Off-site Petroleum Hydrocarbon Contamination Resulting from Losses at the Amoco Former Refinery Sugar Creek, Missouri

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I. Background

The Amoco Former Refinery, located in Sugar Creek, Missouri, began operations in 1904. The facility was expanded and modified over the years until its closure in June 1982. During the 78 years of refinery operations, the crude oil refining capacity increased from 12,000 to 100,000 barrels per day. The products manufactured at the refinery included gasoline, distillate, jet fuels, residual fuels and other petroleum products. Numerous documented releases and spills of various hydrocarbon products from tanks, underground pipes/lines and processing areas were documented beginning in 1950. There are, however, no records of releases and/or spills that occurred between 1904 and 1950.

Petroleum hydrocarbon contamination of the air/atmosphere, soils, surface waters and groundwater was not confined to the facility boundaries. Various hydrocarbon compounds lost to the atmosphere on the former refinery site migrated off-site into adjacent residential areas. Off-site migration of light non-aqueous phase liquids (LNAPLs) and associated dissolved phase hydrocarbon constituents were detected in Sugar Creek, the Norledge Tributary to Sugar Creek and groundwater monitoring wells installed on-site and off-site in and near residential areas located south of the facility. Although many other parts of the refinery and off-site areas also contain hydrocarbon contamination, this report addresses the off-site contamination south of the former refinery site.

II. Geology/Hydrogeology

The geology of the Amoco Former Refinery site is variable. The northern part of the site includes the West Bluffs and East Bluffs areas and the Missouri River Floodplain. The bluff areas contain glacial till, loess, and/or residual soils overlying bedrock in some areas. Glacial till deposits have been described on the West Bluffs area. The till is stiff, reddish-brown, poorly sorted, medium to highly plastic sand, gravelly clay with occasional cobbles and erratics (Woodward-Clyde Consultants, 1987). Observed thickness of the till is up to 20 feet. Loess deposits on the site are generally unstratified, moderately friable, moderately permeable wind blown silts and clays. These loess deposits are confined to the East and West Bluffs areas, where thicknesses vary from 10-40 feet on the East Bluffs to as much as 71 feet on the West Bluffs.

Alluvial deposits are confined to the Missouri River and Sugar Creek floodplains. These deposits vary from 10 feet in the southern part of the site, in the Sugar Creek floodplain, to over 85 feet in parts of the Missouri River floodplain. The deposits in the Missouri River floodplain vary from clays and silts, to fine to coarse sands (with varying amounts of clay and silt), to coarse sand and gravel located immediately above bedrock. The boundaries between the different lithologies vary, as one would expect in a fluvial depositional environment.

Alluvial and colluvial soils dominate the Sugar Creek floodplain area located to the south, in the Norledge Street area, and north-south where the creek runs east of the Crawford Area through the former refinery site. Sugar Creek alluvium deposits are composed of reworked loess and loess derived colluvium. The colluvium deposits are reworked sediments deposited by runoff waters, and consist of loess derived low-plastic, silts and silty clays. Since the colluvium and alluvium deposits are intermixed in the Sugar Creek floodplain areas, these deposits are virtually indistinguishable. The thickness of the Sugar Creek floodplain sediments range from 10 feet (monitoring well A-26) to over 60 feet.

The majority of the facility lies within the Sugar Creek drainage basin, which encompasses approximately 2700 acres (Foster Wheeler Enviresponse, Inc., 1993). Groundwater in the vicinity of the site is derived from the infiltration of meteoric water (precipitation), groundwater flow from areas adjacent to the site, and recharge from surface water. Topographic relief on the site is approximately 200 feet, and substantially affects the surface water and groundwater flow. The groundwater is primarily confined to the unconsolidated sediments in the floodplain areas and unconsolidated sediments deposited over bedrock in the bluffs areas. The downward percolation of water from precipitation, due to gravity, eventually reaches the water table or upper portion of the saturated zone.

On the eastern part of the site (East Bluffs area), groundwater moves west toward Sugar Creek and northwest toward the Missouri River. On the western part of the site (West Bluffs and West Tank areas), groundwater in the loess deposits flows radially outward and down from a topographic high in the West Plant Process Area. A portion of this groundwater discharges east to Sugar Creek, south to an unnamed tributary (Norledge Tributary) of Sugar Creek, west to a tributary of Rock Creek and north toward the Missouri River. In general, a large volume of the upland groundwater flows off-site to the south.

Groundwater flow into Sugar Creek alluvium/colluvium originates in the surrounding uplands (topographically high areas) unconsolidated sediments and fractured water-bearing bedrock. South of the former refinery site, and along the site boundary, the Sugar Creek floodplain is narrow and bedrock is present at relatively shallow depths. The interaction of groundwater occurring in bedrock and Sugar Creek is greater in this area than further downstream (north of Norledge Street). Based on previous studies, where Sugar Creek passes through the site, it is a gaining stream; groundwater flows into the stream from adjacent subsurface sediments. There are no indications that Norledge Tributary and the portion of Sugar Creek located south (off-site) of the site are gaining groundwater from adjacent alluvium/colluvium sediments. During high water stages, Sugar Creek is likely a losing stream, and recharges the groundwater contained in floodplain sediments.

III. Seeps, Spills and Releases

Based on a review of various Amoco documents, numerous hydrocarbon seeps, spills and releases occurred on the former refinery site and off-site since operations began in 1904. Although the focus of this report is the hydrocarbon contamination south of the former refinery site, hydrocarbon spills and releases occurred throughout many parts of the facility. The off-site petroleum hydrocarbon contamination (seeps) along Norledge

Tributary and in the vicinity of Norledge Street and Carlisle Avenue is not anomalous; this hydrocarbon contamination is a result of (and consistent with) Amoco's refinery-wide practices.

Hydrocarbon seeps were documented along Norledge Tributary and Sugar Creek since 1950. As stated in the 1989 Facility Background Report prepared by Woodward-Clyde Consultants (WWC), no written records relating to leaks were found dated earlier than 1950. Although no seeps were documented by Amoco, hydrocarbon seepage undoubtedly occurred prior to 1950. LNAPL and hydrocarbon staining were documented on the surface waters and banks of Norledge Tributary and Sugar Creek.

A natural spring that feeds into Norledge Tributary (the west branch of Sugar Creek) has contained LNAPL since at least 1950. Numerous leaks in tanks and buried lines located east of Willow Avenue in the West Hills Tank Area were detected over the years. Although some leaks were found and repaired, LNAPL continued to flow from the spring into Norledge Tributary. Amoco documents/memos indicate that at least two storage tanks (176 and 177) were erected in 1952 with used steel from dismantled tankage at Hominy, Oklahoma. The bottoms of these tanks were constructed with used steel plates. During hydrostatic testing of these tanks, it was confirmed that the bottoms of the tanks were leaking (Zamansky, 1998; SC158599). It is not known whether other tanks at the former refinery site were also constructed with used steel plates.

In 1964, the amount of LNAPL in the spring feeding into Norledge Tributary was approximately 25 percent. During 1965, the LNAPL in the spring was identified as leaded gasoline (Erickson, 1966). This is consistent with product leakage from tanks (including 176 and 177) and associated underground piping in the West Hills Tank Area (along Willow Avenue), north of Norledge Street, where gasoline products were known to be stored since 1936 (Attachment A). The Norledge Street sump that was installed beginning in 1959 (and completed in 1983) had accumulations of hydrocarbon liquids up to 650 barrels per day (bbl/d). This system was installed to intercept the liquid hydrocarbons that were migrating off-site into the spring and creeks. In 1973 accumulation rates averaged 150-200 bbl/d. It was estimated that the volume of the leak contributing to the sump was 57,300 barrels per year (2,406,600 gallons per year). Prior to the installation of the sump system, a large part of the estimated LNAPL volume drained into Norledge Tributary and Sugar Creek. The petroleum odors reported by residents are consistent with loses of hydrocarbon vapors associated with the above product (gasoline) leaks.

Leaded gasoline in the United States produced between 1950 and 1980 contained concentrations of benzene from 2–5 percent by volume. In the West Hills Tank Area Investigation Work Plan (June 2, 2002, page 2-2), it is stated that individual benzene concentrations measured in a groundwater sample (TKB-157) exceeded the solubility limit of gasoline derived benzene in groundwater (approximately 3 percent by volume). Benzene was present at elevated concentrations over the majority of the West Hills Tank Area; these elevated concentrations also existed in areas where no significant LNAPL was documented. It was concluded that the source(s) of the extremely high concentrations of benzene in groundwater was (were) the release(s) from the LUF (light ultraformer feed) gasoline tank(s) and/or associated underground pipes. LUF gasoline may contain C-6 hydrocarbons (including benzene) up to 5–15 percent by volume. LUF was historically stored in tank 151 (constructed in 1936) in the West Hills Tank Area. Releases of LUF in the West Hills Tank Area, therefore, would be consistent with

elevated benzene concentrations found on-site and off-site in the spring, creeks and groundwater.

In addition to the LNAPL observed in the spring, at least three other seep areas were documented along Norledge Tributary and Sugar Creek. Two of these seep areas are shown on an American Oil Company map (Proposed Ground Water Collecting Facilities Along Burton Street). A third documented seep occurred in a retaining wall in Sugar Creek near the intersection of Norledge Street and Carlisle Avenue (WWC, 1989). Indications are that this seep crossed the creek and impacted the southern bank/valley wall on Sugar Creek (WCC Location Map: Norledge Street/Sugar Creek Perimeter Seeps, Fig. No. 1, 1989; AMO43967 / SC071791). There is a very high probability that LNAPL and/or dissolved phase hydrocarbons entered the groundwater beneath the residences located south and east of the intersection of Norledge Street and Carlisle Avenue as a result of this ongoing seepage. Based on the estimated flow rates calculated for Sugar Creek, Dr. Bedient (2005) concurs that hydrocarbon contaminants crossed Sugar Creek and entered groundwater beneath residences in the area. The approximate locations of the seeps are shown on Attachment A.

Various spill and release areas located on the southern part of the facility include the West Tank Area (put in service in the late 1940's), the West Hills Tank Area (developed in the early 1920's) and the Crawford Area (a major expansion during 1920-1930). Some documented spills and releases in these areas are shown in red on Attachment A. The majority of the spills and releases were from storage tanks and/or associated underground pipes. Several spills/releases were associated with the gasoline storage tanks, including 158, 159, 160, 176, 177 and 151 (constructed between 1936 and 1951), and piping in the West Hills Tank Area.

Releases from the underground lines (pipes) and storage tanks moved down to the water table and appeared at the periphery of the refinery in a spring, on surface waters and on the groundwater (Carver, C.H., 1974). Since the spills/releases that affected off-site properties south of the facility occurred in areas that where put in service from the 1920's to the 1940's, it is highly probable that the off-site hydrocarbon contamination began prior to 1950 (when releases were first reported).

A list of spills and releases beginning in 1950, prepared for the former refinery by Amoco personnel and/or their consultants, was included in the Facility Background Report (WWC, 1989). As stated in the report (page 55), it should not be implied that the included list contains a complete record of all spills and releases since 1904.

IV. Hydrocarbon Contamination

Various assessments have been performed at the Amoco Former Refinery site to determine the extent of liquid hydrocarbons (LNAPL) and hydrocarbon related contamination in air, soils, surface waters and groundwater. Unfortunately, these assessments were performed beginning in the mid-1980's, following the closure of the facility. During the 78 years of refinery operations, the abundance of active spills, releases and seeps resulted in a greater degree of air, soil, surface water and groundwater contamination than reported beginning in the mid-1980's.

A. Air

Air monitoring studies performed beginning in 1988 were not designed to determine the chemicals, such as benzene, that residents were exposed to via air transport over the 78 years of refinery operations. These studies represent a “snapshot” of air quality at the time (day or days) during which the monitoring was conducted. Losses of volatile hydrocarbons (benzene, etc.) to the air/atmosphere from gasoline storage tanks was common. In 1969 it was calculated that for the month of September vapor losses from gasoline storage tanks were 7,664 barrels (321,888 gallon) of light hydrocarbons to the air (Zemansky Deposition, 1998; SC158602). Using Amoco’s calculated losses for September, vapor losses for a one-year (i.e. 1969) period would have totaled approximately 91,968 barrels (3,862,656 gallons) of light hydrocarbons (including benzene). Volatilization of LNAPL, commonly observed on surface waters (Norledge Tributary and Sugar Creek), also contributed hydrocarbon vapors to the atmosphere in the residential neighborhoods located south of the former refinery site. One would expect the hydrocarbon vapor losses to result in the petroleum odors observed/documented by residents.

B. Soils

Vadose zone soils on the former refinery site in the vicinity of spills, releases/leaks contain sorbed phase (residual) and vapor phase hydrocarbon contamination. Vertical and lateral migration of liquid hydrocarbons through vadose zone soils also reached the groundwater in many areas of the site. LNAPL hydrocarbons floating on the groundwater have been noted at several parts of the former refinery site as well as several off-site locations. Dissolved phase hydrocarbon constituents contained in groundwater beneath the site (and off-site) are also the result of the migration of liquid hydrocarbon products (LNAPL) through vadose zone soils.

Several locations along Norledge Tributary and Sugar Creek contain hydrocarbon stained soils due to the various hydrocarbon seeps that occurred in these areas. These areas containing stained soils have been observed since 1950, according to various Amoco documents/reports.

C. Groundwater

The groundwater flow on the southern portion of the site is generally to the south. This flow direction is to a large extent controlled by the topography of the former refinery site. Releases/losses from the West Tank, West Hills Tank and Crawford areas move to the south downhill and down-gradient.

The groundwater was in contact with LNAPL at many areas of the site. In some areas the LNAPL migrated on and with the groundwater down-gradient (to the south) and off-site into creeks, residential areas, etc. The contact of the LNAPL with groundwater served as the source of dissolved phase hydrocarbon contaminants (benzene, etc.) in the groundwater which also moved down-gradient and off-site.

LNAPL and dissolved phase hydrocarbon contaminants associated with groundwater flow migrated into, as well as beneath creeks/streams located off-site. These contaminants infiltrated groundwater beneath residences located south of the site.

D. Surface Waters

Numerous reported releases of petroleum hydrocarbons to the Missouri River, Sugar Creek, Norledge Tributary and other streams in the vicinity of the site have been documented in reports prepared by Amoco personnel and Amoco consultants. Liquid petroleum products (LNAPL) have entered the various surface waters via a natural spring and seeps along valley walls. LNAPL floating on these surface water bodies also resulted in dissolved phase hydrocarbons in the water and volatilization of the LNAPL (airborne hydrocarbon vapors). It has been reported that over the years, children have played in the tributary and creeks in proximity to the former refinery. These children not only inhaled petroleum hydrocarbon vapors (including benzene), but also had dissolved phase petroleum products and LNAPL (gasoline) on their clothing and in contact with their skin.

Although the 1987 WWC report indicates Sugar Creek is a gaining stream as it passes through the former refinery site, there are no data that indicate that Norledge Tributary and Sugar Creek near the south and southeast boundaries of the site are gaining groundwater from adjacent alluvium/colluvium sediments. Groundwater containing dissolved phase contaminants (including benzene), and in many instances LNAPL, could move southward from (and beneath) these streams beneath the adjacent residential areas. During high water stages, Sugar Creek, like many streams, is a losing stream and recharges the groundwater contained in floodplain sediments. Dissolved phase and LNAPL contaminants would move southward away from the creek and enter groundwater beneath the residential areas.

V. Discussion

A. LNAPL and Dissolved Phase Benzene

Amoco was aware of the fact that contaminants were migrating off-site at least as early as 1950. Despite this knowledge, Amoco took little or no action to address the problems. Monitoring wells installed in the early 1980's, both on-site and off-site, contained LNAPL and high concentrations of dissolved phase hydrocarbons (including benzene). Monitoring wells were drilled and installed on various parts of the former refinery and in some off-site areas between 1980 and 2002.

The Norledge residential area located west and southwest of the West Hill Tank Area contains in excess of 30 monitoring and recovery wells. Less than ten monitoring wells were installed off-site in the vicinity of Norledge Street and Carlisle Avenue; no monitoring wells were installed east and south of the intersection of Carlisle Avenue and Norledge Street or east of Sugar Creek. See Attachment B prepared by The Retec Group, Inc. (Norledge Area Study Boundaries and BP property Ownership, Figure 1-2, 2002).

Groundwater data collected from monitoring wells in the Norledge Area in May 1997 contained benzene concentrations varying from non-detect (ND) to 931 ug/L. A plume map (May 1997 Additional Investigation, Figure 3) prepared by TriTechnics Corporation (TTC) using May 1997 groundwater concentration data shows the areal extent of dissolved benzene in the Norledge residential area at that point in time. The off-site

dissolved benzene contaminant plume extends from Evans Street (on the north) to south of Burton Street (on the south) and from Ash Avenue (on the west) to Willow Avenue (on the east) where it continues on-site in the West Hills Tank Area. The apparent sources of this off-site plume are the West Hills Tank Area to the east and the West Tank and West Plant Process areas to the north.

The off-site monitoring wells in the Norledge Area were installed between 1990 and 1997. The May 1997 measurements and resulting plume map represent a "snapshot" of contaminant levels in groundwater 15 years after refinery operations ceased. The data are misleading since not all wells were sampled/tested (off-site and on-site) during this event or other sampling events both prior to and after May 1997.

In the Norledge/Carlisle Area, monitoring well A-26 contained 0.91 feet of LNAPL on January 22, 1987. This well is located approximately 100 feet due west of the intersection of Norledge Street and Carlisle Avenue. It should be noted that the location of this well and other wells discussed in this section were taken from the map prepared by The Retec Group, Inc. (Attachment B). Although LNAPL was not reported during subsequent gauging/sampling events (January 27–April 15, 1987), dissolved benzene concentrations averaged 10,630 ug/L, with a maximum of 14,300 ug/L (Table 8-1; SC017068). In the documents reviewed to date, no analytical results were found between April 15, 1987 and August 5, 1999. The benzene concentration in the sample collected from A-26 on August 5, 1999 was 11,000 ug/L. During the 12-year period (1987-1999) the benzene concentrations in A-26 remained virtually the same; no change in contaminant levels is evident.

Monitoring well MW-107 was installed in 1997 approximately 80 feet north-northeast of the intersection of Norledge Street and Carlisle Avenue, and approximately 25 feet north of Sugar Creek. Between May 22, 1997 and July 18, 2001, MW-107 contained average dissolved benzene concentrations of 15,650 ug/L, and a maximum concentration of 23,300 ug/L (Retec, May 31, 2002, Table 5-1). This well consistently contained benzene concentrations significantly highly than those reported in A-26. It is apparent that MW-107 (and A-26) is located in close proximity to LNAPL.

Monitoring wells MW-19A (total depth = 24 ft.) and MW19B (total depth = 52.5 ft.), located approximately 250 feet northwest of A-26 and 340 feet northwest of MW-107 have contained elevated concentrations of benzene since 1987. Between 1987 and 2001, MW-19A and MW-19B have contained dissolved benzene concentrations averaging over 10,674 ug/L (maximum of 20,000 ug/L) and 9,383 ug/L (maximum of 15,000 ug/L), respectively.

MW-19A and MW19B are located on the southern boundary of the Crawford Area of the former refinery site. The potentiometric surface elevations of these wells are approximately 35 feet higher than elevations in A-26 and MW-107. As a result of the large hydraulic head and steep groundwater gradient between these wells, it is highly probable that the benzene-contaminated groundwater has moved beneath and/or across Sugar Creek beneath the residences in the Norledge/Carlisle Area. The hydrocarbon seep area along Sugar Creek that contained LNAPL for many years also lies between monitoring wells A-26 and MW-107. There is also a high probability that the LNAPL from the seep migrated into groundwater south of Sugar Creek.

A summary of groundwater analytical data from 1987-2002 was included in Appendix C of the May 31, 2002 Norledge Area Corrective Measures Study Addendum prepared by Retec. Since not all monitoring wells (off-site and on-site) were sampled/tested during any sampling event both prior to and after May 1997, a composite dissolved benzene map was needed to show the areal extent of the plume between 1987 and 2002.

A maximum dissolved benzene concentrations plume map was prepared (Figure 1) utilizing analytical data collected from all monitoring wells in the Norledge and Norledge/Carlisle areas (off-site) and adjacent on-site areas. The maximum dissolved benzene concentrations plume contours are displayed on an aerial photograph (Figure 2), overlaying the topography (Figure 3), and overlaying a three-dimensional view of the topography (Figure 4). The maximum concentration of benzene recorded in each monitoring well for sampling events between 1987 and 2002 were posted and contoured. The hydrocarbon seeps in Norledge Tributary and Sugar Creek and LNAPL in monitoring wells MW-54, MW-62 (GeoWest Golden, Inc., 1994) and A-26 noted during this time period were also included on the plume map. The areal extent of the benzene/LNAPL plume, especially in the off-site areas, is considerably larger than the 1997 plume prepared by Retec.

In the Norledge Area, the maximum benzene concentrations plume extends from Evans Street (on the north) to south of Scarritt Street (on the south) and west of Ash Avenue (on the west) to Willow Avenue (on the east) where it continues on-site in the West Hills Tank Area. South of Norledge Street, the plume extends from Willow Avenue (on the west) to east of Carlisle Street and Sugar Creek (on the east) and south of Scarritt Street (on the south). The apparent sources of the off-site plume are the West Hills Tank Area, the West Tank Area and West Plant Process Area.

Contaminant concentrations (and the presence and abundance of LNAPL) prior to the period 1987-2002 were undoubtedly much higher, since numerous high volume seeps, spills, and releases/losses were active during the years of refinery operations. In 1950 seeps, spills and releases were recognized on the facility as well as off-site. Woodward-Clyde Consultants (WWC, 1989) recognized that spills and releases between 1904 and 1950 were probable, although not documented by Amoco.

Independence Waterworks Company filed a lawsuit (Independence Waterworks Co. vs. Standard Oil Co. (Indiana) et al.) against Amoco in 1920 regarding refinery operations. The lawsuit involved the discharge(s)/release(s) of oil products/by-products by Amoco into Sugar Creek and the Missouri River causing the contamination of water supplied to the City of Independence for public and domestic use. This lawsuit indicates those releases from the refinery and off-site contamination occurred at least as early as 1920.

B. Hydrocarbon (Benzene) Vapors

Norledge Area

Petroleum hydrocarbons present as dissolved and liquid (LNAPL) phase on/in Norledge Tributary and the groundwater are sources of vapor phase constituents (including benzene and other volatile hydrocarbons) that migrate upward to the ground surface and into the homes of nearby residents. A subsurface soil gas investigation was conducted in the Norledge Area in 1995. Based on the collection procedure outline in the Revised RFI Report (December 18, 1995; SC046344-SC046347), it appears that the soil gas

results were not representative of benzene vapor concentrations present in subsurface soils and/or groundwater. The purging procedure used prior to the collection of each sample was excessive, thus causing the benzene analytical results to be lower than the actual concentrations present in the near-surface soils. Above background benzene concentrations obtained at three sampling locations (G-010, G-018 and G-019) are valid. Although the soil gas collection technique was partly flawed, the analyses would not yield false positives.

The benzene concentrations measured at locations G-010, G-018 and G-019 were 31.6 ug/L, 32.8 ug/L and 33.2 ug/L, respectively. A comparison of results obtained at these soil gas locations was made with dissolved benzene concentrations obtained from monitoring wells shown on the TTC map (May 1997 Benzene Concentrations in Groundwater; SC150782). Soil gas sample G-010 (31.6 ug/L) is located adjacent to MW-095 where the benzene concentration in groundwater was 30.4 ug/L. Sample G-018 (32.8 ug/L) was located outside the benzene plume, where the groundwater concentration was believed to be non-detect. The G-019 (33.2 ug/L) sample falls within the groundwater plume on the TTC map where the benzene concentrations are 5-100 ug/L.

The vapor concentrations at sample locations G-010, G-018 and G-019 exceed the EPA risk-based concentration (RBC) for benzene of 0.2 ug/L (200ug/m^3) by two orders of magnitude (or over 150 times). It is certain that if the soil gas samples were collected properly, a larger number of detectable vapor concentrations and higher benzene vapor concentrations would have been measured in the Norledge Area. The vertical migration of benzene vapors from relatively shallow groundwater would migrate to the ground surface and into the residents' homes. Residents would be exposed to benzene vapors at the ground surface and in their homes. The petroleum hydrocarbon odors observed by residents are consistent with hydrocarbon vapors reaching the ground surface. This exposure pathway is in addition to the airborne benzene that would reach the residents via atmospheric transport.

Norledge/Carlisle Area

Data collected from monitoring wells A-26, MW-107, MW-19A and MW-19B are crucial to the understanding and interpretation of hydrocarbon exposure (from groundwater contamination) to residents in the Norledge Street/Carlisle Avenue area. Petroleum hydrocarbons present as dissolved and liquid (LNAPL) phase on/in Sugar Creek and the groundwater are sources of vapor phase constituents (including benzene and other volatile hydrocarbons) that migrate upward to the ground surface and into the homes of nearby residents. Although no direct vapor measurements were made in the Norledge/Carlisle Area, a comparison can be made with dissolved phase benzene concentrations in groundwater and corresponding soil vapor results (TriTechnics, 1995) obtained in the Norledge Area, southwest of the West Hills Tank Area.

Soil gas concentrations of between 31.6 ug/L (G-010) and 33.2 ug/L (G-019) were obtained in areas containing dissolved phase benzene concentrations (in groundwater) of 5-100 ug/L in the Norledge Area. The average benzene concentrations (in groundwater) in the Norledge/Carlisle Area vary between 10,630 ug/L (A-26) and 15,650 ug/L (MW-107). Assuming a benzene concentration (in groundwater) of 100 ug/L in the Norledge Area (where soil gas results were obtained), the dissolved phase benzene concentrations in the Norledge/Carlisle Area are approximately 100 to 150 times greater.

To estimate the benzene vapors in the Norledge/Carlisle near-surface soils, two scenarios were considered:

Scenario 1.

1. LNAPL and groundwater containing benzene infiltrated Sugar Creek,
2. Average benzene concentrations found in A-26 (10,630 ug/L) and MW-107 (15,650 ug/L) are present in groundwater in the Norledge/Carlisle Area, south of Sugar Creek. Dissolved benzene concentrations are 100 to 150 times greater than those in the Norledge Area (100 ug/L)
3. Benzene vapors were derived from dissolved phase benzene contained in groundwater, and
4. The benzene vapor (soil gas) concentrations in near surface soils are 100 to 150 times higher than those found in the Norledge Area (30 ug/L).

Using the above assumptions, the concentrations of benzene vapors in near-surface soils in the Norledge/Carlisle Area could vary between 3,000 ug/L and 4,500 ug/L.

Scenario 2.

1. LNAPL and groundwater containing benzene infiltrated groundwater south of Sugar Creek,
2. Due to some dilution (when contaminants moved under/across Sugar Creek), the average benzene concentrations present in groundwater south of Sugar Creek are 50 percent of those found in A-26 and MW-107. Therefore, the average benzene concentrations are assumed to be between 5,315 ug/L and 7,825 ug/L. These concentrations are 50 to 75 times greater than those in the Norledge Area (100 ug/L).
3. Benzene vapors were derived from dissolved phase benzene contained in groundwater, and
4. The benzene vapor (soil gas) concentrations in near surface soils are 50 to 75 times higher than those found in the Norledge Area (30 ug/L).

Based on these assumptions, the concentrations of benzene vapors in near-surface soils in the Norledge/Carlisle area could vary between 1,500 ug/L and 2,250 ug/L.

The above calculated vapor concentrations are extremely high and exceed the EPA risk-based concentration (RBC) for benzene of 0.2 ug/L (200ug/m^3) by four orders of magnitude. Other factors not considered in the above scenarios that would increase the above vapor concentrations include: 1) depth to groundwater in the Norledge/Carlisle Area is less than depth to groundwater in the Norledge Area, therefore, the vertical migration pathway for benzene vapors to the ground surface (and into residences) is shorter, 2) average dissolved benzene were considered; maximum concentrations are considerably higher, and 3) the maximum and average dissolved benzene concentrations in the Norledge/Carlisle Area and the Norledge Area were much higher during refinery operations, when and petroleum product losses, releases and spills were active (1904-1982).

VI. Conclusions

The residents in the areas adjacent to the Amoco Former Refinery were exposed to hazardous chemicals, including benzene, over a period of up to 78 years (1904-1982) while the former refinery was active. It is apparent that following closure of the facility,

the residents continued to be exposed to hydrocarbon vapors; the residents continued to report petroleum (gasoline) odors. The numerous releases of petroleum hydrocarbon products, some of which were documented (after 1950), on the former refinery site migrated off-site into, Norledge Tributary, Sugar Creek (and other surface waters) and groundwater beneath residential areas.

The chemical exposure routes, particularly south of the facility in the Norledge Area and in the vicinity of Norledge Street and Carlisle Avenue consisted of:

1) Dermal, possible ingestion and inhalation,
2) Air/atmospheric transport of benzene and other hydrocarbon constituents,
3) Vapor transport through near-surface sediments of benzene and other hydrocarbon constituents.

Although dermal/ingestion and air transport of petroleum hydrocarbons are significant exposure pathways, they are not specifically addressed in this report. The other major exposure route addressed above is vertical transport of benzene (a known carcinogen) vapors to the ground surface and into homes in the residential areas.

VII. Opinions

- **Releases and spills of petroleum hydrocarbon products on the Amoco Former Refinery site are responsible for off-site contamination present in residential areas south of the facility.**

Numerous releases/spills of petroleum products from tanks, underground pipes/lines and processing areas were documented beginning in 1950. Petroleum hydrocarbon contamination of the air/atmosphere, soils, surface waters and groundwater was not confined to the facility boundaries. Volatile hydrocarbon compounds lost to the atmosphere on the former refinery site migrated off-site into adjacent residential areas. Off-site migration of light non-aqueous phase liquids (LNAPLs) and associated dissolved phase hydrocarbon constituents were detected in Sugar Creek, Norledge Tributary and groundwater monitoring wells installed off-site in residential areas located south of the facility. Although the focus of this report is the hydrocarbon contamination south of the former refinery site, hydrocarbon spills and releases occurred throughout the facility. This contamination was the result of (and consistent with) Amoco's refinery-wide practices.

- **Petroleum hydrocarbon seeps, spills and releases undoubtedly occurred on the former refinery site (and off-site) since operations began in 1904.**

As stated in the 1989 Facility Background Report prepared by Woodward-Clyde Consultants, no written records relating to leaks were found dated earlier than 1950. The seeps and associated contamination documented beginning in 1950, however, were very extensive.

In 1920, Independence Waterworks Company filed a lawsuit (Independence Waterworks Co. vs. Standard Oil Co. (Indiana) et al.) against Amoco. The lawsuit involved the discharge(s)/release(s) of oil products/by-products by Amoco into Sugar Creek and the Missouri River causing the contamination of water supplied to the City of Independence

for public and domestic use. This lawsuit indicates releases of petroleum products from the refinery, and resulting off-site contamination, occurred at least as early as 1920.

- **Benzene and other volatile hydrocarbon constituents migrated into adjoining residential areas via atmospheric transport during the years of active refinery operations (1904-1982).**

Volatile hydrocarbon losses (benzene, etc.) to the air/atmosphere from gasoline storage tanks was common during refinery operations. In 1969 it was calculated that for the month of September vapor losses from gasoline storage tanks were 7,664 barrels (321,888 gallon) of light hydrocarbons to the air. The gasoline storage tanks, constructed as early as 1936, were located in the West Hills Tank Area. Exposure of residents to these volatile gasoline vapors (including benzene), therefore, occurred for decades. Volatilization of LNAPL, commonly observed on surface waters (Norledge Tributary and Sugar Creek), also contributed hydrocarbon vapors to the atmosphere in the residential neighborhoods located south of the former refinery site.

- **Petroleum product (gasoline) seeps into Norledge Tributary and Sugar Creek exposed residents to hazardous chemicals.**

Reported dermal exposure, possible ingestion and inhalation of petroleum hydrocarbons by children playing in Sugar Creek and Norledge Tributary were common during the years of refinery operations. Since LNAPL (identified as gasoline) and dissolved phase hydrocarbons were common on/in surface waters for many years, exposure by residents, especially children, occurred on a regular basis.

- **The degree and extent of off-site groundwater contamination was (is) greater than indicated by Amoco (and their consultants).**

A maximum dissolved benzene concentrations plume map (Figure 1) utilizing analytical data collected from all monitoring wells (between 1987 and 2002) in the Norledge and Norledge/Carlisle areas (off-site) and adjacent on-site areas is more representative of the degree and extent of past groundwater contamination. The hydrocarbon seeps in Norledge Tributary and Sugar Creek and LNAPL in monitoring wells MW-54, MW-62 and A-26, which affect the dissolved phase benzene concentrations, were also included in the plume. This plume is considerably larger than the 1997 plume prepared by Retec.

Contaminant concentrations (and the presence and abundance of LNAPL) prior to 1987-2002 were undoubtedly much higher, since numerous high volume seeps, spills, and releases were active during the years of refinery operations. The plume map (Figure 1), therefore, is conservative concerning conditions predating 1987.

- **Petroleum hydrocarbon vapors (including benzene) originating from the LNAPL/groundwater plume (Figures 1 and 2) have reached the ground surface.**

Following the closure of the refinery, residents in the Norledge and Norledge/Carlisle areas continued to report hydrocarbon odors at the ground surface in the vicinity of their homes. Results of a soil gas survey conducted in 1995 confirmed benzene vapor concentrations in excess of the EPA risk-based concentration (RBC) for benzene in near-surface soils. The vertical migration of benzene vapors from relatively shallow

groundwater, containing LNAPL and dissolved phase hydrocarbons, are apparent sources of the vapors at the ground surface.

During the 78 years of refinery operations, the plume would have contained higher contaminant concentrations. The hydrocarbon vapors (including benzene) reaching the surface, therefore, would have been more abundant and contained higher concentrations. The residents repeatedly reported the strong hydrocarbon odors during the years of refinery operations.

- **The inhalation of hydrocarbon vapors (in particular, benzene) was and is hazardous to the individuals living in off-site areas, such as the Norledge and Norledge/Carlisle areas.**

The vertical (upward) migration of benzene (and other hydrocarbon) vapors from relatively shallow groundwater, especially during the years of active refinery operations, reached the ground surface and probably entered the homes of area residents. Area residents were also exposed to petroleum hydrocarbon vapors resulting from the volatilization of dissolved and liquid (LNAPL) phase hydrocarbons (gasoline) on/in Sugar Creek and Norledge Tributary for many years. Residents would be exposed to benzene vapors at the ground surface as well as in their homes. These exposure pathways are in addition to the airborne benzene that would reach the residents via repeated atmospheric transport.

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