REPORT ON

AMENDMENT NO. 2 TO AGREED ORDER NO. 2692
INTERIM ACTION COMPLETION
KAISER ALUMINUM TRENTWOOD FACILITY
SPOKANE VALLEY, WASHINGTON

by
Haley & Aldrich, Inc.
Spokane, Washington

for
Kaiser Aluminum Washington, LLC
Spokane Valley, Washington

File No. 203232-002
23 January 2023

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Revised 23 January 2023
5 December 2022
File No. 203232-002

Kaiser Aluminum Washington, LLC
15000 East Euclid Avenue
Spokane Valley, Washington

Attention: Brent Downey, Manager of Environmental Affairs
Kaiser Aluminum Trentwood Facility

Subject: Interim Action Completion Report
Kaiser Aluminum Trentwood Facility
Spokane Valley, Washington

Dear Brent Downey:

Haley & Aldrich, Inc. (Haley & Aldrich) is pleased to submit this Interim Action Completion Report for Kaiser Aluminum Washington, LLC (Kaiser). Haley & Aldrich completed the scope of work associated with Task 4, of Phase 1, of the Amendment No. 2 to the Agreed Order No. 2692 between the Washington State Department of Ecology and Kaiser. This report documents the completed work outlined in Task 1, of Phase 1, of the Interim Action Work Plan, dated 5 August 2020.

Sincerely yours,
HALEY & ALDRICH, INC.

Ward D. McDonald, L.G.
Project Geologist

John R. Haney, P.E.
Principal Environmental Engineer

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KAISER ALUMINUM TRENTWOOD FACILITY
SPOKANE VALLEY, WASHINGTON

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January 23, 2023

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1. Introduction

This Interim Action Completion Report (IACR) has been prepared to summarize activities completed for the scope of work described in the Washington State Department of Ecology's (Ecology's) Agreed Order No. 2692 (AO), Amendment No. 2 (AAO-2) (Ecology 2020) for the Kaiser Aluminum (Kaiser) Trentwood Facility (Facility) in Spokane Valley, Washington. AAO-2, effective 29 April 2020, is part of Kaiser's ongoing efforts to remediate soil and groundwater beneath the Facility to levels protective of human health and the environment. The general history and regulatory timeline for the Facility is summarized below:

- 16 August 2005, Kaiser enters into the AO with Ecology based on the results of the Draft RI/FS and data collected from the PCB groundwater plume (herein referred to as "Remelt/Hotline plume") . The AO requires Kaiser to update the RI to evaluate the extent of contamination and a FS to evaluate potential cleanup actions at the Facility.
- May 2012, The Final RI/FS for soil and Groundwater is completed by Hart Crowser (now Haley & Aldrich Inc., [Haley & Aldrich]).
- 12 July 2012, Kaiser enters into Amendment No. 1 of the AO (AAO-1) that includes preparing additional interim action work plans and implementing remedial actions to address TPH and PCBs in groundwater, excavating and disposing contaminated soil (where applicable), and installing protective soil caps.
- Between 2013 and 2018, Kaiser excavates and disposes of contaminated soil and completes soil capping at multiple locations, completes remedial actions for TPH contaminated groundwater, and constructs an *ex situ*, pilot-scale groundwater treatment system to test technologies to remediate PCBs in groundwater.
- 29 April 2020, Kaiser enters into the AAO-2. The scope of work listed in the AAO-2 is based on the completed interim actions items listed in the AO and AAO-1 and is detailed in this report. Additional details of the scope of work are further described in Kaiser's Interim Action Work Plan (IAWP; Hart Crowser, Inc. 2020).

In addition to the general history and regulatory timeframe listed above, the following sections describe the site background, a summary of RI, current characteristics of the Remelt/Hotline plume, and results of the FS; project goal; status of groundwater treatment system testing (pilot studies); and completed work as outlined in Phase I of the AAO-2.

1.1 SITE BACKGROUND

The Facility is approximately 466 acres and located at 15000 East Euclid Avenue, Spokane Valley, Washington (see "Vicinity Map", Figure 1). The Facility is an aluminum sheet, plate, and coil rolling mill that generally can be divided into five operating areas: the Remelt/Hotline area; Cold Rolling Mill/Finishing area (Cold Mill); the Oil Reclamation Building (ORB); the Oil House; and the Wastewater Treatment area. The operating areas are shown on "Site Plan", Figure 2. The Facility originally was constructed in 1942 to provide aluminum for the manufacture of fighter planes and bombers used during World War II.

Historically, PCB-containing oils were used and stored on site. The oils primarily were used for hydraulic equipment, including below-ground, hydraulic cylinders used in the aluminum casting process. The PCBs contained in the hydraulic oils were formulations of Aroclor 1242 and Aroclor 1248. PCB-containing hydraulic oil from equipment releases at the Facility contaminated surface and subsurface soil, groundwater, and the Facility's industrial wastewater conveyance system.

1.1.1 Geology and Hydrogeology

The Facility is located in the Spokane Valley, a valley sedimented with glaciofluvial deposits originating from glacial Lake Missoula flooding events. These high-energy flood waters deposited coarse-grained material (sands, gravels, cobbles, and boulders) within the valley floor. Recent Spokane River alluvium locally covers the glaciofluvial unit, but the alluvium also is coarse-grained sand, gravel, and cobbles, making it difficult to distinguish Spokane River alluvium from the glacial outwash deposits. Sediments underlying the Facility generally consist of poorly sorted sand and gravel with occasional sand lenses and varying amounts of cobbles and boulders.

The Facility is underlain by the Spokane Valley Rathdrum Prairie (SVRP) aquifer. The SVRP aquifer is an unconfined aquifer that flows through the sediments described above and bounded below by igneous and metamorphic bedrock. Groundwater flow beneath the Facility generally is west-southwest with a hydraulic conductivity of approximately 6,692 feet per day (ft/d) (Hart Crowser 2022). The Spokane River is adjacent to the Facility on the south and west.

1.1.2 Remedial Investigation

Haley & Aldrich, Inc. (Haley & Aldrich)[1] conducted the RI in 2005 and in accordance with Task VII of Exhibit B to the AO. The RI was divided into two phases: one phase for soil assessment and one phase for groundwater assessment. The RI report for groundwater describes the magnitude and extent of the Remelt/Hotline plume beneath the Facility (Hart Crowser 2012a). Kaiser also conducts semiannual groundwater monitoring to monitor the stability of the Remelt/Hotline plume; monitoring includes collecting and analyzing select groundwater samples for PCB Aroclors using Environmental Protection Agency (EPA) Method 8082 and PCB congeners using EPA Method 1668. Because detection limits are much lower for the EPA Method 1668 analysis, Kaiser monitors PCB congeners in background wells near the eastern property boundary (MW-04, MW-05, MW-10, and MW-11), upgradient of the Remelt/Hotline plume (RM-MW-05S), at the downgradient limits of the Remelt/Hotline plume (MW-27S and MW-28S), and in the Facility potable water supply well (North Supply Well) where PCB concentrations are less than the reporting and/or detection limits for the EPA Method 8082 analysis. Kaiser monitors the remainder of the Remelt/Hotline plume for PCB Aroclors using the EPA Method 8082 analysis. The April 2022 PCB Aroclor and congener analytical results for the Facility are shown on "PCB Contaminant Plume April 2022", Figure 3 and "Total PCB Congener Analytical Results - April 2022", Figure 4, respectively. Additional details about the Remelt/Hotline plume from the RI and ongoing groundwater monitoring are provided below.

1.1.2.1 Magnitude and Extent of the Remelt/Hotline Plume

The Remelt/Hotline plume begins near the center of the Remelt Area of the Facility and extends to the west-southwest in the same direction as groundwater flow (see Figure 3). Based on historical data, the plume is approximately 400 to 500 feet across at its widest location (depending on seasonal groundwater fluctuations) and approximately 2,700 feet long. Groundwater monitoring data from monitoring wells RM-MW-8S, RM-MW-13S, RM-MW-16S, and RM-MW-17S indicates there are two "hot spots" beneath the Remelt/Hotline area and the plume originates near monitoring well RM-MW-08.

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[1] Hart Crowser merged with Haley & Aldrich, Inc. in August 2020; references to Haley & Aldrich in this report include prior work completed by Hart Crowser.

The two hot spots are present beneath Direct Chill (DC) Furnace 1 (DC-1) and DC-7. Analytical data from the April 2022 groundwater monitoring event indicates total PCB Aroclor concentrations in groundwater below DC-1 and DC-7 were 2,876 nanograms per liter (ng/L) and 3,400 ng/L, respectively (see Figure 3). Analytical data from the April 2022 monitoring event indicates that total PCB congener concentrations in groundwater at monitoring well RM-MW-05S (located upgradient of the Remelt/Hotline plume) were 0.209 ng/L. PCB concentrations generally decrease with depth, as indicated by analytical results from wells completed at deeper depths (RM-MW-04D, RM-MW-02D, etc.) and distance from the two hot spots (see Figure 3).

April 2022 groundwater monitoring analytical results indicate PCB Aroclors in the Remelt/Hotline plume decrease to 26 ng/L in shallow monitoring well MW-26S and to non-detectable levels (less than 5 ng/L) in deeper well MW-24D near the downgradient extent of the plume, east of the Spokane River. PCB congener analytical results from MW-27S indicate PCBs are present in this well at 0.811 ng/L (see Figure 4). Groundwater monitoring data collected to date indicates the Remelt/Hotline plume is stable (i.e., not expanding).

1.1.3 Feasibility Study

Haley & Aldrich used data from the RI to develop remedial alternatives for groundwater cleanup in the FS. There are several primary factors that complicate remediation of the Remelt/Hotline plume including:

- The hot spots beneath the Remelt area are not easily accessible due to Facility infrastructure and production activities;
- The transmissivity of the SVRP aquifer renders complete plume capture infeasible because:
    - the extraction flow rates required to fully capture the plume likely would exceed several million gallons per day (gpd); and
    - the required flow rates likely would dilute PCB concentrations in extracted water to concentrations below current treatment technology capabilities.

Therefore, the remedial alternatives considered focused on mass removal as opposed to plume capture. In 2012, Haley & Aldrich prepared the FS (Hart Crowser 2012b) and a Final Site-Wide FS Technical Memorandum (Hart Crowser 2012c) that presented and evaluated various *in situ* and *ex situ* treatment technologies for remediating the Remelt/Hotline plume.

These documents concluded four technology-based remedial alternatives (Alternatives D1 through D4) were the most practical options to treat contaminated groundwater at the Facility. However, after discussions between Kaiser, Ecology, and Haley & Aldrich, a modified version of Alternative D4 was selected for pilot-scale testing. Alternative D4 includes a combination of institutional controls, groundwater monitoring, monitoring natural attenuation, and extraction of contaminated groundwater with *ex situ* treatment for PCBs. Alternative D4 assumes groundwater will be extracted from a well located west of the Remelt building at a rate of approximately 300,000 gpd (approximately 208 gallons per minute [gpm]), conveyed to an above-ground treatment system, treated to remove PCBs, and then infiltrated back into the subsurface near the head of the Remelt/Hotline plume.

1.1.3.1 Groundwater Treatment Pilot Study

Prior to designing and constructing an *ex situ* treatment system, Kaiser researched technologies that were capable of removing PCBs from groundwater at concentrations typically observed in the downgradient portion of the Remelt/Hotline plume (average of about 200 ng/L). Based on this research, filtration was identified as a potential applicable technology in the FS; specifically, filtration using walnut shells as a filter media. Kaiser had been using a walnut shell filter to reduce PCBs and other contaminants (i.e., oil and grease, total suspended solids [TSS], etc.) in Facility wastewater since 2003 (commonly referred to as the “Trace Oil Filter” [TOF]). The TOF currently operates under Kaiser’s National Pollutant Discharge Elimination System permit (NPDES Permit No. WA0000892).

PCB removal in the TOF is enhanced by dosing influent with castor oil, which is already present in wastewater from manufacturing operations, and the addition of KlarAid (a coagulant) prior to treatment. The castor oil promotes PCB partitioning from the wastewater and KlarAid improves TSS coagulation and removal.

In 2015, Kaiser purchased a pilot-scale version of the TOF (herby referred to as the “walnut shell filtration system” [WSFS]) from Filtra Systems (Filtra) to treat PCBs in groundwater and installed the system in a dedicated building located west of the ORB (herein referred to as the “Pilot Plant”); see “Infrastructure Expansion”, Figure 5, for the location of the Pilot Plant at the Facility. Originally, contaminated groundwater was delivered to the Pilot Plant from Hotline Extraction Well 01 (HL-EW-01); however, currently contaminated groundwater can be extracted and conveyed from two additional wells (see Section 3.1). Extraction well HL-EW-01 is located northeast of the Pilot Plant and downgradient of the Remelt building. The pump in HL-EW-01 currently is set at an elevation of 1923 feet relative to the North American Vertical Datum of 1988 (NAVD88) where historical data indicates PCBs are present in groundwater at greater concentrations than surrounding monitoring wells. After the groundwater is filtered for PCBs by the WSFS at the Pilot Plant, the treated water is then pumped to an infiltration basin located near the northeast corner of the Remelt building.

During operation of the WSFS, Kaiser continued to evaluate additional treatment technologies to achieve the project goals that are detailed in the next section. Additional technologies evaluated included:

- Algae-based treatment technology;
- Solvent extraction and zero valent metal oxidation; and
- Ultraviolet light and the advanced oxidation process (UV/AOP).

Additional details of these technology evaluations are provided in Section 3.3.

2. Project Goal

Kaiser's goal for the project is to remediate soil and groundwater beneath the Facility to levels protective of human health and the environment, within a reasonable timeframe, and meet Ecology screening levels stated in AAO-2:

- 7 picograms per liter (pg/L), adjusted for area background PCB concentrations in monitoring wells MW-17s, HL-MW-32S, HL-MW-23s, MW-12A, MW-23s, MW-27s, and MW-28s (see Figure 3).
- 44,000 pg/L, adjusted for area background PCB concentrations, in each groundwater monitoring well (site wide), excluding the seven monitoring wells listed above and background monitoring wells. [2]

Another Kaiser goal is to consistently extract and treat groundwater with the greatest concentrations of PCBs to increase PCB mass removal from the Remelt/Hotline plume and reduce remediation timeframes. The scope of work in the AAO-2 indicates that "the extraction network shall be designed to extract groundwater at a volume and rate to be measured against screening levels at the Site within a reasonable restoration timeframe"; therefore, the groundwater extraction and treatment flow rate for the full-scale treatment system will be determined based on monitoring data to maximize mass removal and likely will decrease over time as cleanup occurs.

2.1 SCOPE OF WORK

To achieve these goals, and as part of the AAO-2 scope of work, Kaiser increased Pilot Plant infrastructure by expanding the groundwater extraction network and increasing the capacity of the Pilot Plant discharge piping and advanced the development of treatment technologies that potentially could remediate PCBs in groundwater to the screening levels. Kaiser implemented these interim actions in accordance with WAC 173-340-430, the AO, and its amendments. The scope of work for AAO-2 includes:

Task 1. Phase 1 - Interim Action Work Plan (IAWP)
Task 2. Phase 1 - Permits and Substantive Conditions of Permit-Exempt Laws
Task 3. Phase 1 - Interim Action Implementation
Task 4. Phase 1 - Interim Action Completion Report (IACR)
Task 5. Phase 2 - Full-Scale Pump-and-Treat Interim Action Engineering Design Report (EDR)
Task 6. Phase 2 - Permits and Substantive Conditions of Permit-Exempt Laws
Task 7. Phase 2 - EDR Implementation
Task 8. Phase 2 - Interim Action Completion Report
Task 9. Phase 2 - Interim Action Periodic Performance Reports

Haley & Aldrich has prepared this report to satisfy the requirements of Phase 1, Task 4 referenced above. This IACR includes the following sections:

- A summary of Phase 1 (Tasks 1 - 3) work completed:
  - An evaluation of pilot study results;
  - A recommended treatment technology for PCB removal that can be implemented as a full-scale treatment system during the Phase 2 Interim Action (Tasks 5 through 9); and
  - A proposed schedule for full-scale treatment system implementation.

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[2] Area background total PCB concentration will be determined using the process described in Washington Administration Code (WAC) 173-340-709, using data from monitoring wells MW-4, MW-5, MW-10, and MW-11.

3. Phase 1 Work Completed

In accordance with the scope of work outlined in the AAO, Kaiser completed the following tasks:

- Increased the capacity of the groundwater extraction network;
- Increased the capacity of the treated groundwater discharge system;
- Evaluated and developed treatment technologies; and
- Evaluated the need for infrastructure expansion.

Additional details pertaining to these completed tasks are provided in the following sections.

3.1 EXPANSION OF THE GROUNDWATER EXTRACTION NETWORK

The AAO-2 scope of work requires Kaiser to design a full-scale groundwater extraction network that considers seasonal groundwater variability and overall expansion of the treatment system infrastructure, including converting monitoring wells RM-MW-17S and HL-MW-31S to extraction wells. To accomplish these tasks, Kaiser converted the two monitoring wells to extraction wells in March and April 2020 and completed a study of the vertical distribution of PCBs in the Remelt/Hotline Plume (the "transect study") between August 2020 and August 2021. Results of the transect study were then used to inform the design of a full-scale extraction well network. The field activities for the well conversions and transect study are summarized below. Additional findings from the Remelt/Hotline Plume Transect Study are provided in the "Fourth Quarter Remelt/Hotline Plume Transect Study Monitoring Report" (Hart Crowser 2022).

3.1.1 Monitoring Well Conversions

Kaiser converted RM-MW-17S and HL-MW-31S from 2-inch-diameter monitoring wells to 6-inch-diameter extraction wells in March and April 2020 (see Figure 3 for well locations). Kaiser contracted Anderson Environmental Contracting, LLC (AEC) to over-drill the existing wells and construct the new, larger extraction wells. AEC used a Boart Longyear LS250 MiniSonic track-mounted drill rig complete the conversions.

AEC completed each boring using 10-inch-diameter steel casing and the extraction wells were constructed to a depth of approximately 100 feet below ground surface (bgs). Each extraction well was constructed with 6-inch-diameter, schedule-80 polyvinyl chloride (PVC) casing and screens. The well screens are 0.030-inch slot size and installed between approximately 75 feet bgs and 100 feet bgs. The extraction well locations are shown on Figure 5, and the boring and well construction logs for RM-EW-01 (formerly monitoring well RM-MW-17S) and HL-EW-02 (formerly HL-MW-31S) are included in "Boring Logs and Soil Sampling Laboratory Report", Appendix A.

During drilling, Haley & Aldrich collected soil samples at 10 feet intervals between approximately 10 feet bgs and saturated soil (approximately 70 feet bgs). Each soil sample was field-screened for the presence of contaminants using visual and olfactory observations, sheen testing, and a photoionization detector (PID). Based on field screening results, the soil samples did not appear contaminated during drilling. Haley & Aldrich submitted one soil sample from approximately 70 feet bgs in each boring to Eurofins Testing Northwest, LLC (Eurofins) in Spokane Valley, Washington, for chemical analysis; samples were submitted for PCB Aroclor analysis using EPA Method 8082. PCBs were not detected in either soil sample above the method detection limits (MDL); the laboratory report is provided in Appendix A.

After the extraction wells were installed, AEC developed each well using a combination of surging, bailing, and pumping. The wells screens were surged several times using a surge block to remove fines and reestablish the connection with the surrounding aquifer. After surging, AEC bailed the accumulated fines from the wells until water became visually clear. After surging and bailing was conducted, AEC purged each well using a submersible pump to further develop the wells. AEC collected well development water and transported the water to the Pilot Plant for treatment.

3.1.2 Remelt/Hotline Plume Transect Study

The existing monitoring well network at the Facility is sufficient to monitor the horizontal limits of the Remelt/Hotline plume and to track seasonal changes in PCB concentrations in groundwater. However, variations in PCB concentrations between shallow and deep wells indicate there are data gaps and limited information on the vertical extent of PCBs within the Remelt/Hotline plume. In order to better understand that vertical distribution, Kaiser conducted the transect study using a combination of existing monitoring wells and six, newly-installed monitoring wells along a transect between HL-MW-26S on the north and HL-MW-16S on the south (see transect A to A’ on Figure 3). This transect of wells generally is perpendicular to the plume downgradient of the Remelt/Hotline area. Kaiser then used passive, low-density polyethylene samplers to monitor the vertical extent of the plume quarterly for one year (Hart Crowser 2022).

3.1.2.1 Results/Findings

As previously mentioned, data from groundwater compliance monitoring indicates there are two hot spots beneath the Remelt area: one near DC-1 and another near DC-7. Analytical results from the transect study indicate that the greatest concentrations of PCBs across the transect are present in two lobes: one near monitoring well HL-MW-34D at an approximate elevation of 1,870 feet NAVD88 and downgradient of the DC-7 hot spot and one near monitoring well HL-MW-29S at an approximate elevation of 1,930 feet NAVD88 and downgradient of the DC-1 hot spot (Hart Crowser 2022). The transect study data further indicates that the two lobes are present at different elevations in the subsurface and, therefore, the corresponding hot spots near DC-1 and DC-7 could also be present at different elevations.

Haley & Aldrich used data from groundwater monitoring, the transect study, and aquifer characteristics to prepare a fate and transport model to inform the design of an expanded extraction well network for full-scale groundwater treatment. Based on the results of that analysis, Haley & Aldrich recommended extracting groundwater as close as possible to source areas near DC-1 and DC-7. Because of the challenges associated with drilling inside the Remelt building, Haley & Aldrich recommends a phased approach to increasing the extraction well network by first extracting and treating groundwater from RM-EW-01 while monitoring downgradient wells to assess the effectiveness of the extraction well. We recommend monitoring for a minimum of two years while simultaneously using the monitoring data to inform designs for an extraction well near the hotspot beneath DC-1 and to design the associated pumps, piping, and controls to convey extracted groundwater to the Pilot Plant.

3.1.3 Groundwater Extraction Infrastructure

The AAO requires Kaiser to install infrastructure to convey contaminated groundwater from the new extraction wells (RM-EW-01 and HL-EW-02) to the existing Pilot Plant building. Kaiser contracted McClintock & Turk, Inc. (M&T) to install extraction pumps in the wells along with electrical power, controls, and conveyance piping from the wells to the Pilot Plant building. M&T completed this work between 2 June 2022 and 12 August 2022.

M&T installed one Goulds Water Technology (Goulds) 4-inch submersible pump in each extraction well (RM-EW-01 and HL-EW-02). M&T also installed one, 72-inch wide, by 72-inch long, by 72-inch high-high, precast concrete, belowground vault at each wellhead. M&T then installed a combination of belowground and aboveground conveyance piping from each wellhead and manifolded the conveyance piping into two, new, 6-inch-diameter, high density polyethylene (HDPE) pipelines. M&T installed the new 6-inch pipeline between the Remelt building and the Pilot Plant. This 6-inch-diameter pipeline replaced the previous 2-inch-diameter line and increases the treatment capacity of the Pilot Plant as required by the AAO. The newly-installed collection pipeline layout is shown on Figure 5.

3.2 TREATED EXTRACTED GROUNDWATER DISCHARGE SYSTEM

The capacity of the original Pilot Plant treatment system was partially limited by the size, configuration, and condition of the 2-inch-diameter discharge line that was commissioned in 2015. To increase the treatment capacity of the Pilot Plant, Kaiser contracted Commercial Grading Incorporated (CGI) to abandon the original discharge line while simultaneously installing two, new, larger diameter, HDPE discharge lines; sections of the original discharge line were removed if conflicting with new the discharge lines installation. CGI installed one, 4-inch-diameter and one, 6-inch-diameter, HDPE pipelines between the Pilot Plant building and the infiltration basin. These new discharge lines increase the capacity to treat and discharge greater flows and provide additional flexibility for discharge flow rates. The new lines also were installed with cleanouts to enable ongoing maintenance for long-term operation.

CGI also upgraded the infiltration basin to accommodate higher treatment flow rates. CGI excavated the existing infiltration basin to approximately five feet below existing grade and backfilled the excavation with Washington State Department of Transportation (WSDOT) Class A scour protection riprap. The riprap is comprised of angular basaltic material approximately 4 to 8 inches in diameter. The finished infiltration basin is approximately five feet deep, 31 feet wide, and 36 feet long and is secured by chain-link fencing. The treated extracted groundwater discharge system was completed in June 2021; the new discharge line layout is shown on Figure 5.

3.3 TREATMENT TECHNOLOGY DEVELOPMENT

Kaiser commissioned the Pilot Plant in 2015 and began pilot-scale testing using the WSFS between December 2015 and May 2021. During WSFS operations, Kaiser continued to assess treatment technologies with the potential to increase treatment flowrates, treat backwash water generated from WSFS operations, and increase PCB removal efficiency. The treatment technologies assessed during pilot-scale operations include:

- WSFS;
- Algae-based treatment;

- Solvent extraction with zero valent metal (ZVM) oxidation; and
- Ultraviolet light and the advanced oxidation process (UV/AOP).

Descriptions of these technologies, testing conducted, testing results, and findings are provided in the following sections.

3.3.1 WSFS

As previously mentioned, WSFS technology was evaluated by Kaiser in the FS and considered to be a viable technology to remove PCBs from groundwater *ex situ*. Kaiser began pilot testing this filtration technology in 2015. The treatment process typically includes amending influent with castor oil and/or KlarAid (a commercially available coagulant) and then filtering the amended influent using walnut shell media. During testing, Kaiser varied the operating parameters (castor oil and KlarAid amendments, treatment flowrates, and treatment durations) to assess optimum operating conditions. Treated effluent was temporarily stored in a tank (tank T-107) before being pumped and discharged to the infiltration basin. As constructed, the pilot-scale WSFS was designed to treat up to about 75 gpm; however, during operations the treatment flowrate was limited to a maximum of about 32 gpm by friction losses in the original discharge line.

In order to maintain performance and flow rates during operation, the walnut shell media required agitation and backwashing with potable water to remove filtered materials from the filter bed. These agitation cycles were programmed into the WSFS controls to automatically initiate based on specified reductions in pressure across the filtration vessel caused by an accumulation of filtered materials and compaction of the walnut shell media. Agitation cycles included a combination of mechanical mixing and flushing the filter vessel with potable water to remove filtered materials, typically one to three vessel volumes. PCB-contaminated water generated during agitation cycles was then pumped to the backwash water tanks (Tanks 108 and 110). Backwash cycles were conducted by mechanical mixing followed by flushing the filter media with potable water at a flowrate of about 28 gpm. PCB-contaminated water generated during agitation and backwash cycles also was stored, on an as needed basis, in portable frac-tanks staged next to the Pilot Plant building; Kaiser would periodically treat the backwash water using the WSFS when the backwash tanks were approaching full capacity.

Since installing and commissioning the WSFS at the Pilot Plant, Kaiser completed a total of 28 testing runs (Runs 1 through 28) and treated approximately 37,624,759 gallons of groundwater. Testing data indicates that the WSFS removed approximately 37.3 grams of PCBs during operations. Out of the 28 test runs, 9 test runs were used to treat backwash water. The operating conditions used to test the WSFS are summarized in “Walnut Shell Filtration System Pilot Testing Summary”, Table 1 and below.

- Runs 1 through 8 (2015 to 2017) treated approximately 4,631,887 gallons of groundwater with a PCB removal efficiency ranging between approximately 47.7 and 87.9 percent and approximately 6.3 grams of PCBs were removed;
- Runs 10, 12, 14, 16, and 18 (2017 to 2018) treated approximately 9,529,344 gallons of groundwater with a PCB removal efficiency ranging between approximately 32.7 and 75.2 percent and approximately 7.2 grams of PCBs were removed;
- Runs 20, 22, and 24 (2019) treated approximately 14,441,784 gallons of groundwater with a PCB removal efficiency ranging between approximately 57.1 and 71.2 percent and approximately 15.3 grams of PCBs were removed; and

- Runs 26 and 28 (2020 to 2021) treated approximately 6,970,194 gallons of groundwater with PCB removal efficiencies of 0.6 and 86.6 percent, respectively; Runs 26 and 28 removed about 0.1 and 8.4 grams of PCBs, respectively.

Nine test runs were conducted to treat backwash water (Runs 9, 11, 13, 15, 17, 19, 21, 23, and 25). Approximately 252,497 gallons of backwash water were treated. Analytical results, for Runs 15, 21, and 23, indicate that influent and effluent PCB concentrations were less than the MRL; therefore, PCB removal efficiencies were not calculated for these runs. Analytical results for Runs 11, 13, 17, 19, and 25, indicate the PCB removal efficiencies ranged between 45.9 and 76.1 percent; analytical results for Run 9 were not included in these calculations because the effluent PCB concentrations were greater than influent PCB concentrations. Laboratory reports for backwash treatment runs are included in “WSFS Laboratory Reports and Algae-Based Treatment Results”, Appendix B.

PCB concentrations in backwash water were expected to have greater concentrations of PCBs than influent groundwater due to the concentrating effect of the WSFS. Because PCBs were not detected in water samples from several of the backwash water batches, Haley & Aldrich assessed the potential for PCB partitioning within backwash water storage tanks by analyzing the liquids and solids (sludge) accumulated at the bottom of the tanks.

Haley & Aldrich first collected three water/sludge samples from the approximately 1,500 gallons of backwash water generated during Run 11. The backwash water was stored within the Pilot Plant in Tank 109 (T-109) and the samples were collected from the top, middle, and bottom of T-109 (1,500-gallon, 900-gallon, and 0-gallon markers on the tank scale, respectively). Laboratory results from this assessment indicate that PCB concentrations from the top, middle, and bottom of T-109 were 400 ng/L, 3,800 ng/L, and 19,000 ng/L, respectively. These results indicate PCBs generally had partitioned into the sludge, including castor oil solids, at the bottom of the storage tank. It is likely that partitioning occurred when the backwash water was stored for longer periods of time between treatment runs when the WSFS was idle.

3.3.1.1 Findings

Results of pilot testing indicate the WSFS was capable of removing PCBs from groundwater and performed more efficiently with greater concentrations of castor oil and/or KlarAid amendment. However, increased castor oil amendment also increased frequency of system shutdowns and the need for system maintenance to remove castor oil solids accumulated within the walnut shell media, adhered to the agitator, and clogging the plenum filter at the bottom of the filter vessel. Castor oil solids also clogged the influent and effluent conveyance piping over time. These conditions also increased the frequency of agitation and backwash cycles that, in-turn, generated greater volumes backwash water. In general, the walnut shell filter yielded inconsistent performance that ranged between approximately 0.6 and 87.9 percent PCB removal efficiency with an average removal efficiency of about 62.7 percent.

3.3.2 Algae-Based Treatment Technology

As an option for treating WSFS backwash water, Kaiser evaluated algae-based treatment between 2017 and 2018. Kaiser contracted CLEARAS Water Recovery (CWR), a wastewater treatment vendor from Missoula, Montana, to assess the efficacy of using their proprietary algae/membrane filtration system to remove PCBs from backwash water and, possibly, as a primary treatment technology for groundwater. The CWR treatment system is designed to use algae and other microbes to remove nutrients from wastewater, primarily phosphorus and nitrogen. However, because the CWR system uses biomass as a primary treatment mechanism, Kaiser theorized that the system might also be capable of removing PCBs because the affinity PCBs have for absorbing to organic matter.

The CWR treatment system operates in four stages: mixing, recovery, separation, and harvesting. In general, wastewater is blended with algae (mixing stage) before it enters a photobioreactor (PBR) that optimizes biological activity using ultraviolet light as the algae consumes the phosphorus, nitrogen, and carbon dioxide from the wastewater (recovery stage). PCBs likely would also absorb to the biomass generated in the recovery phase. The algae, and absorbed PCBs, are then filtered from the water using a filter membrane (separation stage), the treated water is discharged, and the collected algae is reintroduced to the PBR (harvest stage).

In 2017, Haley & Aldrich submitted backwash water samples from the Pilot Plant’s backwash tank (T-108), to CWR to conduct lab-scale testing. Analytical results from the lab-scale testing indicated PCB concentrations in influent samples were 3,240,000 pg/L and 3,750,000 pg/L and PCB concentrations in corresponding effluent samples were 221 pg/L and 222 pg/L, respectively. The PCB removal efficiency for these tests were greater than 99 percent. Based on these results, Kaiser contracted CWR to conduct pilot-scale testing at the Facility to evaluate system performance treating larger volumes of backwash water and groundwater.

Between 29 October 2018 and 11 November 2018, CWR conducted multiple on-site tests with a trailer-mounted system to assess if their algae-based technology could remove PCBs from groundwater and WSFS backwash water. CWR treated each source water in approximately 80-gallon batches: eight batches of backwash water and ten batches of groundwater. Influent and effluent samples from the batch tests were analyzed for PCB Aroclors using EPA Method 8082 with ultra-low level reporting limits. Analytical results from the batch tests are included in Appendix B. Analytical results indicate that PCBs were not detected in influent or effluent backwash water samples at concentrations greater than the MRL. Total PCBs were detected in influent groundwater samples at concentrations ranging between 200 and 290 ng/L; PCBs were not detected at concentrations greater than the MRL in treated groundwater effluent samples.

PCB removal efficiencies were not calculated for backwash water treatment because PCBs were not detected above the MRL in either influent or effluent samples; therefore, the results of the algae-based treatment technology for treating backwash water were inconclusive. PCB removal efficiencies for groundwater treatment, calculated using the MRL as the effluent concentration, ranged between about 77 and 84 percent with an average of about 80 percent.

To assess if removed PCBs absorbed to the algae during the treatment process, Haley & Aldrich collected three samples from the algae-rich water from the recovery stage, prior to the filter membrane. These samples were submitted to Eurofins for PCB Aroclor analyses using EPA Method 8082. Analytical results indicate PCBs were not detected at concentrations greater than the MRL in the algae-rich water samples.

3.3.2.1 Findings

Results of pilot-testing indicate that PCBs were not removed from treated water by absorption to the organic material (i.e., algae). Instead, it is likely that the PCBs were removed by the membrane filter during the separation stage of treatment. In this respect, the algae-based treatment system performed similar to a reverse osmosis system but without added benefit. Similar to the WSFS, using this technology for treatment produces waste in the form of spent algae that requires management and disposal. In addition, maintaining the algae-based treatment system requires dedicated labor to monitor the system and keep the algae colony viable.

3.3.3 Zero Valent Metal Technology

In 2018, Kaiser assessed ZVM treatment as a potential technology to remove PCBs from backwash water generated from the WSFS and, potentially, as a primary treatment for groundwater. Kaiser engaged ecoSPEARS (eS), an environmental technology company from Altamonte Springs, Florida, to assess ZVM treatment using bench-scale tests and prepare a conceptual design. The conceptual design they developed used an oil-based solvent to extract PCBs from water. PCBs were then separated from the solvent, the solvent was recycled, and the resulting PCB mixture was processed in a ZVM reactor to dechlorinate and/or mineralize PCBs.

eS conducted bench-scale testing of their solvent exchange extraction system (SEES) followed by ZVM treatment using their reductive integrated destruction system (RIDS) on “simulated” backwash water (i.e., water spiked with PCBs to mimic concentrations similar to backwash water generated by the WSFS). Following batch testing, eS reported that the technology was successful at extracting PCBs at rates between 61 and 73 percent and subsequent ZVM treatment achieved PCB removal efficiencies of approximately 90 percent.

3.3.3.1 Findings

Based on limited testing, the SEES/RIDS bench-scale system was capable of removing PCBs from water. However, the conceptual, pilot-scale ZVM system eS designed is more complex than the other technologies Kaiser tested. Firstly, the solvents used in the SEES system must be distilled prior to reuse in the treatment process. Furthermore, the treatment process generates hazardous waste that requires management and disposal. Additional testing would be required to replicate the bench-scale testing on a pilot-scale and/or for continuous flow treatment. Because the ZVM treatment is more complex and the bench-scale results achieved similar performance to the other technologies considered by Kaiser, ZVM treatment was not further considered.

3.3.4 UV/AOP

Kaiser initially considered UV/AOP as a treatment technology during preparation of the FS. At the time, there was not enough research or practical application of the technology to advance the technology for pilot testing. However, since the FS was prepared in 2012, UV/AOP technology had advanced, and Kaiser decided to assess the treatment technology as an alternative to walnut shell filtration. Kaiser engaged CDM Smith (CDM), to conduct lab-scale testing of the UV/AOP in 2020. A description of UV/AOP reaction mechanisms for treating PCB-contaminated water is provided below and in our “UV/AOP Pilot Study Summary-2020” (Hart Crowser 2021).

3.3.4.1 UV/AOP Reaction Mechanism and PCB Breakdown Products

The degradation of dissolved PCBs can occur by direct UV photolysis resulting in dechlorination of the biphenyl structure and by breaking the chemical bonds within the biphenyl rings (also known as cleavage). Direct UV photolysis occurs due to excitation of the ring structure through adsorption of the UV energy and the replacement of the attached chlorine atom with available hydrogen atoms from reactions with water. Degradation also is achieved through an oxidation reaction with the hydroxyl free radical ($\cdot OH$) formed from irradiating hydrogen peroxide (H_2O_2) with UV light.

Photodechlorination reactions are dependent upon the charge of the chlorine-carbon bond where the higher the charge distribution, the more susceptible the bond is for removal of the chlorine atom. With enough residence time and UV energy input, the sequential dechlorination of the PCB congeners present will form biphenyl (PCB-0) where the direct oxidation reaction with OH will result in contaminant mineralization.

The PCB oxidation reaction with OH can occur at three locations on the biphenyl ring structure: at the chlorine-free carbon to carbon (C-C) bond within the phenyl ring (activation energy 0.44 to 0.82 kilocalorie per mol (kcal/mol), the C-C bond between the phenyl rings (activation energy 8.47 kcal/mol) and at the chlorine to carbon (Cl-C) bond within the phenyl ring (activation energy 18.96 kcal/mol)[3]. With the lowest activation energy, cleavage of the phenyl ring occurs predominantly at the ortho non-substituted carbon atom adjacent to the Cl-C bond. Following the cleavage of the phenyl ring at this location, the mineralization of the remaining carbon structure produces carbon dioxide (CO_2), chloride ion (Cl-), and water (H_20). The OH oxidation reaction is more efficient for mono- through tetra-chlorinated biphenyl congeners at a prescribed UV energy level and H_2O_2 concentration because there are more C-C bonds available for attack by the OH without the steric hindrance from adjacent Cl atoms. For more Cl-saturated PCB congeners (e.g., hexa-, hepta-, and penta-chlorinated biphenyl compounds), the locations available for the initial oxidation reaction are limited and thus, the energy and amount of OH required are greater to achieve compound degradation.

3.3.4.1.1 UV/AOP and the Potential for Enhancing Natural Attenuation

The review of current research indicates that UV/AOP treatment and subsequent infiltration of effluent back to the aquifer might also enhance natural attenuation of PCBs in discharged water. Biodegradation of PCBs has been demonstrated to occur under aerobic conditions using indigenous bacteria that are ubiquitous in the environment including strains of Pseudomonas, Burkholderia, and Rhodococcus. Lower chlorine substituted PCB congeners and biphenyl are susceptible to this degradation pathway. These facultative microorganisms utilize enzymes (e.g., biphenyl 2,3 - dioxygenase) associated with the direct metabolic pathway for biphenyl (PCB-0) to dechlorinate and ultimately mineralize PCBs and the biphenyl intermediate (Dietmar et al., 2008).

The breakdown of the hydrogen peroxide within the UV reactor vessel increases the dissolved oxygen (O_2) concentration in the system effluent. Additionally, the introduction of the oxygen-rich process effluent into the infiltration basin promotes aerobic biodegradation of residual PCBs present via the aerobic co-metabolic pathway by indigenous microorganisms present in the subsurface. Since these two processes promote the aerobic degradation of residual, dissolved-phase PCBs present in the process effluent, the application of UV/AOP treatment can accommodate fluctuations in influent PCB concentrations or composition by integrating aboveground and complimentary *in situ* enhanced biodegradation processes.

3.3.4.1.2 UV/AOP and Potential Hydroxylated PCB Byproducts

Recent research conducted at the University of Iowa found that certain breakdown products of PCBs in contaminated sediments were detected at higher concentrations than their commercial PCB counterparts. The study specifically looked at hydroxylated PCBs (OH-PCBs) that are difficult to measure

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[3] Mei-Ling Xin, Yang, J., Li, Yu., 2017. *The mechanism for enhanced oxidation degradation of dioxin-like PCBs (PCB-77) in the atmosphere by the solvation effect*. Chemistry Central Journal. doi 10.1186/s13065-017-0291-3.

because of the lack of analytical standards. Ecology requested Kaiser to assess whether or not the UV/AOP treatment process had the potential to generate OH-PCBs as a byproduct of treatment.

In order to assess the potential for UV/AOP treatment to generate OH-PCBs as a byproduct, Haley & Aldrich first reviewed the research referenced by Ecology. The research indicates that, when identified in sediment samples, OH-PCBs make up less than 0.4 percent of the total PCB mass present. Furthermore, the conditions by which these compounds form in sediments, mediated by microbial activity, are less aggressive than the treatment conditions for UV/AOP. Additionally, the microbial communities in freshwater sediments likely do not compare to the microbial communities present in the SVRP aquifer.

Haley & Aldrich also reviewed laboratory chromatograms of influent and effluent samples for unidentified peaks that might indicate the presence of OH-PCBs and/or evidence of OH-PCB generation. Peaks that suggested OH-PCBs were present, or present in concentrations greater than target PCBs, were not identified.

3.3.4.2 UV/AOP Pilot Scale Study 2020

On 5 December 2018, Kaiser collected approximately 30 gallons of effluent from the TOF units at the wastewater treatment area and a groundwater sample from monitoring well HL-MW-29S and submitted the samples to CDM's laboratory in Bellevue, Washington for bench-scale testing using UV/AOP with hydrogen peroxide as an oxidizer. Results of this testing indicated UV/AOP was capable of destroying PCBs from water, so Kaiser contracted both CDM and eS to construct pilot-scale treatment systems to test at the Facility (referred to herein as the "NeoTech skid unit" and "eS skid unit", respectively).

The NeoTech skid unit was constructed using a commercially available sanitation UV reactor and the eS skid unit was built using proprietary components. Both skid units were delivered to the Facility between April and May 2020, and Haley & Aldrich tested the units between May and October 2020. Results of the skid unit pilot testing are detailed in our report (Hart Crowser 2021) and our findings are summarized below.

3.3.4.3 NeoTech Skid Unit Results

Haley & Aldrich completed nine treatment test runs (Runs 1 through 9) using the NeoTech skid unit. The treatment runs were completed using variable flowrates and hydrogen peroxide additions; treatment flowrates ranged between 4.7 and 25 gpm and the hydrogen peroxide dosing concentrations ranged between approximately 9 and 27 parts per million (ppm). Analytical results indicate influent total PCB congener concentrations ranged between about 110 and 227 ng/L. Analytical results indicate the effluent total PCB congener concentrations ranged between about 2.3 and 127 ng/L. Based on these results, the NeoTech skid unit was capable of PCB destruction efficiencies between about 44 and 98 percent with an average destruction efficiency of about 85 percent. During testing, the system treated 96,192 gallons of groundwater and destroyed approximately 0.6 grams of PCBs.

3.3.4.4 eS Skid Unit Results

Haley & Aldrich completed 21 treatment test runs (Runs 1 through 21) using the eS skid unit with and without hydrogen peroxide dosing. The treatment flowrates ranged between 1 and 3 gpm and the hydrogen peroxide dosing concentrations, when added, ranged between approximately 3 and 9 ppm. Analytical results indicate influent total PCB congener concentrations, ranged between about 128 and

203 ng/L and effluent total PCB congener concentrations ranged between about 4.6 and 126 ng/L. Based on the results, the eS skid unit was capable of PCB destruction efficiencies between 33 and 97 percent with an average destruction efficiency of about 85 percent. During testing, the system treated 6,480 gallons of groundwater and destroyed approximately 0.04 grams of PCBs.

3.3.4.5 Findings

Results from testing the two skid units indicate that UV/AOP is a viable treatment technology for treating PCB contaminated groundwater. Testing also indicates that PCBs primarily are dechlorinated when exposed to UV light alone but dechlorination and mineralization occurs when exposed to UV light and ·OH. Pilot study data further indicate that UV/AOP likely is a more effective, more consistent technology for long-term groundwater treatment compared to walnut shell filtration. Additionally, UV/AOP is less maintenance intensive compared to the WSFS. Based on these findings, Kaiser advanced the UV/AOP treatment technology to the demonstration-scale between 2021 and 2022.

3.3.5 UV/AOP Demonstration-Scale Study 2021 to 2022

Kaiser contracted eS to design and construct a demonstration-scale UV/AOP groundwater treatment capable of operating at flow rates up to 50 gpm. The demonstration-scale treatment system (the “ecoCUBE”) was delivered to the facility in June 2021, and eS installed the system into existing Pilot Plant infrastructure; this required Kaiser to disconnect and to idle the WSFS. Haley & Aldrich began initial testing of the ecoCUBE between June 2021 and March 2022. Further details regarding the design of the ecoCUBE, testing completed, and results/findings are summarized below.

3.3.5.1 ecoCUBE

The ecoCUBE generally consists of a hydrogen peroxide day tank and pump for dosing; two UV/AOP reactors configured to operate in parallel or series; an impeller pump for series operations; associated piping, fittings, and sample ports; and a control panel. The system operates by introducing hydrogen peroxide to influent groundwater. The amended influent then passes through a manifold configured to operate the reactors either in parallel or series configuration. The manifold delivers the influent into the reactor chamber(s) where it is exposed to UV light, OH’s are produced, and PCBs are dechlorinated and mineralized. Treated effluent water exits the reactor(s) and is transferred to the Treated Water Tank (T-107) or is introduced to the secondary reactor, if configured for series operation, before being pumped to the infiltration basin.

3.3.5.2 ecoCUBE Demonstration-Scale Study

Haley & Aldrich conducted 99 test runs (Runs 1 through 99) of the ecoCUBE between 1 July 2021 and 3 March 2022. The testing protocols (i.e., test run longevity and sampling intervals) generally were similar for each run, excluding treatment test Runs 54 through 57, but hydrogen peroxide dosing rates, treatment flowrates, and system configuration (parallel or series) were varied. Runs 54 through 57 were completed separately from the other test runs to assess PCB destruction efficiency of the ecoCUBE using fewer UV lamps. The system setup, sampling, and analyses for each treatment test run are discussed below.

3.3.5.2.1 System Setup, Sampling, and Analyses

Haley & Aldrich conducted each test run for approximately 4 hours (excluding Runs 54 through 57) using general protocols for system setup and startup. Startup protocols included configuring valving for parallel or series operations, priming pumps, and tubing, and calibrating the hydrogen peroxide dosing pump. The system was then started, and the desired treatment and hydrogen peroxide flowrates were set. The system was then allowed to operate for approximately one hour to purge the system of water remaining from previous test runs and to equilibrate to the new operating conditions. The operating parameters for each test run are summarized in "ecoCUBE Operating Parameters", Table 2.

After the system stabilized for one hour, water quality parameters (pH, oxidation reduction potential [ORP], temperature, conductivity, and turbidity) and hydrogen peroxide concentrations were measured from the influent and effluent sample water during the middle and end of each test run. The water quality parameters were measured using Oakton Tester Water Quality meters and the hydrogen peroxide concentrations were measured using a Palintest Photometer 7500. The water quality parameters for parallel and series configuration runs are summarized on "ecoCUBE Water Quality Parameters-Parallel Configuration", Table 3, and "ecoCUBE Water Quality Parameters-Series Configuration", Table 4, respectively.

After recording water quality parameters and hydrogen peroxide concentrations, Haley & Aldrich collected one influent and one effluent sample from the influent and effluent sample ports during each treatment test run. In order to assess average performance over the course of each test run, Haley & Aldrich composited the samples into one influent and one effluent sample representative of the run. Haley & Aldrich composited samples during operations by adding approximately 165 milliliters (mL) to the sample containers during each sampling event. The composite samples were submitted to Eurofins and analyzed for PCB Aroclors by EPA Method 8082. PCB Aroclor analytical results are summarized below and presented in "ecoCUBE Analytical Results - EPA Method 8082A", Table 5.

Haley & Aldrich collected additional influent and effluent samples from test Runs 1, 2, 6, 7, 15 through 53, and 58 through 89 for PCB congener analysis by EPA Method 1668, to assess which reaction mechanism was dominant during treatment: dechlorination or mineralization. The samples were collected by allowing the water to free flow into sample containers during each sampling event and submitted the samples to Eurofins for analysis. Eurofins composited the samples at their laboratory into one influent and one effluent sample representative of the test run prior to analyses. PCB congener analytical results are summarized below and presented in "UV/AOP Laboratory Reports", Appendix C.

3.3.5.2.1.1 Test Runs 54 through 57

Test runs 54 through 57 operated for 2 hours and were completed to assess whether or not a decrease in the number of operating lamps corresponded with a decrease in PCB destruction efficiency. The treatment flowrate for these treatment runs was 15 gpm, the hydrogen peroxide dosing was 18 ppm, and the reactors were configured to operate in parallel. For these test runs, Haley & Aldrich configured the influent manifold so that influent water entered the reactor vessels at the inlets farthest from the rector outlet to allow a longer residence time in the reactor. Haley & Aldrich started Run 54 with four operating UV lamps in each reactor. After the system operated for approximately 2 hours, one influent and one effluent water sample was collected and then one UV lamp was deactivated in each reactor so that each reactor had three operating UV lamps; this also initiated the next run (Run 55). This process was repeated every 2 hours until only one UV lamp was operating in each reactor (Run 57).

3.3.5.2.2 Parallel Configuration

Haley & Aldrich conducted Runs 1 through 41, and 54 through 57, in parallel configurations between 1 July 2021 and 8 December 2021. The treatment flowrates ranged between 15 and 50 gpm, and the hydrogen peroxide dosing ranged between 0 and 36 ppm. The water quality parameter measurements and analytical results for each treatment run are summarized below.

3.3.5.2.2.1 Water Quality Parameter Results

The average influent and effluent water quality parameters for each test run are summarized in Table 3. Haley & Aldrich assessed potential changes to water quality parameters from UV/AOP treatment by calculating the average relative percent differences (RPD) between influent and effluent measurements. Results of this analysis indicate the average RPD for pH is 0.41 percent, for ORP is 6.4 percent, for temperature is 2.9 percent, for conductivity is 0.76 percent, and for turbidity is 37.5 percent. Generally, water quality parameters for influent and effluent were similar.

3.3.5.2.2.2 Analytical Results

Analytical results indicate total Aroclor influent concentrations ranged between 96 and 360 ng/L (Runs 40 and 15, respectively) and effluent concentrations ranged from 59 to 250 ng/L (Runs 36 and Run 12, respectively). Influent and effluent PCB Aroclor concentrations are summarized in "ecoCUBE PCB Aroclor Analytical Results - Parallel Configuration”, Table 6. Except for Run 22, the PCB destruction efficiency ranged between 13.0 percent (Run 9) and 65.3 percent (Run 36); PCB destruction efficiency was not calculated for Run 22 because the influent and effluent PCB concentrations were the same.

Analytical results indicate influent total PCB congener concentrations ranged between 183,794 and 318,509 pg/L (Runs 22 and 35, respectively) and effluent concentrations ranged between 77,600 and 227,646 pg/L (during Runs 36 and 7, respectively). PCB destruction efficiencies ranged between 20.7 and 63.0 percent (Runs 7 and 36, respectively). Runs 1 through 41 and Runs 54 through 57 treated approximately 203,966 gallons of groundwater and destroyed approximately 649.7 grams of PCBs. Influent and effluent PCB Congener concentrations are summarized in “ecoCUBE PCB Congener Analytical Results - Parallel Configuration”, Table 7.

Analytical results for Runs 54 through 57 indicate that total Aroclor influent concentrations ranged between 210 ng/L (Run 54) and 230 ng/L (Run 55 through 57), and total Aroclor effluent concentrations ranged between 96 ng/L (Run 54) and 140 ng/L (Run 57) (see Table 6). The PCB destruction efficiency ranged between 39.1 percent, with one UV lamp activated in each reactor (Run 57), and 61.7 percent, with four UV lamps activated in each reactor (Run 55). In general, the PCB destruction efficiency of the ecoCUBE decreased when UV lamps were deactivated confirming that ecoCUBE performance decreased with a decrease in UV dose. After testing the ecoCUBE in parallel configuration, Haley & Aldrich configured the system in series and resumed testing.

3.3.5.2.3 Series Configuration

Haley & Aldrich conducted Runs 42 through 53, and 58 through 99, in series configurations between 1 July 2021 and 8 December 2021. Treatment flowrates ranged between 10 and 25 gpm and the hydrogen peroxide dosing ranged between 3 and 36 ppm. The water quality parameters for series configuration and analytical results are discussed below.

3.3.5.2.3.1 Water Quality Parameter Results

The average influent and effluent water quality parameters for each treatment test run are summarized in Table 4. Haley & Aldrich assessed potential changes to water quality parameters from UV/AOP treatment by calculating the average relative percent differences (RPD) between influent and effluent measurements. Results of this analysis indicate the average RPD for pH is 0.2 percent, for ORP is 10.4 percent, for temperature is 2.3 percent, for conductivity is 0.6 percent, and for turbidity is 22.2 percent. Generally, water quality parameters for influent and effluent were similar.

3.3.5.2.3.2 Analytical Results

Haley & Aldrich collected influent and effluent water samples and submitted them to Eurofins for PCB Aroclor analysis by EPA Method 8082. Analytical results indicate influent total Aroclor concentrations ranged between 79 ng/L (Run 84) and 210 ng/L (Runs 83 and 85). Influent and effluent total Aroclor concentrations are summarized in “ecoCUBE Analytical Results - Series Configuration” Table 8.

Haley & Aldrich collected effluent samples from the primary and secondary reactors to assess PCB destruction efficiency of each reactor while operating in series. Primary reactor effluent total PCB concentrations ranged between 63 ng/L (Run 68) and 170 ng/L (Run 90). Secondary reactor effluent total PCB concentrations (final effluent concentrations) ranged between 31 ng/L (Runs 66 and 68) and 130 ng/L (Run 91). Based on these results, the PCB destruction efficiency of the primary reactor ranged between 6.3 percent (Run 93) and 61.4 percent (Run 85). The primary reactor PCB destruction efficiency for Runs 90 and 92 were not calculated because the effluent PCB concentrations were greater than the influent concentrations for Runs 90 and 92. This increase in PCB concentrations between influent and effluent samples was likely the result of field-compositing, variations in influent PCB concentrations during the run, and/or variations in sample extraction and analytical procedures. Influent and primary reactor effluent PCB concentrations for Run 91 were equal, resulting in 0 percent destruction efficiency from the primary reactor.

The PCB destruction efficiency for the secondary reactor ranged between 1.4 percent (Run 70) and 61.6 percent (Run 79). The secondary reactor PCB destruction efficiency for Runs 95 and 96 was not calculated because the effluent PCB concentrations were greater than influent PCB concentrations. The total Aroclor analytical data indicates PCB destruction efficiency, in series configuration, ranged between 7.7 percent (Run 92) and 79.3 percent (Runs 66 and 68). Haley & Aldrich used the detected influent concentration and MDL for effluent concentrations to calculate the destruction efficiency for Runs 66, 68, and 79 (see “ecoCUBE PCB Congener Analytical Results - Series Configuration”, Table 9).

Analytical results indicate the influent total PCB congener concentrations ranged between 101,911 and 225,113 pg/L (Runs 69 and 88, respectively); effluent concentrations ranged between 24,432 and 131,264 pg/L (Runs 68 and 43, respectively). Influent and effluent total PCB Congener concentrations are summarized in Table 9. Primary reactor effluent total PCB congener concentrations ranged between 60,213 pg/L (Run 69) and 188,505 pg/L (Run 43). Secondary reactor total PCB effluent concentrations (final effluent concentration) ranged from 24,432 pg/L (Run 68) and 131,264 pg/L (Run 43). Based on this, the total PCB destruction efficiency for the primary reactor ranged between 11.1 percent (Run 43) and 54.2 percent (Run 68). The total PCB destruction efficiency for the secondary reactor ranged between 15.9 percent (Run 53) and 67.0 percent (Run 68). The analytical data indicates total PCB destruction efficiency, in series configuration, ranged between 38.1 percent (Run 43) and 84.89 percent (Run 68). Runs 42 through 53 and Runs 58 through 99 treated approximately 171,758 gallons of groundwater and destroyed approximately 529.3 grams of PCBs.

3.3.5.2.4 Findings

Analytical results indicate that the ability of the ecoCUBE to treat PCB-contaminated groundwater was dependent on several operational parameters: treatment system configuration (parallel versus series), hydrogen peroxide dosing, and treatment flowrates. Analytical data from the ecoCUBE treatment test Runs 1 through 99 indicate that the influent total PCB concentrations ranged between 79 and 360 ng/L, and effluent PCB concentrations ranged between 31 and 250 ng/L. The data also indicates the ecoCUBE PCBs destruction efficiency for parallel configuration averaged 39 percent and in series configuration averaged 55 percent. The ecoCUBE was approximately 16 percent more efficient in destroying PCBs when operating in series; this increase in PCB destruction can be attributed to the increased residency time/UV dose.

Analytical data from the ecoCUBE treatment test runs also indicate that PCB destruction efficiency generally increases with the additional of hydrogen peroxide to the influent as shown in “PCB Destruction Efficiency Compared to Hydrogen Peroxide Concentrations”, Table 10. In general, the analytical data indicates that PCB destruction efficiencies increased between 8 and 25 percent while dosing the influent water with hydrogen peroxide. We tabulated the analytical data for treatment test runs completed at a constant flow rate of 25 gpm to assess how hydrogen peroxide dosing affects PCB destruction efficiency. The tabulated data is shown on “PCB Destruction Efficiency Compared to Hydrogen Peroxide Concentrations at a Treatment Flow Rate of 25 gpm”, Table 11. In general, the analytical data indicates that hydrogen peroxide dosing between 3 and 18 ppm improved the performance of the ecoCUBE and increased the PCB destruction efficiency by approximately 9 percent. However, when increasing hydrogen peroxide concentrations greater than 18 ppm, the performance of the ecoCUBE decreased destruction efficiency approximately 6 percent.

Haley & Aldrich tested ecoCUBE performance at flow rates between 10 and 50 gpm; performance data relative to flow rates tested are summarized in “PCB Destruction Efficiency Compared to Treatment Flow Rates”, Table 12. Analytical data indicates that the PCB destruction efficiency averaged about 78 percent when the treatment flowrate was 10 gpm but decreased to an average of approximately 34 percent with a treatment flowrate of 50 gpm; therefore, the performance of the ecoCUBE generally decreases with increases in treatment flow rate.

In order to further assess UV/AOP treatment system options, Kaiser assessed the performance of the NeoTech reactor against the ecoCUBE in side-by-side testing using the same influent water, flow rates, and hydrogen peroxide dosing. Results of side-by-side testing conducted to date are provided in the section below.

3.3.5.3 ecoCUBE and NeoTech Side-by-Side Demonstration-Scale Study

Kaiser modified the existing piping of the Pilot Plant between March and June 2022 to incorporate the installation of the NeoTech reactor from the NeoTech skid unit to run side-by-side. Haley & Aldrich conducted the side-by-side testing between June 2022 and August 2022. The modifications to the Pilot Plant infrastructure were completed by M&T and included the following:

- installed the NeoTech reactor in the Pilot Plant building;
- modified existing hydrogen peroxide dosing pump, influent pumps and piping, and inline static mixer to convey amended influent water to both systems;
- installed valving for diverting water to both systems;

- configured effluent piping to the NeoTech unit; and
- installed high/low water shutoff relays and various other fail-safe protocols to the systems.

In addition to the modifications listed above, Kaiser, eS, and M&T modified the ecoCUBE to increase the UV dose in an attempt to increase the ecoCUBE performance. The ecoCUBE modifications included:

- doubling the amount of proprietary influent tubing,
- installing 12 additional UV lamps (six additional lamps in each reactor) for a total of ten UV lamps per reactor, and
- installing a single baffle near the effluent side of each reactor with the goal to increase turbid flow within the reactor (i.e., promote increased mixing of influent with UV light).

After the modifications were completed, Haley & Aldrich conducted 12 additional test runs (Runs 1 through 12) to compare the performance of both systems using the same influent and operating parameters. The target operating parameters for the 12 test runs are summarized in “Target Operating Parameters”, Table 13. Runs 1 through 11 were conducted between 16 June and 2 August 2022. The target operating parameters for these runs include flowrates between 5 and 20 gpm per unit and hydrogen peroxide dosing concentrations between 9 and 27 ppm. Test Runs 1 and 2 operated for approximately 7 days, Runs 3 through 11 operated between 3 and 4 days, and Run 12 was initiated to assess the long-term operations of both systems and is still in operation. However, overheating of the UV lamps in the ecoCUBE reactors from long-term operation resulted in damage to the UV lamps and the ecoCUBE was shut down on 19 August 2022. The NeoTech unit is still in operation.

3.3.5.3.1 System Setup, Sampling, and Analyses

Prior to side-by-side testing, Haley & Aldrich completed system start-up protocols which included: configuring valving to divert influent water to both the eS and NeoTech systems, priming pumps and tubing, and calibrating the hydrogen peroxide dosing pump prior to startup. After completing the start-up protocols, the system was started and set the desired treatment and hydrogen peroxide flowrates for both systems. Once the desired flowrates were stable, the system was allowed to operate continuously for the test durations listed in Table 13.

Haley & Aldrich recorded water quality parameters each business day during the course of the test runs and collected one influent and one effluent sample at the end of each run, excluding Run 12. Because Run 12 is ongoing, Haley & Aldrich collects influent and effluent samples once per week. The average water quality parameters for each test run are summarized in “ecoCUBE and NeoTech Water Quality Parameters”, Table 14, and the operating parameters for the ecoCUBE system and NeoTech system are summarized in “ecoCUBE System-Operating Parameters” and “NeoTech System- Operating Parameters”, Tables 15 and 16, respectively.

Haley & Aldrich collected primary samples and two backup samples during test Runs 2 through 12; only primary samples were collected during Run 1. The primary samples were submitted to Eurofins for PCB Aroclor analyses using EPA Method 8082 on a 24-hour turnaround time. If PCBs were not detected at concentrations greater than the MDL in the primary effluent samples, the primary backup samples were submitted to ALS Group, in Kelso, Washington (ALS), for PCB Aroclor analyses using EPA Method 8082 with ultra-low-level MDLs. If PCBs were not detected above the MDL in the primary backup samples, the secondary backup effluent samples were submitted to Eurofins for PCB congener analysis.

The potential changes to water quality parameters from UV/AOP treatment were assessed by calculating the average relative percent differences (RPD) between influent and effluent measurements. Results of this analysis indicate the average RPDs for the ecoCUBE system are 0.3 percent for pH, 3.5 percent for ORP, 8.1 percent for temperature, 0.7 for conductivity, and 70.9 percent for turbidity. Results of this analysis indicate the average RPDs for the NeoTech system are 0.7 percent for pH, 2.9 percent for ORP, 4.0 percent for temperature, 0.7 for conductivity, and 47.1 percent for turbidity. Generally, water quality parameters for influent and effluent were similar.

Analytical results indicate that total PCB influent concentrations ranged between 180 ng/L (Run 1) and 290 ng/L (Run 5) (see “ecoCUBE Treatment System-Analytical Results” and Neotech Treatment System-Analytical Results” Tables 17 and 18, respectively). Analytical results also indicate that ecoCUBE effluent total PCB concentrations ranged between 18 ng/L (Run 5) and 96 ng/L (Run 8). Based on these results, the PCB destruction efficiency for the ecoCUBE ranged between 58.3 and 93.8 percent with an average of 76.7 percent (see Table 17) and approximately 6.2 grams of PCBs were destroyed. Analytical results indicate the PCB destruction efficiency for the NeoTech system ranged between approximately 82.2 and 99.9 percent with an average of 95.5 percent and approximately 7.9 grams of PCBs were destroyed. Analytical results are summarized in Tables 17 and 18 and the laboratory reports are included in Appendix C.

3.3.5.4 Findings

Results of the UV/AOP pilot-scale and demonstration-scale testing indicate that UV/AOP is a viable treatment technology to treat PCB-contaminated groundwater at the Facility. In general, greater PCB concentrations were destroyed from groundwater at lower treatment flowrates (20 gpm or less) and when hydrogen peroxide was added to the influent water at dosing concentrations of about 18 ppm. Because the technology is scalable, it is possible to achieve greater flow rates by increasing the number of UV reactors operating at any given time. Based on pilot testing data, UV/AOP treatment should be capable of achieving the screening levels required by the AAO. An added benefit of the technology is that PCBs are dechlorinated and mineralized into CO_2, Cl-, and H_2O (water) rather than transferring PCBs from water to another media (i.e., filter media) that then must be managed and disposed. In addition, operation and maintenance (O&M) effort primarily consists of periodic monitoring, maintaining hydrogen peroxide dosing, and replacing parts and equipment (a requirement of any treatment system).

3.3.5.4.1 UV/AOP Byproducts Assessment

Haley & Aldrich assessed potential byproducts from UV/AOP treatment by reviewing PCB congener analytical results from the ecoCUBE demonstration-scale study (Runs 1 through 41) and submitting a subset of influent and effluent samples from Run 7 for semi-volatile organic compound (SVOCs) and chloride analyses using EPA Method 8270 and EPA Method 300.0, respectively. PCB congener data from skid unit testing, SVOC, and chloride analytical results were reviewed for evidence of the reductive dechlorination process by comparing influent concentrations against effluent concentrations for each analyte. The PCB congener, SVOCs, and chloride byproduct results are summarized below.

3.3.5.4.1.1 PCB Congener Byproducts

PCB congener data from skid unit testing indicates influent PCBs predominantly are dominated by tri-, tetra-and penta-chlorinated biphenyl compounds (Hart Crowser 2021). Analytical results indicate that treatment with UV alone primarily results in dechlorination of the PCB from higher to lower chlorinated molecules; however, when hydrogen peroxide is used in combination with UV, dechlorination and mineralization are the primary reaction mechanisms (see Table 7).

3.3.5.4.1.2 SVOC and Chloride Byproducts

Analytical results indicate SVOCs were not detected at concentrations greater than the MDL in influent or effluent samples. However, if present it is anticipated that biphenyl (PCB 0) either would undergo direct oxidation with the ·OH formed from the reaction of hydrogen peroxide (H_2O_2) with the UV light or biodegradation under the aerobic conditions in the process effluent.

Analytical results indicate chloride concentrations were 7.6 micrograms (µg/L) and 7.5 µg/L in the influent and effluent samples, respectively. Haley & Aldrich calculated the RPD between the influent and effluent samples to be approximately 1 percent. Based on these results, it does not appear that the dechlorination of PCBs during UV/AOP treatment results in increases of chloride ions in effluent water.

3.3.5.4.2 ecoCUBE and NeoTech Side-by-Side Findings

Side-by-side testing data from the ecoCUBE and NeoTech UV/AOP systems indicate the NeoTech system is capable of achieving a higher average PCB destruction efficiency than the ecoCUBE over a wider range of treatment flow rates and hydrogen peroxide dosing rates. For instance, during Runs 8 and 10, treatment flow rates were approximately 20 gpm and hydrogen peroxide dosing rates were about 27 and 18 ppm, respectively. PCB destruction efficiencies for the ecoCUBE and NeoTech systems during Run 8 were approximately 58 and 95 percent, respectively. PCB destruction efficiencies for the ecoCUBE and NeoTech systems during Run 10 were approximately 86 and 94.6 percent, respectively. These results also indicate that the NeoTech system is capable of destroying PCBs at higher efficiencies using lower concentrations of hydrogen peroxide dosing and, therefore, could be a cost benefit for long-term operations.

The difference in PCB destruction efficiencies observed between the two systems likely is related to several primary factors, including: reactor shape, reactor materials, and the UV dose that each system is capable of achieving. The ecoCUBE reactors are rectangular in shape and much larger than the NeoTech reactor. The NeoTech reactor is cylindrical and much more compact than the ecoCUBE reactors. This larger configuration presents two factors that likely contribute to reduced destruction efficiency: flow through the ecoCUBE reactor likely is less turbulent than flow through the NeoTech reactor; the UV dose in the ecoCUBE reactor likely is reduced as a result. The flat sidewalls of the ecoCUBE reactors likely also reduce the UV dose when compared to the cylindrical walls of the NeoTech reactor that provides a parabolic reflection. The rectangle shape of the ecoCUBE reactor combined with the flow path of water through the reactor, from the bottom to the top, could create stagnant conditions in the corners and preferential pathways near the bottom of each reactor, reducing UV dose.

The reactor materials for each unit also are very different. The ecoCUBE reactor chambers are constructed from aluminum that is about 93 percent reflective and the NeoTech reactor chamber is constructed of stainless steel lined with a proprietary, reflective sleeve that reflects 99 percent of UV light, according to the manufacture’s website. This difference in reflectivity of the reactor materials also could account for the difference in PCB destruction. Additionally, aluminum oxidizes over time which can result in a loss of reflectance in the UV range; the oxidation rate of aluminum also increases with exposure to hydrogen peroxide and water, speeding the oxidation process, reducing the UV dose, and resulting PCB destruction efficiencies.

Analytical results of effluent samples analyzed from the side-by-side testing of the ecoCUBE and NeoTech systems indicate that the ecoCUBE system was able to achieve Ecology's screening level of 44,000 pg/L in four of the eleven tests completed; the NeoTech system achieved Ecology's screening level in each of the eleven tests completed (see Tables 17 and 18). The NeoTech system operated most effectively during Run 5 with a treatment flow rate of 5.5 gpm and measured influent hydrogen peroxide concentration of 8 ppm. During Run 5 the average UV intensity was 13.7 milliwatt per centimeter squared (mW/cm^2) and the destruction efficiency was 99.9 percent. However, the NeoTech system achieved between 82.2 and 99.9 percent destruction efficiency during Runs 2 through 11 and removed PCB mass to below the 44,000 pg/L screening level regardless of influent PCB concentration, treatment flow rate, or peroxide dosing. Based on these findings, Haley & Aldrich recommends advancing UV/AOP treatment for full-scale implementation using reactors that perform similar to the NeoTech system.

3.4 DISPROPORTIONATE COST ANALYSIS

Testing data for the three treatment technologies (WSFS, algae-based treatment, and UV/AOP) indicates that each technology was able to remove PCBs from contaminated groundwater with varying efficiencies. WSFS, algae-based treatment, and UV/AOP, have varying capital and long-term O&M costs associated with implementation. In order to assess these costs, Haley & Aldrich prepared a disproportionate cost analysis (DCA) to compare the estimated expenses associated with each technology if implemented at full-scale. Haley & Aldrich estimated net present value costs associated with each of the three treatment technologies using the following set of assumptions:

- Full-scale treatment flow rate of 200 gpm, continuously;
- Influent total PCB concentrations will be about 210 ng/L (the 95 percent upper confidence limit of influent concentrations observed during pilot testing documented in this report);
- Full-scale design assumptions for each technology are based on average performance during pilot testing;
- Full-scale designs include additional capacity to accommodate component shutdowns for regular maintenance activities;
- Disposal of treatment generated waste is included, if applicable;
- Operational timeframe is 40 years.

For the purposes of the DCA, a treatment flow rate of 200 gpm was assumed; however, the actual target treatment flow rate likely will vary based on treatment system performance and changes with the Remelt/Hotline plume characteristics over time. It should also be noted that influent concentrations likely will increase when the new extraction wells, HL-EW-02 and RM-EW-01, are commissioned. Additional details regarding the capital and operational assumptions used in the DCA for each treatment technology are provided in the following sections. The DCA is presented in "Disproportionate Cost Analysis", Appendix D.

3.4.1 WSFS

Based on analytical results from Runs 1 through 28, the average PCB removal efficiency for the WSFS was 62.7 percent. Based on this data, the WSFS in its present configuration, operating at 50 gpm, is not capable of removing PCBs from groundwater to the screening level listed in the AAO. In order to meet these limits, the DCA assumes that two walnut shell filters operating in series at 50 gpm will achieve the screening level. To achieve the target flow rate of 200 gpm, the DCA assumes four sets of filters

operating in series (eight filters total) are required for treatment and two additional sets of series filters (four filters) are required to accommodate the necessary O&M activities while maintaining full-time operations. Therefore, the DCA assumes that 12 filter units are installed in the Pilot Plant along with the associated additions to existing infrastructure (conveyance piping, utilities, pumps, controls), tankage (feed tanks, filtered water tanks, backwash water storage tanks), and expansion of the building.
The DCA assumes that castor oil and KlarAid amendment rates are 8 and 2 ppm, respectively, and includes O&M costs associated with disposal of spent walnut shell media, castor oil solids, and accumulated sediments in backwash storage tanks. The DCA assumes that the full-scale treatment system will require, on average, one full-time operator (8 hours per day, 5 days per week). The estimated capital cost for the WSFS system is about $6,252,100, the estimated annual O&M cost is about $497,300, and the net present value, assuming 40 years of operations, is $25,187,000.

3.4.2 Algae-Based Treatment

Based on analytical results from ten batch tests of the CWR system, the average PCB removal efficiency was 80 percent. However, the PCB removal efficiency for the system was calculated using the MRL for EPA Method 8082 (46 ng/L). Because the MRL is close to the screening level in the AAO, the DCA assumes that a full-scale CWR system is capable of achieving the screening level. Furthermore, it is assumed that the CWR system is scalable to treat at a continuous flow rate of 200 gpm. In 2019, Kaiser received a cost estimate from CWR to install a full-scale system; the DCA estimate for the CWR system relies on these costs supplied by the vendor. The DCA assumes that the full-scale treatment system will require, on average, two, full-time operators (16 hours per day, 5 days per week). The estimated capital cost for the CWR system is about $3,426,100, the estimated annual O&M cost is $331,200, and the net present value, assuming 40 years of operations, is $16,036,000.

3.4.3 UV/AOP

Results of the UV/AOP treatment technology testing indicates that UV/AOP is a viable treatment technology to treat PCB-contaminated groundwater to the screening levels indicated in the AAO. Demonstration-scale testing of the NeoTech system indicates that treating groundwater at flow rates between 5.5 and 21 gpm and hydrogen peroxide target concentrations between 8 and 27 ppm can achieve PCB destruction efficiencies of between approximately 82.2 and 99.9 percent and meet Ecology’s screening level of 44,000 pg/L. The DCA assumes that ten NeoTech reactors will operate in parallel, each running at 20 gpm (200 gpm total) and two backup reactors are installed for conducting O&M activities (12 reactors total). The DCA also assumes a hydrogen peroxide dosing rate of 18 ppm, which is slightly greater than the average dose used during pilot testing and, therefore, slightly more conservative. The DCA assumes that the full-scale treatment system will require, on average, one, full-time operator (8 hours per day, 5 days per week). The estimated capital cost for the UV/AOP system is about $1,930,200, the estimated annual O&M cost is about $260,900, and the net present value, assuming 40 years of operations, is $11,864,000.

3.5 RECOMMENDATIONS

Side-by-side testing data from the ecoCUBE and NeoTech UV/AOP systems indicate the NeoTech system is capable of achieving a higher average PCB destruction efficiency than the ecoCUBE over a wider range of treatment flow rates and hydrogen peroxide dosing rates. Results also indicate that the NeoTech system is capable of destroying PCBs at higher efficiencies using lower concentrations of hydrogen peroxide dosing and, therefore, could be a cost benefit for long-term operations. Analytical results of effluent samples analyzed indicate that the NeoTech system achieved Ecology's screening level in each of the eleven tests completed.

Results of the DCA indicate that a UV/AOP system requires less capital to construct and is less expensive to operate and maintain while achieving more consistent and better performance than walnut shell filtration or algae-based treatment. Based on these findings, Haley & Aldrich recommends advancing UV/AOP treatment for full-scale implementation using reactors that perform similar to the NeoTech system.

3.6 INFRASTRUCTURE EXPANSION

Kaiser has already expanded the conveyance piping to and from the Pilot Plant building and will evaluate the need to expand the Pilot Plant building structure during the design-phase of the full-scale remediation system. If an increase to the Pilot Plant building footprint is warranted for the full-scale treatment system, Kaiser will expand the existing building, electrical power supply, and other ancillary systems to accommodate the anticipated needs.

Kaiser plans to install internet service to the Pilot Plant building to improve operational efficiency and provide remote monitoring capability for the full-scale treatment system. The internet service also will allow installation of remote monitoring systems to observe discharge at the infiltration basin from the Pilot Plant building during operations. Temperature alarms also will be installed to Pilot Plant to notify Kaiser personnel of potentially freezing conditions and prevent damage to equipment. Kaiser will use data generated during full-scale operations to design an expand the extraction well network, as necessary.

Kaiser will obtain the required permits, or meet the substantive requirements of applicable permits, in accordance with WAC 173-340-400 if and when construction commences. Kaiser also will provide Ecology with engineering design and construction documents as they are generated.

3.7 PROPOSED SCHEDULE

The schedule for deliverables and actions for Phase 2 (Tasks 6 through 9), described in the AAO, are summarized below. The proposed schedule assumes that scheduling conflicts (i.e., report review turnaround and construction equipment/labor availability restrictions) will not occur and is subject to change if conflicts arise (note: this schedule assumes Ecology will review deliverables, with comments/edits incorporated, and deliver them to Kaiser within 30-days after received).

- **31 August 2022 -** Completed work for the IAWP based on "Ecology Approval of Extension Request for Completion of Phase I IA Work", dated 16 February 2022
- **15 October 2022 -** Phase 1 draft IACR due to Ecology
- **22 November 2022 -** Comments and revisions for Phase 1 final IACR due from Ecology
- **5 January 2023 -** Phase 1 final IACR due to Ecology (based on 6 December 2022 extension approved by Ecology) addressing comments/revisions
- **3 March 2023 -** Draft EDR due to Ecology
- **2 April 2023 -** Comments and revisions for final EDR due from Ecology
- **2 May 2023 -** Final EDR due to Ecology addressing comments/revisions
- **1 June 2023 -** Initiation of EDR field work

- **26 February 2024 -** Initiating operation of full-scale pump and treat system
- **27 April 2024 -** Phase 2 draft IACR due to Ecology
- **27 May 2024 -** Comments and revisions for final Phase 2 IACR due from Ecology
- **26 June 2024 -** Final Phase 2 IACR due to Ecology
- **25 August 2024 -** Start Phase 2 IA Periodic Performance Reports Due to Ecology with 6-month reporting thereafter

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