Impact of oil production fluid releases at the USGS' OSPER "B" site, Osage County, OK, USA

J. K. Otton
U.S. Geological Survey, Lakewood, Colorado, USA

W. N. Herkelrath & Y. K. Kharaka
U.S. Geological Survey, Menlo Park, California, USA

R.A. Zielinski
U.S. Geological Survey, Lakewood, Colorado, USA

ABSTRACT: About 20 scientists are investigating the transport, fate, and natural attenuation of salts and organic compounds present in produced water, and their impacts on surface and ground water and ecosystems at research sites located in Osage County in northeastern Oklahoma. At the "B" site, tanks and pits have been a source of releases since 1939. Salt scars extend from the location of three tank batteries down to the Lake Skiatook shoreline. The active production tank battery and adjacent pit have a 60-m-long scar underlain by 1.3 to 1.5 m of saline clayey fill and colluvium. Ground water is a varying mix of sodium-chloride brine from the pit and local magnesium-calcium-sulfate ground water modified by interaction with the sediment. Free and dissolved hydrocarbons move downslope from the pit, but it is uncertain whether free hydrocarbons in wells at the lake's edge are derived from the upslope pit or flooded pits offshore.

1 INTRODUCTION

The U.S. Geological Survey has been conducting investigations at two oil production sites ("A" and "B") in northeastern Oklahoma since February of 2001 as part of the Osage Skiatook Petroleum Environmental Research (OSPER) project. For background information on this project effort and results from investigations at the "A" site refer to Kharaka et al. (this volume). This report focuses on results from the "B" site.

2 OSPER "B" SITE

The "B" research site is located on Skiatook Lake in Osage County about 25 km northwest of downtown Tulsa, Oklahoma. Wells on the lease produce oil from the "Cleveland Sand" (local name) on a small dome with about 10 m of structural relief at depths of 260-305 m. Production began in 1939, water flooding began by late 1951, and by January 1953 there were 10 wells on the lease producing a combined average of 21 bbls/day. Through January 1953 the lease had produced about 110,000 bbls of oil. Current production is approximately 10 bbls/day for all wells on the lease, with a reported 40 bbls/day of coproduced water (S. Hall, lease operator, oral commun. 2002).

The "B" site is in the central part of the lease, at the west end of a small cove, and consists of production processing facilities in a mostly open area on a hillslope and terrace adjacent to the lake. The open area is characterized by grasses and forbs, roads, cut and fill, tanks, pits, salt scars, and isolated oak trees, and is surrounded by a mature oak forest. At least three tank batteries were constructed at this site. An active tank battery and adjacent downslope pit (about 26 m across) are located in the southern part of the site area. A salt scar extends from the east edge of the pit berm down to the lake. An old tank battery site, marked by a flat graded area with some piles of rubble, is in the central part of the site. A second salt scar extends down to the lake from the east edge of this graded area. A tank, injection well, and pit (about 10 m across) are in the north part of the site and a third salt scar extends downslope toward the lake from the east edge of the pit berm. This salt scar terminates in a shallow pit separated from the lake by another low berm. An additional injection well is on the northeastern part of the site across a small creek.

Prior to filling of the lake in the mid-1980s, two contiguous pits were located just beyond the shoreline below the active tank battery. These features are now below the normal pool elevation, however at lowstand, the edge of one pit and the tops of some berms are exposed.

The active tank battery and the unlined pit are the largest sources of ongoing releases. Most produced water from the tank battery is injected via the nearby Class II wells. However, leaks and releases from the tanks enter the pit where the fluid level is controlled by a float-activated sump pump that returns pit water to a storage tank. Site investigations have focused on the releases from the active tank battery and pit.

2.1 *Site field investigations*

Investigations aimed at mapping and characterizing the geology, hydrology, contaminant sources, and impacted areas at the OSPER "B" site and the immediate surrounding areas began in February 2001 (Kharaka & Otton 2003). Drilling and monitoring-well installation started in February 2002. Two wells for stratigraphic and background ground water studies were drilled at locations 130 m and 360 m, respectively, upslope to the west of the "B" site. Onsite, 3 auger wells and 30 direct push wells were completed for ground-water impact studies and local stratigraphic data. Several of the wells below the active tank battery and adjacent pit are now instrumented for continuous data gathering and hydrologic modeling (Herkelrath & Kharaka 2003). Water levels in the pit are also monitored. An EM resistivity survey was conducted across the entire site to determine the extent of conductive, shallow saline surficial sediments and bedrock (Smith et al. 2003).

The mineral composition and sorption properties of selected core samples from impacted and "pristine" areas are being investigated by Rice et al. (2003). The concentrations of nitrates, organic matter, total petroleum hydrocarbons (TPH), conductivity, chlorides, and dehydrogenase activity (DHA) were also determined in selected grab and core samples from these areas to provide data for developing remediation guidelines (Kampbell et al. 2003). Oil, water, brine, and soil samples were characterized and analyzed for geochemical parameters that are indicative of microbial activity. Characterization of the resident microbial populations, as well as the varying stages of weathering and biodegradation of oils, was completed for a number of these samples and reported by Godsy et al. (2003). Offshore investigations of the geochemistry of the lake-bottom waters and shallow sediment in the area of the two flooded pits started in the fall of 2003.

3 SITE GEOLOGY

The OSPER "B" site is entirely underlain by bedrock comprised of shale with lesser siltstone and sandstone that dips 1-2^{o} westward. Site drilling shows that weathered bedrock extends from 3-5 m below the contact with the overlying surficial sediments (Figs. 1 & 2). In all holes, there are a few sandstones 2 to 5 cm thick, some of which are fractured and water bearing. Sandstone layers as much as 30 cm thick are exposed in the west wall of the pit and underlie the tank battery. They were penetrated in an auger hole along the road west of the tanks (BA02, Fig. 2).

Thin, sandy to clayey, sandstone-clast colluvium covers bedrock on the hillslopes. Thickness of the colluvium ranges from about 10 cm upslope west of the tank battery sites to about 1.2 m low on the hillslope. A break-in-slope separates the sloped and terraced areas of the site (bis, Fig.1). An eolian sand layer underlain by clayey sandstone-and-shale-clast colluvium (TC, Fig. 1), and a sandy sandstone-clast alluvium (TA, Fig.1) covers bedrock in the terraced area adjacent to the lake. The eolian sand layer has been largely removed from the terrace by human site activities and erosion (E, Fig. 1). Fill associated with site erosion and pit construction covers the slope around the pit berm and extends part way down the salt scar (Fig. 2).

During lowstands of the reservoir, lake bottom sediments composed of sand and gravel are exposed (Sd, G, VCG, Fig. 1). These sediments represent reworking of TA and TC by wave action.

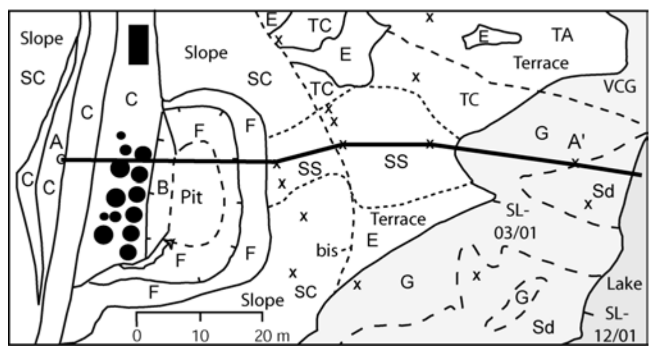

Figure 1. Geology of the active tank battery and pit area. Filled circles are tanks, filled rectangle is a trailer. Slope: SC- slope colluvium over bedrock; C- cut, bedrock with thin veneer of gravel, sand, and silt, some fill near the trailer; B- bedrock in pit wall; F- fill. Terrace: E- eolian sand over colluvium and alluvium; TC- terrace colluvium, eolian sand eroded away; TA- terrace alluvium, eolian sand eroded away. Light gray area- exposed lake bottom at low stand; G- gravel, Sd- sand; VCG- very coarse gravel and boulders. SS- salt-scarred area, fill underlies the upper part of the scar. A-A'- cross section, see Figure 2. SL- shoreline locations, month and year indicated. x- direct push hole; o- auger hole; bis- break in slope.

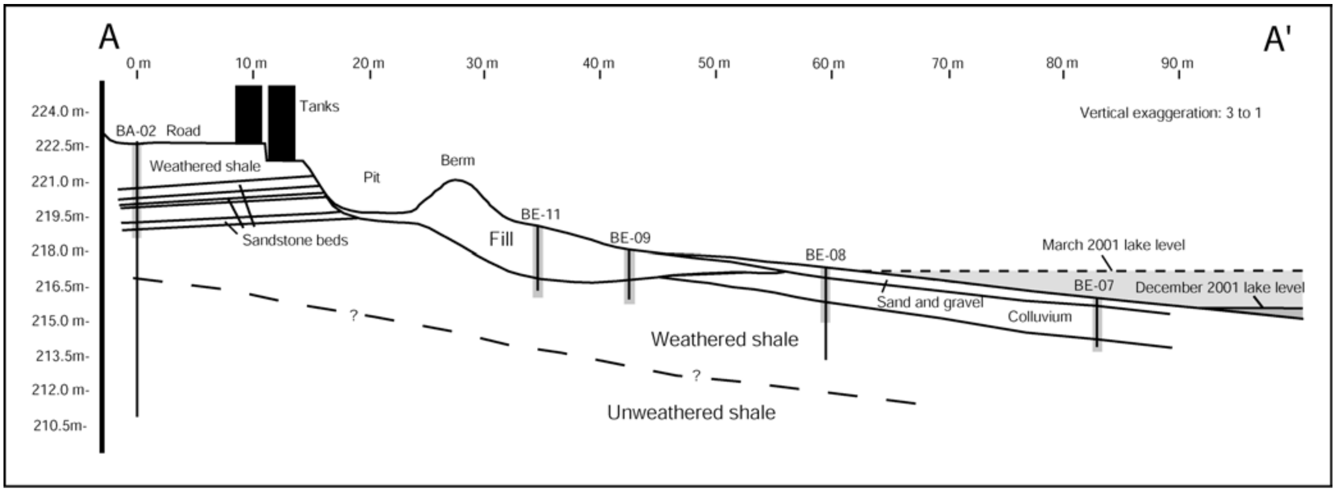

Figure 2. Geologic cross section of the active tank battery and pit area, "B" research site. For location see Figure 1. Vertical lines are boreholes. Shading along the boreholes represents the depth of salt penetration determined by leaching core samples.

4 SITE HYDROLOGY

In the vicinity of the active tank battery, the pit and rainfall are the primary sources for water. The shale bedrock is not thought to be a significant source of shallow ground water. The weathered shale is believed to be relatively impermeable compared to all other units on the site, and has limited storage, and the thin, fractured sandstones have limited storage and transmissivity. In addition to releases and leaks of produced water from the tanks, runoff adds water to the pit, but the catchment area of the pit is limited to the immediate vicinity of the tanks as the ditch on the west side of the road (Fig. 1) diverts surface runoff to the south. Seepage through the walls of the pit is normally slowed by oil-saturated fill that partially seals the pit wall below the sump-pump fill level, however, occasionally the pump fails and the pit fills above this level. When these excursions occur, rapid seepage through the porous, upper part of the east pit wall causes surface flow down the salt scar to the lake.

Below the pit, most shallow ground water flows through the clayey fill and colluvium. The hydraulic gradient is about 0.5m/m. Slug tests indicate that the hydraulic conductivity is 1.0-10.0 cm/day. The Darcy velocity is about 1.8 m per year.

Most rainfall runs off or evaporates from the salt scar area because it is underlain primarily by the clayey colluvium or fill derived from it (Fig. 2) as the eolian sand layer has been eroded away. The drainable porosity of the clay-rich soil is poor. Bare soil on the salt scar dries only near the soil surface. Rainfall generally occurs in short bursts followed by dry periods. When it rains, the available porosity fills quickly and runoff occurs rapidly. After rainfall stops, the water level falls back to levels supported by water in the pit.

The elevation of the lake surface varies in response to water input from storm events, evaporation, and releases by the U.S. Army Corps of Engineers. The normal pool elevation is 218 m above sea level. During the course of this study the pool elevation has varied from a little over normal pool (Figs. 1 & 2) to as low as 215.7 m. The lake-surface elevation affects the local base level for ground water and surface water flow. Areas of ground water seeps are exposed on the lower part of the salt scar during lowstand conditions.

5 PRODUCED WATER AND GROUND WATER CHEMISTRY

Results of water samples from oil wells near both research sites indicate that the produced water is a Na-Ca-Cl brine (~150,000 mg/L TDS), with relatively high concentrations of Mg, Sr, Fe, Mn and NH_4, but low concentrations of SO_4, H_2S and dissolved organics. The chemical composition of Skiatook Lake water and groundwater from drinking water aquifers in the area not impacted by petroleum operations differs considerably from that of the produced water, having much lower TDS (150-520 mg/L), much higher Mg and Ca concentrations relative to Na, and much higher HCO_3 and SO_4 relative to Cl. The lake and potable drinking waters are oxic, with low concentrations of metals, including Fe and Mn, as well as low dissolved organic carbon and organic anions (Kharaka et al., this volume).

Water samples from the pit and from screened intervals in each of the drillholes in Figure 2 were geochemically characterized (Fig. 3). Analysis of water sampled from the deep interval in auger hole BA02 represents the chemistry of local, slightly impacted water in thin, fractured sandstones enclosed by shale. This is a Mg-Na-SO_4 water of modest salinity and likely represents water derived from the weathering of the enclosing shale. The pit water is a Na-Cl brine; however, the salinity (about 35,000 mg/L TDS) is substantially less than the produced water in the storage tank (about 133,000 mg/L TDS). Significant dilution by precipitation and runoff to the pit likely occurs. The water chemistry of holes BE-11, BE-09, and BE-08 shows the variable impact of the saline water releases from the pit. Water from BE-11, just downslope from the berm, is saline but is more dilute than the pit water, having been mixed with local ground water. The water in BE-09 appears to be a diluted pit brine whereas the water in BE-08 is dominated by the local ground water with lesser brine influence. Water from BE-07, which occurs within the outline of one flooded pit, is a dilute brine; however, the brine could have been derived from the active pit upslope or the flooded pit.

In wells BE-09 and BE-07, oil globules were present in the water, a strong oil odor was present, and high measured values for hydrocarbon gases and volatile organic carbon were observed. BE-11 and BE-08 did not have free oil, but oil odor and measured hydrocarbon gases were detected. In BE-07 oil may be derived from the flooded pits.

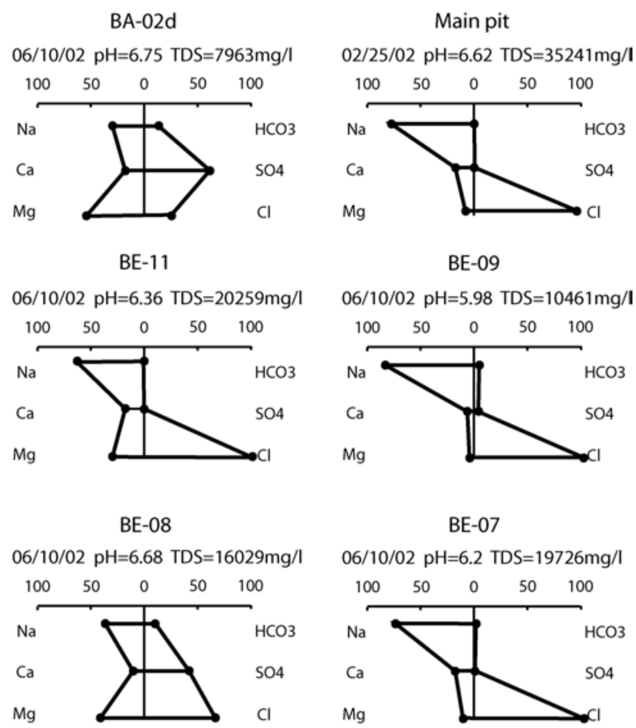

Figure 3. Stiff diagrams showing geochemistry of waters from wells in the active tank battery and pit area. See Figure 2 for location of wells. From Kharaka et al. (2003).

6 CONCLUSIONS

Salts and hydrocarbons in produced waters have impacted shallow ground water and surficial sediments in salt scars at the "B" research site. Shallow ground waters are a mix of the Na-Cl brine in the pit and a Mg-Na-SO_4 local ground water. Salts and possibly hydrocarbons from produced water in the active pit are reaching the littoral zone of the lake, but transport through the clayey colluvium is slow. Surface flow during precipitation events is more rapid, but precipitation plays a limited role in leaching salts from the surficial deposits because of limited penetration. Except where thin, fractured sandstone beds are present, salt penetration into underlying shale bedrock is limited to less than 1 m. Much more work is necessary to document the full extent of ground water salinization, the extent of saline water movement into the lake water column, and the impacts on lake biota.

REFERENCES

Godsy, E.M., Hostettler, F.D., Warren, E., Paganelli, V.V. & Kharaka, Y.K. 2003. The fate of petroleum and other organics associated with produced water from the Osage-Skiatook petroleum environmental research site, Osage County, Oklahoma: *USGS Wat. Res. Invest. Rep.* 03-4260: 85-103.

Herkelrath, W.N. & Kharaka, Y.K. 2003. Hydrologic controls on the subsurface transport of oil-field brine at the Osage-Skiatook petroleum environmental research "B" site, Oklahoma: *USGS Wat. Res. Invest. Rep.* 03-4260: 113-125.

Kampbell, D.H., An, Y-J., Smith, M.W. & Abbott, M.A. 2003. Impact of oil production releases on some soil chemical properties at the OSPER field sites: *USGS Wat. Res. Invest. Rep.* 03-4260: 105-112.

Kharaka Y.K. & Otton, J.K. 2003. Introduction and summary. In Y.K. Kharaka & J.K. Otton (eds.), *Environmental Impacts of Petroleum Production: Initial Results from the Osage-Skiatook Petroleum Environmental Research Sites, Osage County, Oklahoma*, *USGS Wat. Res. Invest. Rep.* 03-4260: 1-13.

Kharaka, Y.K., Otton, J.K. & Abbott, M.M., this volume. Environmental impacts of petroleum production: results from the OSPER "A" site, Osage County, Oklahoma, USA

Kharaka Y.K., Thordsen, J.J., Kakouros, E. & Abbott, M.M. 2003. Fate of inorganic and organic chemicals in produced water from the Osage-Skiatook Petroleum Environmental Research sites, Osage County, Oklahoma: *USGS Wat. Res. Invest. Rep.* 03-4260: 57-84.

Rice, C.A., Cathcart, J.D., Zielinski, R.A. & Otton, J.K. 2003. Characterization of soils and rock at an active oil production site: effects of brine and hydrocarbon contamination: *USGS Geol. Surv. Wat. Res. Invest. Rep.* 03-4260: 137-150.

Smith, B.D., Bisdorf, R.J., Horton, R.J., Otton, J.K. & Hutton, R.S. 2003. Preliminary geophysical characterization of two oil production sites, Osage County, Oklahoma- Osage-Skiatook petroleum environmental research project: *USGS Geol. Surv. Wat. Res. Invest. Rep.* 03-4260: 43-56.