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MEMORANDUM

TO: William Almas
Project Manager
Chevron Business Real Estate Services
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FROM: Charles E. Lambert, PhD, DABT
McDaniel Lambert, Inc.

DATE: January 14, 2013

RE: **Former Chevron San Luis Obispo Tank Farm Proposed Development – Use of Groundwater as a Source of Potable Water**

1.0 Introduction

This memorandum discusses water quality issues if groundwater is utilized as a potable water source as part of a development project in the County of San Luis Obispo. Development in the County is one of the project alternatives proposed by Chevron for the former Chevron San Luis Obispo Tank Farm (the Site) in the Project Description for the San Luis Obispo Tank Farm Restoration and Redevelopment project. Development within the County would require that drinking water be supplied from onsite drinking water wells.

This memorandum clarifies and provides more detail related to the use of on-site wells as a source of potable water for drinking water and other domestic uses.[1] Two issues are discussed in the memorandum. First analytical data from groundwater samples collected from the wells are compared to state and federal drinking water standards and/or screening levels. Second, the memorandum considers the potential for these wells to be contaminated from petroleum-impacted areas on the Site. This assessment confirms the suitability of the onsite wells as a source of drinking water. Additionally, this memorandum recommends that sentinel wells be installed and used to monitor groundwater quality between known contaminant areas and the production wells. If petroleum-related constituents of concern are detected at these sentinel

[1]For the purposes of this document, "other domestic uses" refers to includes all typical uses of water except for consumptive uses (e.g., drinking, food preparation).

wells, treatment methods can be established and the appropriate treatment facilities installed to preclude impacts to the water supply.

2.0 Background

Chevron is proposing a development project on the former San Luis Obispo Tank Farm, located on Tank Farm Road within the County of San Luis Obispo. One project alternative is to permit and construct the project while keeping the Site within County jurisdiction. In this situation the project would be responsible for securing its own water supply.

Under the proposed County development plan, a new water system utilizing groundwater from the Site will provide potable water for both drinking water and other domestic uses to the commercial buildings. The well currently serving the Tank Farm offices will not be used for the proposed water system (Cleath-Harris 2013). In 2002, four water supply wells were constructed and tested in anticipation of future development of the Site (Wells #1-4 in Figure 1; Cleath 2002). As noted by Avocet (2011), all four of these wells were constructed outside and down-gradient of petroleum-impacted areas identified on the Site, with three of the wells situated along the southern perimeter of the Tank Farm (Wells #1-3) and one located north of Tank Farm Road and west of the former northwest operations area (Well #4).

As described in Cleath-Harris 2013, these four existing water wells are proposed to supply potable water associated with development of the Site. Although Well #4 (Figure 1) is no longer on property owned by Chevron, Chevron maintains the water rights to the well. However, the proposed water system will not use the existing well that currently supplies non-potable water to the Tank Farm offices due to the presence of elevated levels of nitrates and other minerals that make it unsuitable as a source of drinking water.

The updated human health risk assessment (HHRA) prepared for the Site assessed the potential health impacts from incidental contact by intrusive workers with shallow groundwater, some associated with petroleum-impacted areas (McDaniel Lambert 2012). At the time the HHRA process was undertaken (2002), the San Luis Obispo Tank Farm Surface Evaluation, Restoration, and Remediation Team (SERRT) anticipated that the City water system would provide future potable water service. Also, the proposed remediation actions include recordation of deed restrictions for potable water wells within petroleum-impacted areas. For these reasons, the SERRT determined that it was not necessary to evaluate the potential health effects from drinking water and other domestic use of Site groundwater (McDaniel Lambert 2004 and 2012). It has been determined that the onsite wells would be needed for potable water if the Property is not annexed to the City. The production wells are outside of petroleum-impacted areas of the Site and analytical results from all four wells meet regulatory requirements for drinking water, as shown in Section 3 below. Therefore there is no need for the HHRA to evaluate the safety of this drinking water source.

3.0 Potential Potable Water Source Quality

As noted above, Wells #1-4 are the anticipated sources of potable water for the proposed development. Three of these water supply wells were installed on the southern portion of the Site (Wells #1-3, south of Tank Farm Road) and the fourth installed west of the former northwest operations area (Well #4), with the construction details from 2002 summarized in Table 1 below.

Table 1. Summary of Well Construction Details

	Drill Depth (ft bgs)	Screen Interval (ft bgs)	Annual Seal Depth (ft bgs)	Pump Rates* (gpm)
Well #1	200	100-180	80	140 (72-hour test)
Well #2	70	30-55	25	30 (12-hour test)
Well #3	110	55-105	50	20 (12-hour test)
Well #4	100	55-75	50	20 (12-hour test)

Notes:
Ft bgs = feet below ground surface
*Pump rates were estimated based on the pumping test data and analysis using the Cooper-Jacob modified Theis Equation; gpm = gallons per minute.

It is noted that Well #2 is located within about 250 feet of the proposed County Development Alternative's waste water treatment plant (WWTP). It is anticipated that there would be no degradation in the quality of water produced from Well #2 due to its operation. The WWTP will consist of a modular package system treating effluent to tertiary standards. Most of that effluent would be recycled for use as gray water or for irrigation. When discharge is necessary, the effluent meeting tertiary treatment standards would be released to one of two locations: 1) a polishing wetland north of Tank Farm Road, approximately 1,000 feet away from and cross-gradient to the well; or 2) to the East Fork of San Luis Obispo Creek approximately 300 feet down gradient from the well.

In addition to pumping (yield) tests, the 2002 well construction activities collected water samples from each well for drinking water analyses (Title 22) including general physical and mineral parameters, other inorganics (metals), volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs) including polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and chlorinated pesticides, as well as total petroleum hydrocarbons (TPH) in the diesel and motor oil ranges (C10-C25 and C25-C40, respectively).

Table 2 (below) summarizes the concentrations of analytes detected in the four wells proposed to supply potable water to the future commercial infrastructure at the Site, as well as the non-detect results for TPH analyses, and compares them to available state and federal drinking water standards and/or health-based screening levels.[2] Specifically, the California and United

[2]Reporting limits for metals analyses ranged from 0.0002 to 0.01 mg/L; VOCs ranged from 0.0005 to 0.001 mg/L; SVOCs/PAHs ranged from 0.1 to 0.3 mg/L; PCBs were 0.0003 mg/L; and chlorinated pesticides ranged from 0.00003 to 0.001 mg/L.

Table 2. Summary of Compounds Detected in Proposed Potable Water Production Wells (from Cleath 2002)

Detected Chemicals	Cal/EPA MCL or Secondary Std[1]	USEPA MCL or Secondary Std[2]	USEPA Tap Water RSL[3]	Well #1	Well #2	Well #3	Well #4
Minerals							
Total Dissolved Solids	500-1000*	500*	NV	**540**	**700**	**810**	**770**
Total Hardness	NV	NV	NV	400	540	520	640
Alkalinity/Bicarbonate	NV	NV	NV	340	480	310	380
Boron	NV	NV	3.1	0.21	0.16	0.23	0.13
Calcium	NV	NV	NV	49	47	66	55
Chloride	250-500*	250*	NV	110	100	250	190
Magnesium	NV	NV	NV	67	100	87	120
Nitrate	45	10	25	0.8	0.7	5.4	4.7
Potassium	NV	NV	NV	1.1	0.7	1.9	0.6
Sodium	NV	NV	NV	54	71	85	38
Sulfate	250-500*	250*	NV	13	76	27	67
Metals (RLs from 0.005 to 0.05 mg/L)							
Barium	1.0	2.0	2.9	0.23	0.13	0.18	0.097
Chromium	0.050	0.10	NV	0.02	0.03	0.03	*<0.01*
Nickel	0.10	NV	0.30	*<0.01*	*<0.01*	0.01	*<0.01*
Vanadium	NV	NV	0.078	*<0.01*	0.01	*<0.01*	0.02
Zinc	5.0*	5.0*	4.7	0.02	*<0.01*	0.01	0.02
Organics (RLs from 0.0005 mg/L)							
trans-1,2-Dichloroethene	0.01	0.1	0.086	0.0005	*<0.0005*	*<0.0005*	*<0.0005*
Toluene	0.15	1.0	0.86	0.0008	0.0017	0.0019	*<0.0005*
Total Petroleum Hydrocarbons							
TPH C10-C25	NV	NV	NV	*<0.1*	*<0.1*	*<0.1*	*<0.1*
TPH C25-C40	NV	NV	NV	*<0.1*	*<0.1*	*<0.1*	*<0.1*

Notes:
All concentrations are in mg/L.
NV = No Value available
[1]Cal/EPA maximum contaminant levels (MCLs) and secondary standards (identified with an asterisk) from Cal/EPA 2012.
[2]USEPA MCLs and secondary standards (identified with an asterisk) from USEPA 2009.
[3]USEPA regional screening levels (RSLs) from USEPA 2012.
Italics indicate not detected at the reporting limit noted.
Bold text identifies standard or screening level exceedances.

States Environmental Protection Agencies (Cal/EPA and USEPA, respectively) maximum contaminant levels (MCLs) are mandatory (enforceable) water quality standards for drinking water contaminants while the secondary standards are non-mandatory water quality standards that are established as guidelines for aesthetic considerations, such as taste, color and odor (USEPA 2009). The USEPA tap water regional screening levels (RSLs) are non-regulatory risk-based concentrations that are considered to be protective for humans (including sensitive groups) over a lifetime and are intended to be used to "screen out" a site where no potential health risk exists or to focus additional evaluation (USEPA 2012). The tap water RSLs are safe levels established based on potential residential exposures via ingestion, inhalation and dermal contact with domestic tap water. As shown in Table 2 the only analyte detected above any of the regulatory standards and/or screening levels was total dissolved solids (TDS), which exceeded the Cal/EPA recommended and USEPA secondary standard of 500 mg/L in all four wells, but is below the Cal/EPA upper limit of 1000 mg/L. No TPH was detected, and the low levels of the toluene detected in three of the four wells may be associated with well construction. The VOC trans-1,2-dichloroethene is not associated with petroleum, and was detected at the reporting limit in only one of the samples collected from the four wells.

3.1 Total Dissolved Solids (TDS)

Potential for Health Impacts

Total dissolved solids is the term used to describe the inorganic salts and small amounts of organic matter present in solution in water that occurs as molecular, ionized, or colloidal matter. The principal constituents of TDS are usually calcium, magnesium, sodium, and potassium cations and carbonate, bicarbonate, chloride, sulfate, and nitrate anions. Reliable data on possible health effects associated with the ingestion of TDS in drinking water are not available (WHO 2003), and no health-based TDS goals have been promulgated by the USEPA or California State Agencies.

Organoleptic Properties

The presence of dissolved solids in water may affect its taste. The palatability of drinking water has been rated by panels of tasters in relation to its TDS level as follows (Bruvold 1969):

- excellent, less than 300 mg/L;
- good, between 300 and 600 mg/L;
- fair, between 600 and 900 mg/L;
- poor, between 900 and 1200 mg/L; and
- unacceptable, greater than 1200 mg/L.

Water with extremely low concentrations of TDS may also be unacceptable because of its flat, insipid taste (WHO 2003).

Corrosive Properties

Certain components of TDS, such as chlorides, sulfates, magnesium, calcium, and carbonates, affect corrosion or encrustation in water-distribution systems. High TDS levels (>500 mg/L) that

include elevated hardness can result in scaling of water pipes, water heaters, boilers, and household appliances such as steam irons.

TDS Acceptability
Water containing TDS concentrations below 1000 mg/liter is usually acceptable to consumers, although acceptability may vary according to circumstances (WHO 2003). However, the presence of high levels of TDS in water may be objectionable to consumers owing to the resulting taste and to excessive scaling in water pipes, heaters, boilers, and household appliances. Water with extremely low concentrations of TDS may also be unacceptable to consumers because of its flat taste; it is also often corrosive to water-supply systems.

4.0 Potential Impacts to Potable Water Supply from Petroleum-Impacted Shallow Groundwater and Subsurface Soil

While groundwater from the production wells is, with the possible exception of TDS, suitable for drinking water and other domestic purposes at the Site, and TPH has not been detected in the production wells, petroleum-related contamination has been detected in subsurface soil and in shallow groundwater in other areas of the Site. As a part of the permitting process for the Site development project, Avocet Environmental, Inc. was asked to evaluate the potential for petroleum-impacted soil at the former tank farm to adversely affect groundwater quality in water-supply wells installed outside of petroleum-impacted areas (Avocet 2011). They concluded that, for a number of reasons briefly summarized below, petroleum is unlikely to directly impact the proposed water production wells. This Technical Memorandum is included as Attachment A to facilitate review of their analysis.

As summarized by Avocet (2011), petroleum released during site operations between 1910 and the early 1980s has impacted soil and groundwater underlying the Tank Farm Site. Three principal areas of subsurface petroleum occurrence have been identified: (1) underlying the former northwest operations area, where residual petroleum is limited to a depth of approximately 25 feet below ground surface (ft bgs), but mostly occurs between 10 and 15 ft bgs; (2) beneath former Reservoir 4, where petroleum-impacted soil and bedrock were found to extend from the ground surface to 50 ft bgs, and (3) underlying most of the property south of Tank Farm Road where impacted soil occurs primarily in the 5- to 25-foot depth range, but reaches to approximately 45 ft bgs beneath former Reservoir 3. Subsurface petroleum contamination at the Site generally is comprised of the less soluble, higher molecular weight fractions. In addition to the high-molecular weight hydrocarbons, lighter fraction petroleum hydrocarbons are present in the former northwest operations area including benzene, toluene, ethylbenzene, and xylenes.

Within the impacted areas, the petroleum does not exist as a contiguous, homogeneous body, but rather occurs primarily within the intergranular space of more permeable sand lenses and, to a lesser degree, as thin films of viscous petroleum in root pores and along fractures in fine-grained silts and clays. Due to the nature of alluvial systems, such as that underlying the Tank Farm, these permeable sand lenses are laterally and vertically discontinuous, separated by fine-

grained, low permeability sediments and the liquid oil has become trapped and is stratigraphically contained by the fine-grained sediments (Avocet 2011). Further, the petroleum itself is hundreds to thousands of times more viscous than water. Baildown tests, analytical testing, computer modeling, and 20 years of monitoring have demonstrated and that subsurface liquid petroleum at the Site has achieved equilibrium and is essentially immobile in this geologic environment (Avocet 2011).

Avocet (2011) noted that the degree of hydraulic communication between the shallow, petroleum-impacted, and deep (e.g., greater than 50 ft bgs) saturated zones, was evaluated based on aquifer tests performed along Tank Farm Road in 1992 and 1996, using two purpose-built "water supply" wells installed within or immediately adjacent to petroleum-impacted soils.[3] Testing before, during, and after the 24-hour aquifer tests determined that no contaminants had been drawn into the wells from the overlying impacted soils, despite 20 feet of drawdown. As such, the report concluded that the degree of communication between the shallow and deep saturated zones is limited. In addition, in 2001, multi-level probes were installed at the direction of the Remediation Technology Panel (RTP) to evaluate vertical conductivity adjacent to petroleum impacted areas. Monitoring of the probes and evaluation of the resulting data showed that there are no consistent upward or downward gradients within the aquifer above the resolvable level of about 0.003 ft/ft (England Geosystem 2001).

To further evaluate the potential for future impacts, Avocet considered the physical and chemical properties of the petroleum, the hydrogeology of the Site, and more than 20 years of groundwater monitoring data. Avocet (2011) concluded that:

> "*the potential for petroleum-impacted soil at the former tank farm to directly affect groundwater quality in water-supply wells installed outside of petroleum-impacted areas and constructed in accordance with County guidance is negligible. However, since polar compounds are being generated as by-products of naturally-occurring petroleum biodegradation and because these soluble nonhydrocarbons are capable of migrating beyond the petroleum source zones, the petroleum has the potential to indirectly affect groundwater quality. Although the relative impact of these polar compounds on water quality is likely low (due to the low toxicity and organoleptic properties) and may prove insignificant compared to the source petroleum, the potential exists for these compounds to be present in wells installed outside of petroleum-impacted areas.*"

Overall, it can be concluded that residual petroleum hydrocarbon contamination present in areas removed from the production wells installed at the SLO Tank Farm is unlikely to present a risk to groundwater collected from Wells #1-4 because: 1) the contamination is distant from the well locations, 2) groundwater is preferentially drawn from the lower portion of the water-bearing zone due to its substantially greater hydraulic conductivity, 3) vertical movement of groundwater from the shallow zone to the deeper water-bearing zone is impeded by the interbedded lenses of silts and clays, and 4) over 20 years of groundwater monitoring data indicate the potential for petroleum-impacted soil at the former Tank Farm to directly affect

[3]These wells are not the proposed water supply wells, and were abandoned shortly after the tests were performed.

groundwater quality in water-supply wells installed outside of petroleum-impacted areas and constructed in accordance with County guidance is negligible.

These conclusions notwithstanding, Chevron believes that it is prudent to ensure that the wells are protected from the "potential" of migrating contaminants. As such, if the County Development Alternative is pursued, Chevron will work with the Central Coast Regional Water Quality Control Board in preparing and implementing a sentinel monitoring program that would include wells positioned and constructed specifically to monitor inflowing water and alert the operators of any approaching petroleum-related constituents of concern.

5.0 Conclusions

Based on the facts that (1) only TDS exceeded any of the drinking water standards and/or screening levels in the groundwater samples collected in 2002 from the four proposed potable water production wells, (2) these TDS values are within the range of acceptable TDS values as defined by California, and while they do exceed a federal secondary (aesthetic) standard the measured levels are qualified as "fair" tasting water, (3) the degree of communication between the shallow and deep saturated groundwater zones at the Site is limited, (4) TPH was not detected in the production well 2002 groundwater samples indicating that neither TPH nor polar biodegradation products were present in the samples, and (5) Avocet concluded that there is negligible potential for petroleum-impacted soil at the Site to directly affect groundwater quality in water-supply wells installed outside the petroleum-impacted areas, groundwater collected from Wells #1-4 appears to be safe to use as potable water for the proposed commercial development at the Site. It is recommended, however, that sentinel wells be used to ensure incoming water remains un-impacted prior to reaching any supply well.

Sincerely,

Charles E. Lambert, PhD, DABT

References

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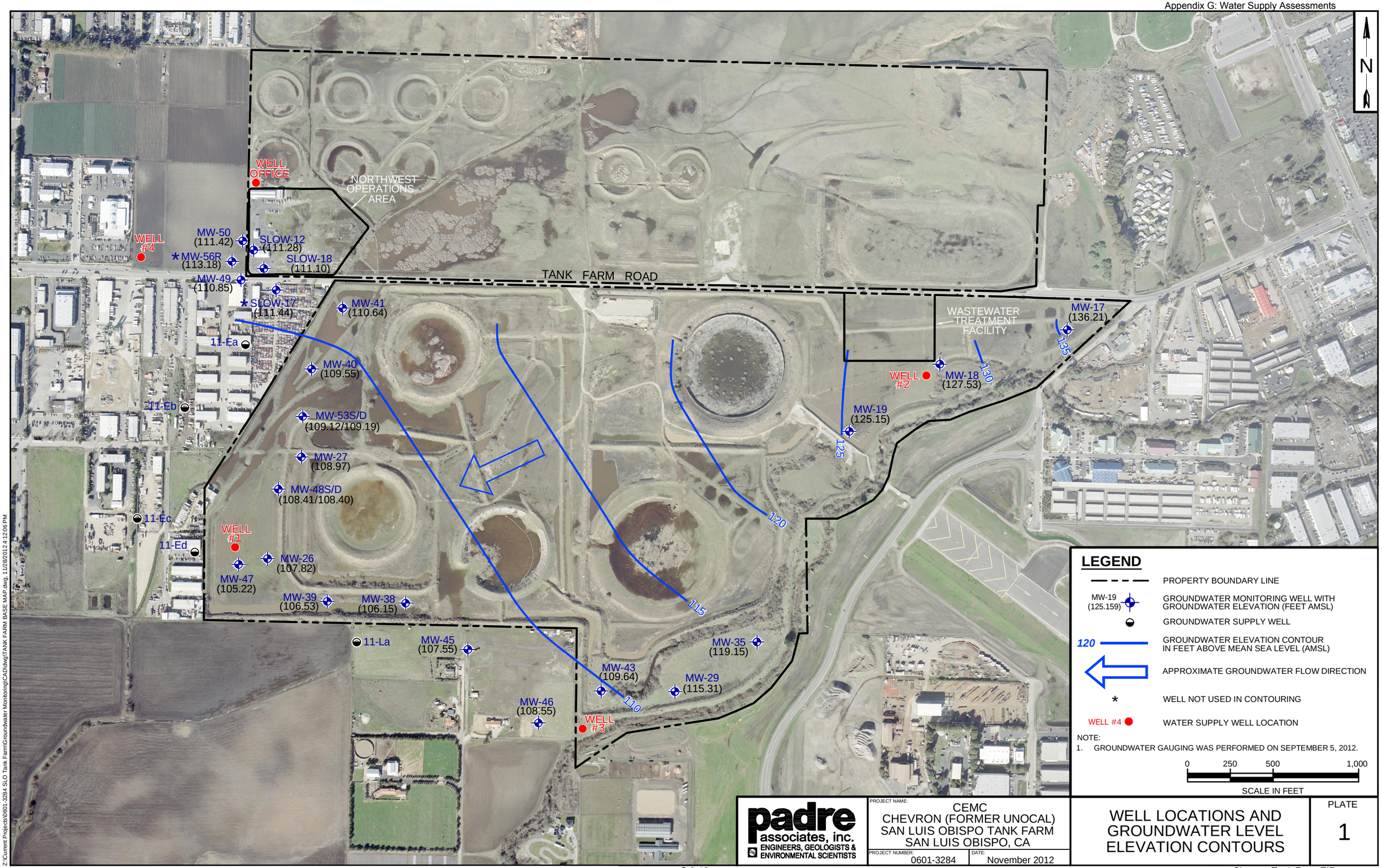
FIGURES



padre associates, inc.
ENGINEERS, GEOLOGISTS & ENVIRONMENTAL SCIENTISTS

PROJECT NAME: CEMC CHEVRON (FORMER UNOCAL) SAN LUIS OBISPO TANK FARM SAN LUIS OBISPO, CA

PROJECT NUMBER: 0601-3284

DATE: November 2012

WELL LOCATIONS AND GROUNDWATER LEVEL ELEVATION CONTOURS

PLATE 1

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ATTACHMENTS

ATTACHMENT A

Technical Memorandum: Environmental Issues Concerning Future Water Supply Wells

Avocet Environmental, Inc., December 2, 2011

AVOCET ENVIRONMENTAL, INC.

December 2, 2011 Project No. 1234.004

Bill Almas
Senior Real Estate Consultant
CHEVRON BUSINESS AND REAL ESTATE SERVICES
4051 Broad Street
San Luis Obispo, California 93401

Technical Memorandum
Environmental Issues Concerning Future Water Supply Wells
Former San Luis Obispo Tank Farm
San Luis Obispo, California

Dear Mr. Almas:

As a part of the permitting process for the former San Luis Obispo (SLO) Tank Farm Remediation and Redevelopment project, a California Senate Bill 610 (SB 610) water supply assessment is being prepared by Cleath-Harris Geologists, Inc. Avocet Environmental, Inc. was asked to prepare a Technical Memorandum in support of this assessment to evaluate the potential for petroleum-impacted soil at the former tank farm to adversely affect groundwater quality in water-supply wells installed outside of petroleum-impacted areas. To evaluate the potential for future impacts, this assessment considered the physical and chemical properties of the petroleum, the hydrogeology of the site, and more than 20 years of groundwater monitoring data.

Our conclusions are that the potential for direct impacts to water supply wells due to migration of separate- or dissolved-phase petroleum is negligible. However, biodegradation of the petroleum is producing polar nonhydrocarbons that may be detected in downgradient wells at low concentrations. These types of dissolved organic compounds are prevalent in the groundwater of aquifers containing decomposing vegetation, which are common throughout the world. The reported low toxicity and taste and odor properties of these compounds, relative to the parent petroleum, suggest that the potential presence of these polar nonhydrocarbons will not limit utilization of the groundwater resource for the proposed project. If future analyses reveal these compounds to be present in water supply wells at unacceptable levels, reliable and cost-effective treatment methods are available for their removal.

Groundwater Exploration

In 2002, Cleath & Associates conducted a site-specific groundwater exploration study for the SLO Tank Farm site. Four wells were installed to depths ranging from 70 to 200 feet below ground surface (bgs). All four wells were constructed outside, but downgradient of petroleum-impacted areas, with three of the wells situated along the southern perimeter of the property and one located north of Tank Farm Road and west of the former operations area. When tested, these wells provided variable production, and recommended pumping rates varied from a low of 20

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gallons per minute (gpm) to 40 gpm in three of the wells. This was less than was anticipated by Cleath. The fourth well, located near the southwest corner of the property, was more productive and Cleath recommended a 140 gpm pumping rate. Groundwater was magnesium bicarbonate/chloride in character and of generally poor quality. TDS concentrations are above the secondary drinking water maximum contaminant level (MCL) of 500 mg/L, ranging from 540 to 810 mg/L. The groundwater is very hard, ranging from 400 to 640 mg/L. None of the water samples collected from the wells exhibited evidence of petroleum-related impacts to groundwater quality.

Hydrogeology

The site is located near the western end of the San Luis Valley, a narrow northwest-trending alluvium-filled basin. At the Tank Farm, the alluvium ranges in thickness from zero at the northeastern corner, where the Franciscan Formation is exposed, to about 180 feet near the southwestern corner. Although the alluvium generally increases in thickness from northeast to southwest, the bedrock surface exhibits considerable relief, producing localized areas (e.g., the area of former Reservoir 5) with very thin accumulations of alluvium. The upper 20 feet of the alluvium generally consists of silty and lean clays with moderate to high plasticity. Lenticular interbeds of fine-grained silty sand and poorly to well-graded sands and gravels predominate below a depth of 20 feet. Typically referred to as the "Franciscan mélange," the Franciscan Formation underlies the alluvium and is comprised of a complex collection of various, generally nonwater-bearing rock types.

The alluvial deposits filling the valley comprise the primary groundwater reservoir serving the San Luis Obispo area and reach a maximum thickness in excess of 200 feet south of the Tank Farm site. During drilling, groundwater is generally encountered in the alluvium at depths ranging from 5 to 27 feet. Groundwater flows principally in thin sandy interbeds within the upper 20 foot fine-grained section and within the coarser-grained sand units below a depth of 20 feet. The coarser-grained units are likely channel deposits that were eroded into finer-grained floodplain deposits.

Groundwater consistently flows to the west-southwest under a hydraulic gradient of approximately 0.007 ft/ft. Water-saturated hydraulic conductivities derived from both lab and aquifer test data are reported to generally range from 10^{-4} to 10 ft/day. For example, water-saturated hydraulic conductivities estimated from testing of the alluvial aquifer using wells on a neighboring property ranged from about 1 to 23 ft/day with an average of 9.7 ft/day; presumably the higher values are representative of the coarser deposits. Assuming a water-saturated porosity of 0.3 ft^3-pores/ft^3-soil, the 0.007 ft/ft gradient, and a hydraulic conductivity of 9.7 ft/day, then the average linear groundwater velocity estimate would be about 100 ft/year.

Multi-level piezometers have been used to determine if vertical gradients exist within the aquifer. Consistent upward and downward vertical gradients significantly above the resolvable level of about 0.003 ft/ft have not been detected at the site.

To determine the degree of hydraulic communication between the shallow, petroleum-impacted, and deep (e.g., greater than 50 feet) saturated zones, aquifer tests were performed on two properties situated along Tank Farm Road (England, Shahin & Associates, 1992; England & Associates, 1996). These tests involved the installation of two "water supply" wells within or immediately adjacent to petroleum-impacted soils and constructed in accordance with County of San Luis Obispo well construction standards (minimum annular seal depth of 50 feet). The tests were monitored by one or more observation wells completed in the shallow saturated zone (<30 feet) and located at varying distances and directions from the water supply well. The water supply wells were pumped for 24 hours while water levels in both the supply and observation wells were continuously recorded using pressure transducers and data loggers. Groundwater samples, collected from the supply well at the beginning, middle, and end of the tests, were submitted to an analytical laboratory and tested for total petroleum hydrocarbons (TPH) and BTEX. The aquifer tests revealed that sustained drawdowns in excess of 20 feet in the supply wells had no significant effect on water levels in the shallow saturated zone. Furthermore, the laboratory analytical results revealed no detectable concentrations of TPH (<100 µg/l) or benzene (<0.5 µg/l). The conclusion of both aquifer tests was that the degree of communication between the shallow and deep (e.g., greater than 50 feet) saturated zones is limited.

Nature and Extent of Contamination

Petroleum released during site operations between 1910 and the early 1980s has impacted soil and groundwater underlying the SLO Tank Farm. A number of investigations have been conducted since the late 1980s to assess the nature and distribution of hydrocarbons in soil and groundwater. These investigations have identified three principal areas of subsurface petroleum occurrence:

- Northwest Area - underlying the former NW Operations Area. This area includes several smaller, separate occurrences that underlie former pipelines and former steel ASTs located north and northeast of the field offices. Vertically, residual petroleum in this area is limited to a depth of approximately 25 feet, but mostly occurs in the 10- to 15-foot depth range.

- Northeast Area - beneath former Reservoir 4. Petroleum-impacted soil and bedrock were found to extend from the ground surface to depths of up to 50 feet.

- Southern Area – underlying most of the property south of Tank Farm Road. Impacted soil occurs primarily in the 5- to 25-foot depth range. Locally, impacted soil extends as deep as 50 feet below Reservoirs 2 and 3. A portion of the subsurface petroleum in this area extends onto private property south of the Tank Farm.

Within these areas, the petroleum does not exist as a contiguous, homogeneous body, but rather occurs largely (in terms of volume) within the intergranular space of more permeable sand lenses and, to a lesser degree, as thin films of viscous petroleum in root pores and along fractures in fine-grained silts and clays (Groundwater Technology, 1991). Due to the nature of alluvial systems, such as that underlying the tank farm, these permeable sand lenses are laterally and

vertically discontinuous, separated by fine-grained, low permeability sediments. Consequently, the liquid oil has become trapped and is stratigraphically contained by the fine-grained sediments.

The viscosity of crude oil samples from the tank farm ranges from 120 to 3,200 centipoise (cP), with an average of about 700 cP. The crude oil's high viscosity alone renders it hundreds to thousands of times less mobile than water. Computer simulations and over 20 years of monitoring demonstrate that the subsurface liquid petroleum plume has achieved equilibrium and is incapable or further lateral migration. Therefore, the potential for liquid petroleum to impact groundwater production wells established outside areas of petroleum-impacted soil is negligible.

The potential for impacts to onsite water production wells constructed outside of petroleum-impacted soil areas are more likely to result from dissolved petroleum constituents. The potential for petroleum to produce a dissolved phase is a function of its chemistry. Petroleum is a mixture consisting of potentially thousands of different chemical compounds comprised principally of hydrogen and carbon. Each of the compounds comprising the mixture has a defined number of carbon atoms (generally ranging from 1 to 40) and a specific atomic structure that determine its unique physical properties (e.g., solubility, volatility, etc.).

It is the relative proportion of the various types of hydrocarbon compounds in the mixture that determine the physical properties of the mixture. For instance, petroleum containing greater proportions of low molecular weight hydrocarbons (compounds comprised of 4 to 10 carbon atoms [C_4-C_{10}]) are more volatile and soluble (i.e., mobile in the environment) than petroleum containing a greater proportion of high molecular weight hydrocarbons (compounds comprised of greater than 10 carbon atoms [$>C_{10}$]). Crude oil at the former SLO tank farm consists almost entirely (95 percent) of C_{10}-C_{40} hydrocarbons with essentially no C_4-C_{10} hydrocarbons (benzene, toluene, ethyl benzene, and xylenes, collectively referred to as BTEX, occur in the C_4-C_{10} range). This is significant because C_{10}-C_{40} hydrocarbons and the polynuclear aromatic hydrocarbons (PAHs) sometimes associated with these petroleum fractions are essentially immobile in the environment.

Of the petroleum-impacted areas, the former NW Operations Area (northwest area of the site) is unique because, in addition to the usual high-molecular weight hydrocarbons, the petroleum contains a light fraction consisting of C_5-C_{14} range hydrocarbons, including BTEX. The petroleum has been ascribed to multiple primary sources including the main oil distribution pipelines, former ASTs, the fire school, and a former gasoline UST. Therefore, although the vast majority of the petroleum impact at the former tank farm is geochemically incapable of generating a dissolved hydrocarbon fraction capable of significantly degrading downgradient groundwater quality, the petroleum underlying the NW Operations Area is capable of producing a dissolved hydrocarbon faction and this area should be avoided to the extent possible when locating future production wells.

Groundwater Monitoring

Regular fluid level and groundwater quality monitoring has been performed at the tank farm since 1990 – providing more than 70 monitoring events for some wells (Padre, 2011). Site groundwater is presently monitored semi-annually in 20 onsite groundwater monitoring wells and 5 offsite downgradient water supply wells per the RWQCB Monitoring and Reporting Program (MRP) 93-120. The well density is highest along the tank farm site southern and western boundaries, as these are hydraulically downgradient of known source areas.

Historically, dissolved TPH concentrations have generally been less than 1,000 µg/L in the wells currently used for monitoring, with the exception of monitoring wells located within and immediately downgradient of the NW Operations Area. As previously described, due to a set of conditions unique to the NW Operations Area, the petroleum in the saturated zone also contains a light fraction (C_5-C_{20}), including benzene. This light fraction is responsible for the NW Operations Area being the only area of the site where groundwater containing dissolved petroleum (TPH and benzene) at concentrations greater than maximum contaminant levels (MCLs) or frequently applied action levels has migrated offsite. Subsequent studies have demonstrated that natural processes have limited dissolved-phase impacts to areas immediately adjacent to the southwest corner of the NW Operations Area[1]. Although onsite and offsite studies have demonstrated a negligible degree of hydraulic communication between the shallow saturated zone and deeper zones capable of yielding sufficient water to a production well, the completion of production wells within and immediately downgradient of the NW Operations Area is not recommended[2].

More than 1,100 groundwater samples have been collected from wells monitoring areas of the former tank farm exclusive of the NW Operations Area[3]. For the most part, these samples were tested for TPH and BTEX, although a significant number were also tested for PAHs. With respect to TPH, there is no MCL; the RWQCB regulates this contaminant on a case-by-case basis, but often ascribes 1,000 µg/L as a reasonable action level. A study of the groundwater monitoring record for areas exclusive of the NW Operations Area indicates that 43 percent (481) of the samples tested for TPH contained detectable (>100 µg/L) concentrations. These concentrations range from 100 to 1,600 µg/L, with an average concentration of about 240 µg/L. The vast majority of detected concentrations are in the 100 to 400 µg/L range, with many fewer in the 400 to 1,000 µg/L. Only 4 out of the 1,118 samples tested for TPH have contained concentrations greater than 1,000 µg/L, and none of these was verified by resampling (i.e., subsequent samples contained less than 1,000 µg/L). Benzene has never been detected (<0.5 µg/L) in the 560 samples collected from monitoring wells outside of the NW Operations Area.

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1 Well OMW-6, situated about 450 feet downgradient of the NW Operations Area, has been sampled on more than 60 occasions since 1990 (through September 2005) and has never contained a detectable concentration of benzene (<0.5 µg/L).

2 It is noteworthy that a water supply well has been situated within the former NW Operations Area for several decades. Although, groundwater produced from this well exceeds drinking water standards for nitrate, petroleum or petroleum-related compounds have not been reported.

3 For purposes of this analysis, Wells SLOW-12, SLOW-17, SLOW-18, MW-49, MW-50, and MW-56, which are located within or downgradient of the NW Operations Area, are not included in the site-wide groundwater dataset.

Therefore, the petroleum geochemistry, which suggests that the weathered petroleum is incapable of generating a dissolved hydrocarbon fraction, and the groundwater monitoring record, which indicates that 43% of the samples contain dissolved TPH at an average concentration of 240 µg/L, appear to be in conflict. To address this apparent disagreement, forensics studies have been undertaken to determine the nature of the dissolved TPH. Notable among these studies is the analysis of 343 groundwater samples for TPH both prior to and following treatment with silica gel. Silica gel removes polar organic compounds, which are not true hydrocarbons since they contain oxygen in their atomic structure. The results showed that prior to silica gel treatment, 172 (about 50%) of the 343 samples contained an average TPH concentration of about 200 µg/L. Following silica gel treatment, only two of the 343 samples contained TPH and the TPH concentration in these two samples (110 µg/L) was just slightly above the detection level of 100 µg/L. The results indicate that essentially all of the TPH detected in wells situated downgradient of petroleum-impacted soil consists of polar nonhydrocarbons.

The polar compounds (polars) in groundwater at petroleum release sites are typically the by-products of biodegradation (CSWRCB, 2010). During biodegradation, petroleum hydrocarbons are sequentially oxidized by microbes, first to alcohols and then to organic acids (which are both polar compounds), and then ultimately to carbon dioxide and water (e.g., Barcelona, et al. 1995; Dragun 1998). Studies at the San Luis Obispo tank farm have established that petroleum biodegradation is an active process at the site and that the concentration of polar nonhydrocarbons naturally attenuates with increasing distance from source areas as the groundwater becomes increasingly oxygenated (England Geosystem, January 25, 2002).

Because these polars are ubiquitous at petroleum release sites and since they possess a higher degree of mobility than the equivalent petroleum fraction, recent studies have focused on the toxicity and organoleptic (taste and odor) properties of the compounds and the relative threat they pose to potable water quality. With respect to toxicity, comparison of the average reference doses (RfDs – the EPA's measure of the oral ingestion toxicity of a substance) for the types of polar compounds common at petroleum release sites indicates that polar compounds are likely of significantly lower toxicity than the equivalent (C_{11}-C_{22}) petroleum fraction (CSWRCB, 2010). Similarly, with respect to organoleptic properties, comparison of odor thresholds for weathered and unweathered dissolved petroleum fractions indicates that the polar compounds likely have higher taste and odor thresholds than the equivalent petroleum fraction (Gibbons, 1940). Based upon the results of these and other studies, the State Water Resources Control Board has recommended to the Regional Boards that "…the focus of the State's resources and cleanup goals at petroleum release sites in California be the petroleum hydrocarbon constituents and not the polar by-products of biodegradation" (CSWRCB, 2010).

These types of dissolved organic compounds are common in the groundwater of aquifers containing decomposing vegetation – such as the colored-water aquifers of Orange County, California, which contain buried ancient redwood forests, and aquifers bordering active marshes and swamps, which are common in the American southeast (vanLoon and Duffy, 2010). Due to the value of these resources, reliable and cost-effective treatment methods, including

nanofiltration, ozone injection, and/or biologically activated carbon, have been established to render the groundwater a viable source of water supply (Sobhani et. al., 2012).

Conclusions

Based upon the available information, the potential for petroleum-impacted soil at the former tank farm to directly affect groundwater quality in water-supply wells installed outside of petroleum-impacted areas and constructed in accordance with County guidance is negligible. However, since polar compounds are being generated as by-products of naturally-occurring petroleum biodegradation and because these soluble nonhydrocarbons are capable migrating beyond the petroleum source zones, the petroleum has the potential to indirectly affect groundwater quality. Although the relative impact of these polar compounds on water quality is likely low (due to the low toxicity and organoleptic properties) and may prove insignificant compared to the source petroleum, the potential exists for these compounds to be present in wells installed outside of petroleum-impacted areas. Since these compounds degrade with increasing distance from the source areas, the greater the distance between the supply well and the petroleum source areas, the lower the potential concentration, if any, of polar nonhydrocarbons.

Historical groundwater monitoring of five off-site water supply wells indicates that approximately 50% of the samples have contained detectable (100-200 µg/L) concentrations of polar nonhydrocarbons. There is no drinking water standard for these polar compounds or for TPH, which would be the likely surrogate used to quantify its occurrence. Furthermore, the likely concentrations are well below the levels commonly addressed by regulatory agencies. Given the general poor quality of the local groundwater (total dissolved solids in excess of 500 mg/L) and the low toxicity and organoleptic properties of the polar nonhydrocarbons, it is unlikely that the possible presence of occasional low concentrations of polar compounds will limit utilization of the groundwater resource for the proposed project. Any future groundwater quality monitoring program developed for the water supply wells should utilize silica gel treatment to provide perspective on the nature of any organic compounds detected in the samples. If future analyses reveal these compounds to be present in water supply wells at unacceptable levels, reliable and cost-effective treatment methods are available for their removal.

If you have any questions regarding this report or require additional information, please do not hesitate to call.

Respectfully submitted,

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