Field Validation of Toxicity Tests to Evaluate the Potential for Beneficial Use of Produced Water

DE-FC26-04NT15544

Project Goal

A combined laboratory and field approach is being used to determine the extent to which laboratory toxicity tests of produced-water samples indicate the potential for environmental impacts. The project is being conducted at a field site at Skiatook Lake, OK, where produced water is leaking from an evaporation pit on the shoreline of the lake.

Performer

Oklahoma State University, Stillwater, OK

Results

Given the interest in reuse of produced water and the need to safely dispose of it, it is important to understand how the results of laboratory bioassays that are used to evaluate produced-water effects in aquatic systems compare with actual observed effects in the field. The present study is addressing this issue by comparing laboratory bioassays of produced water with field evaluations at a site on Skiatook Lake, OK, where produced-water input may be occurring.

The biological effects of water collected from an onshore brine storage pit (a present source of produced water to the lake) and down-slope test wells are being evaluated in laboratory bioassays with standard test species (fathead minnows, Pimephales promelas, and water fleas, Daphnia pulex and Ceriodaphnia dubia). Acute toxicity has been observed in treatments containing 2-10 percent produced water and higher, while chronic effects were seen in samples containing 1-5 percent produced water. Water from the storage pit exhibited acute toxicity at a 30 percent dilution (treatments contained 70 percent of the pit water), while acute effects associated with monitoring wells located along a salt scar that leads from the pit to the lake occurred in treatments containing 3-40 percent well water. Water from wells not in the salt scar, adjacent the storage pit, had lower toxicity but still had brine contamination.

Preliminary toxicity identification evaluations (TIE) indicate the observed effects are occurring primarily from elevated ion levels. Other stressors may include volatile compounds (BTEX), non-polar organics (hydrocarbons), low pH, and ammonia. Toxicity characterization of down-slope wells is ongoing, although initial results suggest excess ions are responsible for the bulk of measured effects.

Elevated conductivity at the sediment-water interface at some offshore locations support previous indications of brine-contaminated pore water in lakebed sediments. Sources of this brine may include upward diffusion from a former (now submerged) brine storage pit and subsurface flow derived from the onshore storage pit. Studies to indicate biological effects associated with this saline water include laboratory sediment bioassays with the midge, Chironomus tentans, placement of caged organisms along underwater transects, (midges and the Asian clam, Corbicula fluminea), and surveys of the resident invertebrate community (both at the site of the submerged former brine pit site and a reference site. To date, no significant field effects have been observed. Fieldwork will continue over the next year, as will additional laboratory studies to identify the primary ions causing toxicity, observed in earlier bioassays. These data will be compared with ion profiles from sediment pore water at the study site.

A view of the brine pit and cove at which the study is being conducted on Skiatook Lake. Photo by J. Bidwell.

Benefits

An understanding of how standard indicators of produced-water quality relate to true effects in the environment will ultimately lead to better decision making with regard to produced-water reuse and surface discharge, help optimize methods for both treatment of produced water and assessment of produced-water quality, and help avoid overregulation in cases where predicted environmental effects are not realized in the receiving system.

Background

Significant quantities of produced water are generated by inland oil and gas facilities in areas where beneficial reuse would provide a cost-effective method of disposal. The quality of produced water, its potential for reuse, and its need for treatment prior to reuse will ultimately be determined by State water quality standards for individual chemical constituents and freshwater toxicity bioassays as mandated by Federal and associated State requirements for effluent discharges. While toxicity testing plays an important role in environmental protection and regulation of wastewater discharges, it is important to understand how well the results of laboratory evaluations actually represent the behavior and potential effects of aqueous wastes in the field. A very limited number of freshwater laboratory bioassays have been conducted on produced water, and practically no field assessments have investigated its influence on freshwater communities.

The field site for the study is located at Skiatook Lake, a 10,500-acre impoundment in Osage County, OK. Osage County ranks among the top oil and gas producing areas in the State, with some 38,000 oil wells. Of these, about 13,000 wells lie within the Skiatook Lake watershed (about 820 square km). In many instances, wells occur within a few tens of meters of the lake shoreline or the banks of streams that feed into the system. The produced waters derived from these wells are normally reinjected into underlying formations for disposal. However, inadvertent spills, leaks, and accidents have led to both historic and recent releases of produced water in the riparian zone and into the lake.

Summary

The project is being conducted in three phases:

Phase I. Characterization of saline water distribution and composition in the sublittoral zone of the lake, including an evaluation of upwelling and sediment toxicity characterization.

Phase II. Aquatic toxicity tests of the produced water derived from the active well at the field site to indicate the potential for toxic effects. Laboratory manipulations of the water samples will be used to identify toxic constituents.

Phase III. This phase represents the field component of the study and includes benthic community assessments, in-situ toxicity tests, and comparison of field and laboratory data.

At the middle of the 2007 field season, components of all three objectives had been addressed. Highlights of the major results are as follows:

Water collected from the onshore brine pit and U.S. Geological Survey test wells at the study site was acutely toxic in laboratory bioassays (48-hour) with both fish (fathead minnows) and invertebrates (water fleas). Chronic tests (7-day) with the water flea, C. dubia, indicate sublethal effects in treatments that contained 1 percent brine and higher.

Toxicity identification evaluation and laboratory analyses indicate that dissolved ions are the primary source of toxic effects but hydrocarbons (BTEX, GRO, and DRO) may also contribute to mixture toxicity. Though hydrocarbons are present in concentrations that alone elicit effects on test organisms, hydrocarbon removal does not affect measured produced water toxicity. High total ammonia and low pH may contribute to observed toxic effects as well.

Groundwater toxicity monitoring has demonstrated that impacts on tested organisms decreases with distance from produced sources, but significant effects are evident in wells contained within the Skiatook Lake conservation pool. Measured effects at each well vary little between sampling periods and effects at each well vary similarly across the study site. The source of this variation has not been determined.

Preliminary results from ion toxicity modeling of groundwater samples suggest dissolved ions as the primary toxicant, though other toxicants may contribute to measured effects at wells located near produced water sources. Spatial modeling of groundwater contamination indicate that the brine injection well, and not the leaking evaporation pit, represents the most significant source of biologically relevant contamination (see figure at end of document).

Four transects were established on the bottom of the lake near the location of a former (now submerged) brine storage pit to facilitate field sampling. These transects also include nearshore areas of possible groundwater seepage that were previously identified by the U.S. Geological Survey.

Lake surface water conductivity at the study site does not differ from that at a reference site (~2 km away). However, conductivity levels at the sediment-water interface were slightly higher than those at the reference site, averaging 283 µS/cm versus 249 µS/cm at the reference site. These data support the idea that buried brine pit sediments or upwelling saline groundwater in the near-shore zone of the lake are causing some degree of sediment salinization.

Lake sediments from both the submerged brine-pit and reference sites have been analyzed for produced water infiltration. Conductivity of porewater derived from reference sediments is similar to that of the overlying lake water. In contrast, salinity of pore water taken from sediments at the submerged brine pit site increases with increasing sediment depth. Hydrocarbons were also observed in sediment samples greater than 20 cm below the sediment surface.

Sediments at both the submerged brine pit and reference sites have been collected for sediment toxicity tests with the midge Chironomus tentans. Preliminary data indicate no effects in these bioassays, but more extensive testing with a variety of brine pit sediment samples is required.

Cages containing both Chironomus tentans and Asian clams were deployed along transects at the study site to evaluate the effects of exposure to sediments in the field. To date, these studies have indicated no consistent effects associated with exposure to the sediments.

Sediment samples were also collected to determine the abundance and diversity of resident benthic macroinvertebrates that occur at the submerged brine-pit and reference sites. Multi-plate benthic invertebrate samplers have recently been deployed to both sites to better characterize epibenthic invertebrate communities.

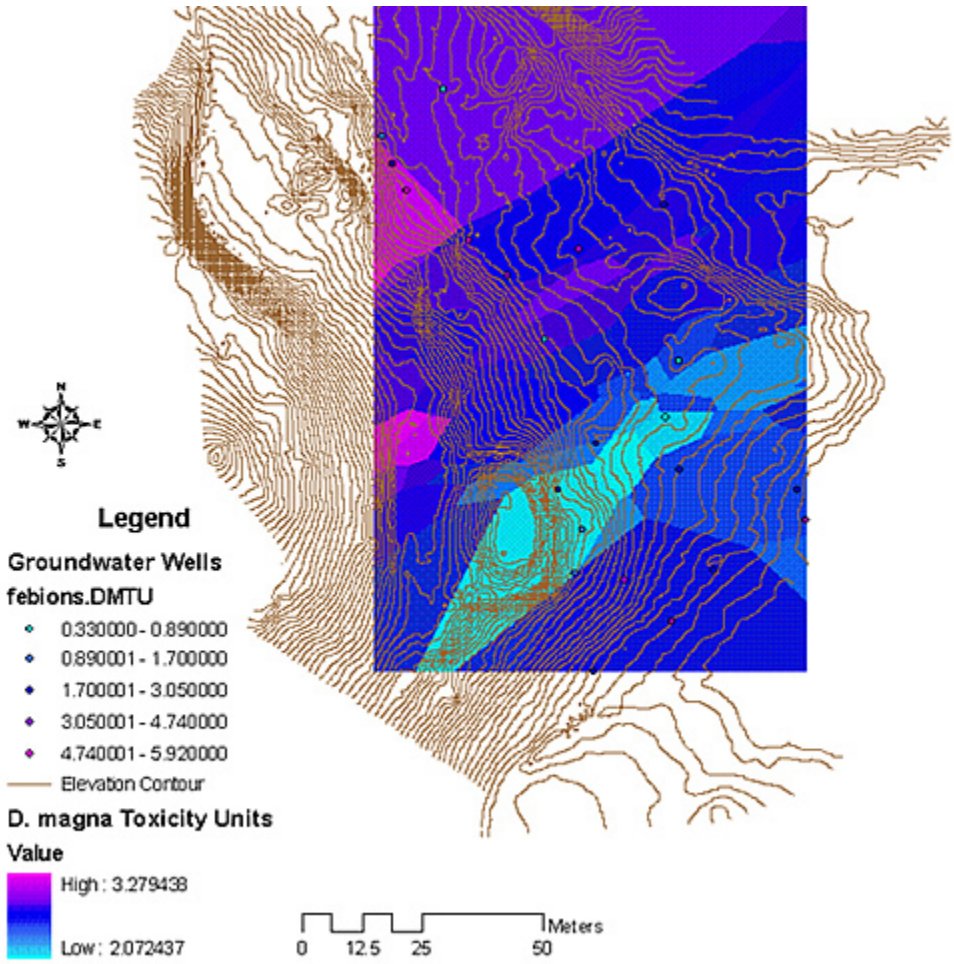
Previous drought conditions severely limited in-situ studies and invertebrate community sampling such that all aquatic locations sampled in the initial 1 year of the study lie well above the current shoreline. Current conditions are conducive to all aquatic sampling and assessment methods proposed. Field work is ongoing.

Results of laboratory bioassays with full-strength produced water from this site are consistent with those of previous studies in that significant effects on tests species were observed. So far, in-field analyses are not indicating measurable toxic effects, even though some degree of brine contamination is apparent in the sediments at the study site. These preliminary results may indicate that saline pore waters in the shallow subsurface are sufficiently diluted as they approach the lake bottom or are sufficiently modified with respect to concentrations of specific toxic constituents.

Additional studies to identify the primary ions causing effects on the laboratory test species and comparisons with ion profiles from sediment pore water will help address this question. Laboratory experiments have shown that while removal of hydrocarbon from raw produced water does not reduce measured acute toxicity, the removed hydrocarbons are present in concentrations sufficient to have acute effects on test organisms. This comparative work will represent a particularly novel approach for study of the effects of produced water in aquatic environments.

Current Status (July 2007)

The project is in its third funding cycle. Data from the first two complete summer field seasons have been collected and are in various stages of analyses. The third summer field season is currently being planned to accommodate drought conditions. Routine monitoring to evaluate basic water chemistry and biological effects of water from the onshore brine pit and test wells at the site has been ongoing since late 2004. During the winter of 2005-2006, chemical and toxicity testing of the produced water was conducted in the laboratory to help indicate the constituents causing observed effects. The 2006 field season commenced in April 2006. Some of the lessons learned in 2005 have been applied to this field season, including more-efficient approaches for divers to sample test water and better procedures for in-situ toxicity evaluations.



Predicted groundwater toxicity to Daphnia magna. Toxicity units (TU's) are acute (48 hr) LC_{50}'s standardized to 100% solution. Increased TU's (warmer colors) indicate increased mixture toxicity.

Funding
The project was selected under solicitation DE-PS26-04NT15460-02, Produced-Water Management.

Project Start: October 1, 2004
Project End: September 30, 2007

Anticipated DOE Contribution: $183,827
Performer Contribution: $46,546 (20 percent of total)

Other Government Organizations Involved: U.S. Geological Survey

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Publications/Presentations
Fisher, J.C. and J.R. Bidwell, "Field validation of toxicity tests to evaluate the beneficial use of produced water," presented November 2, 2005, at Petroleum Environmental Research Forum, Annapolis, MD.

Fisher, J.C. and J.R. Bidwell, “Field validation of toxicity tests to evaluate the beneficial use of produced water,” presented November 5, 2005, at the Oklahoma Academy of Sciences Annual Meeting, Oklahoma City, OK.

Fisher, J.C. and J.R. Bidwell. “Characterizing the effects of produced water intrusion at Skiatook Lake, Oklahoma,” presented April 27, 2006, at the Oklahoma Clean Lakes and Watersheds Association's Annual Meeting, Sequoyah State Park, OK.

Fisher, J.C. and J.R. Bidwell, “Toxicity and effects of produced water intrusion at Skiatook Lake, Oklahoma,” presented May 23, 2006, at the annual meeting of the Ozark-Prairie Chapter of the Society for Environmental Toxicology and Chemistry in Columbia, MO.

Fisher, J.C. and J.R. Bidwell, “Toxicity and effects of produced water intrusion into a reservoir benthos,” presented June 8, 2006, at the annual meeting of the North American Benthological Society in Anchorage, AK.

Fisher, J.C. and J.R. Bidwell, “Biotic effects of produced water intrusion in an Oklahoma reservoir,” presented October 19, 2006, at the 13th International Petroleum Environmental Conference in San Antonio, TX.

Fisher, J.C. and J.R. Bidwell, “Toxicity Assessment of Produced Water and Monitoring to Detect its Potential Intrusion into an Oklahoma Reservoir,” Integrated Petroleum Environmental Consortium proceedings of the 13th Annual International Petroleum Environmental Conference, in San Antonio, TX, October 2006.

Fisher, J.C. and J.R. Bidwell. “Littoral effects of produced water intrusion in an Oklahoma reservoir,” presented November 9, 2006, at the annual meeting of the Society for Environmental Toxicology and Chemistry in Montreal, Canada.

Fisher, J. C., and J. R. Bidwell. 2007. Produced water contamination of groundwater at Skiatook Lake, Oklahoma. Presented at the 2007 OSU Research Symposium, Stillwater, OK.

Fisher, J. C. and J. R. Bidwell. 2007. Characterizing groundwater contamination by petroleum operations. Poster presented April 12 at the Oklahoma Clean Lakes and Watersheds Association's Annual Meeting, Tahlequah, OK.

Sunset Cove at Skiatook Lake in Oklahoma.

The bay area at Skiatook Lake, OK, at which the field study is taking place. Studies are underway to evaluate the effects of produced water that may be entering the sublittoral zone of the system through overland and subsurface flow.