Environmental Aspects of Produced-water Salt Releases in Onshore and Coastal Petroleum-producing Areas of the Conterminous U.S. – A Bibliography

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Open-File Report 2006-1154

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
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U.S. Geological Survey, Reston, Virginia 2006

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Suggested citation:
Otton, J.K,, 2006, Environmental aspects of produced-water salt releases in onshore and estuarine petroleum-producing areas of the United States- a bibliography: U.S. Geological Survey Open-File report 2006-1154, 223p.

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Abstract

Environmental effects associated with the production of oil and gas have been reported since the first oil wells were drilled in the Appalachian Basin in Pennsylvania and Kentucky in the early to mid-1800s. The most significant of these effects are the degradation of soils, ground water, surface water, and ecosystems they support by releases of suspended and dissolved hydrocarbons and co-produced saline water. Produced water salts are less likely than hydrocarbons to be adsorbed by mineral phases in the soil and sediment and are not subject to degradation by biologic processes. Sodium is a major dissolved constituent in most produced waters and it causes substantial degradation of soils through altering of clays and soil textures and subsequent erosion. Produced water salts seem to have the most wide-ranging effects on soils, water quality, and ecosystems. Trace elements, including boron, lithium, bromine, fluorine, and radium, also occur in elevated concentrations in some produced waters. Many trace elements are phytotoxic and are adsorbed and may remain in soils after the saline water has been flushed away. Radium-bearing scale and sludge found in oilfield equipment and discarded on soils pose additional hazards to human health and ecosystems.

This bibliography includes studies from across the oil- and natural-gas-producing areas of the conterminous United States that were published in the last 80 yrs. The studies describe the effects of produced water salts on soils, water quality, and ecosystems. Also included are reports that describe (1) the inorganic chemistry of produced waters included in studies of formation waters for various purposes, (2) other sources of salt affecting water quality that may be mistaken for produced water effects, (3) geochemical and geophysical techniques that allow discrimination of salt sources, (4) remediation technologies designed to repair damage caused to soils and ground water by produced water salts, and (5) contamination by naturally occurring radioactive materials (NORM)at oilfield sites.

Introduction

Environmental effects of produced-water salts have occurred in all regions where oil and gas have been and are produced. The most significant of these effects are (1) degradation of ground and surface water quality; (2) death of plants and destruction of soil textures; (3) resultant erosion of soils and siltation of nearby waterways; (4) contamination of production equipment and soils by radium-bearing produced waters, scale and sludge; and (5) adverse effects on ecosystems.

Numerous investigations of the effects of produced water salt releases across the producing areas of the United States have been conducted, but there has been no previous attempt to compile a bibliography of the resulting reports. Research into the remediation of these effects has been going on for decades and has grown recently with research sponsored by the U.S. Environmental Protection Agency through the Integrated Petroleum Environmental Consortium and by research being conducted at other institutions. The bibliography presented here is intended to provide a reasonably comprehensive compilation of studies conducted within the last 80 yr (through September 2005). It presents the information in three forms, a master bibliography in which all reports are listed alphabetically by author, a state-by-state alphabetical listing derived from the master bibliography, and a topical index of the reports. Some reports cover more than one state and are listed separately under each state.

Included in this bibliography are references that describe:

1. Direct effects on soil, ground water, surface water, and aquatic organisms and waterfowl by produced waters released from oilfield production and gas-processing operations at specific sites.
2. Geochemical data from waters produced with oil and gas, in cases where the reader may make inferences about the potential harmful effects of releases of such produced waters by examining the data.
3. The origins of saline ground or surface waters in oil- and gas-producing areas whether or not the investigator concludes that produced water is the source of the salts.
4. Techniques that might be used to document the sources of salinity using geochemical indicators or geophysics.
5. Geochemistry, occurrence, or effect of NORM, principally radium-226 and radium-228, in produced waters or in solid precipitates (scale and sludge) derived from produced waters.

NORM is treated separately here, as the U. S. Environmental Protection Agency has placed some emphasis on oilfield NORM as a potential radiological hazard associated with oilfield operations and may regulate oilfield NORM in the future (Loren Setlow, U. S. Environmental Protection Agency, oral commun., 2005). Several states have published such regulations. A comprehensive bibliography on oilfield NORM was given by Smith (1997). The bibliography here presented includes many of Smith's references as well as some she did not cite, and numerous others since 1997.

No systematic effort was made to search for papers describing dissolved hydrocarbon phases in water, but some are included that were discovered during the course of this compilation.

Sources

The bibliographic entries, Universal Resource Locators (URLs), and annotations are derived from:

1. The author's files.
2. Keyword searching of selected digital databases available to United State Geological Survey (USGS) employees.
3. Examination of new publications received by the USGS library in Denver.
4. Keyword searches of major online search engines.
5. Searching of online and hard copies of publication lists by Federal and State agencies that study oil and gas environmental problems and water quality problems.
6. Reviews by other authors of papers cited here.

The URL for many reports is also given for those that were active during assembly of this report in 2005. Many reports are followed by annotations.

Qualifications and limitations

This bibliography includes many county or multi-county water quality reports in various states where authors have suggested that oil production may be a source of elevated salinity and concentrations of trace elements or chloride. Many of the included reports will indicate those state agencies that are likely to have additional sources of information on water quality not listed here.

Many studies of suspected contamination by oilfield produced water capture a specific period of time during which the effects were being documented; in some cases, the effects may have been mitigated either by natural processes or by human intervention since a particular study was done and reports were issued.

The bibliography here presented does not include reports in several specific categories, as follows:

1. Online informal reports of oil brine spills into creeks, salt scar damage by oilfield brines, and work by various non-

governmental organizations on brine damage. These reports are likely to be ephemeral and are of unknown reliability.
2. Reports of studies outside of the United States.
3. Documents related to litigation involving alleged soil and water damage from oilfield production activities.
4. County soil surveys by the Natural Resource Conservation Service that may show “brine-damaged soils” or similar map units.
5. Papers describing technologies developed to allow beneficial use or cleanup of produced water unless descriptions of effects are also described.
6. Papers describing analytical methods for oilfield waters.
7. Documents describing regulations for handling and disposing of oilfield brines.
8. Resistivity data for oilfield brines except where geochemical data for the brine is also given and the study is regional in nature.

No attempt was made to evaluate the completeness, scientific accuracy, or reliability of the listed reports. Not all references may be readily accessible.

Maps

Figure 1 shows areas of onshore oil and gas production in the United States. Figure 2 portrays the salinity of produced waters sampled from wells across the United States.

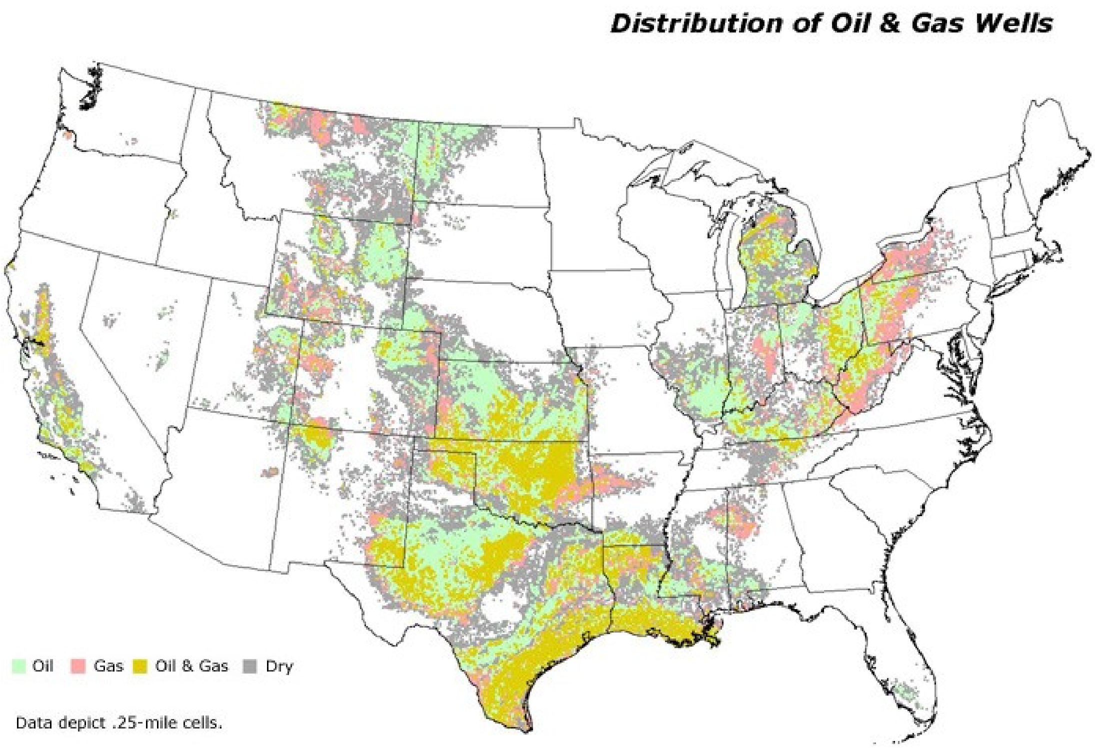

Figure 1- Map showing the distribution of oil and gas wells drilled in the conterminous United States. Individual wells are not represented, but rather 0.25-mile cells that either contain only oil wells (green), only gas wells (red), a mix of oil and gas wells (yellow), or dry holes (gray). Modified from Mast and others (1998).

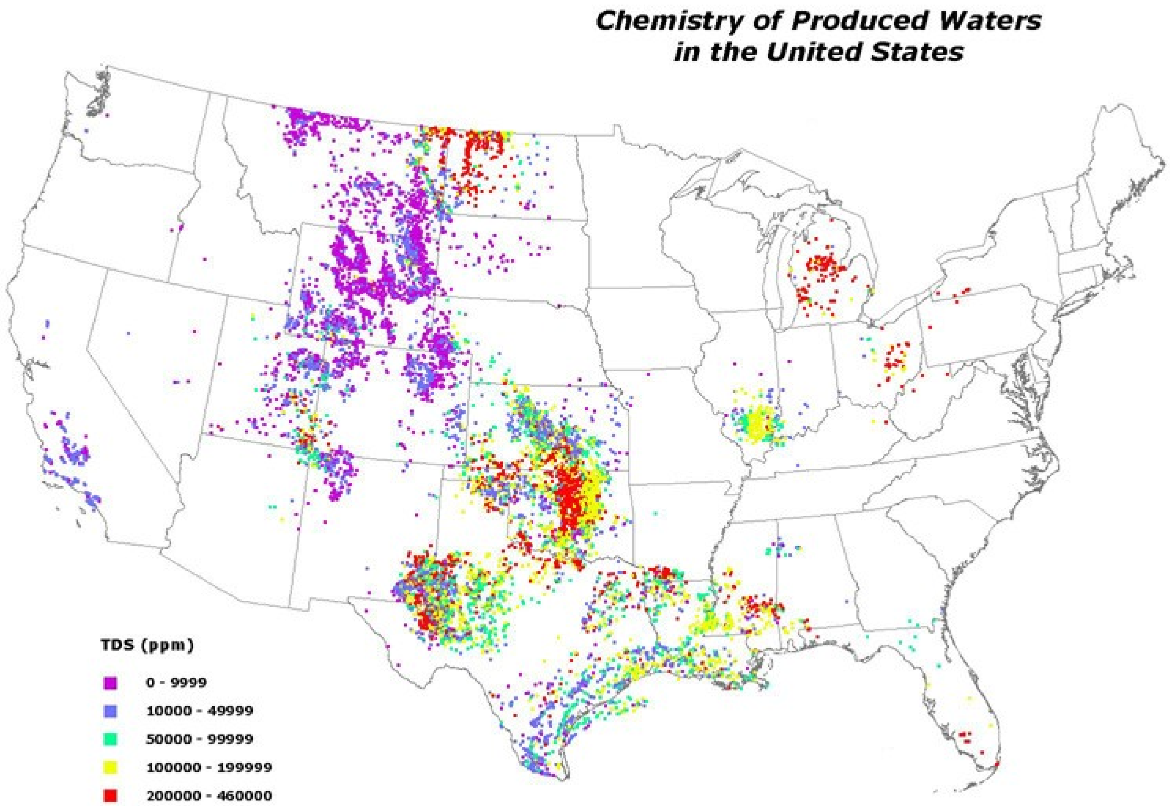

Figure 2- Map showing the salinity of produced waters in samples derived from wells across the conterminous United States. About 58,700 edited records are represented, derived from an online provisional database available at http://energy.cr.usgs.gov/prov/prodwat/into.htm.
The introductory material at that webpage describes the origin and editing of the database, as does the paper by Breit and others (2000).
Note that the Appalachian Basin from western New York to northeast Tennessee and the Sacramento Valley of California are poorly represented in the database (compare with fig. 1).

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NOTE: The author measured toxicity of 36 well-characterized produced water field samples from sites in Wyoming and Colorado to *Ceriodaphnia* and fathead minnows at various dilutions from 100% to 6%. Toxicity was suspected from various components including TDS, hydrocarbons, high sulfate, semivolatiles, low dissolved oxygen, and hydrogen sulfide.

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http://www.kgs.ku.edu/Hydro/Publications/2005/OFR05_27/OFR2005_27.pdf
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Whittemore, D.O., MacFarlane, P.A., Doveton, J.H., Butler, J.J., Jr., Chu, Tyan-Ming, Bassler, Rod, Smith, Martin, Mitchell, James, and Allen, Wade, 1993, The Dakota Aquifer Program Annual Report, FY92: Kansas Geological Survey Open-file Report 93-1, unpaginated. Available online at http://www.kgs.ukans.edu/Dakota/vol3/fy92/index.htm
NOTE: See especially "Salinity source investigations in central Kansas".

Whittemore, D.O., and Pollock, L.M., 1979, Determination of salinity sources in water resources of Kansas by minor alkalai metal and halide chemistry: Manhattan, Kansas, Kansas State University, Kansas Water Resources Research Institute Contribution 208, 28 p.

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The Oklahoma Water Resources Board (OWRB) is the State water agency with the charter to study water quality. The Oklahoma Corporation Commission has responsibility for oil and gas operations in the State with the exception of Native American lands. The Oklahoma Energy Resources Board uses funds from a voluntary fee on oil and gas production to conduct cleanup of orphaned damaged production sites in the State.

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Texas

Various state agencies have investigated the impact of oilfield brines on surface waters and ground waters in the State of Texas. The largest contributions come from the State water agencies which have been known by several names through time: Texas State Board of Water Engineers, 1913-1962; Texas Water Development Board (TWDB), 1957-present; Texas Water Commission, 1962-1965 and 1977-1993; Texas Water Rights Commission, 1965-1977; and the Texas Department of Water Resources, 1977-1985. In 1993, the air, water quality and waste management agencies were merged to form the Texas Natural Resources Conservation Commission. Publications of these various State entities are a major source of information on oilfield brine effects in the State. Many ground water reports, bulletins, and contractor reports of the TWBD are available online at:
http://www.twdb.state.tx.us/publications/pub.asp
A very useful county index for the TWBD reports can be found at:
http://www.twdb.state.tx.us/publications/reports/Publications%20Catalog/County%20Index.pdf
The Railroad Commission of Texas has oversight on oil and gas production operations in Texas and has conducted investigations of oilfield brine contamination and reports have been published by them (see Renfro, 1993, for example). They also conduct well plugging operations to avert brine and hydrocarbon contamination of surface and ground waters and site reclamation efforts.

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Remediation techniques for brine-contaminated soil

Soils affected by oilfield brines undergo substantial changes including the death of vegetation supported by the soil, the loss of the host soil bacterial and other organism populations such as nematodes, mineralogic changes, and additions of substantial loads of salt. These changes impact the capability of the soil to support plant growth. Many remediation strategies have been developed and tested and are referenced here. This list does not capture the substantial remediation technologies that are described in the soil literature for naturally occurring saline soils or soil damaged by salt accumulation as a result of irrigation practices.

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Geochemical techniques for discriminating salt sources

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Geophysical techniques for detecting brine plumes

The high salinities associated with oilfield waters makes them and the rocks and soils they saturate more conductive than the surrounding rock and soil. Several geophysical techniques are capable of distinguishing higher conductivity earth materials at various depths in the subsurface. The studies below describe the use of these techniques in various geologic settings and under various contaminant situations.

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NORM (Naturally occurring radioactive materials)

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Produced-water chemistry-national and regional data

Regional and local variation in the chemistry of produced water contributes to the likelihood of salinity problems caused by past or present releases. The chemistry of produced water may also be distinctive enough to identify its addition to local ground water and surface water. The largest national database is that available at a USGS webpage (see Breit and others, 2000, below), however only the major dissolved constituents are reported. Minor dissolved constituents such as Li, B, Br, and F are phytotoxic and may have a role in ecosystem effects that are not well understood. These elements, along with the isotopic composition of dissolved strontium and other isotopes may also provide an additional chemical fingerprint for produced water contamination. E. Gene Collins and his associates at the U.S. Bureau of Mines laboratory in Bartlesville, Oklahoma report extensive data for trace elements in oilfield brines of the United States. Papers by Collins and his colleagues (see below) provide particularly hard-to-find information.

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