RECAP Evaluation

Henning Management, LLC v Chevron USA, Inc et al;
Docket No. 73318; 31st JDC; Division “C”, Jefferson Davis Parish, LA
Hayes Oil Field, Calcasieu and Jefferson Davis Parish, LA

16th Judicial District Court for the Parish of St. Mary
State of Louisiana
Docket No. 129750

Prepared by

Richard J. Schuhmann, Ph.D.

October 14, 2022

Table of Contents

EXECUTIVE SUMMARY

The Henning property is a 1,246-acre site that spans both Calcasieu and Jefferson Davis Parishes and is part of the Hayes Oil Field. Historic exploration and production activities took place at the site, evidenced by remaining machinery, pits, and land scarring. Contaminants consistent with this type of industrial activity are found in the soil and groundwater at the site in including organic (TPH) and inorganic (arsenic, barium, cadmium) compounds.

It is my understanding that the landowner demands the property be remediated according to the standards required by Statewide Order 29-B, without using RECAP as an exception under Section 319 or Statewide Order 29-B. Further, the landowner has refused to consent to using RECAP as an exception to 29-B to guide this MFP. This RECAP analysis is therefore provided solely as a contrast to and comment on the RECAP analysis provided by ERM (March 4, 2022), aspects of which this report significantly diverges from and disagrees with.

A RECAP Management Option 2 (MO-2) evaluation was conducted to determine if site specific conditions pose a risk to human health or the environment. A total of 37.7 acres of the 1,246-acre site contain arsenic and/or barium at concentrations in excess of the MO-2 recap standard and require remediation. There are groundwater plumes for several RECAP contaminants of concern (TPH-DRO, Benzene, Barium, Cadmium), all of which contain groundwater with CoCs in excess of Groundwater Classification 2 standards and which, if the land is used for residential purposes with on site drinking water wells, would require remediation; however, if the land use is restricted such that there is no on site exploitation of groundwater resources, then GW2 will not be exceeded at the property boundaries and remediation would not be required.

1.0 INTRODUCTION

1.1 Site Description

The subject property is comprised of approximately 1,246 acres located in portions of Sections 16, 17, 18, 19, 20, and 21 in T11S R5W; and Section 24 in T11S R6W in the Hayes Oil Field in Calcasieu and Jefferson Davis Parishes, Louisiana (Figure 1, ICON Figure 1). The site is accessed via La Highway 14E which runs through the west-central portion of the site and borders the southernmost boundary of the property. Surface topography as shown on LIDAR contours in Figure 2 ranges from +5 feet NGVD in Section 18 and the northern portion of Section 19 (forming a very gently east-west ridge), to +1 NGVD in the eastern half of Section 18 (along a drainage feature draining areas north of the ridge) and the southeast quarter of Section 20 (along a drainage feature draining areas south of the ridge).

1.2 Historical Information Related to the Release[1]

The property is part of the Hayes gas field, which was discovered by Gulf Refining Company (Gulf) in 1942 after several wildcats had been drilled in the area beginning about 1936. In January 1941, Gulf began drilling the Calcasieu National Bank #1 well (sn25340) in the southeast quarter of Section 18 on the subject property. In March 1941, 9-5/8" casing was set to 9200 feet and cemented, and after drilling to 10,534 feet the 7" casing was set and extended upward into the 9-5/8" casing a distance of 1593 feet. On July 16, 1941, the bottom of the 7" casing was perforated for a cement squeeze and the well immediately pressured up and Halliburton was hired to lubricate the well (pump a heavy mud column). On July 20, 1941 the well blew out at the well head connection and continued as an uncontrollable blowout until August 13, 1941 when it bridged over and killed itself. Throughout this 23-day period, the well continuously erupted large volumes of salt water and sand mixed with distillate and other substances several hundred feet in the air. For half of this period the well was on fire.

On August 1, 1941, Gulf submitted an application to drill the Calcasieu National Bank #2 well (sn26358) located 800 feet east of the blowout well in Section 18. The CNB #1 bridged over before the first string of casing could be run in the CNB#2. The CNB#2 was completed in April 1942. In December 1951, H.L. Hawkins completed the Hayes Unit #1 (sn44135) in the northwest quarter of Section 20. In May 1952, Gulf completed the Hayes Unit 1 #3 well in Section 17 on the subject property.

Additional development by Gulf proceeded with:

The Hayes U1 #3 well (sn45305) in Section 17 in 1952 (offsite);
Hayes U1 #4 well (sn74797) in Section 18 in 1959 (offsite);
Hayes U1 #5 well (sn65938) in Section 19 in 1957 (offsite);

[1] Historical information related to the releases was compiled by ICON Environmental: Expert Report and Restoration Plan for the Landowners, Henning Management, LLC v Chevron USA, Inc et al; Docket No. 73318; 31st JDC; Division "C", Jefferson Davis Parish, LA, Hayes Oil Field, Calcasieu and Jefferson Davis Parish, LA

Hayes U1 #6/#6d wells (sn103174 / sn105169) in Section 19 in 1964;
Hayes U1 #7 (sn128241) in Section 20 in 1969, and the
Hayes U1 #8 (sn146553) in Section 19 in 1974 (offsite).

Historical imagery indicates that all of these wells tied in to a central production facility located east of the CNB#2 / Hayes U1 #2 well. A 1971 aerial image (Figure 2, ICON Figure 12) shows features associated with this development including:

Two pits at the SWD well site, and a tank battery and production pit east of the #2 well.
Pit features around the #3, #6 and #7 well pads. Production equipment is also apparent around these well pads.

The 1974 image (Figure 3, ICON Figure 13) is of poor quality but shows the pit features appear to remain in use. The 1981 image (Figure 4, ICON Figure 15) is of higher quality and shows:

The pit north of the SWD and south of the #2 well tank battery is no longer visible. Scarring is evident around the tank battery.
The pit north of the #6 well pad appears to have been backfilled but scarring in the former pit area and around the well pad is visible.
The pits at the #7 well appear to still be in use. An area of vegetative scarring is visible north of the #7 well pad.
Pits at the #3 well appear open and holding fluids.

The 1983 aerial image (Figure 5, ICON Figure 16) shows similar features, except the pits at the #3 well pad appear to have been backfilled. The 1994 aerial image (Figure 6, ICON Figure 17) image shows most of the pits have been backfilled with the exception of one north of the #2 well, and one northwest of the #3 well. The tank battery and other production equipment no longer appear visible at the #2 well.

H.L. Hawkins completed the Coastal Hawkins-Hayes Unit 1 #2 well (sn44135) in 1951 in Section 20 just east of the Gulf wells. Pit features are visible on the 1952 image (Figure 7, ICON Figure 11). In June 1963, the Operator of Record changed to Coastal States Gas Producing Company. The same pit features are visible with scarring on the levees visible on the 1971 image (Figure 2, ICON Figure 12). The well was P&A'd by Coastal States in March 1971. By 1974 (Figure 3, ICON Figure 13) the pad and pits are no longer visible.

Coastal States Gas Producing Company drilled the #3 well (sn97657) in 1963, and the #4/#4d (sn100844/sn105813) in 1964 in Section 20. The 1971 image (Figure 2, ICON Figure 12) shows a production pit with scarring on the pit levees located east of the #3 well. The #4 wells had a change in operator in June 1972 to Equipment, Inc. The wells were plugged in December 1973. The #3 well had a change in operator in August 1972 to Thomas Hoffpauir. The #3 was P&A'd in July 1998 by Separation System Co/Hebert Oilfield Construction Inc.

Graham Exploration Ltd drilled the Hayes U1 #3 well (sn195098) in the northwest corner of Section 20 in December 1984. Applications for annular injection in 1991 and 1992 were approved by the DNR OC. The operator of record changed to Petrocana Inc in April 1992, and to United World Energy Corp in 1993. The 1994 aerial image (Figure 6, ICON Figure 17) and 1998 image (Figure 7, ICON Figure 18) shows the well pad with a tank battery on the south side of the access road to the pad. The well was P&A'd in 2012.

Flynn Energy Corp drilled two wells in the northeast corner of Section 19, the U1 #1 (sn206344) in 1987 and the U1 #2 (sn208909) in 1988 at the former location of the Gulf #8 well. An application for annular injection was approved in 1989. The operator of record changed to Coda Energy in August 1990, and to Petrocana Inc in April 1991, and to United World Energy Corp in July 1993. The #1 well was P&A'd in 1999, and the #2 well is listed as temporarily inactive. The 1998 aerial image (Figure 13, ICON Figure 18) indicates that separation equipment and a tank battery was located at the #1 well pad. The 2004 image (Figure 8, ICON Figure 19) shows that the well pad remains but no production equipment is visible.

Flynn Energy Corp drilled the Walker Properties #2 well (sn207055) in 1987 on the same footprint as the Gulf production facility in Section 18. The well was dry and P&A'd. Petrocana Inc. re-entered the well as the Walker Properties #1 (sn213760) in 1991. A series of unsuccessful completions were attempted through 1992. The operator of record changed to United World Energy Corp in July 1993. The well is currently shut in.

Sources of soil contamination at the site consist of historical pits, surface discharges from production equipment, and the Calcasieu Natl Bank #1 (sn25340) blowout as determined from scarring and vegetative stress on historical aerial images.

1.3 Land Use

The site currently supports residential, agriculture and recreational land uses and is within several miles of Hayes, Louisiana, a town comprised of 299 housing units which supports 676 residents (2020 data).[2] To establish appropriate RECAP standards, the site is considered non-industrial and non-industrial land use values were applied in the Screening and Management Option evaluations.

2.0 INVESTIGATION

Site investigation data relied explicitly upon in this assessment were collected by ICON Environmental Services Inc. (ICON) between October 2019 and August 2021, and samples collected and split with ERM between November 2021 and January 2022. These data consisted of chemical analyses of soil (Tables 1a, 1b, 1c, 1d) and groundwater (Table 2), potentiometric groundwater elevations in the upper alluvial unit (Figure 9, ICON Figure 9), and a cross-sectional lithological characterization of the subsurface from borings (Figure 10, ICON Figure 8).

[2] US Census Bureau, https://data.census.gov/cedsci/profile/Hayes_CDP,_Louisiana?g=1600000US2233490

2.1 Geologic and Hydrologic Conditions[3]

The NRCS maps the soils in the subject assessment area as prime farmland (Figure 11, ICON Figure 4), with the following soil types:

> Midland Silty Clay Loam, rarely flooded (Mn): This poorly drained soil was formed from late Pleistocene age loamy alluvium on terraces, with rare to no flooding and no ponding, and is classified as prime farmland. Maximum salinity is nonsaline to very slightly saline (0 to 2 mmhos/cm), with a maximum sodium adsorption ratio (SAR) of 5.
>
> Edgerly Loam (Mr): This poorly drained soil was formed from Pleistocene age loamy fluviomarine deposits on flats, with rare to no flooding and no ponding, and is classified as prime farmland. Maximum salinity is nonsaline to slightly saline (0 to 4 mmhos/cm) with a maximum SAR of 4.
>
> Mowata-Vidrine complex (MwA): This poorly drained soil was formed from late Pleistocene age loamy fluviomarine deposits on drainageways, with rare to no flooding and no ponding, and is classified as prime farmland. Maximum salinity is nonsaline to very slightly saline (0 to 2 mmhos/cm) with a maximum SAR of 2.
>
> Crowley-Vidrine complex (Cr/CrA): This somewhat poorly drained soil was formed from Pleistocene age clayey fluviomarine deposits on terraces, with no flooding or ponding, and is classified as prime farmland. Maximum salinity is nonsaline to very slightly saline (0 to 2 mmhos/cm) with a maximum SAR of 10.

The Louisiana Geological Survey (LGS) maps the surface geology of the subject property and surrounding areas as “Ppbe”, the Beaumont Alloformation, the Pleistocene stratigraphic sequence underlying the oldest and topographically highest of the Prairiesurfaces west of the Mississippi alluvial valley. It exhibits the relict channels of the Red River (Figure 6). The principal potable aquifer in this area is the Chicot Aquifer (200 and 500-foot sands). Shallow geology was determined from lithological descriptions of core samples, driller’s logs of water wells, and geophysical logs of some of the oil wells. Shallow lithology is depicted on an East-West Cross Section diagram (Figure 10, ICON Figure 8). The general shallow geology is as follows:

> 0-20 to 40 feet bls: Clay and Silty Clay, gray with red and orange staining, stiff to med soft, with a layer of shell fragments at approximately 10 feet bls. Low pressure on HPT logging indicates this stratum is permeable to water.
>
> ~20 to 50 feet bls: SILT, Clayey Silt, and Silty Sand, herein termed the

[3] The site geology, hydrology, and hydrogeology was compiled by ICON Environmental: Expert Report and Restoration Plan for the Landowners, Henning Management, LLC v Chevron USA, Inc et al; Docket No. 73318; 31st JDC; Division “C”, Jefferson Davis Parish, LA, Hayes Oil Field, Calcasieu and Jefferson Davis Parish, LA; hydraulic gradients, conductivities, well yields, were calculated independently

Shallow Aquifer System. Near Bayou Lacassine, the saturated permeable strata are comprised of almost 30 feet of saturated silt with sand at the base that thins laterally to the west away from the bayou. At distances of approximately one mile from the bayou, the saturated permeable strata occur at depths of 30 to 45 feet and appear to have been deposited as sinuous channel fill over 8 feet thick along the axis of the channel and grading laterally to thicknesses of less than one foot (see Isopach Map in Figure 12, ICON Figure 36). Static groundwater in this stratum occurs at depths of ~2 to 6 feet bls.

~40 feet thick in the east to 80 feet thick in the west: stiff CLAY that comprises the confining unit for the Chicot Aquifer. Thin zones of low pressure on HPT logging in this stratum indicates the presence of permeable lenses of silt.

~100 to ~130 feet bls: Sand and Gravel of the Chicot Aquifer. Static groundwater in the Chicot occurs at depths of 40 to 46 feet bls.

1190’: Base of the Underground Source of Drinking Water (USDW), as found in the well file for the Hayes SWD #1, sn970423 in Section 19 T11S R5W.

Groundwater flow was determined by measuring depth to static groundwater level relative to the surveyed top of well casing elevation. Potentiometric measurements on May 21, 2021 in the monitoring wells (Figure 9, ICON Figure 9) show overall groundwater primarily flows to the northward. The highest potentiometric elevations (over +4 feet NAVD88) were in the northeast corner of Section 29 occur in areas of highest land surface elevation (+5 feet NAVD88), and the lowest (-1.62 feet NAVD88 in H10) was located along a drainage ditch near the northern drainage feature. The defined hydraulic gradients to the northwest (H18 ~> H2; i ~ 1.1) and northeast (H1 ~> H20; i ~ 0.9) are both ~1E-03 ft./ft.

2.2 Groundwater Classification

Hydraulic Conductivity

ICON performed aquifer tests (slug tests) at the site, including in Monitoring Wells H3, H9, H18, H20. These data were analyzed using the Hvorslev Method and Bouwer and Rice Method, both methods supported by RECAP guidance.[4] The geometric mean hydraulic conductivity for the Hvorslev Method was 1.32E-03 cm/sec, and 8.06E-04 cm/sec for the Bouwer and Rice Method, resulting in a combined geometric mean hydraulic conductivity for the site of 1.03 cm/sec (Table 3).

Well Yield

Hydraulic conductivity can be used to estimate yield from a hypothetical water supply well. The estimated well yield equation is derived from the Cooper and Jacob (1946) modification to the

[4] RECAP, 2003, Appendix F, Table F-2, page TF-1

Theis (1935) nonequilibrium well equation using some assumptions and logarithmic functions.[5] The estimated well yield for a confined aquifer is as follows:

$$Q = \frac{6o\ h_c K\ b}{9.3 + \log(K\ b)}$$

Where
Q = yield from pumping well (gpm)
h_c = confining head above the upper stratigraphic boundary of the aquifer (ft.)
K = hydraulic conductivity of the aquifer media (cm/sec)
b = saturated aquifer thickness (ft.)

RECAP requires using the geometric mean when averaging a number of hydraulic conductivity results from a site.[6] Using the geometric mean hydraulic conductivity determined for each slug test at each boring (3 slug tests at each of the 4 borings) of the Hvorslev Method and Bouwer and Rice Method, and the saturated aquifer thickness and confining head at each boring, a distribution of twelve Well Yields (Q) were calculated. These values ranged from 755 gpd to 4855 gpd, with a geometric mean of 1652 gpd (Table 4).

Subsequent slug test data were collected by ERM at MW-1, MW-2, MW-3, MW-4, MW-5, MW-6, MW-7, MW-8, MW-9, MW-9d, MW-10, MW-11, and H-27. The results of these slug tests indicate a broad range of hydraulic conductivities that do not follow a geographic pattern and instead are an indication of the relative inhomogeneity of the underlying water bearing unit as a function of geology. ICON addressed these new data in their October 14, 2022 submission, quantifying yields from water bearing units “A Bed” and “B Bed” within the shallow aquifer. A future water well driller would be seeking a water bearing unit or series of water bearing units to exploit; the data clearly indicate there is sufficient yield from the shallow aquifer to provide greater than 800 gpd either from locations screened either exclusively in the B Bed or from other locations screened across a combination of A Bed and B Bed.

Shallow Aquifer Water Quality - TDS
A series of monitoring wells (H3, H32, H33, H34) were installed to collect groundwater quality data on the property as distant to the east of historical onsite production activities as possible in order to better represent un-impacted conditions and reflect the background TDS. Data from these wells (Table 5) indicate a mean TDS concentration of 980 mg/L with a 95UCL of 1275 mg/L (Table 6). Although these “background” data may suggest some degree of impact from historic oilfield operations, the 95UCL was applied as representative of the site.

RECAP Shallow Aquifer Classification
RECAP (2003) classifies groundwater by its current or potential use, maximum sustained yield, and background concentration of total dissolved solids (TDS).[7] Given the observed well yield

---

[5] RECAP, 2003, Appendix F, page TF2-4
[6] RECAP, 2003, Appendix F, page F-6
[7] RECAP, 2003, pages 49-52

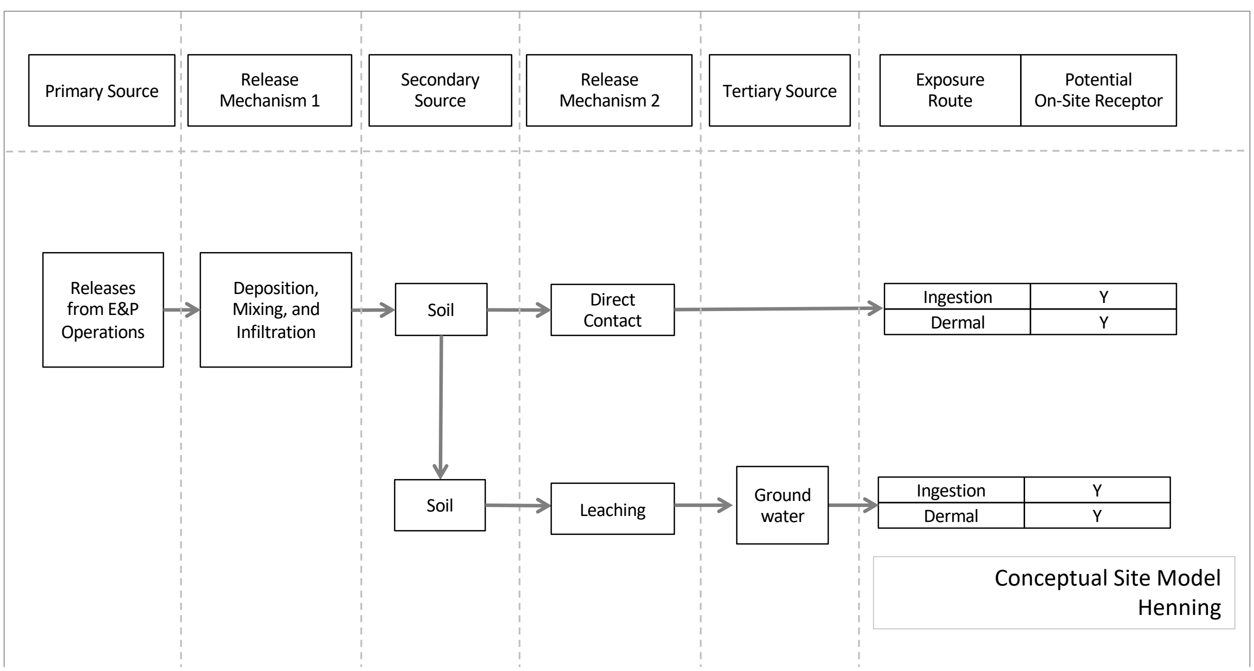
based upon the geometric mean of hydraulic conductivity results (1652 gpd), and 95 UCL water quality (1275 mg/L), the upper groundwater is classified by RECAP as a Class 2C for subsequent evaluations. Class 2C groundwater occurs within an aquifer that could potentially supply drinking water to a domestic water supply based upon quantity and quality. The aquifer must be able to transmit water to a well at a maximum sustainable yield of greater than or equal to 800 gpd and have a TDS concentration greater than 1,000 mg/L but less than or equal to 10,000 mg/l.[8]

2.3 Constituents of Concern

From a review of ICON field data and the historic use of areas of the property for oilfield activities, the likely RECAP constituents of concern (CoCs) appear to be those related to the former use of the property and are clustered within those areas: TPH-DRO, TPH-ORO, Arsenic, Barium, and Cadmium.

2.4 Conceptual Site Model

Given the site history and the nature and distribution of CoCs at the site, the following conceptual site model (CSM) was developed to guide subsequent RECAP evaluations.



[8] RECAP, 2003, page 51

3.0 RECAP EVALUATION

3.1 Screening Option

3.1.1 Background

For the screening analysis, groundwater in the shallow aquifer was assessed as were unsaturated soils extending from the surface to 15 ft. bgs, which are considered surface soils consistent with RECAP.[9] The appropriate RECAP screening standards for soil and groundwater were identified and are defined as follows:

Soil_SSni[10]
The SoilSSni represents a constituent concentration in soil that is protective of human health for non-industrial land use. The Soil_SSni values were obtained from Table 1.[11] The exposure pathways addressed by the Soil_SSni include the ingestion of soil, the inhalation of volatile emissions released from soil to the ambient air, and dermal contact with soil.

Soil_SSGW[12]
The Soil_SSGW represents a constituent concentration in soil that is not expected to result in the leaching of an unacceptable constituent concentration from soil to shallow aquifer system groundwater. The Soil_SSGW serves to protect groundwater meeting the definition of Groundwater Classification 1 and is applicable to groundwater meeting the definition of Groundwater Classifications 1, 2, and 3. Thus, the Soil_SSGW represents the constituent concentration in soil that will not result in a groundwater concentration that exceeds the GWSS. As an alternative to applying the Soil_SSGW at the AOI, the soil to groundwater pathway may be evaluated using the Synthetic Precipitation Leaching Procedure (SPLP) (refer to Appendix H). The soil to groundwater pathway shall be evaluated for surface soil and subsurface soil.

GW_SS[13]
The GW_SS serves to protect groundwater meeting the definition of Groundwater Classifications 1, 2, and 3. The GW_SS represents a constituent concentration in groundwater that is protective of human health. The GW_SS were obtained from Table 1. The exposure pathways addressed by the GW_SS include the ingestion of groundwater and the inhalation of volatile emissions associated with indoor groundwater use. Exposure assumptions representative of a non-industrial (residential) RME scenario were applied and a risk-based standard was developed for both carcinogenic and noncarcinogenic health effects; the lower of the two values was identified as the GW_SS. The GW_SS is applicable to groundwater meeting the definitions of Groundwater

---

[9] RECAP, 2003, Appendix H, page H-7
[10] RECAP, 2003, page 54
[11] RECAP, 2003, Table 1, Screening Option, Screening Standards for Soil and Groundwater
[12] RECAP, 2003, page 55
[13] RECAP, 2003, page 58

Classifications 1, 2, and 3. A dilution and attenuation factor shall not be applied to the GWSS.

The soil and groundwater sampling analytical results were compared to the above screening standards (*i.e.* Soil_SSni, Soil_SSGW, and GW_SS). Based upon this comparison, the constituents of concern (CoC) for each screening standard were identified.

3.1.2 Soil Direct Contact (Soil_SSni)

Soil direct contact screening standards for non-industrial sites (SOIL_SSni) are developed considering direct contact exposure with soil includes ingestion, dermal contact, and inhalation of volatile emissions to ambient air. CoCs that exceeded the non-Industrial soil screening standard are Arsenic, Barium, and TPH-DRO. These results are shown numerically in Table 7 and their distribution appears graphically in Figure 14.

3.1.3 Soil to Groundwater (Soil_SSGW)

The Soil_SSGW represents a constituent concentration in soil that is not expected to result in the leaching of an unacceptable constituent concentration from soil to groundwater, and represents the constituent concentration in soil that will not result in a groundwater concentration that exceeds the GWSS.[14]

Soil to groundwater screening standards (SOIL_SSGW) are developed with specific simplifying assumptions regarding site size (<0.5 acre) and leachate dilution, as well as chemical behavior (e.g. leachability by different test methods). CoCs that exceeded the soil to groundwater screening pathway for groundwater protection are Barium, and TPH-DRO. These results are shown numerically in Table 8 and their distribution appears graphically in Figure 15.

3.1.4 Groundwater (GW_SS)

Groundwater screening standards (GW_SS) serve to protect groundwater meeting the definition of Groundwater Classifications 1, 2, and 3 and represents a constituent concentration in groundwater that is protective of human health.[15] CoCs that exceeded the groundwater screening standards are Arsenic, Barium, Cadmium, TPH-ORO TPH- DRO, and Benzene. GW_SS exceedances are shown numerically in Table 9 and appear graphically in Figure 16.

3.1.5 Surface Water

One surface water sample (SW-BO-13') was collected which contained TPH-DRO at a concentration in excess of the GW_SS (0.182 mg/L); however, given there are no screening standards for surface water, the assessment of this sample is set aside for this evaluation.

---

[14] RECAP, 2003, page 55
[15] RECAP, 2003, page 58

3.1.6 Screening Option Results

The screening reveals that the primary CoC is Barium, which resides primarily, although not exclusively, within the top 2 ft. of surface soils, and concentrations in excess of the screening level are clustered within several geographic areas. Groundwater CoCs are distributed more widely across the site and evaluated subsequently under the Management Option 2 as Points of Compliance (POCs). Based upon these results, preliminary AOIs for the soil-to-groundwater pathway were established for further evaluation under a RECAP Management Option.

3.2 Areas of Investigation

3.2.1 Soil to Groundwater ($Soil_{GW2}$) AOIs

The soil AOIs are three-dimensional spaces which contains all data points with constituent concentrations above the Soil_SSGW as well as those points with concentrations equal to or less than the screening standards. Based on the identified sampling locations where Soil_SSGW were exceeded, horizontal and vertical AOI boundaries were delineated for Barium and separately for TPH-DRO.

The Soil-to-Groundwater (SGW) AOIs for Barium appear graphically in Figure 17 and the geometries of the Soil AOIs are as follows:

Soil-to-Groundwater AOI-1
SGW AOI-1 is trapezoidal in shape, 5.4 acres in area, oriented in the direction of groundwater flow with a width (S_w) of 518 ft. (158 m) and a length (L) of486 ft. (148 m). The AOI depth is set at 2 ft. bgs. As defined in RECAP,[16] given the depth of impact is less than or equal to 15 ft bgs, the AOI is delineated for surface soil (the soil interval extending from ground surface to the depth of impact). SGW AOI-1 contains the following borings: MW-2, MW-3, H-9, H-11, H-11N, H-11S, and H-12.

Soil-to-Groundwater AOI-2
SGW AOI-2 is rectangular in shape, 3.48 acres in area, oriented in the direction of groundwater flow with a width (S_w) of 531 ft. (162 m). and a length (L) of 286 ft. (87 m). Given the depth of impact is less than or equal to 15 ft bgs, the AOI is delineated for surface soil (the soil interval extending from ground surface to the depth of impact). SGW AOI-2 contains the following borings: H-8, H-8N, H-8N2, H-8S, H-8S2, H-8E, H-8W, H-15N, H-15W, H-16, H-16R, H-16N, H-16S, H-16E, H-16W, H-22, H-22N, H-22S, H-22S2, H-22E, and H-22W.

Soil-to-Groundwater AOI-3
Soil AOI-3 is rectangular in shape, 1.88 acres in area, oriented in the direction of groundwater flow with a width (S_w) of 492 ft. (150 m). and a length (L) of 166 ft. (50 m).

---

[16] RECAP, 2003, page 36

The AOI depth is set at 2 ft. bgs. As defined in RECAP, given the depth of impact is less than or equal to 15 ft bgs, the AOI is delineated for surface soil (the soil interval extending from ground surface to the depth of impact). SGW AOI-3 contains the following borings: H-1, H-1R, H-17, H-18, H-18SW, H-19, H-19R, H-19NE, H-19SW

Soil-to-Groundwater AOI-4

Soil AOI-4 is rectangular in shape, 1.66 acres in area, oriented in the direction of groundwater flow with a width (S_w) of 318 ft. (97 m) and a length (L) of 232 ft. (71 m). The AOI depth is set at 2 ft. bgs. As defined in RECAP, given the depth of impact is less than or equal to 15 ft bgs, the AOI is delineated for surface soil (the soil interval extending from ground surface to the depth of impact). SGW AOI-4 contains the following borings: H-24 H-24N, H-24S, H-24E, H-24W, H-24NE, H-24NW, H-28, H-28N, H-28S, H-28E, and H-28W.

Soil-to-Groundwater AOI-5

Soil-to-Groundwater AOI-5 is rectangular in shape, 0.76 acre in area, oriented in the direction of groundwater flow with a width (S_w) of 236 ft. (72 m) and a length (L) of 139 ft. (42 m). The AOI depth is set at 2 ft. bgs. As defined in RECAP, given the depth of impact is less than or equal to 15 ft bgs, the AOI is delineated for surface soil (the soil interval extending from ground surface to the depth of impact). SGW AOI-5 contains the following borings: H-5 and H-6.

Soil-to-Groundwater AOI-6

Soil AOI-6 is rectangular in shape, 3.64 acres in area, oriented in the direction of groundwater flow with a width (S_w) of 423 ft. (129 m) and a length (L) of 388 ft. (118 m). The AOI depth is set at 2 ft. bgs. As defined in RECAP, given the depth of impact is less than or equal to 15 ft bgs, the AOI is delineated for surface soil (the soil interval extending from ground surface to the depth of impact). SGW AOI-6 contains the following borings: H-4, H-4N, H-4N2, H-4S, H-4E, H-4E2, H-4W, H-4W2

3.2.2 Barium Soil Direct Contact (Soilni) AOIs

Five barium $Soil_{ni}$ AOIs were defined and their associated borings and Barium soil concentrations appear in Table 10. The areal extent was defined for each AOI-1 (7 acres), AOI-2 (4.25 acres), AOI-3 (1.25 acres), AOI-4 (3.34 acres), AOI-5 (0.76 acres), and AOI-6 (4.5 acres) and the AOIs appear graphically in Figure 18. A 95 UCL concentration was calculated for each AOI except for AOI-5 for which there were only two data points and the mean CoC concentration value was used (Table 11).

3.3 Management Option 1

3.3.1 RECAP Management Option 1 Requirements

Under RECAP a Submitter may choose to evaluate the soil or groundwater under the screening option and/or Management Option 1 (MO-1) prior to conducting a MO-2 evaluation. Given the magnitude of this site (1,246 acres) and the resulting AOIs (0.76 – 48.5 acres), a MO-1 evaluation is not an option for $Soil_{ni}$ or SoilGW2 as the total area of impacted soil as well as each of the resulting AOIs are greater than 0.5 acres;[17] therefore an MO-2 evaluation is necessary for these pathways.

3.4 Management Option 2

A Management Option 2 evaluation (MO-2) functions as a tier 2 evaluation to determine if site specific conditions pose a risk to human health or the environment. Evaluation of the Class 2 aquifer will also be performed under MO-2 for consistency with the soil pathways.

3.4.1 Soil Direct Contact ($Soil_{ni}$) Evaluation

Management Option 2 provides for the development of soil and groundwater RS using currently recommended default exposure assumptions and toxicity criteria. The resulting MO-2 RS are intended to represent constituent concentrations in media that are protective of human health and the environment under site-specific conditions.[18]

The CoCs exceeding SOIL_SSni were comprised of two metals (arsenic, barium), and diesel range total petroleum hydrocarbons (TPH). The health effects associated with exposure to the metals are taken from LDEQ RECAP[19] and appear below.

Constituent	**CAS#**	**Critical Effect(s)/Target Organ(s)**	**Carcinogen**
Arsenic	7440-38-2	Skin effects (hyperpigmentation and keratosis); Vascular effects	Yes
Barium	7440-39-3	Kidney effects (weight gain)	No

Historically, cleanup guidelines were often expressed in concentrations of diesel range organics (DRO) and gasoline range organics (GRO) TPH. DRO are semivolatile components of TPH consisting of C-10 to C-28 alkanes.[20] The table below shows overlap between TPH DRO (Aliphatic C-10 to C-28) with >C8-C16 and >C16-C35 TPH alkanes in RECAP.

[17] RECAP, 2003, page 95
[18] RECAP, 2003, page 3
[19] RECAP 2003, Appendix G, Guidelines for Addressing Additive Health Effects under the RECAP
[20] Sigma Aldrich, https://www.sigmaaldrich.com/technical-documents/articles/reporter-us/dro-eph-etph-gro.html

Constituent	CAS#	Critical Effect(s)/Target Organ(s)	Carcinogen
Aliphatics >C8-C16	NA	Liver effects; Hematological system effects	No
Aliphatics >C16-C35	NA	Liver effects	No

There is no additivity between site CoCs as health effects are independent.

3.4.1.1 Barium Reference Dose Update

For the development of the SS and MO-1 RS LDEQ obtained toxicity values from a hierarchy of references, beginning with the US EPA Integrated Risk Information System (IRIS) (EPA, http://www.epa.gov/iris/), which contains verified reference doses and cancer slope factors and up-to-date health risk and EPA regulatory information for numerous constituents. Since RECAP 2003 was published, the US EPA has updated the oral reference dose (RfDo) for Barium (entered in IRIS in 1998) from 0.07 mg/kg-day,[21] to 0.2 mg/kg-day (revised in IRIS in 2005). The health effect associated with barium ingestion is restricted to nephropathy. Employing this RfDo revision into the foundational equation used for the development of the Soil_SSni RS results in a change in the $Soil_{ni}$ RS value resulting from the MO-2 evaluation.

3.4.1.2 Consideration of Acute Health Risks

Acceptable risk levels for site management decisions under the MO-2 are determined in accordance with specified guidelines, including a consideration of Acute Health Risks. Specifically, for residential (*i.e.* non-industrial, ni) land use, acute toxicity may be a concern for a child receptor engaging in soil pica behavior, especially for CoCs found at the site such as barium and cadmium.[22]

Soil pica is the recurrent incidental consumption of unusually high amounts of soil (*e.g.* 1,000−5,000 mg/day or more). In soil pica behavior, surface soils (top 2-3 inches) are generally the primary source of consumed materials. Pica behavior first appeared in literature in the 13th century.[23] In the United States, the incidence of families reporting pica behavior in children was documented in early literature: 1957 (10% – 14%),[24] 1966 (11%).[25] A 1988 study external to the United States (in Jamaica) found similar results, with 10.5% of the children observed exhibiting pica behavior (consuming between 20 and 60,692 mg/day).[26]

---

[21] RECAP, 2003, Appendix H Equations, Worksheet SF & RfD

[22] RECAP, 2003, pages 64-67

[23] Pica: Common but Commonly Missed, Rose, E.A., J.H. Porcerelli, A.V. Neale, JABFP September-October 2000, Vol. 13, No.5

[24] Cooper, M. (1957) Pica: A survey of the historical literature as well as reports from the fields of veterinary medicine and anthropology, the present study of pica in young children, and a discussion of its pediatric and psychological implications. Springfield, IL: Charles C. Thomas.

[25] Barltrop, D. (1966) The prevalence of pica. Am J Dis Child 112(2):116−123.

[26] Calabrese, E.J., and Stanek, E.J. (1993) Soil pica: not a rare event. J Environ Sci Health, A28(2):373384.

According to LDEQ, pica ingestion rates of 25,000 – 60,000 mg/day should be considered in developing SS and RS based upon the protection of chronic health effects potentially associated with soil pica for the child receptor. [27] According to the US EPA, survey response studies of reported soil ingestion behavior conducted in numerous locations in the US and of different populations consistently yield a certain proportion of respondents who acknowledge soil ingestion by children. Hand-to-mouth soil ingestion incidents are likely to represent a quantity of soil consistent with the definition of soil pica and the associated ingestion rate of 1,000 mg/day, which is the current US EPA recommended value for use in risk assessments involving soil pica for children 1 to <6 years old.[28] For the purpose of this MO-2 evaluation, the US EPA value of 1000 mg/day is adopted.

3.4.1.3 Barium Evaluation and MO-2 RS Determination

Development of the Barium MO-2 Soil RS, a non-cancer assessment, was performed as follows:

$$Soil_{ni,N-I} = \frac{(THQ * BW_c * AT_{nc} * 365\ d/yr)}{\left[EF_{ni} * ED_c * \left(\left(\frac{IRS_C}{RfD_O}\right) * 1E-6\right)\right]}$$

Where:

Acronym	Definition	Value
THQ	Target Hazard Quotient	1.0 (dimensionless)
BW_c	Body Weight (child)	15 kg
AT_{nc}	Averaging Time (non-carcinogen, child)	6 years
EF_{ni}	Exposure Frequency (non-industrial)	350 days/yr
ED_c	Exposure Duration (child)	6 years
RfD_o	Reference Dose (oral)	CoC specific (mg/kg-day)
IRS_c	Soil Ingestion Rate (child, pica)	1000 (mg/day)
RfDo	Oral Reference Dose	0.2 (mg/kg-day)

$$Soil_{ni,N-I} = \frac{(1 * (15\ kg) * (6\ yr) * 365\ d/yr)}{\left[(350\ d/yr) * (6\ yr) * \left(\left(\frac{1000\ mg/day}{0.2\frac{mg}{kg-d}}\right) * 1E-6\right)\right]}$$

$$Soil_{ni,N-I} = 3{,}129\ \frac{mg}{kg}$$

Substitution of the revised RfDo and IRSc results in a revised $Soil_{ni}$ of 3,129 mg/kg for barium. Comparing this $Soil_{ni}$ value with ICON soil data for 0-2 ft. reveals the following exceedances for barium (Table 12).

[27] RECAP, 2003, page 67
[28] US EPA, Exposure Factors Handbook, 2017 update, Chapter 5 Soil and Dust Ingestion, pages 5-50, 5-51

A comparison between the $Soil_{ni}$ (3,129 mg/kg) and the AOI 95 UCL values reveals barium exceedances exist for AOI-3 (4486 mg/kg), AOI-4 (4847 mg/kg), and AOI-6 (5594 mg/kg).

3.4.1.2 Arsenic Evaluation and MO-2 RS Determination

Development of the Arsenic MO-2 Soil RS, a non-cancer assessment, was performed as follows:

$$Soil_{ni,N-I} = \frac{(THQ * BW_c * AT_{nc} * 365\ d/yr)}{\left[EF_{ni} * ED_c * \left(\left(\frac{IRS_C}{RfD_O}\right) * 1E-6\right)\right]}$$

Where:

Acronym	Definition	Value
THQ	Target Hazard Quotient	1.0 (dimensionless)
BW_c	Body Weight (child)	15 kg
AT_{nc}	Averaging Time (non-carcinogen, child)	6 years
EF_{ni}	Exposure Frequency (non-industrial)	350 days/yr
ED_c	Exposure Duration (child)	6 years
RfD_o	Reference Dose (oral)	3E-04 (mg/kg-day)
IRS_c	Soil Ingestion Rate (child, pica)	1000 (mg/day)
RfDo	Oral Reference Dose	3E-04 (mg/kg-day)

$$Soil_{ni,N-I} = \frac{(1 * (15\ kg) * (6\ yr) * 365\ d/yr)}{\left[(350\ d/yr) * (6\ yr) * \left(\left(\frac{1000\ mg/day}{3E-04\ \frac{mg}{kg-d}}\right) * 1E-6\right)\right]}$$

$$Soil_{ni,N-I} = 4.69\ \frac{mg}{kg}$$

Substituting the US EPA IRSc (1000 mg/day) results in a revised $Soil_{ni}$ of 4.7 mg/kg for arsenic. Comparing this $Soil_{ni}$ value with ICON soil data for 0-2 ft., and the 0-4 ft. where several samples were collected, reveals the following exceedances for arsenic (Table 13). Although some of the arsenic exceedances reside within preexisting AOIs, given the new spatial distribution, new arsenic AOIs are necessary.

3.4.1.4.1 Evaluation of Arsenic $Soil_{ni}$ AOIs

Five arsenic $Soil_{ni}$ AOIs were defined (Table 14, Figure 19). 95 UCLs were calculated for each AOI-1 (6.262 mg/kg), AOI-2 (7.491 mg/kg), and AOI-3 (7.568 mg/kg); AOI-4 (5.55 mg/kg) and AOI-5 (7.175 mg/kg) only contain two points where arsenic data was collected and the mean of these points was used.

3.4.2 Soil to Groundwater ($Soil_{GW}$) Evaluation

3.4.2.1 $Soil_{GW}$ Method 4 - Site-Specific Soil/Water Partition Coefficient

The MO-2 soil-to-groundwater evaluation is predicated upon POCs residing within a property of interest and POEs being the property boundary or "fenceline". The concentrations of CoCs in soil are evaluated in order to determine whether they pose a risk to off site migration of CoCs in groundwater at concentrations greater than the groundwater standard (in this case GW2).[29] While this hypothetical may accurately reflect an industrial site, it is not representative of the future intended use of this site (*i.e.* non-industrial, residential), and the reality of multiple POEs in the form of on site drinking water wells that render the evaluation of off site migration irrelevant and ICON groundwater plume maps showing CoC concentration in excess of the GW2 standard(s) relevant. Notwithstanding this discordancy, an MO-2 soil-to-groundwater assessment follows in case the future use of the property is restricted.

Given some limited collocated groundwater and soil data are available where groundwater data indicate the GW2 has been exceeded, site-specific soil/water partition coefficients were calculated for Arsenic and Barium and used to develop a site-specific SoilGW. The steps conducted were as follows.[30]

(1) Identify site-specific soil and groundwater concentrations (GW_{conc} and $Soil_{conc}$) that are representative of site-specific partitioning of the COC between soil and groundwater (e.g., the soil and groundwater sampled should be: (a) from the same location; (b) in communication with each other; (c) and at equilibrium and/or declining conditions. Three CoCs qualified for this analysis: Arsenic (Boring H-3) and Barium (Boring H-12) and Cadmium (Boring H-16).

(2) Identify the appropriate groundwater RECAP Standard based on the current or potential use of the impacted groundwater (See Section 2.10 for groundwater classifications) in Table 3. For GW2, the site-specific DAF is not applied to the GW2 risk-based value to define the acceptable concentration in groundwater for the soil/water partition equation in Step (3). The groundwater is classified as GW2 and RS values for each are available in Table 3 and were used directly without applying a site specific DAF.

(3a) Calculate a site-specific water/soil partition coefficient (K_d) using the site-specific soil and groundwater data identified in Step (1). The soil/water partition equation is used to calculate the K_d from the constituent concentration adsorbed to the soil organic carbon and the soil leachate concentration in the zone of contamination.[31] Using EQ31 from RECAP 2003, which is a simple rearrangement of Equation 10 from the US EPA Soil Screening Guidance, Users Guide (1996), the soil leachate concentration is calculated from the concentration of CoCs in soil where:

[29] RECAP, 2003, Appendix H, page H-5
[30] RECAP, 2003, Appendix H, pages H-95 – H-96
[31] RECAP, 2003, Appendix H, page H-88

$$C_T = C_L \left[K_d + \left(\frac{\theta_w}{\rho_b}\right)\right]$$

$$\frac{C_T}{C_L} - \left(\frac{\theta_w}{\rho_b}\right) = K_d$$

θ_w = water filled soil porosity (L_{water}/L_{soil}) = 0.21
ρ_b = dry soil bulk density (g/cm^3) = 1.7

$$\frac{\theta_W}{\rho_b} = \frac{0.21\ \frac{mL_{water\ voids}}{mL_{soil}}}{1.7\ g_{soil}/mL_{soil}} = \frac{0.12\ mL_{water}}{g_{soil}} = \frac{0.12\ L_{water}}{kg_{soil}}$$

Site Specific K_d Calculations

Arsenic (H-3)
$Soil_{conc}$ = 6.7 mg/kg (0-2'), 4.03 mg/kg (4-8'), 3.59 mg/kg (10-12') = 4.6 mg/kg average
GW_{conc} = 0.0269 mg/L
GW2 = 0.01 mg/L

$$K_d = \left(\frac{4.6\ mg/kg_{soil}}{0.0269\ mg/L_{water}}\right) - \left(\frac{0.12\ L_{water}}{kg_{soil}}\right) = \frac{171\ \frac{mg}{kg}}{\frac{mg}{L}}$$

Barium (H-12)
$Soil_{conc}$ = 290 mg/kg (0-4'), 422 mg/kg (4-6'), 220 mg/kg (8-10') = 305 mg/kg average
GW_{conc} = 2.11 mg/L
GW2 = 2 mg/L

$$K_d = \left(\frac{305\ mg/kg_{soil}}{2.11\ mg/L_{water}}\right) - \left(\frac{0.12\ L_{water}}{kg_{soil}}\right) = \frac{145\ \frac{mg}{kg}}{\frac{mg}{L}}$$

Cadmium (H-16)
$Soil_{conc}$ = <0.491 mg/kg (0-2'), <0.491 mg/kg (4-6'), 0.621 mg/kg (10-12') = 0.534 mg/kg average
GW_{conc} = 0.00750 mg/L
GW2 = 0.005 mg/L

$$K_d = \left(\frac{0.534\ mg/kg_{soil}}{0.00750\ mg/L_{water}}\right) - \left(\frac{0.12\ L_{water}}{kg_{soil}}\right) = \frac{71\ \frac{mg}{kg}}{\frac{mg}{L}}$$

Cadmium (H-18) – note: included as supporting data; however, results are questionable
$Soil_{conc}$ = <0.493 mg/kg (0-4'), <0.493 mg/kg (4-6'), <0.493 mg/kg (8-10') = 0.493 average
GW_{conc} = 0.00730
GW2 = 0.005 mg/L

$$K_d = \left(\frac{0.493\ mg/kg_{soil}}{0.00730\ mg/L_{water}}\right) - \left(\frac{0.12\ L_{water}}{kg_{soil}}\right) = \frac{67\ \frac{mg}{kg}}{\frac{mg}{L}}$$

Applying the calculated site specific K_d for barium, the following leachate concentrations are developed for each AOI.

AOI	$C_{soil, Ba}$ 95UCL (mg/kg)	K_d Ba (site specific) (mL/g)	n_w (mL/mL)	$p_{b,soil}$ (g/mL)	C_L (mg/L)
AOI-1	2378	145	0.21	1.7	16
AOI-2	2604	145	0.21	1.7	18
AOI-3	4210	145	0.21	1.7	29
AOI-4	5315	145	0.21	1.7	37
AOI-5	2735	145	0.21	1.7	19
AOI-6	5594	145	0.21	1.7	39

(3b) Calculate the groundwater RS identified in Step (2) as follows (EQ37):

$$Soil_{GW} = \left(\frac{GW2}{GW_{conc}}\right)(Soil_{conc})$$

Where
$Soil_{GW}$ = soil concentration protective of groundwater (mg/kg) (site specific)
GW2 = groundwater RECAP Standard (mg/l)
GW_{conc} = site-specific groundwater concentration at the POC (mg/l)
$Soil_{conc}$ = site-specific soil concentration at the POC (mg/kg)
(4a) Calculate a site-specific $DF_{Summers}$ (EQ61) and a site-specific $DAF_{Domenico}$. The site-specific $DF_{Summers}$ was developed using the Summers Model:

Site Specific $Soil_{GW}$ Calculations
Arsenic (H-3)
$Soil_{conc}$ = 6.7 mg/kg (0-2'), 4.03 mg/kg (4-8'), 3.59 mg/kg (10-12') = 4.6 mg/kg average
GW_{conc} = 0.0269 mg/L
GW2 = 0.01 mg/L

$$Soil_{GW} = \left(\frac{0.01\ mg/L}{0.0269\ mg/L}\right)(4.6\ mg/kg)$$

$$Soil_{GW} = 1.7\ mg/kg$$

Barium (H-12)
$Soil_{conc}$ = 290 mg/kg (0-4'), 422 mg/kg (4-6'), 220 mg/kg (8-10') = 305 mg/kg average
GW_{conc} = 2.11 mg/L
GW2 = 2 mg/L

$$Soil_{GW} = \left(\frac{2\ mg/L}{2.11\ mg/L}\right)(305\ mg/kg)$$

$$Soil_{GW} = 289\ mg/kg$$

Cadmium (H-16)
$Soil_{conc}$ = <0.491 mg/kg (0-2'), <0.491 mg/kg (4-6'), 0.621 mg/kg (10-12') = 0.534 mg/kg average
GW_{conc} = 0.00750 mg/L
GW2 = 0.005 mg/L

$$Soil_{GW} = \left(\frac{0.005\ mg/L}{0.00750\ mg/L}\right)(0.534\ mg/kg)$$

$$Soil_{GW} = 0.356\ mg/kg$$

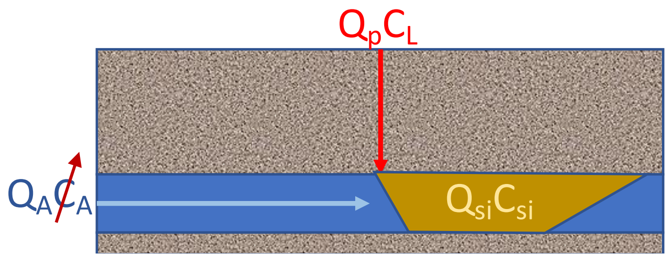
Cadmium (H-18) – note: included as supporting data; however, results are questionable
oil_{conc} = <0.493 mg/kg (0-4'), <0.493 mg/kg (4-6'), <0.493 mg/kg (8-10') = 0.493 average
GW_{conc} = 0.00730
GW2 = 0.005 mg/L

$$Soil_{GW} = \left(\frac{0.005\ mg/L}{0.00730\ mg/L}\right)(0.493\ mg/kg)$$

$$Soil_{GW} = 0.338\ mg/k$$

Summers Dilution Factor

Under MO-2, the Summers model was used to calculate a site-specific dilution factor ($DAF_{Summers}$) for a COC in soil water (*i.e.* C_L) moving from the soil column into the adjacent groundwater. The Summers model accounts for dilution of infiltrating water into the underlying aquifer from upgradient flow but no dilution/dispersion resulting from subsequent down-gradient transport (*i.e.* x = 0). $DF_{Summers}$ is the ratio of the chemical concentration in the soil leachate entering the aquifer (C_L) to the resulting chemical concentration in the underlying groundwater (C_{si}) and is calculated using the Summers equation which is a rearrangement of a mass balance on the system.



$$Q_A C_A + Q_p C_L = Q_{si} C_{si}$$

$$\frac{C_L}{C_{si}} = \frac{(Q_p + Q_A)}{Q_p}$$

Where
Q_p : volumetric flow rate of pore water infiltrating into aquifer (m^3/year)
Q_a : volumetric flow rate of groundwater through the aquifer beneath the source (m^3/year)
C_L : concentration of contaminant dissolved in infiltrating pore water (mg/L)
C_{si} : dissolved phase concentration of contaminant in impacted groundwater (mg/L)

$$Q_p = (I)(S_w)(L)$$

$$Q_A = (D_v)(S_d)(S_w)$$

Where
I : infiltration rate (m/yr)
S_w : width of impacted area perpendicular to groundwater flow direction (m)
L : length of impacted area parallel to groundwater flow direction (m)
D_v : Darcy groundwater velocity (K grad(h); m^3/m^2-year)
S_d : thickness of groundwater plume (m)

Resulting in the Summers equation:

$$\frac{C_L}{C_{si}} = \frac{\left((I)(S_w)(L)\right) + \left((D_v)(S_d)(S_w)\right)}{(I)(S_w)(L)}$$

Measured site-specific parameters were used for parameters S_w, and L. The LDEQ infiltration rate (I) value of 0.1 m/yr was used.[32]

The Darcy velocity (Dv) was a site specific parameter calculated using the product of the geometric mean hydraulic conductivity (K = 1.03 cm/sec) and the hydraulic gradient (~1E-03 m/m), which were discussed in prior sections of this report.

The S_d (the thickness of the contaminated groundwater within the permeable zone) is defined as the sum of the advective and dispersive components of plume depth.

$$S_d = h_{adv} + h_{disp}$$

When

$$h_{adv} = B\left[1 - exp\left(\frac{(-IL)}{(BD_v)}\right)\right]$$

$$h_{disp} = (2\alpha_z L)^{0.5}$$

[32] RECAP, 2003, Appendix H, page H-25; Soil Screening Guidance, User's Guide, EPA 1996

The parameter B (average aquifer thickness) was determined for each AOI using alluvial thickness defined by ICON's isopach at discrete points (Figure 12, ICON Figure 36) and interpolations using adjacent well data where data gaps existed and calculated dispersive flow depths. All calculated S_d values were greater than the aquifer thickness (B); therefore, S_d was set to the thickness of the aquifer.[33] A summary of calculation parameters appears in Table 15.

Substituting the values developed above into the Summers equation, a dilution factor (DF) was calculated for each AOI (Table 16), with values ranging from 1.01 to 1.10 (*i.e.* negligible dilution). These values are consistent with the relative properties of the AOI surfaces (large areas for infiltration as defined by L) and subsurfaces (low Dv for dilution of infiltrating leachate).

(4b) The $DAF_{Domencio}$ was developed using the Domenico analytical solute transport model; the $DAF_{Domenico}$, or DAF2 is representative of dilution and attenuation of the constituent concentration associated with groundwater migration from the source area to the nearest downgradient property boundary:

Domenico Model

A site-specific longitudinal dilution and attenuation factor (DAF2) is calculated under MO-2 using the Domenico model (EQ65) and site-specific data and/or default parameters. The Domenico mathematical model was developed for a finite source and incorporates one-dimensional groundwater velocity, longitudinal and transverse dispersion, with retardation and decay as appropriate.[34] The LDEQ allows the use of a Domenico DAF only if it is based on the modeling to a maximum distance of 2000 feet and if constituent retardation (R_i) and first-order degradation rate (λ_i) values are set to LDEQ default values: λ_i = 0 day; R_i = 1.[35]

The Domenico mathematical model solves for the concentration of a CoC a given distance from a source.

$$C_x = C_{si}\left\{exp\left[\frac{x}{2\alpha_x}\left(1-\sqrt{1+\frac{4\lambda_i\alpha_x R_i}{v}}\right)\right]\left(erf\left[\frac{S_w}{4\sqrt{\alpha_y x}}\right]\left(erf\left[\frac{S_d}{2\sqrt{\alpha_z x}}\right]\right)\right)\right\}$$

Rewritten to observe the relative dilution at the specified distance the equation becomes the Domenica DAF.

$$\frac{C_{si}}{C_{x_i}} = \frac{1}{\left\{exp\left[\frac{x}{2\alpha_x}\left(1-\sqrt{1+\frac{4\lambda_i\alpha_x R_i}{v}}\right)\right]\left(erf\left[\frac{S_w}{4\sqrt{\alpha_y x}}\right]\left(erf\left[\frac{S_d}{2\sqrt{\alpha_z x}}\right]\right)\right)\right\}}$$

---

[33] RECAP, 2003, Appendix H, page H-128

[34] Domenico, P.A., An analytical model for multidimensional transport of a decaying contaminant species, Journal of Hydrology, Volume 91, Issues 1–2, 15 May 1987, Pages 49-58

[35] RECAP, 2003, Appendix H, page 127

Using the product of the 95 UCL barium leachate concentration previously developed for each AOI and the Summers DF (~1) to provide C_{si} values,[36] the Domenico DAF equation was used to calculate Domenico DAFs for the six soil-to-groundwater AOIs (Table 17).

The Domenico DAF equation was also used to calculate Domenico DAFs for the three borings (H-3, H-12, H-16) for which the product of the groundwater RS values (calculated in Step 3b) and the Summers DF (~1) was used to provide C_{si} values for arsenic, barium, and cadmium (Table 18).[37]

(5) Multiply the $Soil_{GW}$ calculated in Step (3) by the site-specific $DF_{Summers}$ and the site-specific $DAF_{Domenico}$ calculated in Step (4) to yield the maximum theoretical constituent concentration in soil [leachate] that will not cause the groundwater RECAP Standard to be exceeded ($Soil_{GW2}$) as follows (EQ35):

$$Soil_{GW2} = (C_{soil})(DF_{Summers})(DAF2_{Domenico})$$

Arsenic
C_{soil} = 1.7 mg/kg (from step 3)
$DF_{Summers}$ ~ 1.0

Barium
C_{soil} = 289 mg/kg (from step 3)
$DF_{Summers}$ ~ 1.0

Cadmium
C_{soil} = 0.356 mg/kg (from step 3)
$DF_{Summers}$ ~ 1.0

POC	CoC	C_{soil} (mg/kg)	$DF_{Summers}$ C_L/C_{si}	$DAF2_{Domenico}$	$Soil_{GW2}$ (mg/kg)
H-3	Arsenic	1.7	1	887	1507
H-12	Barium	289	1	55.0	15903
H-16	Cadmium	0.356	1	124	44

None of these three CoCs (arsenic, barium, cadmium) are found in on site soils in excess of these levels; therefore, based upon the site specific partitioning of arsenic, barium and cadmium from these three borings into the underlying groundwater, and the subsequent theoretical transport of these CoCs to the fence line, the concentration of the CoCs at the fence line will not exceed the GW2 standards.

3.4.3 Evaluation of a Groundwater Classification 2 Aquifer

[36] Note: any value can be input as the C_{si} in this calculation as the ratio (DAF) of C_{si}:C_x does not change
[37] Note: any value can be input as the C_{si} in this calculation as the ratio (DAF) of C_{si}:C_x does not change

A class 2 aquifer is evaluated under MO-2 by identifying the CoCs in RECAP Table 3 and their associated GW2 values then multiplying those GW2 values by their associated site specific DAF2 factor. The DAF2 factors are developed by establishing the shortest downgradient distance from the groundwater source "Point of Compliance" (POC) to the property boundary "Point of Exposure" (POE) in conjunction with the aquifer thickness (S_d). Specifically, the applicable steps are as follows:[38]

(1) Identify the GW2 in Table 3.
(2) Calculate a site-specific DAF2 based on the shortest distance between the POC and the nearest downgradient property boundary (POE).
(3) Determine the product of GW2 x DAF2; this is the groundwater RS.
(4) Determine the CC in groundwater at the POC.
(5) Compare the groundwater CC to the calculated RS.

The results of this analysis appear in Table 19. As calculated previously for discrete POCs, given the distances between most of the POCs and POEs, the $DAF2_{Domenico}$ factors are of such a magnitude that groundwater observed at POEs will not exceed the GW2 (*i.e.* CC at POC is less than GW2*DAF2). This is despite the fact that GW2 is exceeded at every POC in the above table.

4.0 CONCLUSIONS

Three soil AOIs created for barium - AOI-3 (1.25 acres in area), AOI-4 (3.34 acres in area), and AOI-6 (4.5 acres in area) - exceed the $Soil_{ni}$ and require remediation. All five Soil AOIs created for arsenic (24.56 acres total) exceed the $Soil_{ni}$ and require remediation. Some of the arsenic AOIs overlap with barium AOIs; therefore, the total acreage requiring soil remediation is not simply additive. Taking into account overlapping AOIs, 37.71 total acres of soil require remediation for barium and/or arsenic in excess of the MO-2 RS (Table 20).

Groundwater within plumes defining areas in which the GW2 is exceeded require remediation if the land is to be for future residential use; however, if the land use is restricted such that, for example, on site groundwater is not extracted and used for human consumption, The results from the Domenico Model show that GW2 will not be exceeded at the property boundaries and remediation would not be required. It is my understanding that further groundwater sampling and contaminant plume definition may occur; once that is complete then a more accurate quantification of groundwater volume requiring remediation can be made.

---

[38] RECAP, 2003, Appendix H, page H-45