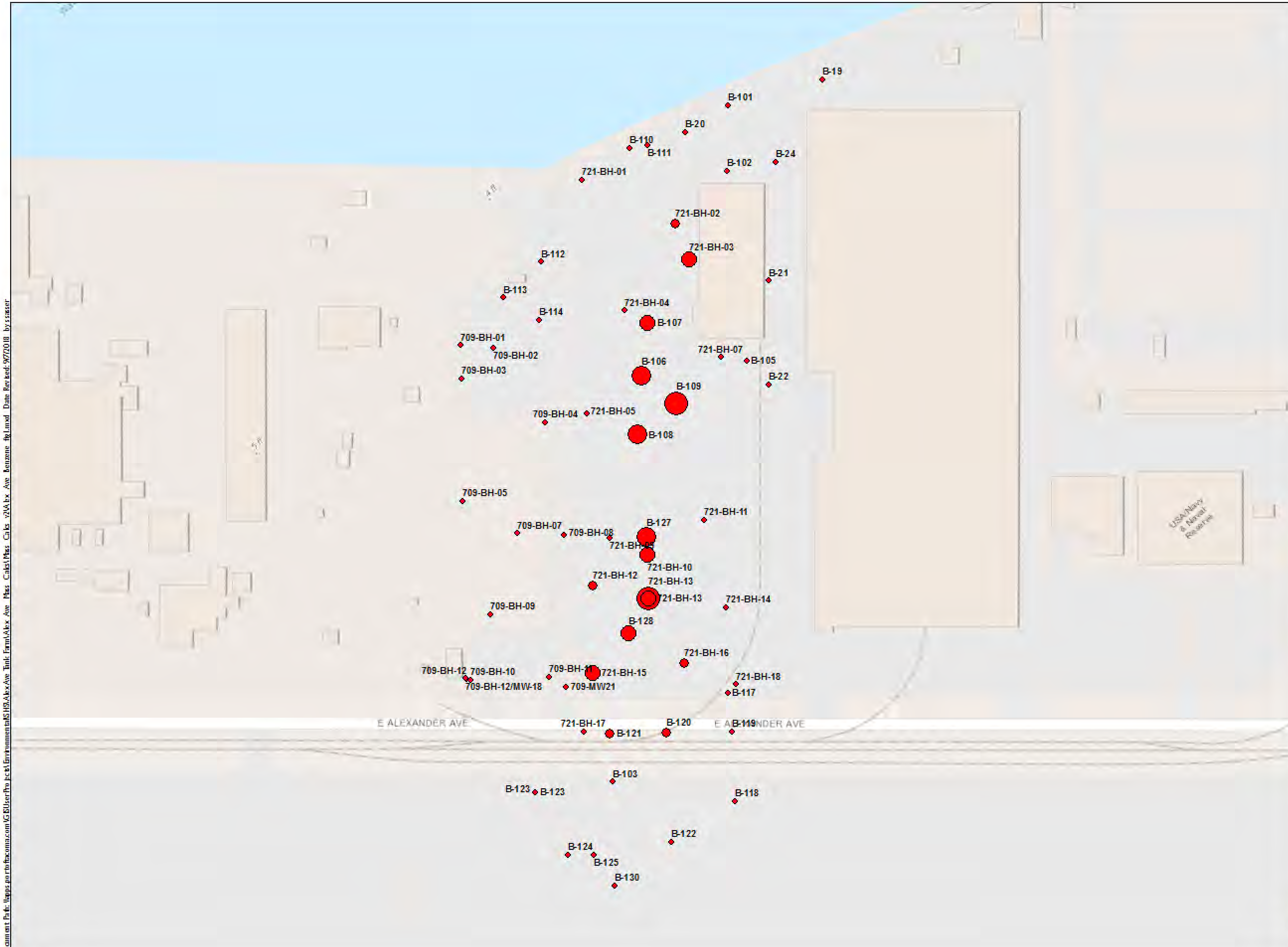
Port of Tacoma

People. Partnership. Performance.

# Data

- Benzene soil data queried from the Aspect project database and the OCC/GHD database.
- Data filtered by: 1) date collected (2012 and 2014) and 2) depth (5 to 10 ft below ground surface) and 3) space (excluded PSE collected data south of bldg. 50). Result = 61 records
- Units converted to mg/kg
- Non-detects set to equal .5 of the reporting limit
- Used the highest value where duplicate values exist

# Alexander Avenue Soil Benzene 5 to 10 ft bgs (2012-2014)




**Benzene (mg/kg)**

- 0.000180 - 0.85
- 0.85 - 3.9
- 3.9 - 10.0
- 10.0 - 22.0
- 22.0 - 36.0

0 200
Feet

Data Source: Aspect Project database and the OCC/GHD database

Port of Tacoma

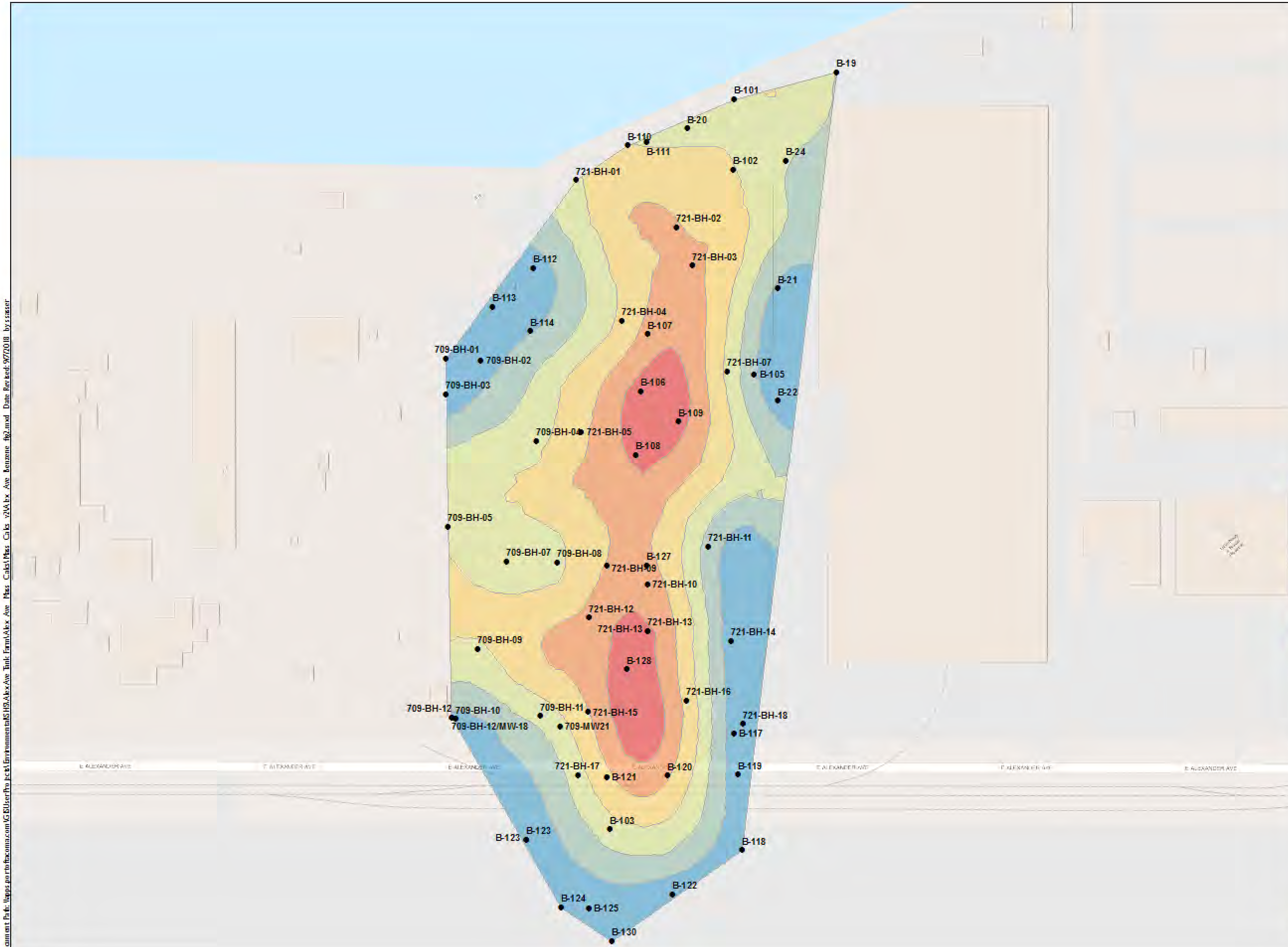
# Soil Benzene Mass

- Use concentrations (mg/kg): . 0.003 , 0.03 (Method A Unrestricted Land Use), 0.3, 3, and 19 (See slides 8-11 to see how the Hot Spot Analysis produced this number)
- Interpolate a kriged surface using Arcmap Geostatistical Analyst

**Calculate the total benzene mass:**

- Mass = Soil Concentration X UCF X Soil Bulk Density X Soil Volume
- UCF = unit conversion (1 kg = 1x10^6 mg)
- Soil bulk density = 42.5 (kg/ft^3)
- Soil Volume = (ft^3) = area above target (ft^2)*thickness (5-ft)*soil porosity (0.3)
- Calculate mass, volume and area for each target concentration.

# Alexander Avenue Soil Benzene 5 to 10 ft bgs (2012-2014)




- Sample Locations

**Benzene Minimum (mg/kg)**

- 0.00018
- 0.003
- 0.03
- 0.3
- 3
- 19

0 200

Feet

Data Source: Aspect Project database and the OCC/GHD database

DISCLAIMER: The information included on this map has been compiled by Port of Tacoma staff from a variety of sources and is subject to change without notice. These data are intended for informational purposes and should not be considered authoritative for engineering, navigational, legal and other site-specific uses. The Port of Tacoma makes no representations or warranties, express or implied, as to accuracy, completeness, timeliness, or rights to the use of such information.

# Soil Benzene Mass/Volume Results

| Benzene Target Concentration (mg/kg) | Benzene Mass (Kilograms) | Disposal Mass (1.5 x Volume)(tons)* | Total DisposalVolume (ft^3)* | Impacted Area (Acres) | Mean Benzene Concentration (mg/kg) |
|---|---|---|---|---|---|
| >.003 | 2,377 | 2,132,550 | 1,421,700 | 9.3 | 3.9 |
| >.03** | 2,376 | 1,742,475 | 1,161,650 | 7.6 | 4.8 |
| >.3 | 2,353 | 1,126,125 | 750,750 | 4.9 | 7.4 |
| >3 | 2,164 | 532,875 | 355,250 | 2.3 | 14.3 |
| >19*** | 1,304 | 136,500 | 91,000 | 0.6 | 33.7 |
| | | | | | |
| | | | | | |
| | | | | | |

## Other Notes/Information:

| | |
|---|---|
| Total Benzene Mass (kg) | 2,377 |
| Total Volume (ft^3) | 1,705,900 |
| Working Outline (acres) | 11.2 |

* removed .3 pore space from all volume calcs
** .03 mg/kg is Method A Unrestricted Level
*** 19.00 mg/kg is the average surface value of the GI* hot spot method

Notes: Ordinary Kriging, max values, log transformed, range = 250', anisotropic = no, non-detects = 1/2 value, cell size 10'X10', cell thickness = 5'

$$mass = kriged\ concentration \frac{\mu g}{kg} \cdot \frac{1kg}{1x10^9\ \mu g} \cdot 42.5 \frac{kg}{ft^3} \cdot volume$$

# Soil Benzene
# Mass / Volume Results

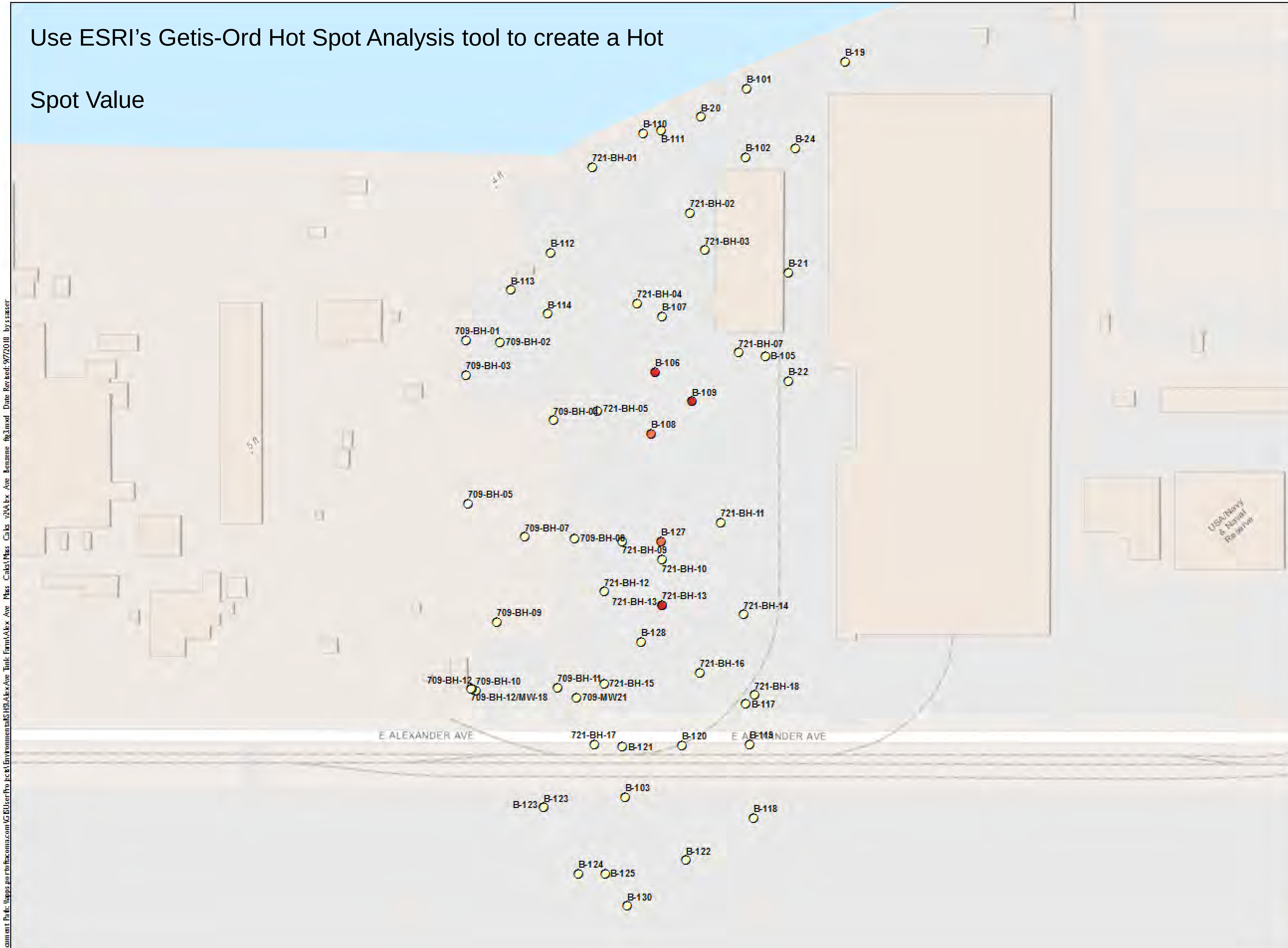
| Target Concentration | Benzene Mass | Affected Soil Volume and Area |
| --- | --- | --- |
| (mg/kg) | (%) | (%) |
| | | |
| .003 | 100% | 83% |
| .03 | 99% | 68% |
| .3 | 99% | 44% |
| 3 | 91% | 21% |
| 19 | 55% | 5% |

# Getis-Ord Hot Spot Analysis

Port of Tacoma

1. Run the Hot Spot tool in Arcmap
2. Create a map displaying the results of the analysis
3. Create a minimum bounding polygon encompassing all of the hot spots
4. Extract the kriged benzene cell values within the minimum bounding polygon
5. Create a table with the average benzene concentrations for the locations identified as hot spots and the average of all interpolated cells within the minimum bounding polygon

Use ESRI's Getis-Ord Hot Spot Analysis tool to create a Hot Spot Value




# Alexander Avenue Soil Benzene Getis-Ord Hot Spot Analysis 5 to 10 ft bgs (2012-2014)

**Soil Benzene Hot Spot Analysis**

Gi_Bin

- Cold Spot - 99% Confidence
- Cold Spot - 95% Confidence
- Cold Spot - 90% Confidence
- Not Significant
- Hot Spot - 90% Confidence
- Hot Spot - 95% Confidence
- Hot Spot - 99% Confidence

0 200

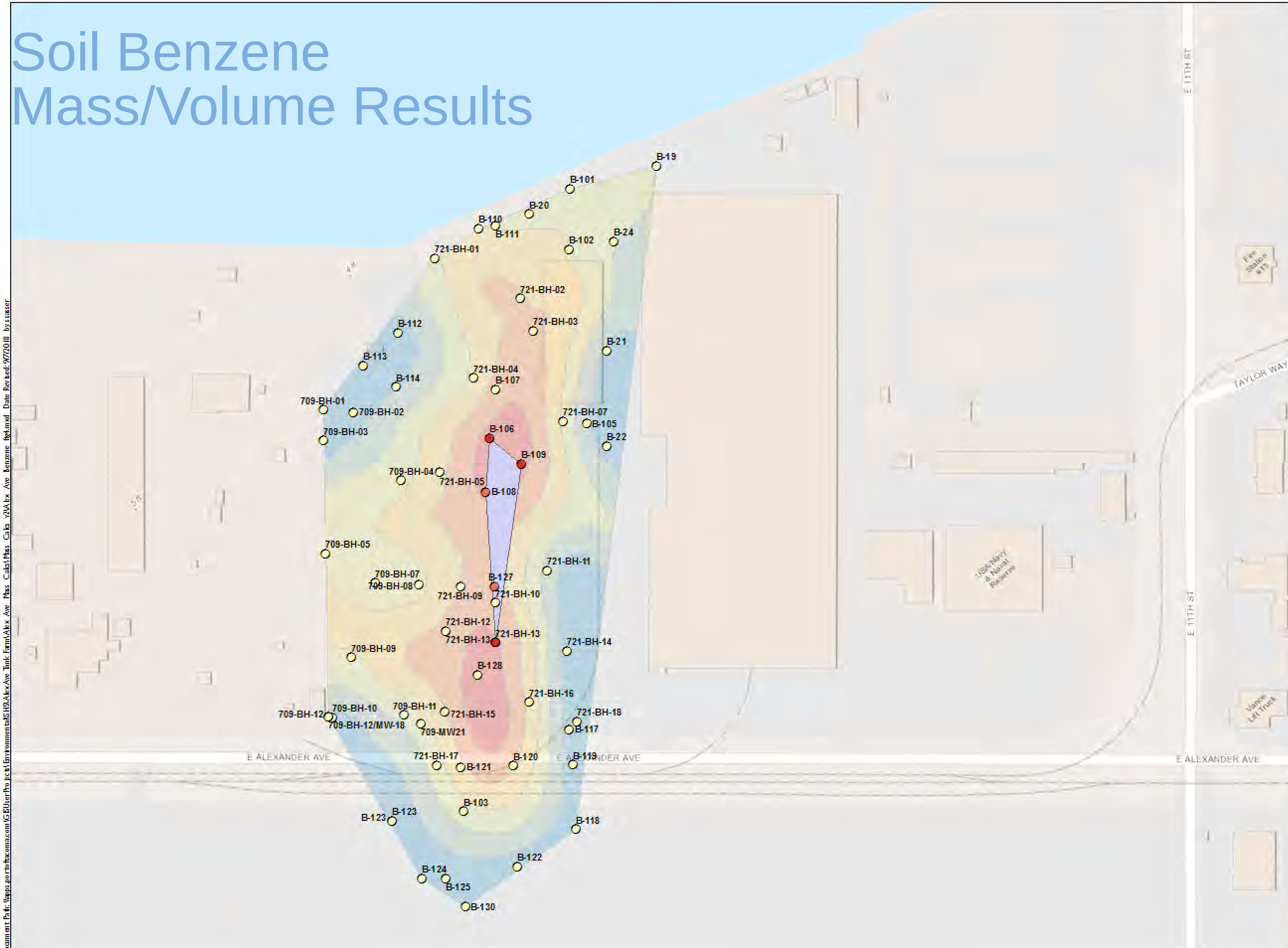
Feet

Data Source: Aspect Project database and the OCC/GHD database

Port of Tacoma

DISCLAIMER: The information included on this map has been compiled by Port of Tacoma staff from a variety of sources and is subject to change without notice. These data are intended for informational purposes and should not be considered authoritative for engineering, navigational, legal and other site-specific uses. The Port of Tacoma makes no representations or warranties, express or implied, as to accuracy, completeness, timeliness, or rights to the use of such information.

# Soil Benzene Mass/Volume Results




## Alexander Avenue Soil Benzene Getis-Ord Hot Spot Analysis 5 to 10 ft bgs (2012-2014)

**Soil Benzene Hot Spot Analysis**

Gi_Bin

- Cold Spot - 99% Confidence
- Cold Spot - 95% Confidence
- Cold Spot - 90% Confidence
- Not Significant
- Hot Spot - 90% Confidence
- Hot Spot - 95% Confidence
- Hot Spot - 99% Confidence

**Hot Spot Minimum Bounding Box**

0 200

Feet

Data Source: Aspect Project database and the OCC/GHD database

Port of Tacoma

# Soil Benzene Hot Spot Results

| Location | Benzene (mg/kg) | Qualifier | |
|---|---|---|---|
| B-106 | 22 | | |
| B-109 | 36 | | |
| B-108 | 18 | | |
| B-127 | 18 | | |
| 721-BH-13 | 30 | J | |
| | | | |
| Average | 24.8 | | |
| | | | |
| Grid Volume Results and Target (Hot Spot) Concentration | | | |
| | | | |
| Grid Volume (ft^3) | Grid Area (Acres) | Average Benzene Gridded Hotspot (mg/kg) | |
| 91,350 | 0.6 | 19 | |

APPENDIX D

# Shoreline Preliminary Cleanup Level and Remediation Level Calculations

# APPENDIX D
# SHORELINE PRELIMINARY CLEANUP LEVEL AND REMEDIATION LEVEL CALCULATIONS SUMMARY

## Preliminary Cleanup Levels—Angled Shoreline Wells

### *Application of Preliminary Cleanup Levels at Angled Shoreline Wells and Remediation Levels*

The groundwater conditional point of compliance (CPOC) for the Site, based on protection of surface water, is the point or points where groundwater flows to surface water (i.e., the groundwater-surface water interface at the shoreline). Because it is difficult to measure compliance at the groundwater-surface water interface at the Site (most of the slope is underwater and the shoreline is heavily armored with rock), Ecology is approving the use of upland monitoring wells (angled shoreline wells) along the Hylebos and Blair Waterways[1], where groundwater concentrations will be measured to establish compliance with the groundwater proposed cleanup levels (pCULs) at the CPOC, taking into consideration estimated natural attenuation rates between the wells and point where groundwater flows into the surface water, in accordance with WAC 173-340-720(8). Compliance with pCULs at the CPOC is proposed to be measured at proposed angled shoreline wells; and the concentrations that will be used to demonstrate compliance at the CPOC will be determined based on estimated nearshore attenuation in the groundwater-surface water transition zone.

Based on existing data, *preliminary* groundwater concentrations at the proposed angled shoreline wells estimated to demonstrate compliance with pCULs at the CPOC have been calculated and are presented below for benzene and total petroleum hydrocarbons (TPH) in the diesel and oil ranges (TPH-D/O) without silica gel cleanup (SGC). These groundwater compliance concentrations may be refined later (the engineering design report will define how to calculate “final” groundwater compliance concentrations at the angled wells). The groundwater compliance concentrations for TPH-D/O with SGC and for gasoline-range TPH (TPH-G) at the angled wells were not calculated because cleanup criteria have already been met (there were no detections above cleanup levels [CULs] at the shoreline wells and seeps during the remedial investigation [RI]).

### *Method*

Groundwater concentrations at the angled shoreline wells to demonstrate compliance with pCULs at the CPOC were calculated using concentration versus distance analysis (Equation F.5).[2] Equation F.5 can be

[1] The upland wells used to demonstrate compliance along the Blair Waterway may be vertical or angled wells installed along the shoreline or at locations closer to the source, as determined based on the results of the pre-remedial investigation. For simplicity, the upland wells proposed to be used to demonstrate compliance at the CPOC along the Blair Waterway are referred to herein as ‘angled wells’ or ‘angled shoreline wells’.

[2] Ecology. 2005. Guidance on Remediation of Petroleum-Contaminated Ground Water by Natural Attenuation. Publication No. 05-09-091 (Version 1.0). Washington State Department of Ecology. July.

rearranged to solve for the $C_{start}$ concentration in the upgradient source area well necessary for the concentration at the corresponding downgradient shoreline well to meet the screening criteria.

$$C_{start} = \frac{C_{CUL}}{e^{x*\frac{k}{v_c}}}$$

Where $C_{start}$ is the concentration at the upgradient monitoring well; $C_{CUL}$ is the regulatory cleanup level; *x* is the travel distance between the two sampling locations; and $k/v_c$ is the slope of the natural log transformed concentration versus distance trend line ($k$ = bulk attenuation rate, and $v_c$ is contaminant velocity). Concentration values are rounded to two significant figures.

### *Data*

- Concentration data (y): Water quality data from the August 2016 sampling event at well/seep pair MW-104-15 and SP-103 was used in this analysis.[3]
- Distance data (x): The distance between shoreline well MW-104-15 and seep SP-103 is approximately 48 feet (ft). The distance between the angled well (to be installed during design) and seep SP-103 is estimated at 15 ft.

### *Shoreline Preliminary Groundwater Compliance Concentrations Results*

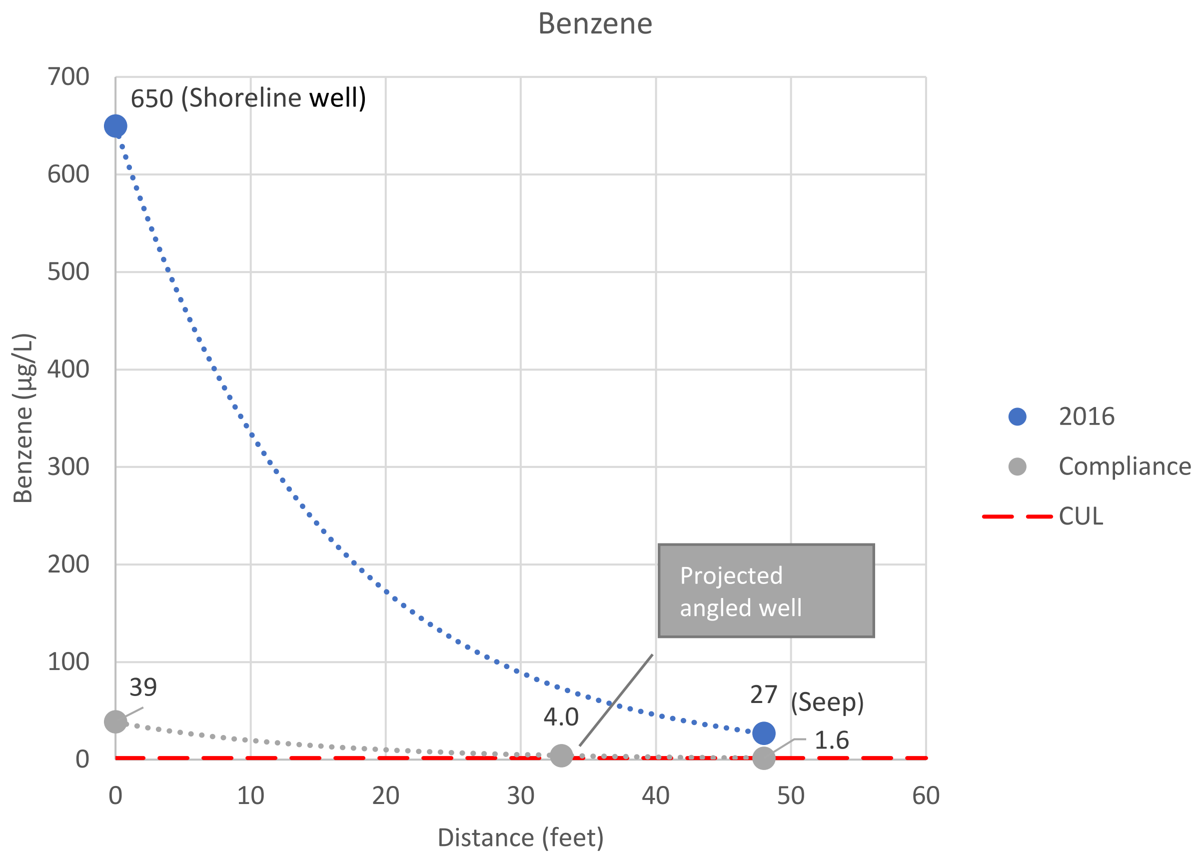
When groundwater concentrations demonstrating compliance with pCULs at the CPOC are met at the angled wells, Model Toxics Control Act Method B groundwater CULs, based on protection of surface water, will be met at the point where groundwater flows into surface water (CPOC):

**Shoreline Groundwater Compliance Concentrations (Hylebos Waterway)**

- Benzene = 4.0 micrograms per liter (µg/L; for groundwater protection of surface water CUL of 1.6 µg/L)
- TPH-D/O without SGC = 680 µg/L (for groundwater protection of surface water CUL of 500 µg/L)
- TPH-G = 2,200 µg/L (for groundwater protection of surface water CUL of 800 µg/L)
  - Note: TPH-G shoreline pCULs already being met at shoreline wells upgradient of proposed angled wells, and Method B CULs currently being met at shoreline seeps; TPH-G remediation levels (RLs) not likely to be needed for the Hylebos Hot Spot.

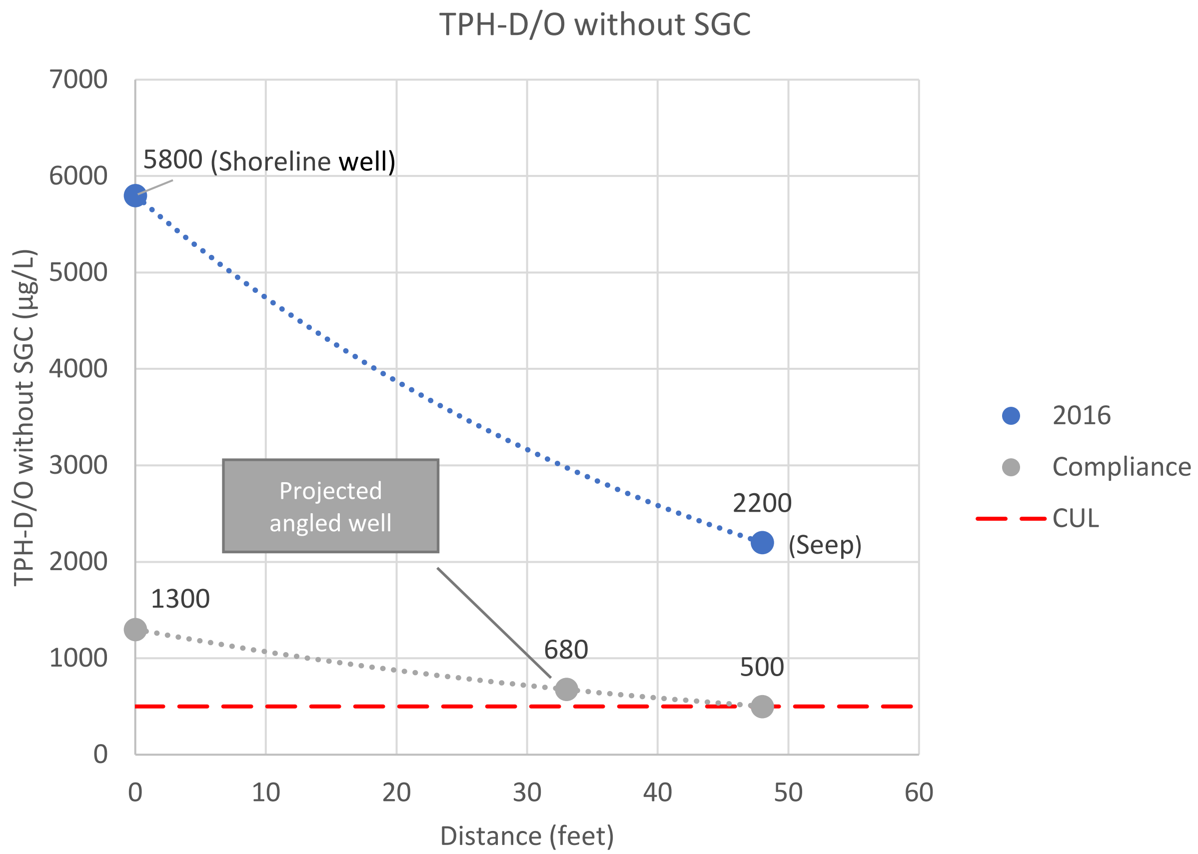
Note also that there is insufficient data available to perform the same analysis for the Blair Waterway shoreline. The Blair Waterway groundwater concentrations in angled shoreline wells (or upland vertical wells) demonstrating compliance at the CPOC will be developed during the engineering design phase for the final remedial action.

[3] There have been three sampling events that captured shoreline well and seep concentration at the same time at well/seep pairs MW-104-15 and SP-103, and MW-95-15 and SP-102. Samples were collected in May 2015, May 2016, and August 2016. A third well/seep pair, MW-110-15 and SP-101, has one paired sampling event, collected in May 2015. August 2016 data from MW-104-15 and SP-103 were used for the analysis at the request of the Washington State Department of Ecology because concentrations are highest at this well/seep pair.



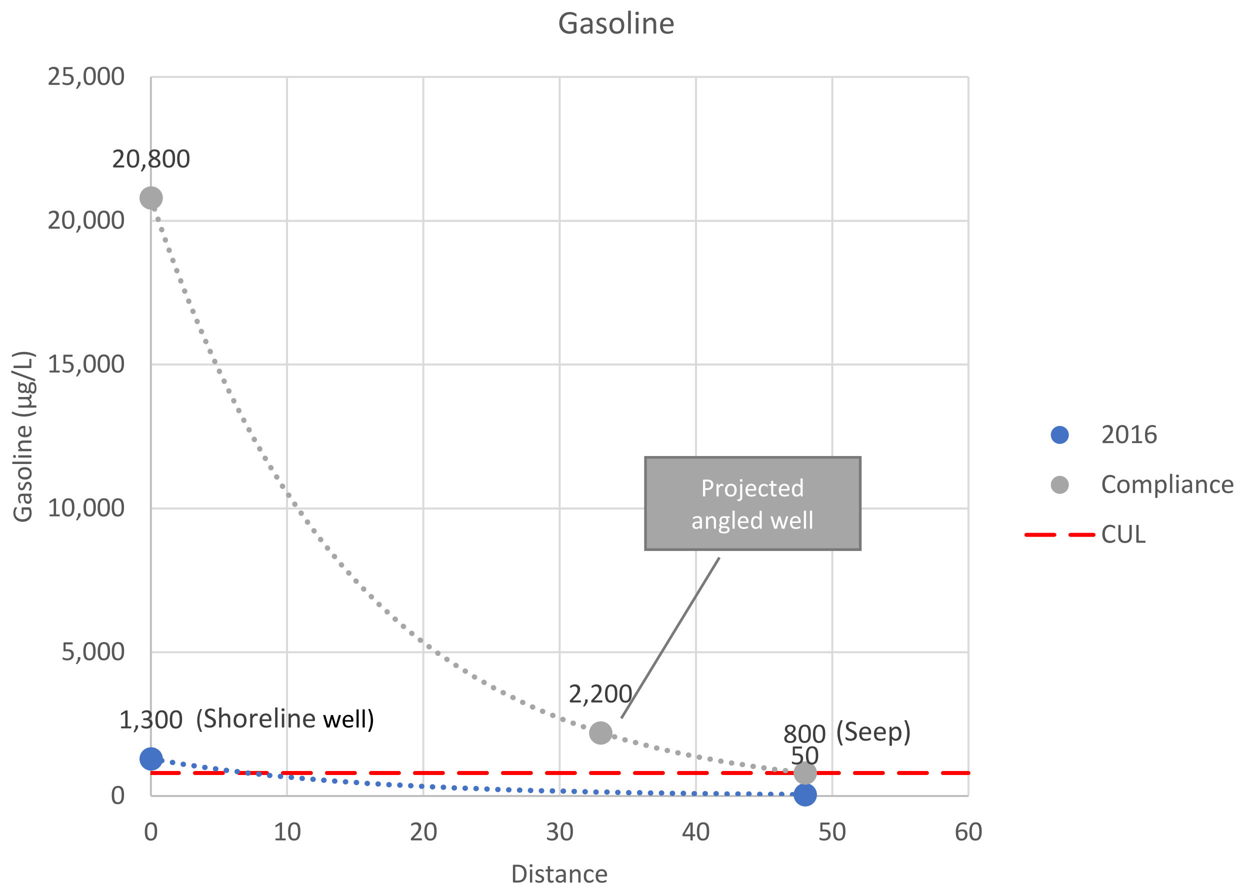

| Benzene | | | | | | |
|---|---|---|---|---|---|---|
| Location | Sample Date | Distance (ft) | Matrix | Value (µg/L) | ln | Qualifier |
| MW-104-15 | 02-Aug-16 | 0 | Groundwater | 650 | 6.48 | |
| SP-103 | 01-Aug-16 | 48 | Seep | 27 | 3.30 | |

| | | |
|---|---|---|
| Slope (k/vc) = | -0.0663 | |
| Groundwater CUL = | 1.6 | µg/L |
| x (distance between 15-ft angled shoreline well and & seep SP-103) = | 15 | feet |
| Concentration at 15-ft angled well demonstrating compliance at CPOC = | 4.0 | µg/L |
| Attenuation factor = | 2.5 | |




| DRO+ORO without SGC | | | | | | |
|---|---|---|---|---|---|---|
| Location | Sample Date | Distance (ft) | Matrix | Value (µg/L) | ln | Qualifier |
| MW-104-15 | 02-Aug-16 | 0 | Groundwater | 5,800 | 8.67 | |
| SP-103 | 01-Aug-16 | 48 | Seep | 2,200 | 7.70 | |

| | | |
|---|---|---|
| Slope (k/vc) = | -0.0202 | |
| Groundwater CUL = | 500 | µg/L |
| x (distance between 15-ft angled shoreline well and & seep SP-103) = | 15 | feet |
| Remediation Level at MW-104-15= | 1,300 | µg/L |
| Concentration at 15-ft angled well demonstrating compliance at CPOC = | 680 | µg/L |
| Attenuation factor = | 1.4 | |




| GRO | | | | | | |
|---|---|---|---|---|---|---|
| Location | Sample Date | Distance (ft) | Matrix | Value (µg/L) | ln | Qualifier |
| MW-104-15 | 02-Aug-16 | 0 | Groundwater | 1,300 | 7.17 | |
| SP-103 | 01-Aug-16 | 48 | Seep | 50 | 3.91 | U (1/2 DL) |

| | | |
|---|---|---|
| Slope (k/vc) = | -0.0679 | |
| Groundwater CUL = | 800 | µg/L |
| x (distance between 15-ft angled shoreline well and & seep SP-103) = | 15 | feet |
| Concentration at 15-ft angled well demonstrating compliance at CPOC = | 2,200 | µg/L |
| Attenuation factor = | 2.8 | |

# Remediation Levels—Hot Spots

## *Application of Remediation Levels*

RLs will serve as preliminary criteria for transitioning between treatment technologies at the Hylebos Hot Spot and the Blair Hot Spot. The RL is the value at which the hot spot concentrations predict compliance with cleanup standards (i.e., when groundwater CULs based on protection of surface water are met at the point where groundwater discharges to surface water), based on concentration versus distance analysis. RLs are presented below for benzene and TPH-D/O without SGC. RLs for TPH-D/O with SGC and for TPH-G were not calculated because cleanup criteria have already been met (there were no detections above CULs at the CPOC during the RI).

## *Method and Data Set*

RLs were calculated using concentration versus distance analysis (Equation F.5) in a similar manner to the calculation of shoreline pCULs. See the *Preliminary Cleanup Levels – Angled Shoreline Wells* section above for details.[4]

## *Data*

- Concentration data (y): Water quality data from the August 2016 sampling event were used to model the attenuation in concentration of TPH-D/O and benzene that occurs between the Hylebos Hot Spot and the CPOC.
- Distance data (x): The distances between wells was measured along a straight transect through the center of the groundwater plume.

## *Hot Spot Remediation Level Summary*

Hot spot RLs will be used to transition between treatment technologies.

**Hylebos Hot Spot**

- Benzene = 86 µg/L (for groundwater protection of surface water CUL of 1.6 µg/L)
- TPH-D/O without SGC = 2,600 µg/L (for groundwater protection of surface water CUL of 500 µg/L)
- TPH-G = 85,000 µg/L (for groundwater protection of surface water CUL of 800 µg/L)
  - Note: TPH-G RL already being met at Hylebos Hot Spot, and CULs currently being met at shoreline seeps; TPH-G RLs not likely to be needed for Hylebos Hot Spot.

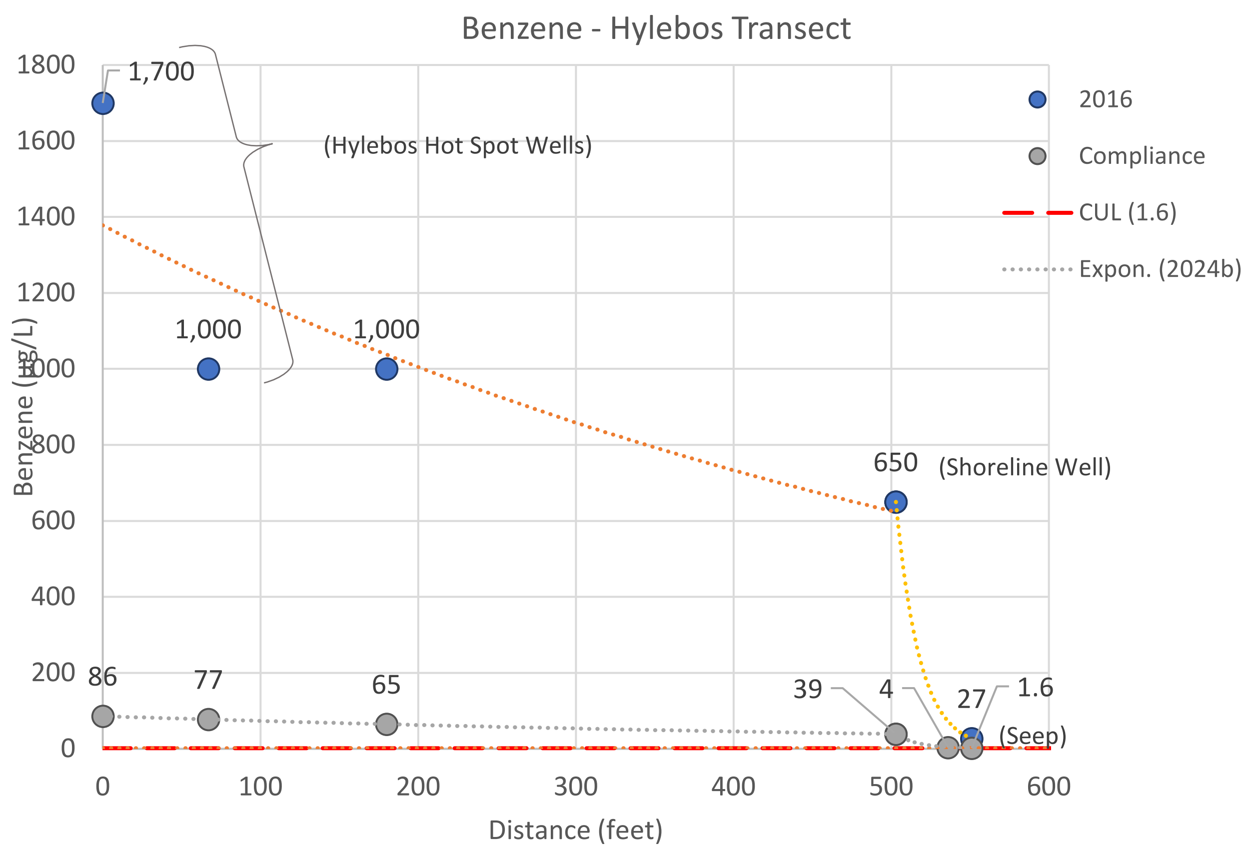
**Blair Hot Spot**

- Benzene = 2,600 µg/L (for groundwater protection of surface water CUL of 1.6 µg/L)

[4] Ecology. 2005. Guidance on Remediation of Petroleum-Contaminated Ground Water by Natural Attenuation. Publication No. 05-09-091 (Version 1.0). Washington State Department of Ecology. July.

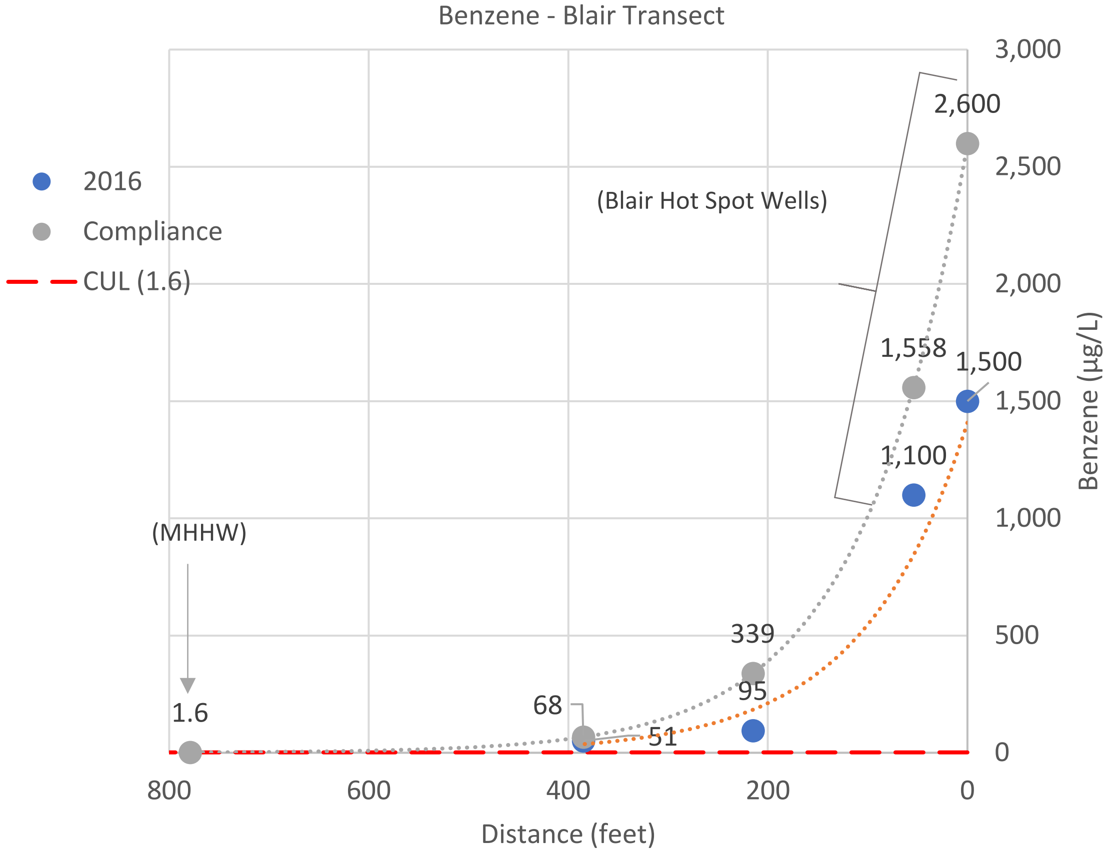
- TPH-D/O without SGC = 7,300 µg/L (for groundwater protection of surface water CUL of 500 µg/L)
- TPH-G = 4,600 µg/L (for groundwater protection of surface water CUL of 800 µg/L)—currently meeting CUL
  - Note: Data not available to confirm whether CULs are currently being met at the Blair Waterway and whether a TPH-G RL will be needed for the Blair Hot Spot.

Benzene concentrations are already below the Blair Hot Spot RL in the Blair Hot Spot.




| Benzene | | | | | | |
|---|---|---|---|---|---|---|
| Location | Sample Date | Distance(ft) | Matrix | Value (µg/L) | ln | Qualifier |
| MW-109-15 | 02-Aug-16 | 0 | Groundwater | 1,700 | 7.44 | |
| 721-MW6-15 | 02-Aug-16 | 67 | Groundwater | 1,000 | 6.91 | |
| 721-MW11-15 | 01-Aug-16 | 180 | Groundwater | 1,000 | 6.91 | |
| MW-104-15 | 02-Aug-16 | 503 | Groundwater | 650 | 6.48 | |

| | | |
|---|---|---|
| Slope (k/vc) = | -0.0016 | |
| x (distance between MW-109-15 and MW-104-15) = | 503 | feet |
| Remediation Level at Hylebos Hot Spot = | 86 | µg/L |



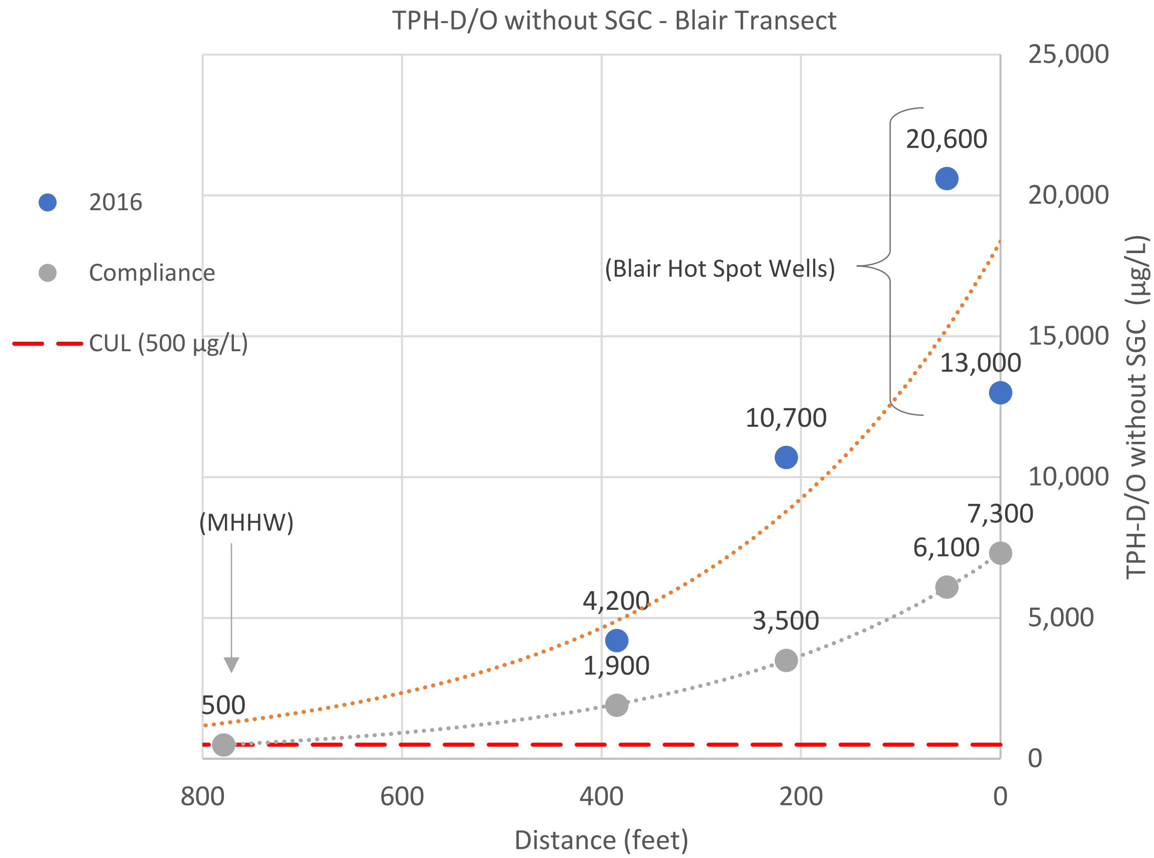

Blair Hot Spot

| Benzene | | | | | | |
|---|---|---|---|---|---|---|
| Location | Sample Date | Distance(ft) | Matrix | Value (µg/L) | ln | Qualifier |
| 721-MW15-15 | 01-Aug-16 | 0 | Groundwater | 1,500 | 7.31 | |
| 721-MW2 | 01-Aug-16 | 54 | Groundwater | 1,100 | 7.00 | |
| HC-N11-6 | 01-Aug-16 | 215 | Groundwater | 95 | 4.55 | |
| MW-130-15 | 01-Aug-16 | 385 | Groundwater | 51 | 3.93 | |
| MHHW | | 779 | | | | |

| | | |
|---|---|---|
| Slope (k/vc) = | -0.0095 | |
| x (distance between 721-MW-15-15 and the Blair Waterway) = | 779 | feet |
| Remediation Level at Blair Hot Spot = | 2,600 | µg/L |

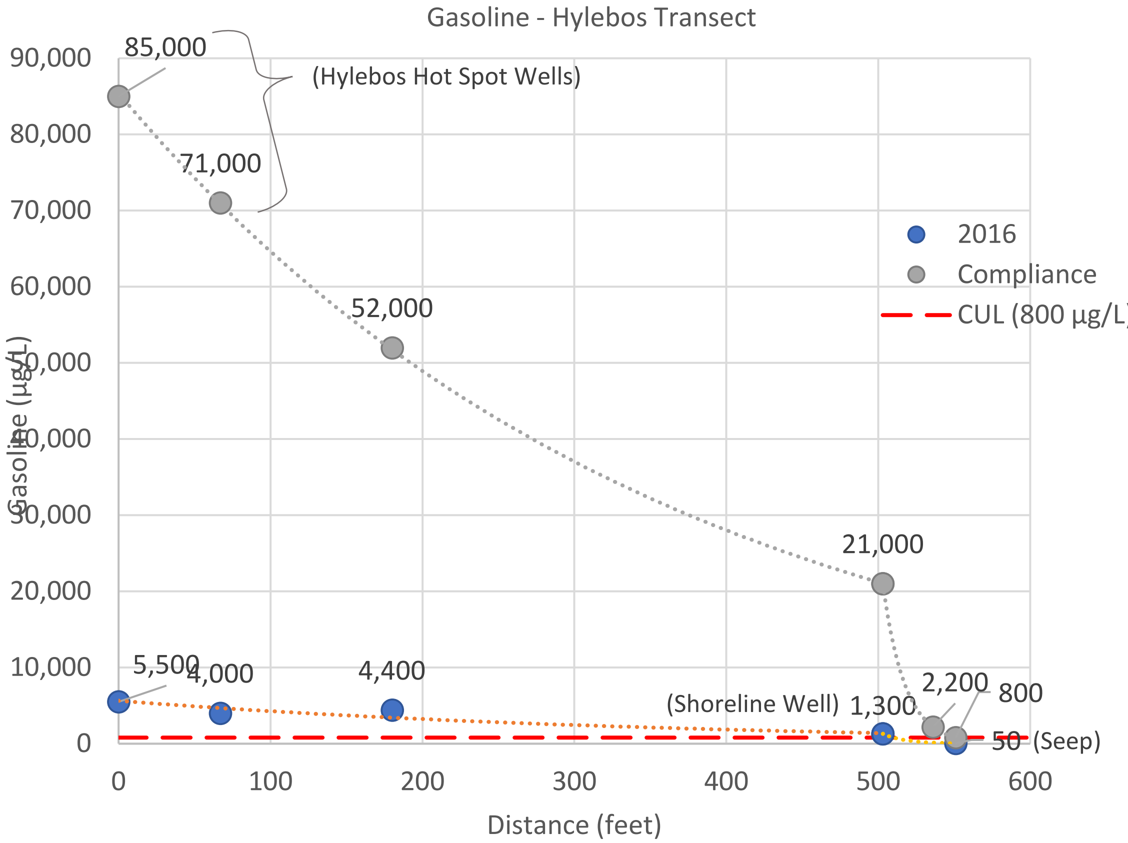

| DRO+ORO without SGC | | | | | | |
|---|---|---|---|---|---|---|
| Location | Sample Date | Distance(ft) | Matrix | Value (µg/L) | ln | Qualifier |
| MW-109-15 | 02-Aug-16 | 0 | Groundwater | 14,600 | 9.59 | |
| 721-MW6-15 | 02-Aug-16 | 67 | Groundwater | 7,300 | 8.90 | |
| 721-MW11-15 | 01-Aug-16 | 180 | Groundwater | 10,300 | 9.24 | |
| MW-104-15 | 02-Aug-16 | 503 | Groundwater | 5,800 | 8.67 | |

| | | |
|---|---|---|
| Slope (k/vc) = | -0.0014 | |
| x (distance between MW-109-15 and MW-104-15) = | 503 | feet |
| Remediation Level at Hylebos Hot Spot = | 2,600 | µg/L |



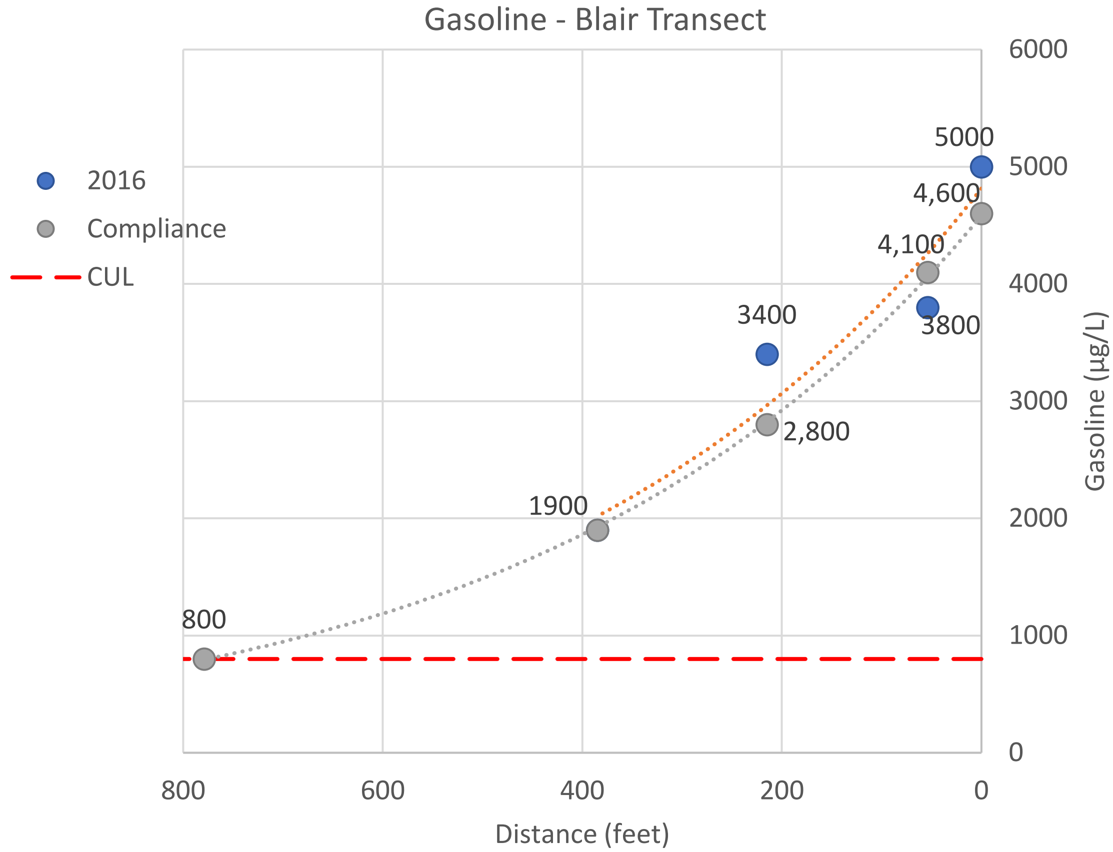

| DRO+ORO without SGC | | | | | | |
|---|---|---|---|---|---|---|
| Location | Sample Date | Distance(ft) | Matrix | Value (µg/L) | ln | Qualifier |
| 721-MW15-15 | 01-Aug-16 | 0 | Groundwater | 13,000 | 9.47 | |
| 721-MW2 | 01-Aug-16 | 54 | Groundwater | 20,600 | 9.93 | |
| HC-N11-6 | 01-Aug-16 | 215 | Groundwater | 10,700 | 9.28 | |
| MW-130-15 | 01-Aug-16 | 385 | Groundwater | 4,200 | 8.34 | |
| MHHW | | 779 | | | | |

| | | |
|---|---|---|
| Slope (k/vc) = | -0.0034 | |
| x (distance between 721-MW-15-15 and the Blair Waterway) = | 779 | feet |
| Remediation Level at Blair Hot Spot = | 7,300 | µg/L |




| GRO | | | | | | |
|---|---|---|---|---|---|---|
| Location | Sample Date | Distance(ft) | Matrix | Value (µg/L) | ln | Qualifier |
| MW-109-15 | 02-Aug-16 | 0 | Groundwater | 5,500 | 8.61 | |
| 721-MW6-15 | 02-Aug-16 | 67 | Groundwater | 4,000 | 8.29 | |
| 721-MW11-15 | 01-Aug-16 | 180 | Groundwater | 4,400 | 8.39 | |
| MW-104-15 | 02-Aug-16 | 503 | Groundwater | 1,300 | 7.17 | |

| | | |
|---|---|---|
| Slope (k/vc) = | -0.0028 | |
| x (distance between MW-109-15 and MW-104-15) = | 503 | feet |
| Remediation Level at Hylebos Hot Spot = | 85,000 | µg/L |




| GRO | | | | | | |
|---|---|---|---|---|---|---|
| Location | Sample Date | Distance(ft) | Matrix | Value (µg/L) | ln | Qualifier |
| 721-MW15-15 | 01-Aug-16 | 0 | Groundwater | 5,000 | 8.52 | |
| 721-MW2 | 01-Aug-16 | 54 | Groundwater | 3,800 | 8.24 | |
| HC-N11-6 | 01-Aug-16 | 215 | Groundwater | 3,400 | 8.13 | |
| MW-130-15 | 01-Aug-16 | 385 | Groundwater | 1,900 | 7.55 | |
| MHHW | | 779 | | | | |

| | | |
|---|---|---|
| Slope (k/vc) = | -0.0023 | |
| x (distance between 721-MW-15-15 and the Blair Waterway) = | 779 | feet |
| Remediation Level at Blair Hot Spot = | 4,600 | µg/L |

APPENDIX E

# Soil Cleanup Level Calculations Summary

**Appendix E**
**Soil Cleanup Level Calculation Summary**
**Alexander Avenue Cleanup Site**
**Tacoma, Washington**

## Default Industrial Direct Contact Soil Cleanup Level for Petroleum Hydrocarbons[1]

***MTCA Equation 745-3***

$$\frac{HI \times ABW \times AT \times 365\, days / year}{EF \times ED \times \left[\left(SIR \times CF \times AB1 \times \left(1 / RfDo\right)\right) + \left(SA \times CF \times AF \times ABS \times \left(1 / RfDd\right)\right)\right]}$$

| | | |
|---|---|---|
| **Industrial Petroleum Hydrocarbon Cleanup Level (mg/kg) =** | **16,809** | |
| | **17,000** | *two significant digits* |

| | | | |
|---|---|---|---|
| Hazard Index (HI) | 1 | unitless | |
| Average Body Weight (ABW) | 70 | kg | |
| Averaging Time (AT) | 20 | years | |
| Exposure Frequency (EF) | 256 | days/year | |
| Exposure Duration (ED) | 20 | years | |
| Soil Ingestion Rate (SIR) | 100 | mg/day | (outdoor worker) |
| Conversion Factor (CF) | 1.00E-06 | kg/mg | |
| Gastrointestinal Absorption Factor (AB1) | 1 | unitless | |
| Dermal Surface Area (SA) | 2500 | $cm^2$ | |
| Adherence Factor (AF) | 0.2 | $mg/cm^2$ - day | |
| Dermal Absorption Fraction (ABS; volatile petroleum with vapor pressure < benzene) | 0.03 | unitless | |
| Oral Reference Dose (RfDo) | 0.02 | mg/kg-day | |
| Dermal Reference Dose (RfDd). Derived by RfDo x GI. | 0.016 | mg/kg-day | |
| Gastrointestinal Absorption Conversion Factor (GI) - Converts oral RfD to a dermal RfD | 0.8 | unitless | |

[1] Assumed that the entire petroleum fraction is associated with the Aromatic 10-12 carbon range fraction

**Abbreviations and Acronyms:**

$cm^2$ = square centimeters
kg = kilograms
kg/mg = kilograms per milligram
$mg/cm^2$-day = milligrams per square centimeters per day
mg/day = milligrams per day
mg/kg-day = milligrams per kilogram per day

APPENDIX F

# Estimated Restoration Time Frame Calculations

# APPENDIX F
# RESTORATION TIME FRAME ANALYSIS

## Restoration Time Frame Analysis—By Alternative

Cleanup actions must provide for a reasonable restoration time frame. There are two steps in evaluating if a cleanup action time frame is reasonable: 1) estimating the restoration time frames; and 2) evaluating if the time frame is reasonable as outlined in Washington Administrative Code (WAC) 174-340-360(4)(b). The objective of this appendix is to complete Step 1 by estimating restoration time frames to reach cleanup levels (CULs) or screening levels (SLs) at the standard point of compliance (POC)[1] or the conditional point of compliance (CPOC; where proposed),[2] and remediation levels (RLs; where proposed), for each Alternative. Step 2, evaluation of reasonableness, is included in Section 6 of the feasibility study (FS) text. Restoration time frames are estimated by evaluating the current natural attenuation rates and making assumptions about how much the applied technologies will accelerate decay.

Natural attenuation of benzene, gasoline-range total petroleum hydrocarbons (TPH-G), and diesel-range TPH (TPH-D) at the Port of Tacoma (Port) and Mariana Properties, Inc. (Mariana) Alexander Avenue Petroleum Tank Facilities site (Site) were analyzed in the *Natural Attenuation and Restoration Timeframe Evaluation* (Port 2017). The analysis follows the methods described in the Washington State Department of Ecology's (Ecology's) guidance document, *Guidance on Remediation of Petroleum-Contaminated Groundwater by Natural Attenuation* (2005), and from the US Environmental Protection Agency's (EPA's) guidance, *Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities* (2009). Time series analysis was used to assess plume stability and estimate attenuation rates. The analysis included statistical significance testing of the linear regression using an 85 percent confidence level. Benzene trends, overall, did much better in the statistical significance testing than gasoline-range organics (GRO) and diesel-range organics (DRO) trends. Therefore, greater confidence can be given to restoration time frame estimates calculated from benzene attenuation rates in comparison to the other analytes (GRO and DRO). The benzene plume is shrinking—91 percent of the wells analyzed (21 out of 23) have declining trends, and 11 wells had declining trends significantly different from zero. Where applicable for evaluation of light non-aqueous phase liquid (LNAPL) petroleum degradation/attenuation, natural source zone depletion (NSZD) rates were used. While the GRO/DRO data available are insufficient to perform a restoration time frame analysis, the restoration time frames for these

[1] The standard POC for groundwater is throughout the Site.

[2]The proposed CPOC for groundwater in some alternatives is the point or points at which groundwater emanates into the surface water. As described more fully in Section 3 of the feasibility study text, compliance with CULs at the CPOC is proposed to be measured at proposed upland angled (or vertical) wells; and the concentrations that will be used to demonstrate compliance at the CPOC will be determined based on estimated nearshore attenuation in the groundwater-surface water transition zone. For the purposes of this appendix, the upland angled (or vertical) wells that will be used to demonstrate compliance with CULs at the CPOC are termed "angled wells" or "proposed angled wells".

constituents are anticipated to be similar to benzene; and even if longer or shorter, the results would not be anticipated to be significantly different enough to impact the selection of a final remedy.

Note that a restoration time frame analysis for dissolved-phase benzene and total petroleum hydrocarbons on the Blair Waterway side of the Site was not performed. The analysis was not possible because there is insufficient data available to determine the contaminant attenuation rates as groundwater approaches the Blair Waterway; therefore, CULs and/or RLs could not be calculated for the angled wells along the Blair Waterway for demonstrating compliance at the CPOC, RLs could not be calculated for groundwater approaching the waterway, and a restoration time frame could not be accurately estimated. These evaluations will be performed during the engineering design phase, during which, the necessary data needed will be collected.

Additional information on the methods is presented below, followed by restoration time frame analysis for each alternative. The restoration time frames provided assume that implementation of the final remedy will begin in 2021. The evaluations are done using wells from the 15-foot (ft) zones, where most of the contaminant mass is located.

### *Method*

Restoration time frames were estimated using the concentration versus time approach (temporal analysis at a point in the plume) described in the *Guidance on Remediation of Petroleum-Contaminated Groundwater by Natural Attenuation* (Ecology 2005). For each well within the plume, the time to reach the target concentration for that well can be estimated using the following equation (Eqn. F.2 from Ecology 2005):

$$t = \frac{\ln\left(\frac{SL}{C_{current}}\right)}{-k_{point}}$$

Where $t$ is the time it will take for the contaminant concentration to reach a specified concentration; *SL* is the screening level (or any concentration of interest: SL, CUL, RL); $C_{current}$ is the current contaminant concentration; and $-k_{point}$ is the attenuation rate (decay rate constant). The $-k_{point}$ value is derived from the slope of natural log groundwater concentration vs. time plot at a well, these values were calculated for a subset of wells in the network in the *Natural Attenuation and Restoration Timeframe Evaluation* (Port 2017). Benzene trend analysis was performed at each well including testing of statistical significance at an 85 percent confidence level. For wells where the statistical test failed, an average attenuation rate was applied. The average benzene attenuation rate was determined by averaging the decay rates of the wells with statistically significant trends within each attenuation zone as presented in the *Natural Attenuation and Restoration Timeframe Evaluation* (Port 2017). For restoration time frame and cost estimate considerations, the longer restoration time frame estimate was applied.

Current contaminant concentrations are represented by averaging the last two sampling events (collected in May 2016 and August 2016).

Where LNAPL is present, NSZD rates (measured in units of gallons per acre per year [gal/acre/yr]), based on Interstate Technology & Regulatory Council (ITRC) guidance (ITRC 2018), were used to evaluate depletion/degradation rates of LNAPL petroleum. Using the estimated mass/volume of TPH over specific areas with measurable LNAPL, the NSZD rates were used to determine how much mass/volume of TPH would be degraded each year in order to estimate restoration time frames to reach various RLs or CULs.

## *Background and Assumptions*

In the *Natural Attenuation and Restoration Timeframe Evaluation* (Port 2017), the Site was broken into attenuation zones to account for variations in decay rates across the site, the zones are the source zone (SZ), the attenuation zone (AZ), and the groundwater to surface water transition zone (TZ). The source zone (corresponding roughly to the limits of the Blair Hot Spot) is defined by the area of the well network where LNAPL was detected during the remedial investigation (RI; Aspect 2016, Figure 6.2-2).[3] Surrounding the source zone is the attenuation zone, the area where benzene was detected above screening criteria during the RI. The transition zone designation includes the hyporheic zone and is intended to describe the area near the shoreline where seawater intrusion into groundwater is occurring because of tidal fluctuations and where geochemical conditions change relative to the attenuation zone that enhance biodegradation processes.[4] Measurement of geochemical indicators at select wells found elevated sulfate in shoreline wells, likely indicating seawater influence (Aspect 2016). The transition zone is defined as the area from the mean higher high-water (MHHW) line to approximately 50 ft inland; however, tidal fluctuations have been observed as far upland as 200 ft. This evaluation indicates that attenuation rates are generally depressed in areas where LNAPL is present.

**Table: Site Attenuation Rates and Half-life Values for Benzene (Port 2017)**

| *Natural Attenuation Zone* | *Wells with significant trends* | *Average attenuation rate ($k_{point}$)* | *Average $t_{1/2}$ - attenuation* |
|---|---|---|---|
| *SZ* | 709-MW-09-15, 721-MW15-15, 721-MW2, 721-MW8-15 | $-3.16 \times 10^{-4}$ | 6 |
| *AZ – 15 foot* | 709-MW-11-15, 709-MW-17-15, MW-130-15 | $-9.50 \times 10^{-4}$ | 2 |
| *AZ – 25 foot* | MW-110-25 and MW-137-25 | $-2.47 \times 10^{-3}$ | 1 |
| *TZ* | 721-MW9-15 and 95-15 | $-6.60 \times 10^{-4}$ | 3 |

[3] LNAPL was either directly observed, or trace LNAPL was observed in soil borings in the form of sheen and a strong TPH odor.

[4] Processes that enhance biodegradation in the transition zone include the influx of electron acceptors, such as dissolved oxygen and sulfate, transported into the transition zone with the tidally driven seawater, and infusion of atmospheric oxygen due to tidal pumping (cyclic displacement of vadose zone soil vapor due to tidal fluctuations).

The estimated decay rates for benzene generally agree with those reported in several separate studies (Newell et al. 2002, Peargin 2002, USGS 2006). Newell calculated the following median point decay rate constant for benzene: 0.33 per year (2.1-year half-life) for 159 benzene plumes at service station sites in Texas. Peargin (2002) calculated rates from wells that were screened in areas with residual non-aqueous-phase liquid (NAPL); the mean decay rate for benzene was 0.14 per year (half-life of 5 years). Site biodegradation decay rates range from a half-life of 1 to 6 years with a mean of 3 years (Port 2017).

Natural attenuation rates will be enhanced by implementing *in situ* bioremediation. Benzene and TPH bioremediation degradation rates were estimated from two other marine shoreline sites where *in situ* anaerobic bioremediation was implemented through injection of nitrate as a terminal electron acceptor. Treatment degradation rates were 3–12 times faster than were observed pre-treatment (LAI 2018). For the purposes of estimating restoration time frames at the Alexander Avenue former tank farm, it is assumed that bioventing technology will accelerate decay by 1.5 times in the Blair Hot Spot and 3 times in the Hylebos Hot Spot (slower rate anticipated in the Blair Hot Spot is due to greater concentration of TPH mass and decay rate observations in the natural attenuation analysis; Port 2017). Enhanced *in situ* bioremediation (EISB) would accelerate decay by 3 times in the Blair Hot Spot and 6 times in the Hylebos Hot Spot in the downgradient dissolved plume.

For the calculations presented below, it was also assumed that the post-treatment attenuation rate would be equal to the pre-treatment attenuation rate. It is typically observed that, as groundwater contaminant concentrations are reduced over the long term, the attenuation rate declines as indicated at the lower end of a typical logarithmic (or hyperbolic) concentration-versus-time curve (Ecology 2005, EPA 2017). Therefore, the attenuation rate following treatment may in fact be lower than prior to treatment, though it is difficult to predict to what degree.

## Alternative 1: No Action with Compliance Monitoring

Alternative 1 consists of compliance monitoring only to confirm human and ecological receptors are not being adversely exposed to Site contaminants.

- Benzene cleanup criteria: Meet the groundwater CUL (benzene = 1.6 micrograms per liter [μg/L]; based on protection of surface water) at CPOC.
    - Time frame = 29 years
    - Action = transition from annual/biennial performance monitoring of groundwater to long-term (5-year) performance monitoring
- Benzene cleanup criteria: Meet groundwater CULs (benzene = 1.6 μg/L; based on protection of surface water) at the standard POC (Site-wide).
    - Time frame = 152 years
    - Action = long term performance monitoring, transition to confirmation monitoring upon reaching CULs

- Other milestones: Benzene vapor intrusion SL (benzene = 24 µg/L).
  - Time frame = 85 years
  - Action = no action.

Restoration time frame estimated by evaluating natural attenuation at well 721-MW2-15. 721-MW2-15 was chosen because it is anticipated to be the final well at the Site to reach CULs (based on current concentration and contaminant decay rate). The trend at this location is statistically significant from zero; therefore, the well-specific decay rate was applied to the estimated restoration time frame.

Note that, because groundwater trends have a relationship to soil in the smear zone, and the soil CULs for GRO and DRO are related to residual saturation concentrations, the soil cleanup restoration time frames are anticipated to be similar to those for groundwater for Alternative 1.

### *Alternative 1—Restoration Time Frame Backup*

**721-MW2**

**Benzene Groundwater Concentration Data**

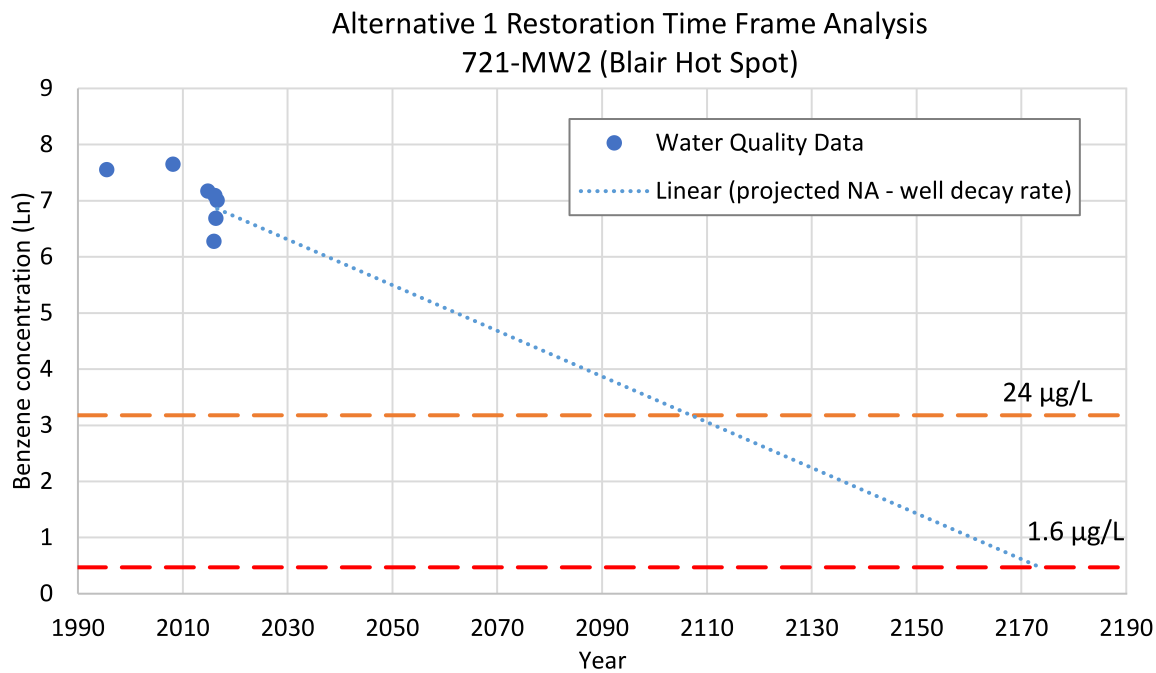
| Sample Date | Value (µg/L) | ln | Qualifier |
|---|---|---|---|
| 7/14/1995 | 1900 | 7.55 | |
| 2/16/2008 | 2100 | 7.65 | |
| 10/16/2014 | 1300 | 7.17 | |
| 12/9/2015 | 530 | 6.27 | J |
| 2/22/2016 | 1200 | 7.09 | J |
| 5/10/2016 | 800 | 6.68 | |
| 8/1/2016 | 1100 | 7.00 | |

**Input Variables (Eqn. F.2)**

| | | |
|---|---|---|
| Well decay rate (slope) = | -1.11E-04 | statistically different from zero |
| VI SL = | 24 | µg/L |
| Groundwater CUL = | 1.6 | µg/L |
| C_current (2016 concentration) = | 950 | µg/L |

**Results**

| | | | |
|---|---|---|---|
| Year VI SL will be met Site-wide | 2106 | 85 | years from 2021 |
| Year pCUL will be met Site-wide | 2173 | 152 | years from 2021 |


Alternative 1 Restoration Time Frame Analysis
721-MW2 (Blair Hot Spot)
Water Quality Data
Linear (projected NA - well decay rate)
24 µg/L
1.6 µg/L
Benzene concentration (Ln)
Year
0
1
2
3
4
5
6
7
8
9
1990
2010
2030
2050
2070
2090
2110
2130
2150
2170
2190

**MW-104-15**

**Benzene Groundwater Concentration Data**

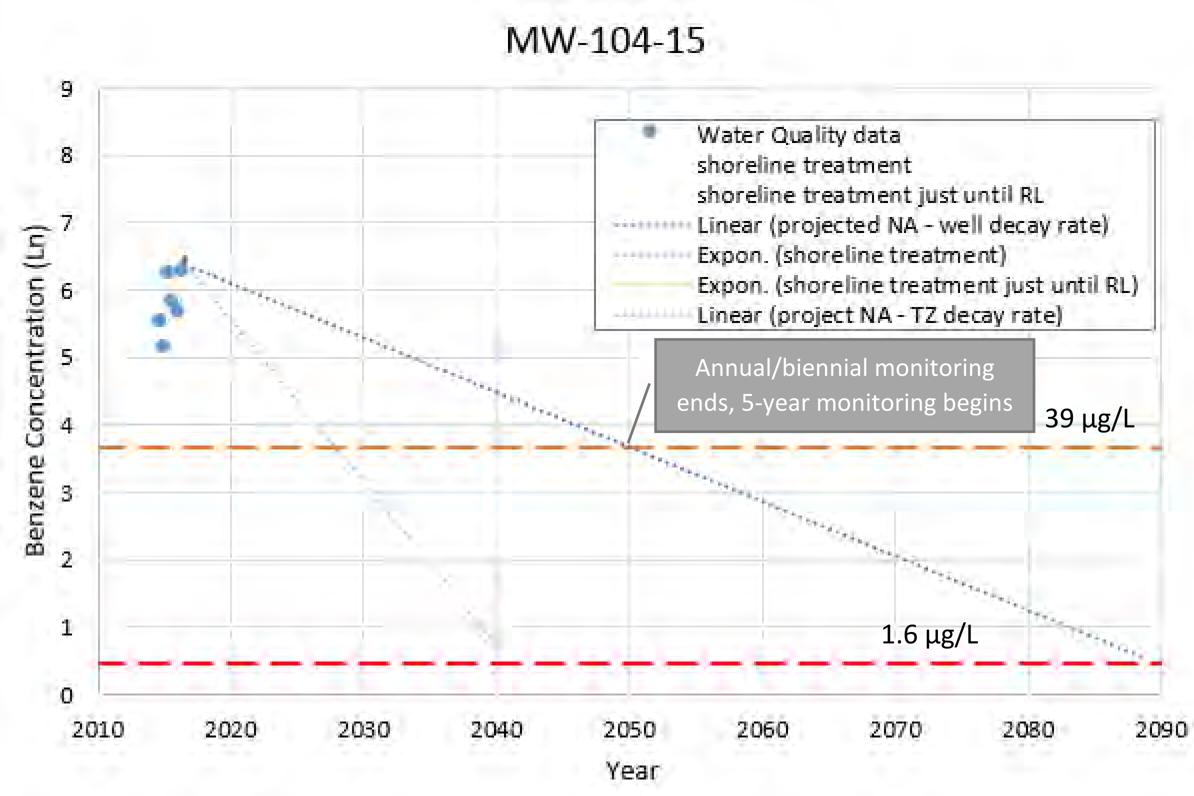
| Sample Date | Value (µg/L) | ln | Qualifier |
|---|---|---|---|
| 10/15/2014 | 250 | 5.52 | |
| 1/26/2015 | 170 | 5.14 | |
| 5/18/2015 | 510 | 6.23 | |
| 8/28/2015 | 340 | 5.83 | |
| 12/8/2015 | 0.2 | -2.30 | U |
| 2/22/2016 | 290 | 5.67 | |
| 5/10/2016 | 530 | 6.27 | |
| 8/2/2016 | 650 | 6.48 | |

**Input Variables (Eqn. F.2)**

| | | |
|---|---|---|
| Well decay rate (slope) = | -2.22E-04 | NOT statistically different from zero |
| Transition zone decay rate = | -6.60E-04 | NA Memo (Port 2017) |
| Shoreline well conc. protective of CPOC | 39 | µg/L, from Appendix D |
| Groundwater CUL = | 1.6 | µg/L |
| C_current (2016 concentration) = | 590 | µg/L |

**Results**

| | | | | |
|---|---|---|---|---|
| well decay rate | Year GW CUL will be met at CPOC | 2050 | 29 | years from 2021 |
| TZ decay rate | Year GW CUL will be met at CPOC | 2027 | 6 | years from 2021 |



## Alternative 2: Site-Wide MNA and Shoreline EISB

Alternative 2 includes shoreline EISB and Site-wide monitored natural attenuation (MNA), as well as the common remedial components; institutional and engineering controls and compliance monitoring. An RL for the Hylebos Hot Spot is proposed to transition between treatment technologies. Time estimates to reach benzene RLs and cleanup criteria are summarized below.

- Benzene cleanup criteria: Meet concentrations in groundwater in angled wells (benzene = 4 µg/L) that demonstrate compliance with CULs at the CPOC (benzene = 1.6 µg/L).
  - Time frame = 5 years
  - Action = continue to perform shoreline injections until Hylebos Hot Spot RL is met (benzene = 86 µg/L)
- Hylebos Hot Spot RL (benzene = 86 µg/L; TPH-D/O = 2,600 µg/L):
  - Time frame = 21 years
  - Action = discontinue shoreline treatment, commence Site-wide MNA.

### *Site-wide Milestones*

- Benzene vapor intrusion SL met (benzene = 24 µg/L) and
  - Time frame = 85 years (64 years after shoreline treatment completed)
  - Action = end MNA monitoring, begin 5-year reviews/performance monitoring
- Benzene groundwater CUL (benzene = 1.6 µg/L; based on protection of surface water) is met at the standard POC.
  - Time frame = 152 years (67 years after vapor intrusion SL met) respectively (see Alternative 1)
  - Action = end 5-year reviews/performance monitoring, transition to confirmation monitoring upon reaching CULs.

The text below discusses these restoration time frames in greater detail and is organized by where the analysis was focused (i.e., MW-104-15, MW-109-15, and 721-MW2-15).

The time frame to meet the groundwater CUL at the CPOC was estimated by evaluating natural attenuation and the anticipated effects of bioremediation treatment at shoreline well MW-104-15. MW-104-15 was chosen because it is anticipated to be the final well along the shoreline to reach RLs and CULs. The calculations assume shoreline treatment begins in 2021, well MW-104-15 is downgradient of the treatment system, and bioinjections accelerate the decay rate by a factor of six (LAI 2018).

The shoreline bioremediation system will continue to operate until upgradient concentrations have attenuated sufficiently to be protective of the surface water body without operation of the shoreline system. An upgradient RL for the Hylebos Hot Spot was calculated in Appendix D based on the estimated attenuation between the hot spot and Hylebos shoreline. Well MW-109-15 was chosen to estimate the time frame to meet the RL because it is anticipated to be the last well on the Hylebos-side of the groundwater divide to reach the CULs (based on current concentration and contaminant decay rate).

Note that, because groundwater trends have a relationship to soil in the smear zone, and the soil cleanup levels for GRO and DRO are related to residual saturation concentrations, the soil cleanup restoration time frames are anticipated to be similar to those for groundwater for Alternative 2.

### *Alternative 2—Restoration Time Frame Backup*

**MW-104-15**

**Benzene Groundwater Concentration Data**

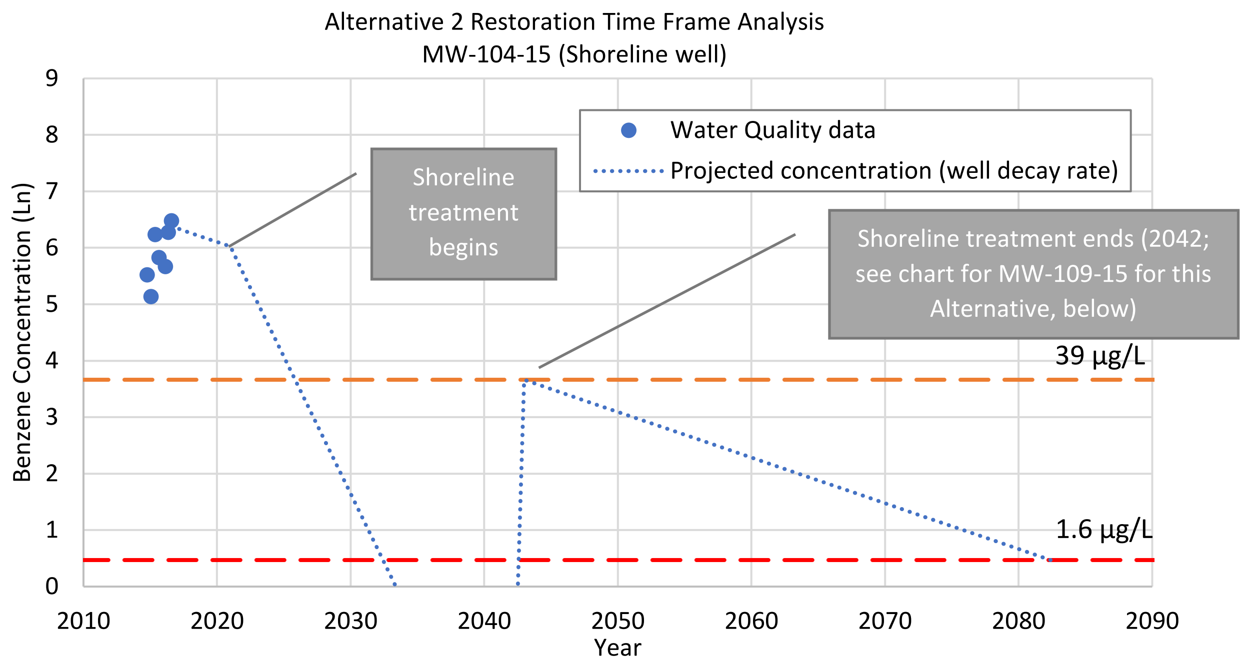
| Sample Date | Value (µg/L) | ln | Qualifier |
|---|---|---|---|
| 10/15/2014 | 250 | 5.52 | |
| 1/26/2015 | 170 | 5.14 | |
| 5/18/2015 | 510 | 6.23 | |
| 8/28/2015 | 340 | 5.83 | |
| 12/8/2015 | 0.2 | -2.30 | U |
| 2/22/2016 | 290 | 5.67 | |
| 5/10/2016 | 530 | 6.27 | |
| 8/2/2016 | 650 | 6.48 | |

**Input Variables (Eqn. F.2)**

| | | |
|---|---|---|
| Well decay rate (slope) = | -2.22E-04 | not statistically different from zero |
| Transition zone decay rate = | -6.60E-04 | NA Memo (Port 2017) |
| Shoreline well conc. protective of CPOC = | 39 | µg/L, from Appendix D |
| Groundwater CUL = | 1.6 | µg/L |
| C_current 2016 concentration = | 590 | µg/L |

**Results**

| | | | | |
|---|---|---|---|---|
| well decay rate | Year GW CUL will be met at CPOC | 2026 | 5 | years from 2021 |
| TZ decay rate | Year GW CUL will be met at CPOC | 2022 | 1 | years from 2021 |




Assumptions: EISB accelerates decay by a factor of 6; natural attenuation rate returns to baseline after shoreline treatment is terminated.

**MW-109-15**

**Benzene Groundwater Concentration Data**

| Sample Date | Value (µg/L) | ln | Qualifier |
|---|---|---|---|
| 10/16/2014 | 1900 | 7.55 | |
| 5/19/2015 | 1500 | 7.31 | |
| 12/9/2015 | 790 | 6.67 | J |
| 2/24/2016 | 1000 | 6.91 | |
| 5/10/2016 | 1400 | 7.24 | |
| 8/2/2016 | 1700 | 7.44 | |

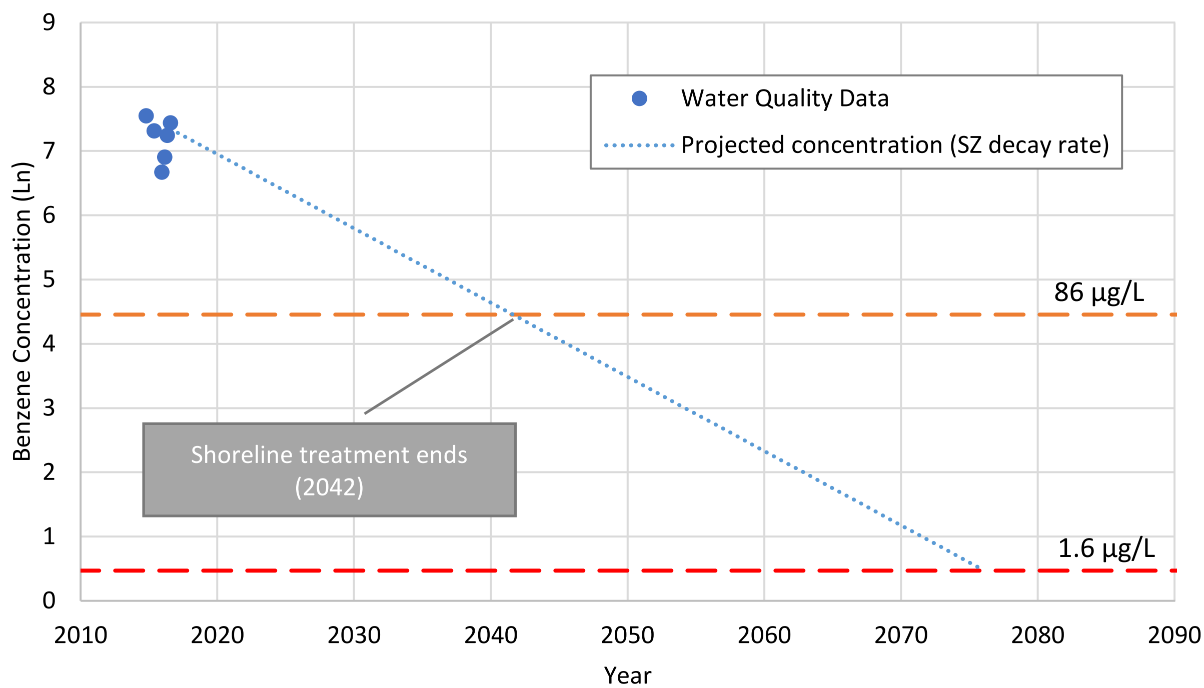
**Input Variables (Eqn. F.2)**

| | | |
|---|---|---|
| Well decay rate (slope) = | -4.38E-04 | NOT statistically different from zero |
| Source zone decay rate = | -3.16E-04 | NA Memo (Port 2017) |
| Hylebos Hot Spot RL = | 86 | µg/L, from Appendix C |
| Groundwater CUL = | 1.6 | µg/L |
| C_current (2016 concentration) = | 1550 | µg/L |

**Results**

| | | | | |
|---|---|---|---|---|
| SZ decay rate | Year Hylebos Hot Spot RL will be | 2042 | 21 | years from 2021 |

Alternative 2 Restoration Time Frame Analysis
MW-109-15 (Hylebos Hot Spot)



## Alternative 3: Hot Spot Bioremediation, Shoreline Bioremediation, MNA

Alternative 3 includes hot spot bioremediation (bioventing and EISB in combination or alone), as well as the remedial components of Alternative 2: shoreline bioremediation, MNA, institutional and engineering controls, and compliance monitoring. A CPOC at the location where groundwater emanates to surface water is proposed for groundwater under this Alternative; this is the same CPOC as proposed for Alternative 2. Compliance with CULs at the CPOC is proposed to be measured at angled wells near the shoreline for Alternative 3. RLs are proposed to guide operations of the proposed bioremediation system at the shoreline and in the Hylebos and Blair soil hot spots, and to transition from MNA to compliance monitoring. The time estimates to reach each RL and cleanup standard are summarized below.

- Benzene cleanup criteria: Meet concentrations in groundwater in angled wells (benzene = 4 µg/L) that demonstrate compliance with CULs at the CPOC (benzene = 1.6 µg/L).
  - Time frame = 5 years of shoreline bioremediation (see Alternative 2 analysis of MW-104-15)
  - Action = discontinue shoreline treatment
- Hylebos Hot Spot RL (benzene = 86 µg/L; TPH-D/O = 2,600 µg/L):
  - Time frame = 9 years of bioventing (7 years to reach the RL with additional 2 years to demonstrate compliance at angled wells and, by extension, the CPOC to account for groundwater travel time to the waterway)
  - Action = discontinue bioventing at the Hylebos Hot Spot (optional: continue bioventing until bioventing at Blair Hot Spot discontinued); commence MNA
- Blair Hot Spot RL (LNAPL < 0.1 ft):
  - Time frame = 9 years of EISB and bioventing to reach residual saturation (LNAPL thickness target)
    - *Time frame to reach TPH direct contact CUL (17,000 milligrams per kilogram [mg/kg]) = 13 years (4 years to reach CUL after EISB discontinued).*
  - Action = discontinue EISB, continue bioventing if monitoring data indicates it is still effectively enhancing petroleum degradation; commence MNA
    - *Blair Hot Spot soil: cleanup action projected to meet Model Toxics Control Act (MTCA) Method A soil CUL (TPH-D/O = 2,000 mg/kg) in 40 years (based on MNA rates w/no LNAPL present).*

### *Site-wide Milestones*

- Benzene vapor intrusion SL (benzene = 24 µg/L)
  - Time frame = 29 years (20 years after EISB completed)
  - Action = end MNA, transition to 5-year reviews/performance monitoring

- Benzene groundwater CUL (benzene = 1.6 µg/L; based on protection of surface water) is met at the standard POC
  - Time frame = 94 years (65 years after vapor intrusion SL met)
  - Action = end 5-year reviews/performance monitoring transition to confirmation monitoring.

The text below discusses these restoration time frames in greater detail and is organized by where the analysis was focused (i.e., well 721-MW2-15, MW-104-15, and MW-109-15).

In the same way as Alternative 2, the time frame to meet the groundwater CUL at the CPOC was estimated by evaluating natural attenuation and the anticipated effects of bioremediation treatment at shoreline well MW-104-15. And well MW-109-15 was used to estimate the time frame to meet the Hylebos Hot Spot RL for benzene (86 µg/L).

For the Blair Hot Spot RL, bioventing and EISB are proposed with the goal of treating to concentrations that are protective of human health direct contact and achieve theoretical elimination of LNAPL. Accordingly, the RL is a mass reduction target based on achieving the lower of the TPH pCUL for soil (17,000 mg/kg) and the residual saturation concentration for gasoline and middle distillates (diesel-range hydrocarbons) in fine-to-medium sand. MTCA Table 747-5 provides residual saturation limits for weathered gasoline and middle distillates in coarse sand and gravelly soils. Lithologies observed in Site soil cores include fine-to-medium sand and silty sand. Residual saturation increases with higher LNAPL viscosity and smaller pore size, consequently Site-specific residual saturation will be higher than the default MTCA levels (1,000 mg/kg for weathered gasoline and 2,000 mg/kg for middle distillates diesel-range hydrocarbons). If Site-specific soil conditions are accounted for, residual saturation at the Site is likely to be approximately the same as the TPH hot spot value of 19,000 mg/kg in the 5–10-ft depth interval determined by Ecology (Appendix C), which also aligns closely with the extent of observed LNAPL in Site monitoring wells in the source zone/Blair Hot Spot.[5]

### *Restoration Time Frame Backup*

Plume mass calculation:

$$Plume\ mass\ (kg) = \frac{A * C_{average} * b * \rho}{UCF}$$

Where, A = planar area (48,000 square feet [ft$^2$] for Blair Hot Spot)

$C_{average}$ = average concentration in mg/kg

b = plume thickness (5-ft; based on the 5–10-ft interval evaluated in the hot spot analysis, Appendix C, includes the ‘smear’ zone where the majority of the contaminant mass is located)

$\rho$ = soil bulk density (42.5 kilograms per cubic feet [kg/ft$^3$])

[5] This value is also consistent with data for empirical relationships between LNAPL type, soil type, and residual saturation that has been compiled in multiple academic and regulatory agency documents (Mercer and Cohen 1990, Brost and DeVaull 2000, Adamski et al. 2003). These compilations are consistent with the expected increase in residual saturation with higher LNAPL viscosity and smaller pore sizes (finer-grained materials).

UCF = unit conversion factor (1,000,000; converts mg to kg)

The current average TPH concentration in the 19,000 mg/kg hot spot (from App 4) is 28,248 mg/kg:

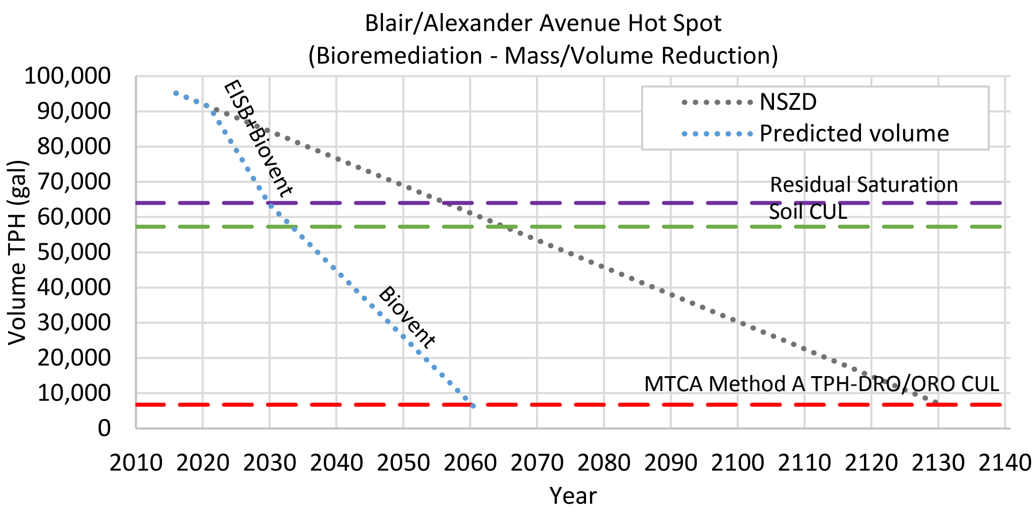
$$Plume\ mass = 48{,}000\ ft^2 * 28{,}248\frac{mg}{kg} * 5ft * 42.5\ \frac{kg}{ft^3} = 288{,}130\ kg$$

The mass value can be converted to a volume using the equation, $density = mass/volume$, and assuming a TPH density of 0.8 kilograms per liter (kg/L; gas and diesel mixture):

$$Volume\ TPH = \frac{288{,}130\ kg}{0.8\frac{kg}{L}} \text{ = 360,162 liters (or 95,155 gallons)}$$

The same approach was applied to estimate gallons of TPH equivalency for the residual saturation limit: 19,000 mg/kg, the CUL for soil, 17,000 mg/kg, and the MTCA Method A CUL, 2,000 mg/kg.

Assumptions: EISB and bioventing accelerates NSZD rate[6] to the typical upper-end value of 2,800 gal/acre/yr, and bioventing alone accelerates NSZD to the median value of 1,700 gal/acre/yr (ITRC 2018).




[6] NSZD rates stated are from the ITRC guidance for the middle 50 percent of the 25 NSZD study sites evaluated.

**721-MW2**

**Benzene Groundwater Concentration Data**

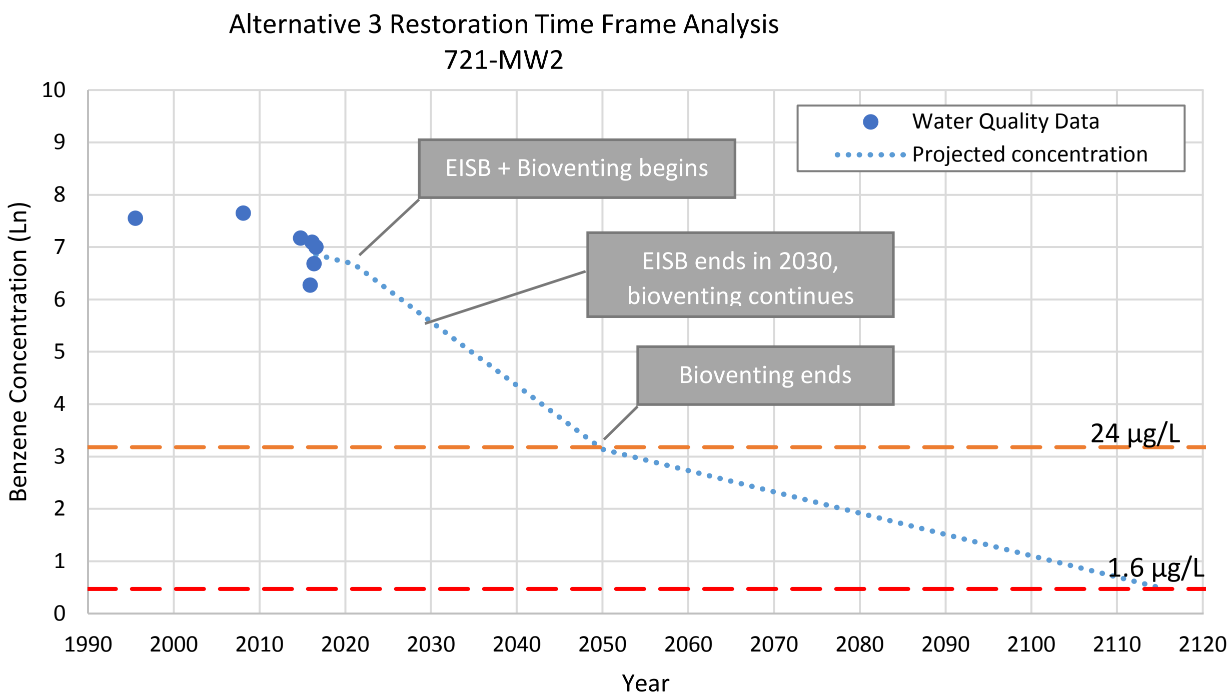
| Sample Date | Value (μg/L) | ln | Qualifier |
|---|---|---|---|
| 7/14/1995 | 1900 | 7.55 | |
| 2/16/2008 | 2100 | 7.65 | |
| 10/16/2014 | 1300 | 7.17 | |
| 12/9/2015 | 530 | 6.27 | J |
| 2/22/2016 | 1200 | 7.09 | J |
| 5/10/2016 | 800 | 6.68 | |
| 8/1/2016 | 1100 | 7.00 | |

**Input Variables (Eqn. F.2)**

| | | |
|---|---|---|
| Well decay rate (slope) = | -1.11E-04 | statistically different from zero |
| VI SL = | 24 | μg/L |
| Groundwater pCUL = | 1.6 | μg/L |
| C_current (2016 concentration) = | 950 | μg/L |

**Results**

| | | | |
|---|---|---|---|
| Year VI SL will be met Site-wide | 2050 | 29 | years from 2021 |
| Year pCUL will be met Site-wide | 2115 | 94 | years from 2021 |



Assumptions: EISB plus bioventing only accelerates decay by 3 times at the Blair Hot Spot (versus 6 times assumption at the Hylebos Hot Spot) because of the presence of LNAPL, when soil concentrations are below residual saturation, bioventing alone is estimated to achieve decay acceleration of 3 times.

**MW-109-15**

**Benzene Groundwater Concentration Data**

| Sample Date | Value (µg/L) | ln | Qualifier |
|---|---|---|---|
| 10/16/2014 | 1900 | 7.55 | |
| 5/19/2015 | 1500 | 7.31 | |
| 12/9/2015 | 790 | 6.67 | J |
| 2/24/2016 | 1000 | 6.91 | |
| 5/10/2016 | 1400 | 7.24 | |
| 8/2/2016 | 1700 | 7.44 | |

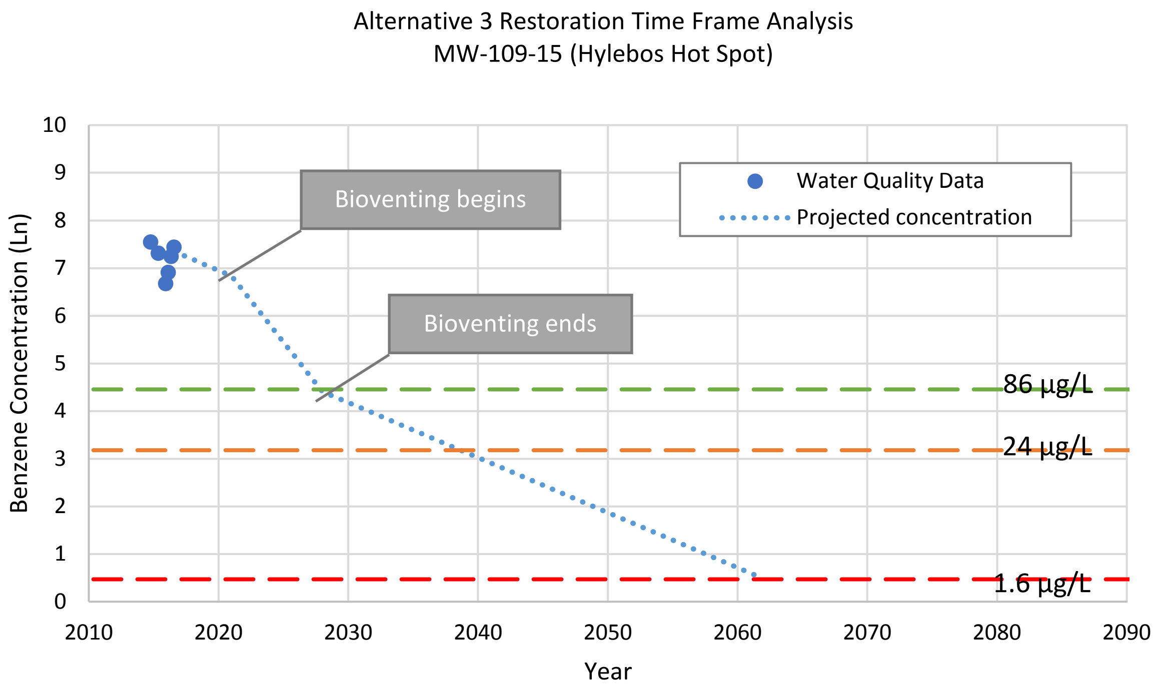
**Input Variables (Eqn. F.2)**

| | | |
|---|---|---|
| Well decay rate (slope) = | -4.38E-04 | NOT statistically different from zero |
| Source zone decay rate = | -3.16E-04 | NA Memo (Port 2017) |
| Groundwater CUL = | 1.6 | µg/L |
| Hylebos Hot Spot RL = | 86 | µg/L, from Appendix C |
| C_current (2016 concentration) = | 1550 | µg/L |

**Results**

| | | | | |
|---|---|---|---|---|
| SZ decay rate | Year Hylebos hot spot RL will be met | 2028 | 7 | years from 2021 |
| SZ decay rate | Year VI SL will be met at well | 2039 | 18 | years from 2021 |
| SZ decay rate | Year pCUL will be met at well | 2062 | 41 | years from 2021 |

| | | | | |
|---|---|---|---|---|
| well decay rate | Year Hylebos hot spot RL will be met | 2025 | 4 | years from 2021 |




Assumptions: Bioventing accelerates decay by 3 times.

## Alternative 4: Hot Spot Bioremediation, MNA

Alternative 4 includes hot spot bioremediation (bioventing and EISB in combination), as well as MNA, institutional and engineering controls, and compliance monitoring. A CPOC at the location where groundwater emanates to surface water is proposed for groundwater under this Alternative; this is the same CPOC as proposed for Alternatives 2 and 3. Compliance with CULs at the CPOC is proposed to be measured at angled wells near the shoreline for Alternative 4. RLs are proposed to guide bioremediation technologies at the Hylebos and Blair soil hot spots, and to transition from MNA to compliance monitoring. The time estimates to reach each RL and cleanup standard are summarized below.

- Benzene cleanup criteria: Meet concentrations in groundwater pCULs in angled wells (benzene = 4 µg/L) that demonstrate compliance with CULs at the CPOC (benzene = 1.6 µg/L).
  - Time frame = 5 years, based on treatment at the Hylebos Hot Spot
  - Action = discontinue EISB at the Hylebos Hot Spot
- Hylebos Hot Spot RL (EISB RL – benzene = 86 µg/L; bioventing RL – benzene = 24 µg/L):
  - Time frame = 5 years of EISB and bioventing (3 years to reach RL with up to 2 additional years to demonstrate compliance at angled wells and, by extension, the CPOC to account for groundwater travel time to the waterway)
  - Action = discontinue EISB, continue bioventing until vapor intrusion SL is met

- Time frame = 2 additional years bioventing after completion of EISB) (7 years total)
- Action = discontinue bioventing; optional – continue bioventing if monitoring data indicates it is still effectively enhancing petroleum degradation

- Blair Hot Spot RL (LNAPL < 0.1 ft; groundwater benzene = 2,600 µg/L, TPH-D/O = 7,300 µg/L; TPH-G = 4,600 µg/L):
  - Time frame = 9 years of EISB and bioventing to reach residual saturation (LNAPL target thickness)
    - *Time frame to reach TPH direct contact CUL (17,000 mg/kg) = 13 years (4 years to reach CUL after EISB discontinued)*
  - Action = discontinue EISB, continue bioventing and commence MNA sampling/monitoring until vapor intrusion SL is met
    - *Blair Hot Spot soil: cleanup action projected to meet MTCA Method A soil CUL (TPH-D/O = 2,000 mg/kg) in 2061, 40 years (based on MNA rates w/no LNAPL present).*

### *Site-wide Milestones*

- Benzene vapor intrusion SL (benzene = 24 µg/L)
  - Time frame = 29 years (20 years after EISB completed),
  - Action = end bioventing at both hot spots and discontinue MNA sampling, transition to 5-year reviews/performance monitoring
- Benzene groundwater CUL (benzene = 1.6 µg/L; based on protection of surface water) is met at the standard POC
  - Time frame = 94 years (65 years after vapor intrusion SL met), respectively
  - Action = end 5-year reviews/performance monitoring, transition to confirmation monitoring.

The text below discusses these restoration time frames in greater detail and is organized by where the analysis was focused (i.e., well 721-MW2-15, MW-104-15, and MW-109-15).

The time frame to meet the groundwater CUL at the CPOC is estimated by evaluating the anticipated effects of bioremediation treatment (EISB and bioventing) at the Hylebos Hot Spot, using well MW-109-15, and the downgradient projections presented in Appendix D.

For the Blair Hot Spot, the anticipated effect of bioremediation treatment (EISB and bioventing) are estimated by the same method as Alternative 3.

**MW-109-15**

**Benzene Groundwater Concentration Data**

| Sample Date | Value (µg/L) | ln | Qualifier |
|---|---|---|---|
| 10/16/2014 | 1900 | 7.55 | |
| 5/19/2015 | 1500 | 7.31 | |
| 12/9/2015 | 790 | 6.67 | J |
| 2/24/2016 | 1000 | 6.91 | |
| 5/10/2016 | 1400 | 7.24 | |
| 8/2/2016 | 1700 | 7.44 | |

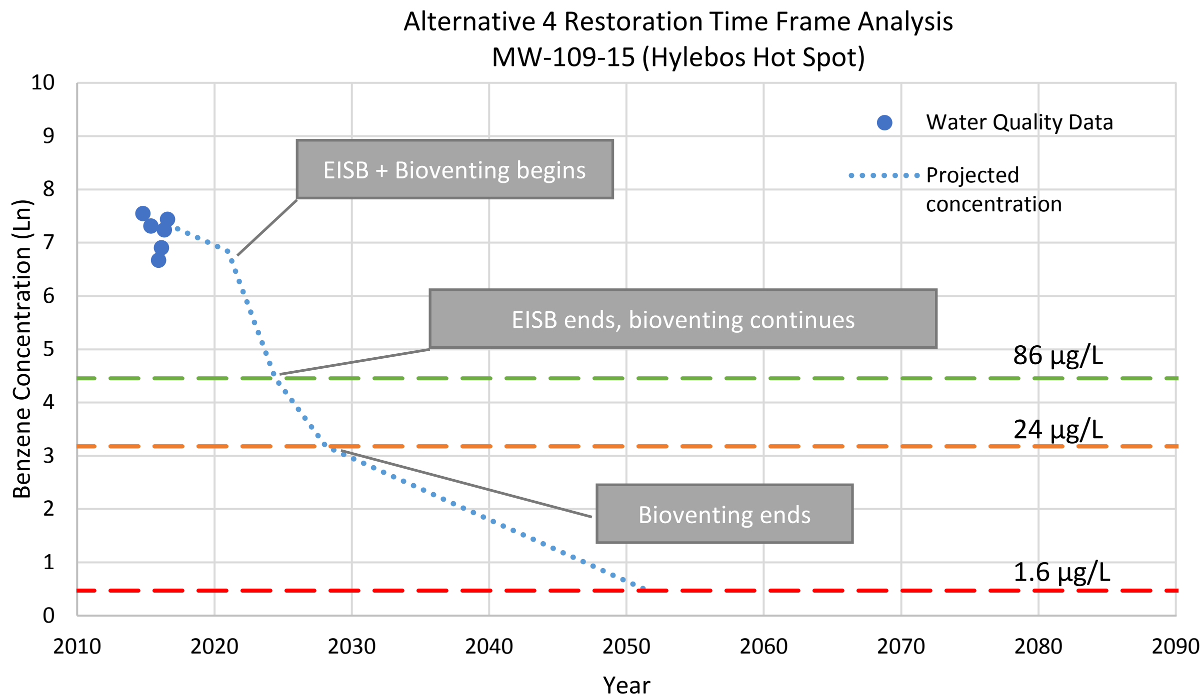
**Input Variables (Eqn. F.2)**

| | | |
|---|---|---|
| Well decay rate (slope) = | -4.38E-04 | NOT statistically different from zero |
| Source zone decay rate = | -3.16E-04 | NA Memo (Port 2017) |
| Groundwater pCUL = | 1.6 | µg/L |
| Hylebos hot spot RL = | 86 | µg/L |
| C_current (2016 concentration) = | 1550 | µg/L |

**Results**

| | | | | |
|---|---|---|---|---|
| SZ decay rate | Year Hylebos hot spot RL will be | 2024 | 3 | years from 2021 |
| | Year VI SL will be met at well | 2028 | 7 | years from 2021 |
| | Year pCUL will be met at well | 2051 | 30 | years from 2021 |

| | | | | |
|---|---|---|---|---|
| well decay rate | Year Hylebos hot spot RL will be | 2023 | 2 | years from 2021 |
| | Year pCUL will be met | 2042 | 21 | years from 2021 |




Assumptions: EISB and bioventing accelerates decay by 6 times, bioventing alone accelerates decay by 3 times.

## Alternative 5: Hot Spot Excavation, Alexander Avenue Bioremediation, Shoreline Bioremediation, MNA

Alternative 5 includes hot spot excavation and bioremediation under Alexander Avenue, as well as the remedial components of Alternative 2: shoreline bioremediation, MNA, institutional and engineering controls, and compliance monitoring.

- Benzene cleanup criteria: Meet concentrations in groundwater in angled wells (benzene = 4 µg/L) that demonstrate compliance with CULs at the CPOC (benzene = 1.6 µg/L).
  - Time frame = 5 years (see Alternative 2 analysis of MW-104-15)
  - Action = discontinue shoreline treatment, transition to MNA everywhere except Alexander Avenue until vapor intrusion SL met
- Hot spot excavation soil RLs (total TPH =19,000 mg/kg, benzene = 19 mg/kg—values from hot spot analysis, Appendix C):
  - Time frame = 1–2 years
  - Action = discontinue excavation at Hylebos and Blair Hot Spots when confirmation samples are below RLs
- Alexander Avenue bioremediation RL (LNAPL < 0.1 ft)
  - Time frame = 9 years of EISB and bioventing
    - *Time frame to reach TPH direct contact CUL (17,000 mg/kg) = 13 years (4 years to reach CUL after EISB discontinued).*
  - Action = discontinue EISB, continue bioventing until TPH soil CUL met and (if applicable) transition to MNA monitoring until vapor SL is met

### *Site-wide Milestones*

- Benzene vapor intrusion SL (benzene = 24 µg/L)
  - Time frame = 11 years
  - Action = transition from MNA monitoring to 5-year reviews/performance monitoring
- Benzene groundwater CUL (benzene = 1.6 µg/L; based on protection of surface water) is met at the standard POC
  - Time frame = 22 years, (11 years after vapor intrusion SL is met)
  - Action = end 5-year reviews/performance monitoring, transition to confirmation monitoring.

In the same way as Alternative 2, the time frame to meet the groundwater CUL at the CPOC was estimated by evaluating natural attenuation and the anticipated effects of bioremediation treatment at shoreline well MW-104-15. See Alternative 2 analysis of MW-104-15.

Soil RLs will be used to determine the limits of excavation in the Hylebos and Blair Hot Spots. Sidewall confirmation samples will be evaluated against the RLs, 19 mg/kg for benzene and 19,000 mg/kg for

TPH. When RLs are met, excavation will be complete (except along the Alexander Avenue right-of-way, beneath which excavation will not be possible). It is assumed that the remedy will be implemented in 2021 and soil removal will be immediate; therefore, it is estimated that soil RLs will be met within 1 year.

The Alexander Avenue RL for terminating EISB is LNAPL of less than 0.1 ft, which is approximated by the hot spot value of 19,000 mg/kg; 19,000 mg/kg of total TPH is the approximate concentration for residual saturation if Site-specific soil conditions are accounted for (see text for Alternative 3). To estimate plume mass reduction under Alexander Avenue, the same plume mass/NSZD method was applied as under Alternative 3 for treatment of the entire Blair Hot Spot. The area of the Blair Hot Spot beneath Alexander Avenue was measured using an image overlay of the Blair Hot Spot in Google Earth, the footprint under the road is approximately 0.2 acres, or 8,700 $ft^2$.

The time frame to meet the vapor intrusion SL (benzene = 24 µg/L) and groundwater CUL (benzene = 1.6 µg/L; based on protection of surface water) at the standard POC was estimated by evaluating natural attenuation well 721-MW12-15. Well 721-MW12-15 was chosen to estimate restoration time frames because it is anticipated to be the final well outside of the hot spot excavation footprint to reach cleanup standards (based on current concentration and contaminant decay rate). It was assumed that once the hot spots are excavated and treatment is active under Alexander Avenue, the remaining wells in the dissolved phase plume will experience a decay rate acceleration of 2 times.

### *Alternative 5 Restoration Time Frame Backup*

Plume mass calculation:

$$Plume\ mass\ (kg) = \frac{A * C_{average} * b * \rho}{UCF}$$

Where, A = planar area (8,700 $ft^2$ for portion of Blair Hot Spot that is under Alexander Avenue)
$C_{average}$ = average concentration in mg/kg
b = plume thickness (5 ft; based on the 5–10-ft interval evaluated in the hot spot analysis, Appendix C, includes the 'smear' zone where the majority of the contaminant mass is located)
$\rho$ = soil bulk density (42.5 kg/$ft^3$)
UCF = unit conversion factor (1,000,000; converts mg to kg)

The current average TPH concentration in the 19,000 mg/kg hot spot (from App 4) is 28,248 mg/kg:

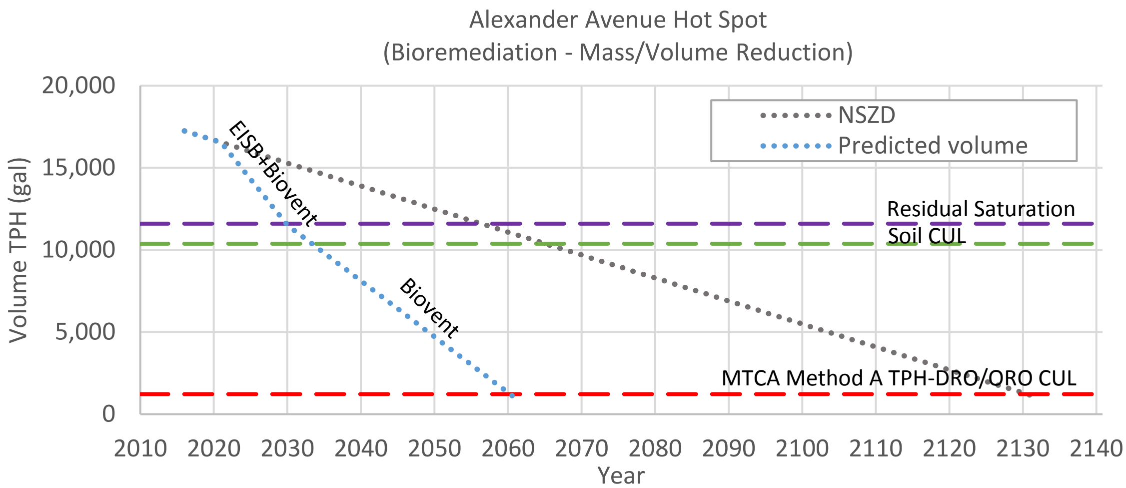
$$Plume\ mass = 8{,}700\ ft^2 * 28{,}248 \frac{mg}{kg} * 5ft * 42.5\ \frac{kg}{ft^3} = 288{,}130\ kg$$

The mass value can be converted to a volume using the equation, $density = mass/volume$, and assuming a TPH density of 0.8 kg/L (gas and diesel mixture):

$$Volume\ TPH = \frac{288{,}130\ kg}{0.8\frac{kg}{L}}$$ = 65,279 liters (or 17,247 gallons)

The same approach was applied to estimate gallons of TPH equivalency for the residual saturation limit, 19,000 mg/kg, the CUL for soil, 17,000 mg/kg, and the MTCA Method A CUL, 2,000 mg/kg.

Assumptions: EISB and bioventing accelerates NSZD rate[7] to the typical upper end value of 2,800 gal/acre/yr, and bioventing alone accelerates NSZD to the median value of 1,700 gal/acre/year (ITRC 2018).




**721-MW12-15**

**Benzene Groundwater Concentration Data**

| Sample Date | Value (µg/L) | ln | Qualifier |
|---|---|---|---|
| 7/30/2012 | 450 | 6.11 | |
| 10/16/2014 | 560 | 6.33 | |
| 12/9/2015 | 150 | 5.01 | J |
| 2/24/2016 | 150 | 5.01 | |
| 5/11/2016 | 290 | 5.67 | |
| 8/1/2016 | 590 | 6.38 | |

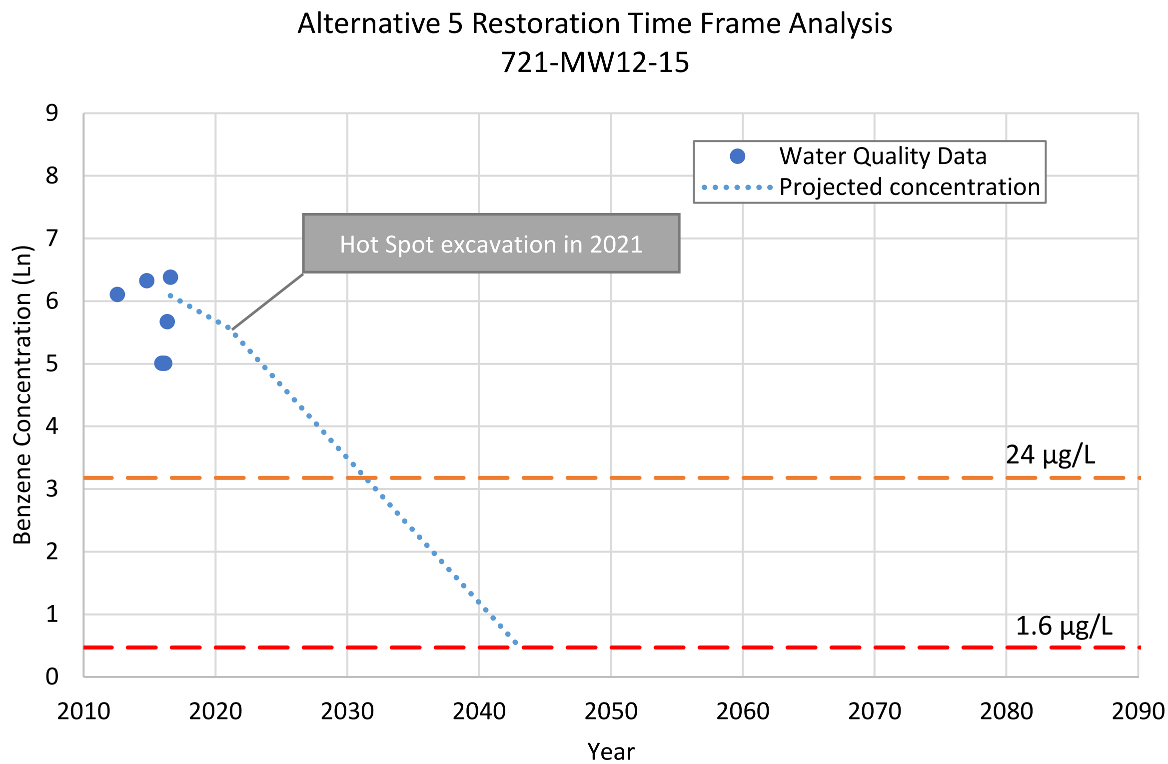
**Input Variables (Eqn. F.2)**

| | | |
|---|---|---|
| Well decay rate (slope) = | -3.92E-04 | NOT statistically different from zero |
| Source zone decay rate = | -3.16E-04 | NA Memo (Port 2017) |
| VI SL = | 24 | µg/L |
| Groundwater CUL = | 1.6 | µg/L |
| C_current (2016 concentration) = | 440 | µg/L |

**Results**

| | | | | |
|---|---|---|---|---|
| SZ decay rate | Year VI SL will be met at well | 2032 | 11 | years from 2021 |
| | Year pCUL will be met at well | 2043 | 22 | years from 2021 |

[7] NSZD rates stated are from the ITRC guidance for the middle 50 percent of the 25 NSZD study sites evaluated.




Assumptions: Once hot spots are excavated, well decay rates will accelerate by 2 times.

## Alternative 6: Extended Remedial Excavation, Alexander Avenue Bioremediation, and MNA for Deep Groundwater

Alternative 6 includes extended remedial soil excavation, Alexander Avenue bioremediation, MNA for deep groundwater, and compliance monitoring. The standard POC for groundwater is proposed for this alternative. The time estimates to reach each RL and cleanup standard are summarized below.

- Hot spot excavation soil CULs (total TPH = 2,000 mg/kg, benzene = 0.03 mg/kg):
  - Time frame = 2–3 years
  - Action = discontinue excavation at Hylebos and Blair Hot Spots when confirmation samples are below soil CULs
- Alexander Avenue bioremediation soil CUL (total TPH = 2,000 mg/kg)
  - Time frame = 28 years of EISB and bioventing, and groundwater EISB performance monitoring
  - Action = discontinue EISB and bioventing.

### *Site-wide Milestones*

- Benzene vapor intrusion SL (benzene = 24 µg/L)
  - Time frame = 11 years (8 years after remedial excavation is complete)

  - Action = begin MNA monitoring in deep groundwater zone
- Benzene groundwater CUL (benzene = 1.6 µg/L; based on protection of surface water) is met at the standard POC:
  - Time frame = 22 years
  - Action = end MNA monitoring in deep groundwater, transition to Site-wide groundwater confirmation monitoring.

Soil CULs will be used to determine the limits of excavation in the Hylebos and Blair Hot Spots. Sidewall confirmation samples will be evaluated against the RLs (benzene = 0.03 mg/kg and total TPH = 2,000 mg/kg). When CULs are met, excavation will be complete (except along the Alexander Avenue right-of-way, beneath which excavation will not be possible). It is assumed that the remedy will be implemented in 2021 and soil removal will be immediate; therefore, it is estimated that soil RLs will be met within 1 year.

The Alexander Avenue pCUL for terminating EISB and bioventing RL is 2,000 mg/kg total TPH. To estimate plume mass reduction under Alexander Avenue, the same plume mass/NSZD method was applied as under Alternative 5.

The time frame to meet the vapor intrusion SL (benzene = 24 µg/L) and groundwater CUL (benzene = 1.6 µg/L; based on protection of surface water) at the standard POC was estimated by evaluating natural attenuation well 721-MW15-25. Well 721-MW15-25 was chosen to estimate restoration time frames because it has the highest benzene concentrations in the 25-ft zone and is anticipated to be the final well under this Alternative to reach cleanup standards. It was assumed that once soil excavation is complete, the remaining wells in the dissolved phase plume will experience a decay rate acceleration of 2 times.

### *Alternative 6 Restoration Time Frame Backup*

Plume mass calculation:

$$Plume\ mass\ (kg) = \frac{A * C_{average} * b * \rho}{UCF}$$

Where, A = planar area (8,700 ft$^2$ for portion of Blair Hot Spot that is under Alexander Avenue)
$C_{average}$ = average concentration in mg/kg
b = plume thickness (5 ft; based on the 5–10-ft interval evaluated in the hot spot analysis, Appendix C, includes the 'smear' zone where the majority of the contaminant mass is located)
$\rho$ = soil bulk density (42.5 kg/ft$^3$)
UCF = unit conversion factor (1,000,000; converts mg to kg)

The current average TPH concentration in the 19,000 mg/kg hot spot (from App 4) is 28,248 mg/kg:

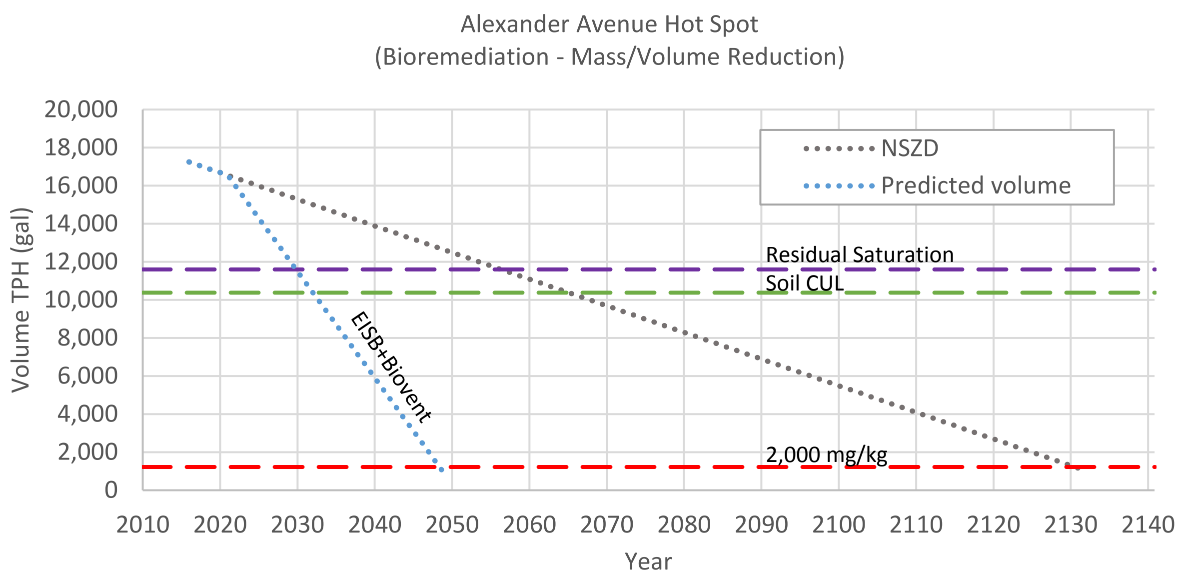
$$Plume\ mass = 8{,}700\ ft^2 * 28{,}248 \frac{mg}{kg} * 5ft * 42.5\ \frac{kg}{ft^3} = 288{,}130\ kg$$

The mass value can be converted to a volume using the equation, $density = mass/volume$, and assuming a TPH density of 0.8 kg/L (gas and diesel mixture):

$$Volume\ TPH = \frac{288{,}130\ kg}{0.8\frac{kg}{L}}$$ = 65,279 liters (or 17,247 gallons)

The same approach was applied to estimate gallons of TPH equivalency for 2,000 mg/kg.

Assumptions: EISB and bioventing accelerates NSZD rate[8] to the typical upper-end value of 2,800 gal/acre/yr (ITRC 2018).




[8] NSZD rates stated are from the ITRC guidance for the middle 50 percent of the 25 NSZD study sites evaluated.

## 721-MW15-25

**Benzene Groundwater Concentration Data**

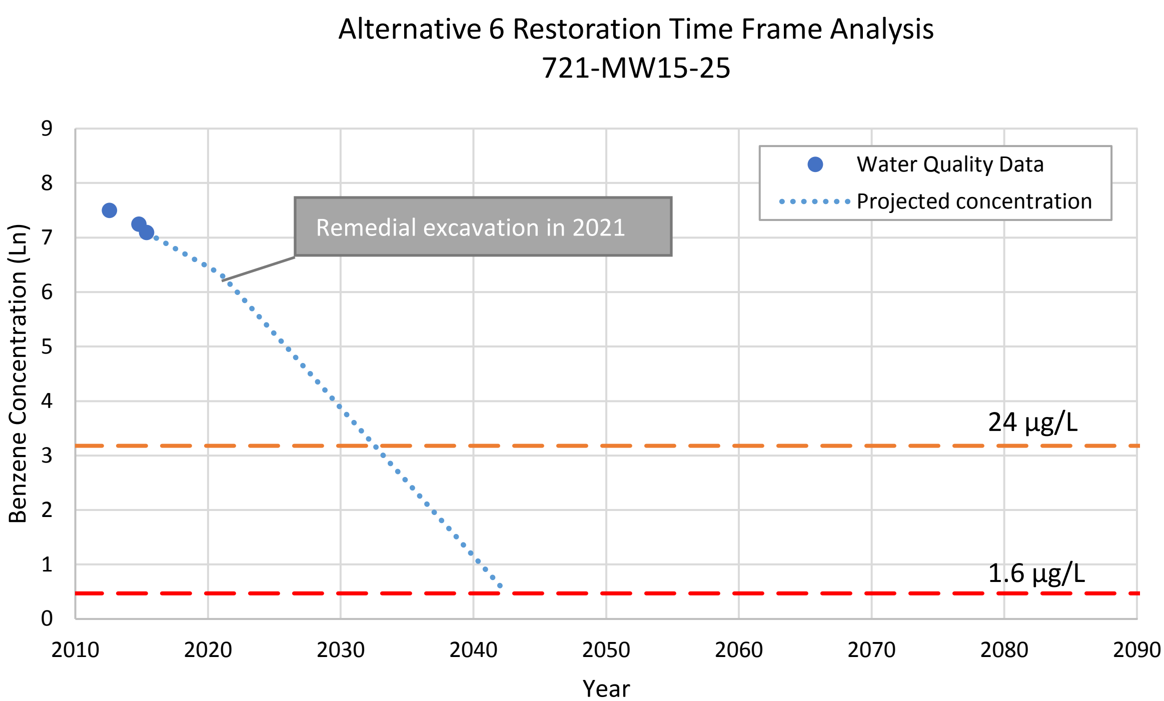
| Sample Date | Value (µg/L) | ln | Qualifier |
|---|---|---|---|
| 7/30/2012 | 1800 | 7.50 | |
| 10/17/2014 | 1400 | 7.24 | |
| 5/19/2015 | 1200 | 7.09 | |

**Input Variables (Eqn. F.2)**

| | | |
|---|---|---|
| Well decay rate (slope) = | -3.73E-04 | NOT statistically different from zero |
| 25-ft attenuation zone decay rate = | -2.47E-03 | NA Memo (Port 2017) |
| VI SL = | 24 | µg/L |
| Groundwater pCUL = | 1.6 | µg/L |
| C_current (2015 concentration) = | 1200 | µg/L |

**Results**

| | | | | |
|---|---|---|---|---|
| well decay rate | Year VI SL will be met at well | 2032 | 11 | years from |
| | Year CUL will be met at well | 2042 | 22 | years from |



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