# *Environmental issues of petroleum exploration and production: Introduction*

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Energy is the lifeblood of our planet Earth, an essential commodity that powers the expanding global economy. Starting in the 1950s, oil and natural gas became the main sources of primary energy for the increasing world population, and this dominance is expected to continue for several more decades (Edwards, 1997; Energy Information Administration [EIA], 2004). In the United States, petroleum production started in 1859 when Drake's well was drilled near Titusville, Pennsylvania, and oil and natural gas currently supply approximately 63% of the energy consumption; forecasts indicate that by 2025, their use will increase by about 40% to 28.3 million bbl/day and to 31.4 tcf/yr (EIA, 2004). The clear benefits of petroleum consumption, however, can carry major environmental impacts that may be regional or global in scale, including air pollution, global climate change, and oil spills. This volume of *Environmental Geosciences*, covering environmental impacts of petroleum exploration and production, does not address these major impacts directly because air pollution and global warming are issues related primarily to petroleum and coal uses, and major oil spills are generally attributed to marine petroleum transportation, such as the Exxon Valdez's 1989 spill of 260,000 bbl of oil into Prince William Sound, Alaska.

Exploration for and production of petroleum, however, have caused local detrimental impacts to soils, surface and groundwaters, and ecosystems in the 36 producing states in the United States (Richter and Kreitler, 1993; Kharaka and Hanor, 2003). These impacts arose primarily from the improper disposal of some of the large volumes (presently estimated at ~20 billion bbl/yr total produced) of saline water produced with oil and gas, from accidental hydrocarbon and produced-water releases, and from abandoned oil wells that were orphaned or not correctly plugged (Kharaka et al., 1995; Veil et al., 2004). Impacts and ground-surface disturbances, in the order of several acres per well, can also arise from related activities such as site clearance, construction of roads, tank batteries, brine pits and pipelines, and other land modifications necessary for the drilling of exploration and production wells and construction of production facilities. The cumulative impacts from these operations are high, because a total of about 3.5 million oil



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and gas wells have been drilled to date in the United States, but currently, only about 900,000 are in production (Otton et al., 2002).

Prior to the institution of federal regulations in the 1970s, produced waters, which are highly saline (3000 to more than 350,000 mg/L total dissolved solids [TDS]) and may contain toxic metals, organic and inorganic components, and radium-226/228 and other naturally occurring radioactive materials, were commonly discharged into streams, creeks, and unlined evaporation ponds, causing salt scars and surface and groundwater pollution (Kharaka et al., 1995; General Accounting Office [GAO], 2003). These historical (legacy) releases and the ongoing improper disposal of some produced water have become important national issues that concern petroleum producers, land owners, and state and federal regulators. More recently, new environmental laws and improved industry practices and technology have reduced the most detrimental effects of petroleum activities. In addition, some operators have taken steps, at times voluntarily, to reverse damages resulting from petroleum operations (GAO, 2003). Regulations governing the onshore and offshore disposal of produced water and costs of its management are given in a recent paper (Veil et al., 2004).

This special edition of *Environmental Geosciences* resulted from the Division of Environmental Geosciences oral session ''Exploration and Production Environmental Issues and Best Management Practices: Impacts on Water, Soils, and Ecosystems,'' presented during the 2004 AAPG-SEPM Annual Convention. The session conveners and chairs, Yousif Kharaka and Jim Otton (U.S. Geological Survey) contacted a substantial number of scientists from the petroleum industry, universities, and governmental agencies, aiming to attract general presentations and case histories covering the broad spectrum of views and perspectives. Ten abstracts, out of 20 submitted, were selected for presentation at the half-day session, and seven manuscripts from five presenters are included in this volume.

Two papers report on case studies of low-cost methods for remediation of oil and brine spills that could be used by small independent petroleum producers. The first paper, by Moralwar et al., reports on the effectiveness of a method of remediation, using hay and fertilizer but without gypsum, as amendments for remediation of both oil and brine in a contaminated site located in the Tallgrass Prairie Preserve in Osage County, Oklahoma. The second paper, by Harris et al., describes another site at this Preserve, where a subsurface drainage system was installed to intercept brine from a pipe leak. This resulted in reducing the Cl and Na concentrations in the soil by an average of 93 and 78%, respectively, in the 4 yr after the system was installed. More importantly, approximately 95% of the site revegetated during this period.

Arid Wyoming is one of a few western states that allows discharge of oil field-produced water that meet certain criteria into surface waters for beneficial use by livestock and wildlife. Ramirez reports on 65 wetland sites receiving produced-water discharges in Wyoming that were surveyed in 1996 and 1999, documenting the risks to fish and migratory birds caused by inefficient oil-water separation that causes a chronic discharge of oil into some wetlands. Over 62% of the sites surveyed had inadequate measures to exclude wildlife, particularly migratory birds, from entering oil pits.

Fisher and Sublette report on details of a total of 18,349 oil and saltwater releases that were reported to the Oklahoma Corporation Commission for the 10-yr period from 1993 to 2003. The releases resulted from leaks from lines, tanks, wellheads, and pits and were caused by overflows (tank, pit, and dike), intentional dumping or other illegal activity, storms, fires or explosions, accidents, and corrosion. They report that quantified releases of oil and saltwater had a median volume of 10 and 40 bbl, respectively, and that approximately 34% of releases resulted in reported injury to environmental receptors, including surface water, crops or livestock, soil, fish, or wildlife.

The Bemidji research site, a shallow aquifer located in northern Minnesota, has been the subject of intensive investigations since it became contaminated after a buried high-pressure pipeline ruptured in 1979, spilling an estimated 10,500 bbl of crude oil on the land surface. Cleanup operations by the pipeline company removed most of the oil, but about 2500 bbl collected in topographic low areas and infiltrated into the subsurface. Bekins et al. summarize the distribution of oil and the methanogenic and other pathways of oil degradation in this system. They show that obtained subsurface oil degradation rates are highly variable and strongly influenced by small-scale variations in hydrologic conditions, especially nutrient transport to the oil body by recharge.

The impacts of past exploration and production operations (legacy issues) are the subjects of papers by Otton et al. and Kharaka et al. These authors are involved in a multidisciplinary investigation to study the fate, natural attenuation, and impacts of produced water and associated oil at the Osage–Skiatook Petroleum Environmental Research (OSPER) A and B sites in northeast Oklahoma. Both reports cover OSPER A, where about 2.5 ha (6.1 ac) of land has been impacted by oil operations that started in 1913 and were largely terminated by 1937. Impacts include salt scarring, soil salinization, and brine and petroleum ground and surface contamination caused by the leakage of produced water and hydrocarbons from brine channels and pits, and accidental releases from flowlines and tank batteries. Groundwater impacts are being investigated by a geophysical survey of ground conductance and salt-concentration measurements of aqueous extracts of core samples and by repeated sampling of 44 wells (1–36 m [3.3–118 ft] deep) completed with slotted polyvinyl chloride tubing. Results indicate a three-dimensional plume of high-salinity water (5000–30,000 mg/L TDS) with chemical and isotopic characteristics similar to those of the source produced water. Results clearly show that large amounts of salts and organics remain in the local rocks and groundwater after more than 65 yr of natural attenuation.

Petroleum exploration and production environmental issues discussed in the seven reports in this special *Environmental Geosciences* volume are widespread in all the petroleum-producing states. The reported case studies of success and lessons learned, we believe, are important in understanding the long- and short-term impacts of surface disturbances and of produced-water and hydrocarbon releases from petroleum fields to develop realistic remediation plans. Remediation is particularly needed in many of the aging and depleted fields, where land use is changing from petroleum production to residential, agricultural, or recreational uses. Our hope for this volume coincides with that of the Division of Environmental Geosciences mission, which is to offer AAPG members an opportunity to increase their knowledge about the environment and the petroleum industry.

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