SGW-62894
Revision 0

CYANIDE SAMPLING AT THE 200 WEST PUMP AND TREAT, FY 2016 THROUGH FY 2018

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

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

CH2MHILL
Plateau Remediation Company

P.O. Box 1600
Richland, Washington 99352

Approved for Public Release;
Further Dissemination Unlimited

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Contents

1 Introduction 1

1.1 Purpose 1

1.2 Site Description and History 1

1.3 200 West P&T Discharge Limits for Cyanide 3

2 Cyanide in Groundwater 4

3 Cyanide in the 200 West P&T Effluent 14

4 Conclusions 24

5 Path Forward 24

6 References 24

Figures

Figure 1. 200 West P&T with Project Components, Well Locations, and Piping Routes 2

Figure 2. Areas Where Cyanide is Detected in Groundwater Extracted for Treatment at the 200 West P&T 5

Figure 3. Detections of Cyanide Near WMA B-BX-BY in 2017 and 2018 7

Figure 4. Detections of Cyanide Near WMAs T and TX-TY in 2017 and 2018 11

Figure 5. 200 West P&T Process Identifying the 2017 and 2018 Cyanide Sampling Locations in Yellow Highlight 15

Tables

Table 1. B Complex Area Groundwater Contaminant Concentrations 4

Table 2. Cyanide Concentrations in 200-BP-5 Operable Unit Extraction Wells in 2017 and 2018 9

Table 3. Cyanide Concentrations in 200-ZP-1 Operable Unit Extraction Wells in 2017 and 2018 13

Table 4. Total Cyanide Concentrations in 200 West P&T Effluent Samples, 2015 – 2018 16

Table 5. Free Cyanide Concentrations in 200 West P&T Effluent Samples, 2017 – 2018 19

Table 6. Free Cyanide Concentrations in 200 West P&T Effluent Tank Samples and Operational Status of 200-BP-5 OU Groundwater Extraction Wells, 2017 – 2018 21

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Terms

COC	contaminant of concern
EPA	U.S. Environmental Protection Agency
ERDF	Environmental Restoration Disposal Facility
HCN	hydrogen cyanide
MCL	maximum contaminant level
MSU	modular storage unit
MTCA	“Model Toxics Control Act—Cleanup”
OU	operable unit
P&T	pump and treat
PQL	practical quantitation limit
ROD	record of decision
WMA	waste management area

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1 Introduction

The 200 West Pump and Treat (P&T) was implemented as a final remedy for the 200-ZP-1 Operable Unit (OU) in 2012. The system has a 9,500 L/min (2,500 gal/min) capacity and removes contaminants of concern (COCs) from groundwater using ion exchange, anoxic and aerobic bioreactors, and air stripping. By 2016, it was also being used to treat contaminated groundwater from the 200-UP-1 OU and 200-BP-5 OU, contaminated perched water from the 200-DV-1 OU, and leachate from the Environmental Restoration Disposal Facility (ERDF). In 2018, the facility began receiving purgewater from the Modular Storage Units (MSUs). The water is treated inside the facility to meet injection criteria for protection of groundwater, and the treated water is injected into the aquifer in the 200-ZP-1 OU and 200-UP-1 OU. During 2017, 30 extraction wells (in the 200-ZP-1, 200-UP-1, 200-BP-5, and 200-DV-1 OUs) and 29 injection wells were in use, and the treatment plant was operating at an average capacity of 7,436 L/min (1,963 gal/min) (Section 4.8 in DOE/RL-2017-68*, Calendar Year 2017 Annual Summary Report for Pump-and-Treat Operations in the Hanford Central Plateau Operable Units*, and Table 12-3 in DOE/RL-2017-66, *Hanford Site Groundwater Monitoring Report for 2017*).

1.1 Purpose

The purpose of this report is to present the results of total and free cyanide sampling of the 200 West P&T effluent water in 2016, 2017, and 2018. The sampling was conducted to evaluate whether the treated water meets the criteria specified in supporting regulatory documents for injection into the aquifer.

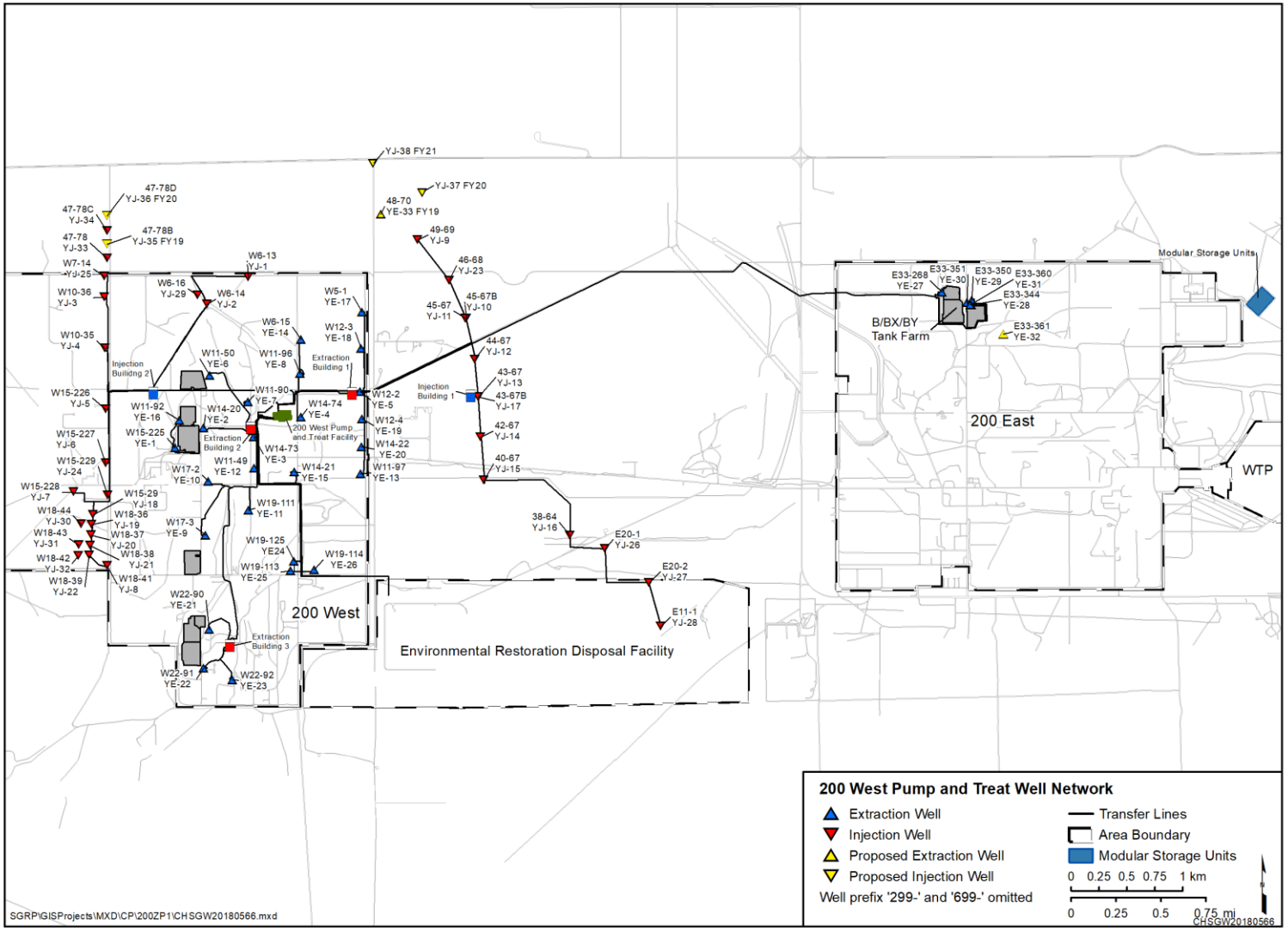
1.2 Site Description and History

Since 2016, the 200 West P&T has received contaminated water from the 200-ZP-1 OU groundwater, 200-UP-1 OU groundwater, 200-BP-5 OU groundwater, 200-DV-1 OU perched water, and ERDF leachate (Figure 1). In 2018, the U.S. Environmental Protection Agency (EPA) and U.S. Department of Energy, Richland Operations Office approved using the 200 West P&T to treat purgewater from the MSUs located on the Central Plateau, approximately 8 km (5 mi) east of the 200 West P&T (Figure 1). Each extraction and injection well shown in Figure 1 has a well name (e.g., 299-E33-268) and a 200 West P&T identification number (e.g., YE-27). 200 West P&T identification numbers begin with “YE-” for extraction wells and “YJ-” for injection wells.

The 200 West P&T began operating in 2012 to capture and treat contaminated groundwater from the unconfined aquifer in the 200-ZP-1 OU. Groundwater remediation within the 200-ZP-1 OU is conducted in accordance with a record of decision (ROD) issued in 2008 (EPA et al., 2008, *Record of Decision Hanford 200 Area 200-ZP-1 Superfund Site Benton County, Washington*).

The 200 West P&T treated water must meet the injection criteria specified in the 200-ZP-1 OU ROD (EPA et al., 2008) for protection of groundwater. The 200-ZP-1 OU ROD does not identify cyanide as a COC and, therefore, does not specify an injection criterion for cyanide.

The Waste Management Area (WMA) S-SX groundwater extraction system in the 200-UP-1 OU began operating in late 2012 in accordance with an interim remedial action ROD issued in 2012 (EPA et al., 2012, *Record of Decision for Interim Remedial Action Hanford 200 Area Superfund Site 200-UP-1 Operable Unit*). The WMA S-SX system pumps groundwater to the 200 West P&T for treatment and injection. The 200-UP-1 OU interim ROD does not identify cyanide as a COC.



Modified from Figure 2.1 in DOE/RL-2017-68, *Calendar Year 2017 Annual Summary Report Pump-and-Treat Operations in the Hanford Central Plateau Operable Units*.

Figure 1. 200 West P&T with Project Components, Well Locations, and Piping Routes

In 2015, the 200 West P&T began treating contaminated groundwater extracted from the U Plant area in the 200-UP-1 OU and from the 200-BP-5 OU. Groundwater remediation for the U Plant area is conducted in accordance with the interim ROD for the 200-UP-1 OU (EPA et al., 2012). The non-time-critical removal action for the 200-BP-5 OU is conducted in accordance with the action memorandum issued in 2016 (DOE/RL-2016-41, *Action Memorandum for 200-BP-5 Operable Unit Groundwater Extraction*).

In 2016, the 200 West P&T began treating contaminated perched water extracted from the 200-DV-1 OU and contaminated leachate from ERDF. The non-time-critical removal action for the 200-DV-1 OU is conducted in accordance with the action memorandum issued in 2014 (DOE/RL-2014-34, *Action Memorandum for 200-DV-1 Operable Unit Perched Water Pumping/Pore Water Extraction*). ERDF leachate is collected in accordance with the ROD issued in 1995 (EPA et al., 1995, *Record of Decision U.S. DOE Hanford Environmental Restoration Disposal Facility, Hanford Site, Benton County, Washington*).

In 2018, the 200 West P&T began treating contaminated purgewater generated during well development activities and stored at the MSUs in the 200 East Area. Treatment of purgewater at the 200 West P&T is a pilot test conducted in accordance with the test plan issued in 2018 (DOE/RL-2018-28, *Optimization Test Plan for Treating Water from Modular Storage Units at 200 West Pump & Treat Facility*).

Among these regulatory documents for the waste streams added to the 200 West P&T influent in 2015 and 2016, only the action memorandum for the 200-BP-5 OU (DOE/RL-2016-41) identifies cyanide as a COC. When it started treating 200-BP-5 OU groundwater, the 200 West P&T was required to meet injection criteria for cyanide in the treated water injected into the aquifer.

1.3 200 West P&T Discharge Limits for Cyanide

Cyanide in water is regulated as free cyanide. Free cyanide refers to hydrogen cyanide (HCN) and cyanide ion. Total cyanide includes free cyanide, dissociable (weak and moderately strong) metal cyanide complexes, and strong metal cyanide complexes such as ferrocyanide.

The EPA established the maximum contaminant level (MCL) as 200 µg/L for free cyanide and allows for analysis of total cyanide for determining compliance with the *Safe Drinking Water Act* (EPA 815-B-16-012, *Cyanide Clarification of Free and Total Cyanide Analysis for Safe Drinking Water Act [SDWA] Compliance*). The MCL set for cyanide is based on best available science to prevent potential health problems and also considers cost, benefits, and the ability of public water systems to detect and remove contaminants using suitable treatment technologies. A total cyanide concentration <200 µg/L can be reported as free cyanide <200 µg/L. Free cyanide analytical methods are required if the total cyanide concentration is >200 µg/L.

The State of Washington groundwater cleanup level is 4.8 µg/L for free cyanide. The state cleanup level is a risk-based concentration calculated using the reference dose and default exposure assumptions and equations published in WAC 173-340, “Model Toxics Control Act—Cleanup” (MTCA) Method B. This cleanup level considers possible health effects and exposure over a lifetime, but does not consider cost, benefits, or suitable treatment technologies.

The action memorandum for the 200-BP-5 OU non-time-critical removal action (DOE/RL-2016-41, Table 1) lists the federal MCL for cyanide as 200 µg/L and indicates the state cleanup level in footnote b of the table. Table 1 in DOE/RL-2016-41 (shown as Table 1 in this document) does not specify that the federal MCL is for free cyanide based on analysis of total cyanide and that the state MTCA Method B cyanide limit is for free cyanide. (Note: DOE/RL-2017-11, *Removal Action Work Plan for the 200-BP-5 Operable Unit Groundwater Extraction*, issued on May 23, 2017, clarifies that the state MTCA Method B cyanide limit in footnote b is for free cyanide.)

Table 1. B Complex Area Groundwater Contaminant Concentrations

B Complex Area Groundwater Concentration Data from 2014 and 2015					
Contaminant	**Average**	**Maximum**	**Minimum**	**MCL**	**Units**
Technetium-99	12,113	42,000	562	900	pCi/L
Uranium	221	5,600	4.5	30	µg/L
Nitrate (NO_3)	532	1,780	54	45[a]	mg/L
Iodine-129	2.2	3.7	Nondetect	1	pCi/L
Cyanide	364	1,680	8.4	200[b]	µg/L
Tritium	12,199	25,000	3,970	20,000	pCi/L

Source: DOE/RL-2016-41, *Action Memorandum for 200-BP-5 Operable Unit Groundwater Extraction*. Cyanide concentrations provided in this table from DOE/RL-2016-41 are total cyanide.

a. 45 mg/L (expressed as the NO_3 ion) is an equivalent concentration to the federal drinking water standard for nitrate (10 mg/L expressed as NO_3-N). To convert nitrate as the NO_3 ion, the NO_3-N drinking water standard value is multiplied by 4.43.

b. For cyanide, the State of Washington groundwater cleanup level of 4.8 µg/L is calculated based on the WAC 173-340, "Model Toxics Control Act—Cleanup," Method B value.

MCL = maximum contaminant level

Special sampling for cyanide was conducted in 2017 and 2018 to confirm the 200 West P&T effluent discharge is meeting the state cleanup level.

2 Cyanide in Groundwater

This chapter summarizes 2017 and 2018 cyanide groundwater monitoring results near WMA B-BX-BY in the 200-BP-5 OU and near WMA T and WMA TX-TY in the 200-ZP-1 OU, areas where groundwater is extracted for treatment at the 200 West P&T (Figure 2). Cyanide groundwater contamination is present in other Central Plateau locations (downgradient of WMA C, southeast of the former 216-B-5 Reverse Well, and in Gable Gap), but no extraction wells are located in those areas. Additional information about the sources and extent of cyanide contamination in Central Plateau groundwater is available in Sections 9.7 and 12.7 of DOE/RL-2017-66.

Fifteen monitoring wells are sampled quarterly at WMA B-BX-BY in accordance with DOE/RL-2012-53, *Groundwater Quality Assessment Plan for the Single-Shell Tank Waste Management Area B-BX-BY* (Figure 3). The samples are analyzed for total cyanide and, beginning in 2017, for free cyanide. Total cyanide has exceeded 200 µg/L in one well near this WMA since 1999 and in multiple wells since 2012 and 2013. Total cyanide in wells 299-E33-20, 299-E33-31, 299-E33-38, 299-E33-44, 299-E33-47, and 299-E33-337 exceeded 200 µg/L in 2017 and/or 2018 (Figure 3). Free cyanide concentrations exceeded the 4.8 µg/L MTCA Method B cleanup level in wells 299-E33-20, 299-E33-41, 299-E33-44, 299-E33-47, and 299-E33-337 in 2017 and/or 2018; the maximum concentration was 16.7 µg/L in well 299-E33-44 on May 10, 2018. This result is flagged "NQ" indicating that associated laboratory and field quality control samples were out of limits.

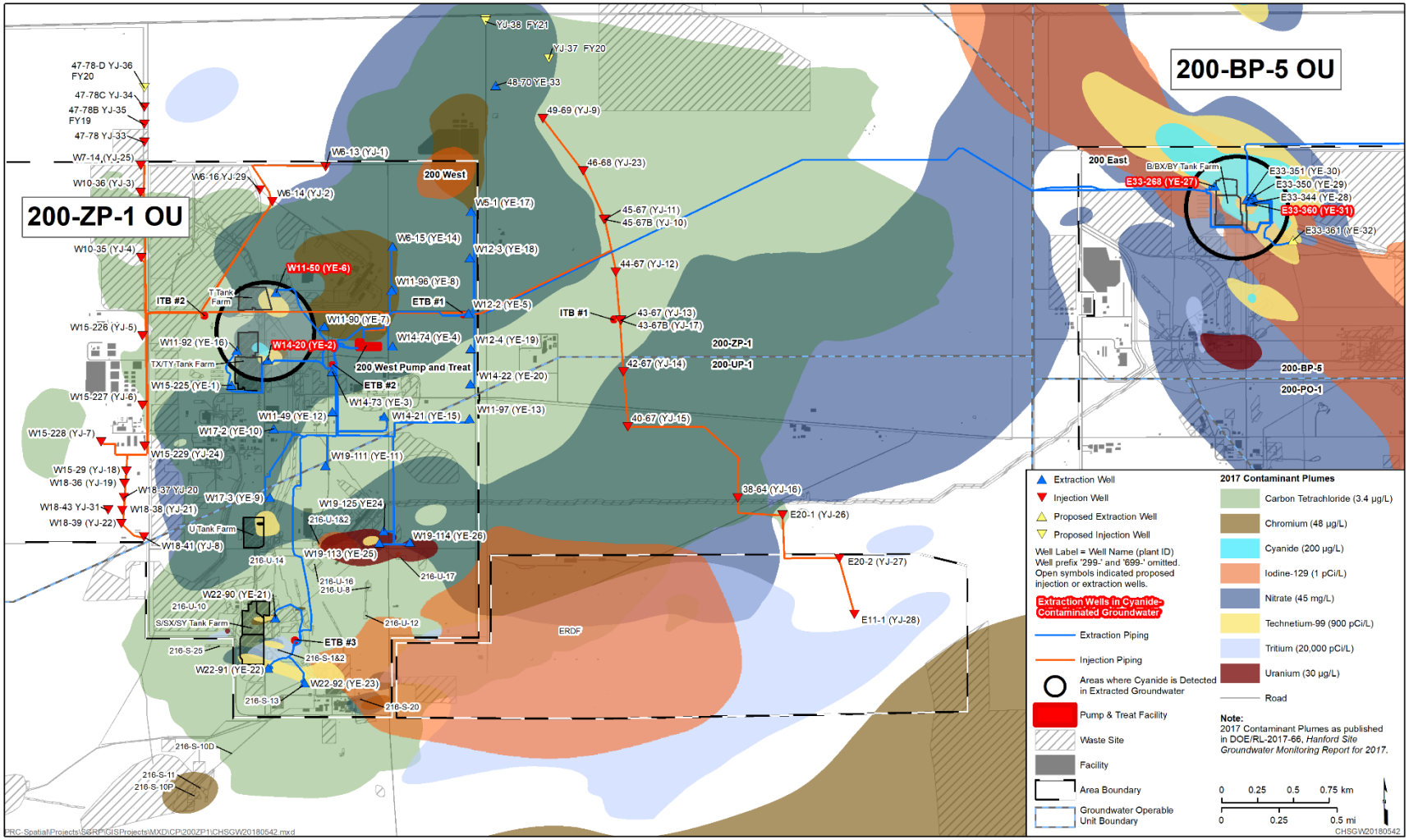


Figure 2. Areas Where Cyanide is Detected in Groundwater Extracted for Treatment at the 200 West P&T

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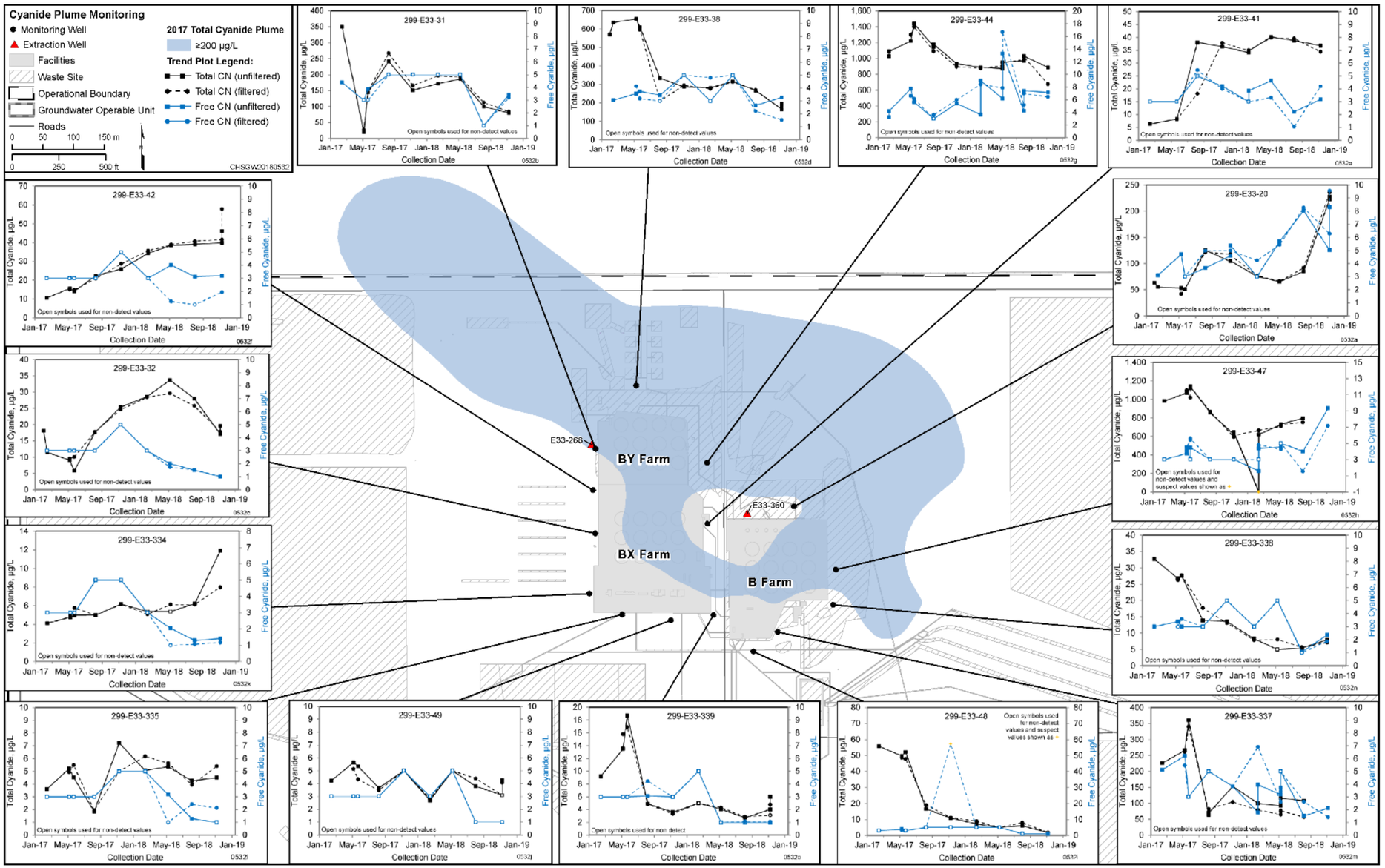

Figure 3. Detections of Cyanide Near WMA B-BX-BY in 2017 and 2018

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Groundwater wells 299-E33-268 (YE-27) and 299-E33-360 (YE-31) near WMA B-BX-BY have extracted contaminated 200-BP-5 OU groundwater for treatment at the 200 West P&T (Figure 3). Well 299-E33-268 (YE-27) is on the west side of the BY Tank Farm, and well 299-E33-360 (YE-31) is on the north side of the B Tank Farm. Cyanide concentrations in these two extraction wells are the highest in the 200 West P&T extraction well network. Total cyanide concentrations in 2017 and 2018 ranged from 71.5 to 372 µg/L, and free cyanide concentrations were near or below detection limits, with a maximum of 8.36 µg/L (Table 2).

Table 2. Cyanide Concentrations in 200-BP-5 Operable Unit Extraction Wells in 2017 and 2018

Sample Collection Date	Free Cyanide Concentration (µg/L)		Total Cyanide Concentration (µg/L)		HEIS Numbers	
	200-BP-5 OU					
	299-E33-268 (YE-27)*	299-E33-360 (YE-31)	299-E33-268 (YE-27)*	299-E33-360 (YE-31)	299-E33-268 (YE-27)	299-E33-360 (YE-31)
03/01/2017	8.36 B	--	372 D	--	B394V6	--
03/10/2017	7.64 BA	--	296 DA	--	B394N5	--
03/15/2017	3.00 U	3.31 B	308 D	71.5	B399L8	B399M4
03/29/2017	3.00 U	--	359 D	--	B39546	--
06/09/2017	5.37 BA	--	297 DA	--	B3B237	--
06/09/2017	3.37 B	--	306 D	--	B3B334	--
08/10/2017	--	3.00 U	--	201 D	--	B3C109
08/10/2017	--	3.00 U	--	197 D	--	B3C108
08/10/2017	--	3.00 U	--	148	--	BC3112
08/10/2017	--	3.00 U	--	212 D	--	B3C111
11/30/2017	--	3.00 U	--	272 D	--	B3FP50
11/30/2017	--	3.19 B	--	276 D	--	B3FP51
11/30/2017	--	3.00 U	--	274 D	--	B3FP55
11/30/2017	--	3.00 U	--	272 D	--	B3FP54
12/12/2017	--	--	--	242	--	B3FH09
03/07/2018	--	1.00 U	--	185	--	B3FP57
03/07/2018	--	1.61 B	--	172	--	B3HW97
03/07/2018	--	1.00 U	--	165	--	B3HW93
03/07/2018	--	1.00 U	--	171	--	B3HW94
06/21/2018	--	1.00 U	--	158	--	B3JL88
06/21/2018	--	1.57 B	--	156	--	B3JL99
06/21/2018	--	1.00 U	--	152	--	B3JL90
06/21/2018	--	1.00 U	--	164	--	B3JLB0
08/30/2018	--	3.19	--	183	--	B3KL15
08/30/2018	--	4.02	--	176	--	B3KL16
08/30/2018	--	4.64	--	184	--	B3KL18

Table 2. Cyanide Concentrations in 200-BP-5 Operable Unit Extraction Wells in 2017 and 2018

Sample Collection Date	Free Cyanide Concentration (µg/L)		Total Cyanide Concentration (µg/L)		HEIS Numbers	
200-BP-5 OU						
	299-E33-268 (YE-27)*	299-E33-360 (YE-31)	299-E33-268 (YE-27)*	299-E33-360 (YE-31)	299-E33-268 (YE-27)	299-E33-360 (YE-31)
08/30/2018	--	4.02	--	181	--	B3KL19
12/27/2018	--	--	--	205	--	B3MC77

*Not used for extraction after June 15, 2017.

Note: Shaded cells denote filtered results.

HEIS = Hanford Environmental Information System

OU = operable unit

Laboratory qualifiers:

A = The Sample Issue Resolution form indicates a problem with the chain of custody.

B = The analyte was detected at a value less than the contract-required limit, but greater than or equal to the method detection limit.

D = Analyte was identified in an analysis at a secondary dilution factor (i.e., dilution factor different than 1.0).

U = The analyte was not detected above the method detection limit.

Perched water extraction wells 299-E33-344 (YE-28), 299-E33-350 (YE-29), and 299-E33-351 (YE-30) are near WMA B-BX-BY (Figure 2). Concentrations of total cyanide did not exceed 200 µg/L in 2017 or 2018. Perched water does not contribute significant cyanide concentrations to the 200 West P&T. The purgewater from the MSUs did not contribute any cyanide concentrations in 2018, but could potentially in the future if any groundwater injection or extraction wells with cyanide contamination are redeveloped (e.g., 200-BP-5 OU wells).

Beginning in 2017, six monitoring wells are sampled monthly at WMA T and WMA TX-TY and analyzed for total cyanide and free cyanide (Figure 4). Total cyanide was detected near these WMAs in samples collected in 2011 and 2012 (the most recent analyses for cyanide prior to 2017) but did not exceed 200 µg/L. Total cyanide in wells 299-W10-26, 299-W14-11, and 299-W14-18 exceeded 200 µg/L in 2017 and 2018. Free cyanide concentrations exceeded the 4.8 µg/L MTCA Method B cleanup level in wells 299-W10-26, 299-W14-11, 299-W14-13, and 299-W14-18 in 2017 and 2018 and in well 299-W10-27 once in 2018; the maximum concentration was 66.0 µg/L (flagged as suspect) in well 299-W10-26 on November 13, 2017 (Figure 4).

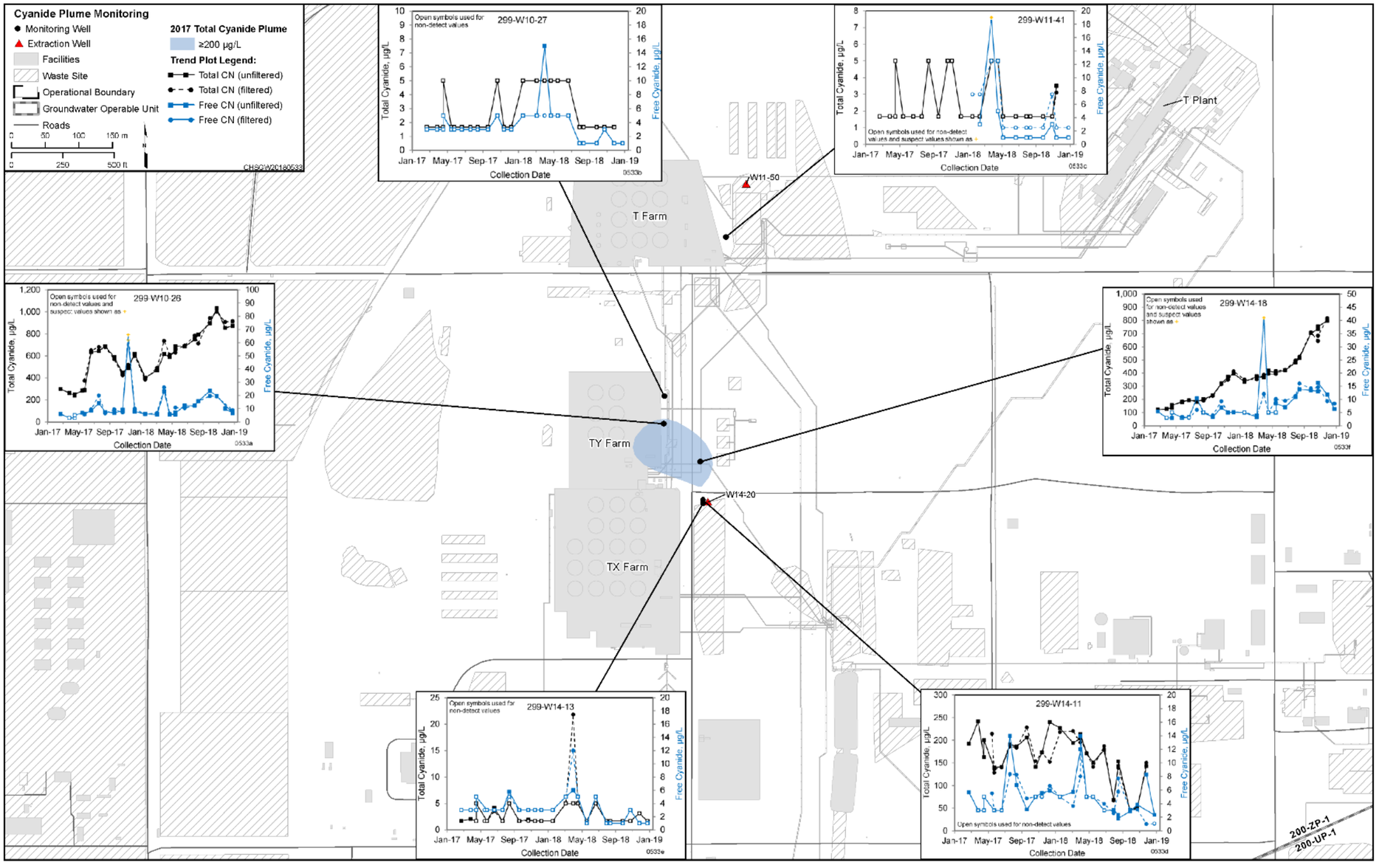

Figure 4. Detections of Cyanide Near WMAs T and TX-TY in 2017 and 2018

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Groundwater wells 299-W14-20 (YE-02) and 299-W11-50 (YE-06) extract contaminated 200-ZP-1 OU groundwater for treatment at the 200 West P&T (Figure 4). Well 299-W14-20 (YE-02) is at the northeast corner of the TX Tank Farm, and well 299-W11-50 (YE-06) is near the northeast corner of the T Tank Farm. These two extraction wells are near monitoring wells where total cyanide was detected previously. Cyanide was not detected in well 299-W11-50 (YE-06) in 2017 or 2018 (Table 3). Total cyanide concentrations in well 299-W14-20 (YE-02) did not exceed 200 µg/L and free cyanide did not exceed the 4.8 µg/L MTCA Method B cleanup level in 2017 or 2018 (Table 3).

Table 3. Cyanide Concentrations in 200-ZP-1 Operable Unit Extraction Wells in 2017 and 2018

Sample Collection Date	Free Cyanide Concentration (µg/L)		Total Cyanide Concentration (µg/L)		HEIS Numbers	
200-ZP-1 OU						
	299-W11-50 (YE-06)	299-W14-20 (YE-02)	299-W11-50 (YE-06)	299-W14-20 (YE-02)	299-W11-50 (YE-06)	299-W14-20 (YE-02)
03/01/2017	3.00 U	3.00 U	1.67 U	21.60	B394V2	B394V4
03/08/2017	3.00 U	3.00 U	1.67 U	19.80	B393Y5	B393W9
03/08/2017	3.00 U	--	1.67 U	--	B393X7	--
03/15/2017	3.00 U	--	1.67 U	--	B399L2	--
03/29/2017	3.00 U	3.00 U	1.67 U	23.20	B39542	B39544
06/08/2017	3.00 U	3.00 U	1.67 U	26.20	B3B1R1	B3B1P5
06/08/2017	3.00 U	3.00 U	1.67 U	26.00	B3B330	B3B328
06/08/2017	3.00 U	4.37 B	1.67 U	25.60	B3B331	B3B329
09/26/2017	3.00 U	3.00 U	1.67 U	27.90	B3C0L3	B3C0K4
09/26/2017	3.00 U	3.00 U	1.67 U	26.00	B3C0L2	B3C0K3
09/26/2017	3.00 U	3.00 U	1.67 U	25.20	B3C0L6	B3C0K7
09/26/2017	3.00 U	3.00 U	1.67 U	26.50	B3C0L5	B3C0K6
11/29/2017	--	3.00 U	--	27.90	--	B3FNP3
11/29/2017	--	3.00 U	--	28.90	--	B3FNP4
11/29/2017	--	3.00 U	--	30.50	--	B3FNP7
11/29/2017	--	3.00 UA	--	29.70 A	--	B3FNP6
12/21/2017	3.00 UA	--	1.67 UA	--	B3FNR1	--
12/21/2017	3.00 U	--	--	--	B3FNR2	--
12/21/2017	3.00 U	--	1.67 U	--	B3FNR5	--
12/21/2017	3.00 U	--	--	--	B3FNR4	--
03/05/2018	1.00 U	1.46 B	1.67 U	26.00	B3FP52	B3FP30
03/05/2018	1.00 U	4.60	1.67 U	--	B3HW13	B3H9J2
03/05/2018	1.00 U	1.00 U	1.67 U	26.60	B3HW14	B3HW08
03/05/2018	--	1.02 B	--	27.10	--	B3HW05
03/05/2018	1.00 U	1.00 U	1.67 U	26.50	B3HW16	B3HW10
05/23/2018	--	2.31	--	31.70	--	B3JK46

Table 3. Cyanide Concentrations in 200-ZP-1 Operable Unit Extraction Wells in 2017 and 2018

Sample Collection Date	Free Cyanide Concentration (µg/L)		Total Cyanide Concentration (µg/L)		HEIS Numbers	
200-ZP-1 OU						
	299-W11-50 (YE-06)	299-W14-20 (YE-02)	299-W11-50 (YE-06)	299-W14-20 (YE-02)	299-W11-50 (YE-06)	299-W14-20 (YE-02)
05/23/2018	--	1.31 B	--	32.20	--	B3JK47
05/23/2018	--	5.00 UN	--	32.30	--	B3JK48
05/23/2018	--	5.00 UN	--	31.20	--	B3JK49
06/20/2018	1.00 U	1.00 U	1.67 U	31.60	B3JKX7	B3JKX1
06/20/2018	1.00 U	1.10 B	1.67 U	30.10	B3JL94	B3JL92
06/20/2018	1.00 U	1.00 U	1.67 U	31.70	B3JKX9	B3JKX3
06/20/2018	1.00 U	1.81 B	1.67 U	29.30	B3JL95	B3JL93
08/29/2018	1.00 UA	3.40 A	1.67 UA	35.80 A	B3KKM1	B3KKL3
08/29/2018	1.00 UA	1.13 BA	1.67 UA	34.90 A	B3KKM2	B3KKL4
08/29/2018	1.00 UA	2.57 A	1.67 UA	37.00 A	B3KKM4	B3KKL6
08/29/2018	1.00 UA	3.19 A	1.67 UA	37.40 A	B3KKM5	B3KKL7
11/19/2018	1.00 U	1.22 B	1.67 U	32.70	B3MFC0	B3MFB3
11/19/2018	1.00 U	1.48 B	1.67 U	31.70	B3MFB9	B3MFB2
11/19/2018	1.00 U	1.22 B	1.67 U	30.90	B3MFC3	B3MFB6
11/19/2018	1.00 U	1.73 B	1.67 U	30.80	B3MFC2	B3MFB5

Note: Shaded cells denote filtered results.

HEIS = Hanford Environmental Information System

OU = operable unit

Laboratory qualifiers:

A = The Sample Issue Resolution form indicates a problem with the chain of custody.

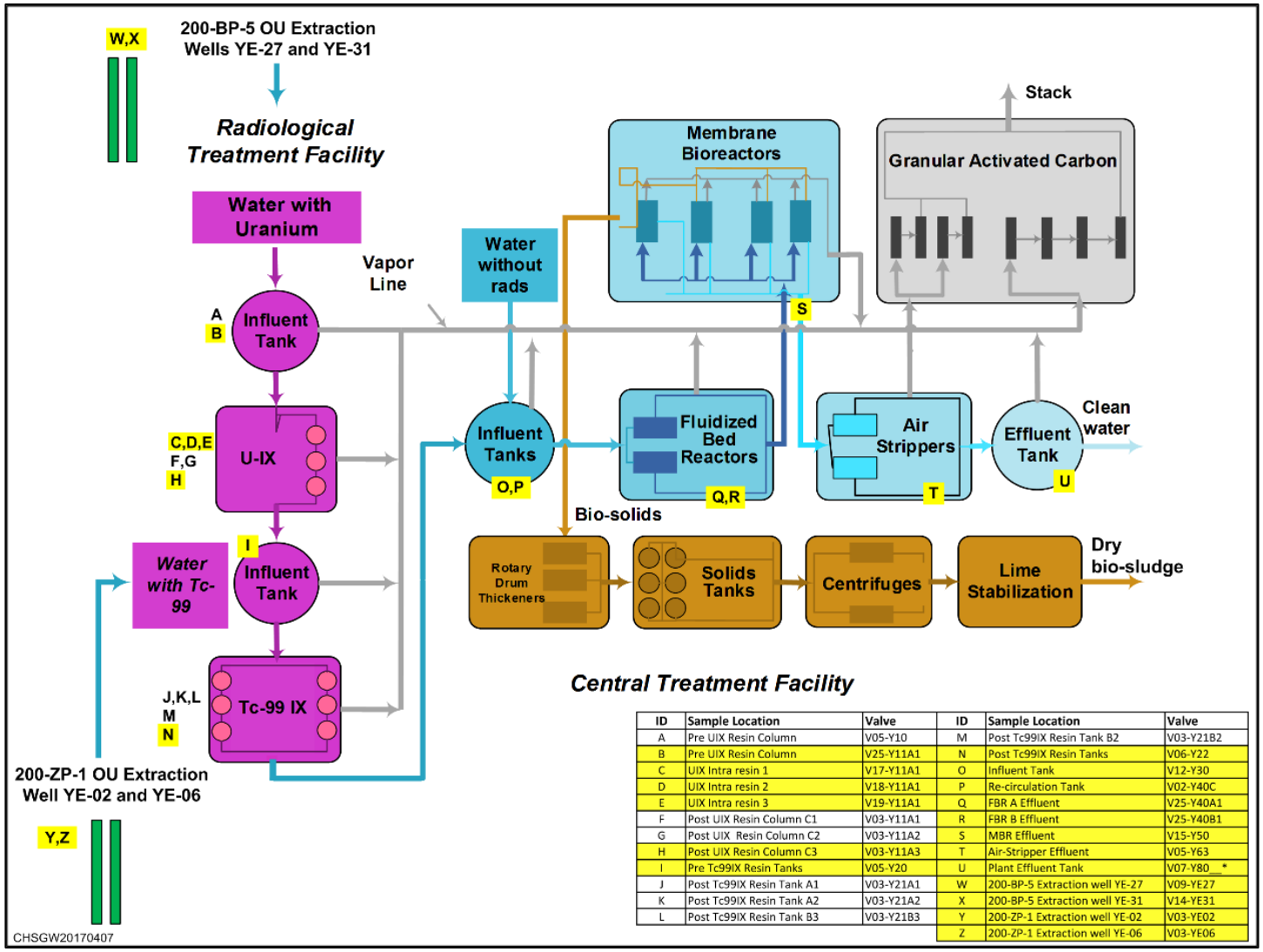
B = The analyte was detected at a value less than the contract-required limit, but greater than or equal to the method detection limit.

D = Analyte was identified in an analysis at a secondary dilution factor (i.e., dilution factor different than 1.0).

U = The analyte was not detected above the method detection limit.

3 Cyanide in the 200 West P&T Effluent

When the 200 West P&T began to treat extracted groundwater from the 200-BP-5 OU in 2015, cyanide was added as a constituent for process monitoring at various points throughout the treatment process (Figure 5). The action memorandum for 200-BP-5 OU groundwater extraction included cyanide as a COC, and the treated water was required to meet injection criteria for cyanide. Because cyanide was not a COC in the RODs for the 200-ZP-1 OU and 200-UP-1 OU (EPA et al., 2008; EPA et al., 2012), the RODs did not establish injection criteria for cyanide.



ID	Sample Location	Valve	ID	Sample Location	Valve
A	Pre UIX Resin Column	V05-Y10	M	Post Tc99IX Resin Tank B2	V03-Y21B2
B	Pre UIX Resin Column	V25-Y11A1	N	Post Tc99IX Resin Tanks	V06-Y22
C	UIX Intra resin 1	V17-Y11A1	O	Influent Tank	V12-Y30
D	UIX Intra resin 2	V18-Y11A1	P	Re-circulation Tank	V02-Y40C
E	UIX Intra resin 3	V19-Y11A1	Q	FBR A Effluent	V25-Y40A1
F	Post UIX Resin Column C1	V03-Y11A1	R	FBR B Effluent	V25-Y40B1
G	Post UIX Resin Column C2	V03-Y11A2	S	MBR Effluent	V15-Y50
H	Post UIX Resin Column C3	V03-Y11A3	T	Air-Stripper Effluent	V05-Y63
I	Pre Tc99IX Resin Tanks	V05-Y20	U	Plant Effluent Tank	V07-Y80__*
J	Post Tc99IX Resin Tank A1	V03-Y21A1	W	200-BP-5 Extraction well YE-27	V09-YE27
K	Post Tc99IX Resin Tank A2	V03-Y21A2	X	200-BP-5 Extraction well YE-31	V14-YE31
L	Post Tc99IX Resin Tank B3	V03-Y21B3	Y	200-ZP-1 Extraction well YE-02	V03-YE02
			Z	200-ZP-1 Extraction well YE-06	V03-YE06

Modified from Figure 2.9 in DOE/RL-2016-69, *Calendar Year 2016 Annual Summary Report for the 200-ZP-1 and 200-UP-1 Operable Unit Pump-and-Treat Operations*.

Note: Valve V20-Y80_* replaced valve V07-Y80_* at the effluent tank (sampling location U) in August 2017.

Figure 5. 200 West P&T Process Identifying the 2017 and 2018 Cyanide Sampling Locations in Yellow Highlight

Extracted groundwater near WMA B-BX-BY in the 200-BP-5 OU is combined with radiologically contaminated groundwater from the 200-UP-1 and 200-ZP-1 OUs and is treated through the radiological treatment facility (shown in magenta in Figure 5). Process and effluent samples were analyzed for total cyanide in 2015 through 2018. Concentrations of total cyanide in the 200 West P&T effluent (sample location "U" in Figure 5) were all below 200 µg/L (Table 4).

Four effluent samples in 2016 had total cyanide concentrations exceeding 4.8 µg/L, the MTCA cleanup value for free cyanide (Table 4). Because the analytical methods used in 2015 and 2016 measured total cyanide, the results could not be used to determine if the free cyanide MTCA Method B cleanup level had been exceeded.

Table 4. Total Cyanide Concentrations in 200 West P&T Effluent Samples, 2015 – 2018

Sample Collection Date	Total Cyanide Concentration (µg/L)			HEIS Numbers	Analytical Laboratory
	Sample	Replicate Sample	Split Sample		
11/11/2015	3.0 BH	3.7 BH	--	B33M61, B33M66	TASL
11/11/2015	3.8 BH	3.1 BH	--	B33M60, B33M65	TASL
01/12/2016	3.0 U	3.0 U	--	B33YR8, B33YV0	ALS
02/23/2016	5.3 BC	6.6 BC	--	B34FC9, B34FD5	ALS
03/15/2016	3.6 U	3.6 U	--	B34PX9, B34PY5	ALS
04/13/2016	3.6 UH	3.6 UH	--	B34W00, B34W06	ALS
05/20/2016	1.67 U	1.88 B	--	B35H57, B35H62	GEL
05/27/2016	1.67 U	1.67 U	--	B35L11, B35L18	GEL
06/27/2016	5.3 BY	4.9 BY	--	B35WJ5, B35WK1	ALS
07/20/2016	8.4 BNY	12.0 Y	--	B36269, B36275	ALS
08/22/2016	3.6 UH	3.6 UH	--	B36K35, B36K41	ALS
09/14/2016	4.2 B	4.2 B	--	B36KF9, B36KF3	ALS
10/31/2016	3.6 UH	3.6 UH	--	B37H07, B37H01	ALS
	--	--	3.24 B	B37NP6	GEL
11/30/2016	10 C	11 C	--	B38246, B38253	ALS
	--	--	2.72 B	B38256	GEL
11/30/2016	2.95 B	2.92 B	--	B38247, B38254	GEL
12/29/2016	4.1 B	3.6 U	--	B38599, B385B6	ALS
	--	--	1.72 B	B385B9	GEL
12/29/2016	1.72 B	1.95 B	--	B385B9, B385B7	GEL
01/25/2017	3.86 B	4.03 B	--	B38H33, B38H31	GEL
01/25/2017	1.67 UXH	1.67 UXH	--	B38H33A, B38H31A	GEL
01/25/2017	3.9 BA	3.6 UA	--	B38H84, B38H85	ALS
02/15/2017	3.17 B	3.21 B	--	B38WR9, B38WY2	GEL
02/15/2017	5.9 BC	8.9 BC	--	B38WR8, B38WY1	ALS

Table 4. Total Cyanide Concentrations in 200 West P&T Effluent Samples, 2015 – 2018

Sample Collection Date	Total Cyanide Concentration (µg/L)			HEIS Numbers	Analytical Laboratory
	Sample	Replicate Sample	Split Sample		
03/01/2017	3.67 B	4.34 B	--	B394N8, B394P0	GEL
03/10/2017	1.67 U	1.67 U	--	B395D5, B395F3	GEL
03/15/2017	1.67 U	1.67 U	--	B394W4, B394W6	GEL
03/29/2017	7.12 G	7.16 G	--	B39508, B39510	GEL
04/12/2017	1.67 U	1.67 U	--	B39H33, B39H41	GEL
04/13/2017	1.67 U	1.67 U	--	B39552, B39554	GEL
05/19/2017	5.37	5.66	--	B395R9, B39HD1	GEL
06/20/2017	1.67 U	1.67 U	--	B3B982, B3B989	GEL
08/16/2017	1.67 U	4.97 B	--	B3C4K1, B3C4L0	GEL
08/16/2017	2.68 B	2.57 B	--	B3C4K0, B3C4K9	GEL
09/06/2017	1.67 U	1.67 U	--	B3D022, B3D031	GEL
09/06/2017	1.67 U	1.67 U	--	B3D021, B3D030	GEL
10/16/2017	1.67 U	1.67 U	--	B3FC42, B3FC52	GEL
10/16/2017	1.78 B	1.91 B	--	B3FC41, B3FC51	GEL
11/14/2017	2.25 B	2.11 B	--	B3FN52, B3FN58	GEL
11/14/2017	2.04 B	1.90 B	--	B3FN53, B3FN59	GEL
12/13/2017	1.67 U	1.87 B	--	B3FNB1, B3FYL5	GEL
12/13/2017	1.67 U	1.80 B	--	B3FNB0, B3FYL4	GEL
01/17/2018	1.67 U	1.67 U	--	B3FYV9, B3H005	GEL
01/17/2018	1.67 U	1.67 U	--	B3H000, B3H007	GEL
02/14/2018	1.67 U	1.67 U	--	B3HMH3, B3HMJ0	GEL
02/14/2018	1.67 U	1.67 U	--	B3HMH4, B3HMJ1	GEL
03/13/2018	3.73 B	4.02 B	--	B3HMT9, B3HMV5	GEL
03/13/2018	11.2	10.3	--	B3HMV0, B3HXP7	GEL
04/24/2018	1.67 U	1.92 B	--	B3J6W1, B3J6W8	GEL
04/24/2018	1.67 U	1.67 U	--	B3J6W2, B3J6W9	GEL
05/22/2018	1.67 U	1.67 U	--	B3JKL0, B3JKL6	GEL
05/22/2018	1.67 U	1.67 U	--	B3JKL1, B3JKL7	GEL
06/18/2018*	1.67 U	--	--	B3K463	GEL
06/27/2018	1.67 U	1.67 U	--	B3JW40, B3JW48	GEL
06/27/2018	1.67 U	1.67 U	--	B3JW39, B3JW47	GEL
07/05/2018*	1.67 U	--	--	B3K4P7	GEL
07/11/2018*	7.30	--	--	B3K4W2	GEL

Table 4. Total Cyanide Concentrations in 200 West P&T Effluent Samples, 2015 – 2018

Sample Collection Date	Total Cyanide Concentration (µg/L)			HEIS Numbers	Analytical Laboratory
	Sample	Replicate Sample	Split Sample		
07/25/2018	1.67 U	1.67 U	--	B3K643, B3K649	GEL
07/25/2018	1.67 U	1.67 U	--	B3K644, B3K650	GEL
08/22/2018	1.67 U	1.67 U	--	B3KK25, B3KK33	GEL
08/22/2018	1.67 U	1.67 U	--	B3KK26, B3KK34	GEL
09/06/2018*	1.67 NU	--	--	B3L4R3	GEL
09/25/2018	1.90 B	2.17 B	--	B3L292, B3L298	GEL
09/25/2018	2.07 B	1.84 B	--	B3L293, B3L299	GEL
10/24/2018	3.22 B	1.67 U	--	B3M2C6, B3M2D4	GEL
10/24/2018	2.79 B	1.89 B	--	B3M2C5, B3M2D3	GEL
11/08/2018*	1.67 U	--	--	B3MF13	GEL
11/15/2018	1.67 U	1.67 U	--	B3MDY9, B3MF00	GEL
11/15/2018	1.67 U	1.67 U	--	B3M2M0, B3M2M9	GEL
12/17/2018	12.5	12.5	--	B3MR52, B3MR60	GEL
12/17/2018	13.1	12.9	--	B3MR51, B3MR59	GEL

*Sampled from Valve V07-Y80 to support Modular Storage Unit transfers.

Note: Shaded cells denote filtered samples.

ALS = ALS Laboratory

FY = fiscal year

GEL = GEL Laboratory

HEIS = Hanford Environmental Information System

P&T = pump and treat

TASL = Test America St. Louis Laboratory

Laboratory qualifiers:

A = The Sample Issue Resolution form indicates a problem with the chain of custody.

B = The analyte was detected at a value less than the contract-required limit, but greater than or equal to the method detection limit.

C = The analyte was detected in both the sample and the associated quality control blank, and the sample concentration was ≤5X the blank concentration.

G = The result has been reviewed and determined to be correct.

H = Laboratory holding time exceeded before the sample was analyzed.

N = Laboratory spike sample recovery is outside control limits.

U = The analyte was not detected above the method detection limit.

X = Other specific flags and notes required to properly qualify the result are described in the hardcopy sample data summary package and/or case narrative. For the two samples with the "X" laboratory qualifier, the RESULT_COMMENT field states "Holding time exceeded."

Y = The result is suspect.

Beginning in 2017, the process and effluent samples are analyzed for both total and free cyanide at the locations highlighted in yellow in Figure 5. Previous cyanide sampling locations are shown without highlighting in Figure 5.

One effluent sample in 2017 had a free cyanide concentration that exceeded the MTCA Method B cleanup level of 4.8 µg/L (6.03 µg/L and 6.66 µg/L in duplicate samples; Table 5). This detection has associated uncertainty because it is close to the laboratory method detection limit for free cyanide (3.00 µg/L) and less than the laboratory practical quantitation limit (PQL) for free cyanide (10.00 µg/L). A higher degree of uncertainty is associated with this detection because it is less than the PQL for free cyanide in 2017.

Table 5. Free Cyanide Concentrations in 200 West P&T Effluent Samples, 2017 – 2018

Sample Collection Date	Free Cyanide Concentration (µg/L)			HEIS Numbers	Analytical Laboratory
	Sample	Replicate Sample	Split Sample		
01/25/2017	3.00 UXH	3.00 UXH	--	B38H33A, B38H31A	GEL
02/15/2017	3.00 U	3.00 U	--	B38WR9, B38WY2	GEL
03/01/2017	3.00 U	3.00 U	--	B394N8, B394P0	GEL
03/10/2017	3.00 U	3.00 U	--	B395D5, B395F3	GEL
03/15/2017	3.00 U	3.00 U	--	B394W4, B394W6	GEL
03/29/2017	6.03 BG	6.66 BG	--	B39508, B39510	GEL
04/12/2017	3.00 U	3.00 U	--	B39H33, B39H41	GEL
04/13/2017	3.00 U	3.00 U	--	B39552, B39554	GEL
05/19/2017	3.00 U	3.00 U	--	B395R9, B39HD1	GEL
6/20/2017	3.00 U	3.00 U	--	B3B982, B3B989	GEL
08/16/2017	3.00 U	3.00 U	--	B3C4K1, B3C4L0	GEL
08/16/2017	3.00 U	3.00 U	--	B3C4K0, B3C4K9	GEL
09/06/2017	3.00 U	3.00 U	--	B3D022, B3D031	GEL
09/06/2017	3.00 U	3.00 U	--	B3D021, B3D030	GEL
10/16/2017	3.00 U	3.00 U	--	B3FC42, B3FC52	GEL
10/16/2017	3.00 U	3.00 U	--	B3FC41, B3FC51	GEL
11/14/2017	3.00 U	3.00 U	--	B3FN52, B3FN58	GEL
11/14/2017	3.00 U	3.00 U	--	B3FN53, B3FN59	GEL
12/13/2017	3.00 U	3.00 U	--	B3FNB1, B3FYL5	GEL
12/13/2017	3.00 U	3.00 U	--	B3FNB0, B3FYL4	GEL
01/17/2018	3.00 U	3.00 U	--	B3FYV9, B3H005	GEL
01/17/2018	3.00 U	3.00 U	--	B3H000, B3H007	GEL
02/14/2018	3.00 U	3.00 U	--	B3HMH3, B3HMJ0	GEL
02/14/2018	3.00 U	3.00 U	--	B3HMH4, B3HMJ1	GEL
03/13/2018	2.77	2.52	--	B3HMT9, B3HMV5	GEL
03/13/2018	2.52	3.01	--	B3HMV0, B3HXP7	GEL
04/24/2018	1.00 U	2.14	--	B3J6W1, B3J6W8	GEL
04/24/2018	1.00 U	1.00 U	--	B3J6W2, B3J6W9	GEL

Table 5. Free Cyanide Concentrations in 200 West P&T Effluent Samples, 2017 – 2018

Sample Collection Date	Free Cyanide Concentration (µg/L)			HEIS Numbers	Analytical Laboratory
	Sample	Replicate Sample	Split Sample		
05/22/2018	1.00 U	1.00 U	--	B3JKL0, B3JKL6	GEL
05/22/2018	1.00 U	1.00 U	--	B3JKL1, B3JKL7	GEL
06/18/2018*	1.00 U	--	--	B3K463	GEL
06/27/2018	1.00 U	1.00 U	--	B3JW40, B3JW48	GEL
06/27/2018	1.00 U	1.00 U	--	B3JW39, B3JW47	GEL
07/05/2018*	1.00 U	--	--	B3K4P7	GEL
07/11/2018*	7.80	--	--	B3K4W2	GEL
07/25/2018	1.00 U	1.00 U	--	B3K643, B3K649	GEL
07/25/2018	1.00 U	1.00 U	--	B3K644, B3K650	GEL
08/22/2018	1.00 U	1.00 U	--	B3KK25, B3KK33	GEL
08/22/2018	1.00 U	1.00 U	--	B3KK26, B3KK34	GEL
09/06/2018*	1.00 U	--	--	B3L4R3	GEL
09/25/2018	1.00 U	1.00 U	--	B3L292, B3L298	GEL
09/25/2018	1.00 U	1.00 U	--	B3L293, B3L299	GEL
10/24/2018	2.55	1.00 U	--	B3M2C6, B3M2D4	GEL
10/24/2018	3.56	2.80	--	B3M2C5, B3M2D3	GEL
11/08/2018*	1.00 U	--	--	B3MF13	GEL
11/15/2018	1.00 U	1.00 U	--	B3MDY9, B3MF00	GEL
11/15/2018	1.00 U	1.00 U	--	B3M2M0, B3M2M9	GEL
12/17/2018	4.86	4.86	--	B3MR52, B3MR60	GEL
12/17/2018	5.29	3.56	--	B3MR51, B3MR59	GEL

*Sampled from Valve V07-Y80 to support Modular Storage Unit transfers.

Note: Shaded cells denote filtered samples.

FY = fiscal year

GEL = GEL Laboratory

HEIS = Hanford Environmental Information System

P&T = pump and treat

Laboratory qualifiers:

B = The analyte was detected at a value less than the contract-required limit but greater than or equal to the method detection limit.

G = The result has been reviewed and determined to be correct.

H = Laboratory holding time exceeded before the sample was analyzed.

U = The analyte was not detected above the method detection limit.

X = Other specific flags and notes required to properly qualify the result are described in the hardcopy sample data summary package and/or case narrative. For the two samples with the "X" laboratory qualifier, the RESULT_COMMENT field states "Holding time exceeded."

The analytical method was modified in 2018 to achieve a lower method detection limit (1.0 µg/L) and PQL (2.0 µg/L) for free cyanide.

Two effluent samples in 2018 had free cyanide concentrations that exceeded 4.8 µg/L (Table 5). The July 2018 concentration (7.80 µg/L) is above the laboratory PQL for free cyanide in 2018, but the result is likely a false positive because free cyanide in samples from upstream locations were below detection. The December 2018 concentrations in both the unfiltered sample (4.86 µg/L) and filtered sample (5.29 µg/L) appear to be real.

Because the incoming free cyanide is treated through blending, ion exchange, and air stripping, detections of free cyanide in the treated effluent are unlikely, as explained in the following paragraphs.

The highest cyanide concentrations treated at the 200 West P&T are in the groundwater extracted using 200-BP-5 OU wells 299-E33-268 (YE-27) and 299-E33-360 (YE-31) (Table 2). The cross-site transfer line that conveys water from the 200-BP-5 OU extraction wells to the 200 West P&T froze from December 17, 2016, through February 21, 2017, due to low flow and adverse weather. Extraction from well 299-E33-268 (YE-27) resumed on February 22, 2017, and from well 299-E33-360 (YE-31) on March 10, 2017. Groundwater extraction from well 299-E33-268 was discontinued on June 15, 2017, but is continuing from well 299-E33-360. Figure 1 illustrates the cross-site transfer line and extraction wells.

Even though the higher cyanide 200-BP-5 OU wells were online starting February 22, 2017, free cyanide exceeded the 4.8 µg/L MTCA Method B cleanup level in only 1 of 13 treated effluent samples collected from March through December 2017 (Table 6). The only detection of free cyanide in the treated effluent in 2017 was on March 29 while extraction well 299-E33-360 (YE-31) was offline. During January through December 2018, free cyanide exceeded the 4.8 µg/L MTCA Method B cleanup level in only 2 of 17 samples of treated effluent (Table 6). During this time, 200-BP-5 OU extraction well 299-E33-360 (YE-31) was operating at a flow rate of 630 L/min (165 gal/min). Operation of the 200-BP-5 OU groundwater extraction wells has no discernible effect on the occurrence of free cyanide in the 200 West P&T treated effluent.

Table 6. Free Cyanide Concentrations in 200 West P&T Effluent Tank Samples and Operational Status of 200-BP-5 OU Groundwater Extraction Wells, 2017 – 2018

Sample Collection Date	Free Cyanide Concentration in 200 West P&T Effluent Tank Samples (µg/L)		Flow Rate from 200-BP-5 OU Extraction Wells (L/min [gal/min])	
	Sample	Duplicate Sample	299-E33-268 (YE-27)	299-E33-360 (YE-31)
01/25/2017	3.00 UXH	3.00 UXH	0*	0*
02/15/2017	3.00 U	3.00 U	0*	0*
03/01/2017	3.00 U	3.00 U	379 (100)	114 (30)
03/10/2017	3.00 U	3.00 U	379 (100)	114 (30)
03/15/2017	3.00 U	3.00 U	303 (80)	114 (30)
03/29/2017	6.03 BG	6.66 BG	303 (80)	0
04/12/2017	3.00 U	3.00 U	322 (85)	151 (40)
04/13/2017	3.00 U	3.00 U	322 (85)	151 (40)
05/19/2017	3.00 U	3.00 U	0	0
06/20/2017	3.00 U	3.00 U	0	530 (140)

Table 6. Free Cyanide Concentrations in 200 West P&T Effluent Tank Samples and Operational Status of 200-BP-5 OU Groundwater Extraction Wells, 2017 – 2018

Sample Collection Date	Free Cyanide Concentration in 200 West P&T Effluent Tank Samples (µg/L)		Flow Rate from 200-BP-5 OU Extraction Wells (L/min [gal/min])	
	Sample	Duplicate Sample	299-E33-268 (YE-27)	299-E33-360 (YE-31)
08/16/2017	3.00 U	3.00 U	0	530 (140)
	3.00 U	3.00 U		
09/06/2017	3.00 U	3.00 U	0	530 (140)
	3.00 U	3.00 U		
10/16/2017	3.00 U	3.00 U	0	0
	3.00 U	3.00 U		
11/14/2017	3.00 U	3.00 U	0	630 (165)
	3.00 U	3.00 U		
12/13/2017	3.00 U	3.00 U	0	630 (165)
	3.00 U	3.00 U		
01/17/2018	3.00 U	3.00 U	0	630 (165)
	3.00 U	3.00 U		
02/14/2018	3.00 U	3.00 U	0	630 (165)
	3.00 U	3.00 U		
03/13/2018	2.77	2.52	0	630 (165)
	2.52	3.01		
04/24/2018	1.00 U	2.14	0	630 (165)
	1.00 U	1.00 U		
05/22/2018	1.00 U	1.00 U	0	630 (165)
	1.00 U	1.00 U		
06/18/2018	1.00 U	--	0	630 (165)
06/27/2018	1.00 U	1.00 U	0	630 (165)
	1.00 U	1.00 U		
07/05/2018	1.00 U	--	0	630 (165)
07/11/2018	7.80	--	0	630 (165)
07/25/2018	1.00 U	1.00 U	0	630 (165)
	1.00 U	1.00 U		
08/22/2018	1.00 U	1.00 U	0	630 (165)
	1.00 U	1.00 U		
09/06/2018	1.00 U	--	0	630 (165)
09/25/2018	1.00 U	1.00 U	0	630 (165)
	1.00 U	1.00 U		

Table 6. Free Cyanide Concentrations in 200 West P&T Effluent Tank Samples and Operational Status of 200-BP-5 OU Groundwater Extraction Wells, 2017 – 2018

Sample Collection Date	Free Cyanide Concentration in 200 West P&T Effluent Tank Samples (µg/L)		Flow Rate from 200-BP-5 OU Extraction Wells (L/min [gal/min])	
	Sample	Duplicate Sample	299-E33-268 (YE-27)	299-E33-360 (YE-31)
10/24/2018	2.55	1.00 U	0	630 (165)
	3.56	2.80		
11/08/2018	1.00 U	--	0	630 (165)
11/15/2018	1.00 U	1.00 U	0	630 (165)
	1.00 U	1.00 U		
12/17/2018	4.86	4.86	0	630 (165)
	5.29	3.56		

*The cross-site transfer line froze from 12/17/2016 through 02/21/2017.

Note: Shaded cells denote filtered samples.

OU = operable unit

P&T = pump and treat

Laboratory qualifiers:

B = The analyte was detected at a value less than the contract-required limit, but greater than or equal to the method detection limit.

G = The result has been reviewed and determined to be correct.

H = Laboratory holding time exceeded before the sample was analyzed.

U = The analyte was not detected above the method detection limit.

X = Other specific flags and notes required to properly qualify the result are described in the hardcopy sample data summary package and/or case narrative. For the two samples with the "X" laboratory qualifier, the RESULT_COMMENT field states "Holding time exceeded."

Free cyanide is unlikely to be detectable in 200 West P&T effluent. The maximum free cyanide concentration in the 200-BP-5 OU extraction wells was 8.36 µg/L (Table 2). At the 200 West P&T, the 200-BP-5 OU groundwater is mixed with large volumes of water with lower or undetectable free cyanide concentrations. Free cyanide naturally hydrolyzes in water to produce aqueous HCN. The aqueous HCN can then volatilize as HCN gas. The 200 West P&T air strippers enhance this volatilization, and the downstream granular-activated carbon filters remove the HCN gas. In 2017 and 2018, cyanide was detected in samples of the granular-activated carbon filter.

The main form of cyanide present in the 200 West P&T influent is metal complexed cyanide. This nonfree (metal complexed) cyanide can convert to free cyanide under very acidic conditions (pH <2), but free cyanide is typically not detected after the ion exchange columns, indicating that conversion to free cyanide is not occurring. The DOWEX® 21K ion exchange resin in use at the 200 West P&T has high adsorption capacities. While it was designed to remove uranium, sampling provides clear evidence that this resin is highly effective at removing metal cyanide complexes. In 2018, exhausted resin was sent to a laboratory where testing confirmed that total cyanide is being adsorbed effectively.

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4 Conclusions

Of the 32 samples of 200 West P&T effluent collected from January 2017 through December 2018, free cyanide was:

- Not detected in 27 samples
- Detected in 1 sample at a concentration >4.8 µg/L but lower than the PQL
- Detected in 2 samples at a concentration <4.8 µg/L and higher than the PQL
- Detected in 2 samples at a concentration >4.8 µg/L and higher than the PQL

Analytical uncertainty is associated with the detection that was >4.8 µg/L and less than the PQL. One detection that was >4.8 µg/L and higher than the PQL is likely a false positive because the upstream samples were nondetect. The other detection that was >4.8 µg/L and higher than the PQL appears to be real. Because most of the free cyanide results were less than the laboratory detection limit for free cyanide and two of the three detections >4.8 µg/L have associated uncertainty, it appears that concentrations of free cyanide in the 200 West P&T effluent rarely exceed the 4.8 µg/L MTCA Method B cleanup level. Continued monitoring will provide a more robust statistical measure of the results.

5 Path Forward

Monitoring for total cyanide and free cyanide will continue at the following locations:

- Monthly at the 200 West P&T effluent tank (sample location "U" in Figure 5)
- Bimonthly at the other 13 sampling locations shown in Figure 5 for the 200 West P&T
- Quarterly at the 15 wells shown in Figure 3 for WMA B-BX-BY
- Monthly at two of the six wells (299-W10-26 and 299-W14-18) shown in Figure 4 for WMA T and WMA TX-TY and quarterly at the other four wells.

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