

GUIDELINE DEVELOPMENT FOR USE OF MONITORED NATURAL ATTENUATION AT CONTAMINATED SITES IN ALBERTA.

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ABSTRACT: The use of monitored natural attenuation (MNA) is rapidly gaining acceptance with industry, consultants, and regulators as a remediation option for contaminated sites. Case studies for contaminants such as fuel hydrocarbons, chlorinated solvents, and heavy metals document the efficacy of MNA under favourable site conditions. However, from the regulatory perspective, emphasis must be placed on demonstrating and ensuring that MNA processes (particularly biodegradation processes) are occurring at a site, and that applicable remediation criteria will be met in a reasonable timeframe without compromising human or environmental health.

In the United States, the Environmental Protection Agency (EPA), Department of Defense (DOD), and the American Society for Testing and Materials (ASTM) have developed and published protocols and guidelines for the use of MNA. In Europe, the United Kingdom has developed its own protocol based on EPA documents. The Netherlands has developed a decision-making guideline for evaluating natural attenuation. In Canada there are currently no formal policies or regulations regarding the use of natural attenuation.

Alberta has begun the process of developing a formal guideline for the use of MNA at contaminated sites. In developing the guideline, Alberta Environment must ensure that all potentially affected parties are adequately protected during implementation of MNA, particularly in instances of offsite contamination. As part of the guideline development process, an evaluation of MNA potential and efficacy was conducted in 2001. Studies regarding sampling techniques and protocols for MNA evaluation in slow recharge wells in clay soils are currently underway. This paper will review the results of those studies and Alberta Environment's approach to MNA Guideline development and implementation for contaminated sites in Alberta.

INTRODUCTION

Alberta Environment (AENV) has adopted a formal position accepting the use of monitored natural attenuation (MNA) at contaminated sites. The need for a detailed

guidance document originally stemmed from a goal to develop and implement a credible, responsible and practical remediation management framework for upstream oil and gas lease sites that is supported by science-based remediation objectives and protective of human health and the environment. MNA is included as a remediation option capable of meeting those objectives. The scope of MNA applicability has been broadened to include all contaminated sites and other risk management issues.

To assist with the implementation and regulatory review of MNA at contaminated sites, AENV has begun the development of an MNA Guideline. The Guideline is based on a review of regulations, guidelines, and protocols for MNA that have been developed by other regulatory agencies around the world (Epp, 2000). Based on this review, recommendations for discussion were made for preliminary meetings of an advisory group to develop the content of the Guideline. The review also served to guide further work to address geologic, climatic, and political conditions specific to Alberta.

1.0 LEGISLATION REVIEW PROCESS

Documents reviewed included protocols and guidances from the USEPA (USEPA Directive, 1999), ASTM (ASTM, 1998), and DOD (Weidemeier *et al.*, 1995). In addition, all 50 US states were contacted to determine if a formal approach to MNA existed in their legislation. A similar process was used for agencies in Canada and Europe. Only those agencies with a formal approach to MNA were included in the final review.

All agencies had the following information requirements in common:

- Lines of Evidence
- Source Removal
- Site characterization
- Modeling
- Monitoring
- Performance evaluation
- Contingency measure development

The decision matrices developed by the UK Environment Agency (Environment Agency, 2000) and TNO (Sinke, 1998) in the Netherlands do not rely on scoring mechanisms to evaluate the potential for MNA, such as those employed by the USEPA. Rather, the focus of the UK and TNO guidance is a conceptual model that describes hydrogeological, biochemical, and geochemical characteristics at a site. The model is continually challenged and revised as additional data are collected during successive stages of the assessment (Environment Agency, 2000). This approach provides for a more straightforward and practical evaluation of MNA. For this reason, the UK Environment

Agency document was used as the template for developing Alberta Environment's Guideline.

2.0 ONGOING MNA RESEARCH IN ALBERTA

During formulation of MNA guideline content, AENV is participating in ongoing research to evaluate MNA potential at several types of contaminated sites. The goal of the research was to provide some indication of the potential for, and efficacy of, MNA under Alberta's climatic and soil conditions. In Alberta, overburden soils generally consist of lacustrine clays and clayey till with an hydraulic conductivity range of 10^{-5} to 10^{-7} cm/s (Hendry, 1988). Some areas of the province do contain coarser grained deposits with higher hydraulic conductivities but those areas are typically limited to river valleys and buried valleys. Groundwater temperature in the clay and till deposits does not generally exceed 10°C.

Initially, a contaminant plume database review was conducted by Komex International (2001) to evaluate evidence of natural attenuation using existing groundwater data from upstream oil and gas sites. Groundwater data from Komex and AENV files were used for a variety of oilfield facilities. The types of sites reviewed included wellsites, satellites, batteries, compressor stations and gas processing plants.

The second phase of the study involved a preliminary assessment of an easy-to-use technique designed to evaluate biological activity. Six hydrocarbon-contaminated sites with varying hydrogeologic and contaminant mixtures were identified. A series of Biological Activity Response Tests (BART™) have been developed by Droycon Bioconcepts Inc. to evaluate biological activity associated with a variety of biological reactions. This study evaluated the use of BART™ kits to estimate bioactivity for aerobic, denitrifying, iron-related and sulphate-reducing bacteria in response to differing contaminant exposures. Biological aggressivity is measured by visual observance of colorimetric or physical changes (*e.g.*, formation of nitrogen foam) within the test vials over a period of time. Higher aggressivity is indicated by a shorter reaction time.

The third phase of the study involved an evaluation of a variety of sampling techniques applicable to lacustrine clay and clayey till. A concern is that AENV's currently recommended sampling approach of purging up to three pore volumes of standing water, or until the well is dry, may adversely affect analytical results of samples collected to support MNA. A second concern is that these wells may simply not provide sufficient sample volumes for lab analysis of MNA data. A literature review of low flow techniques, and new sampling tools and equipment was conducted (University of Alberta, 2002) as a precursor to field evaluation of the most promising equipment. Additionally, a field trial was undertaken to assess how current purging practices influence MNA data.

3.0 RESEARCH RESULTS

3.1 Historical Data Review

Analysis of historical data generally supported the concept that natural attenuation occurs for petroleum hydrocarbons (PHC) at upstream oil and gas sites. Based on the data, the large majority of plumes were interpreted to be either stable or shrinking. Analysis of inorganic and non-PHC organic plumes showed a lower percentage of shrinking plumes and a higher percentage of expanding plumes. No simple correlation was found between plume behaviour and basic hydrogeologic characteristics.

In summary, plume lengths in all overburden types tended to be longer for inorganic and non-PHC plumes compared to PHC plumes. Sulphate reduction was interpreted to be the most important of the potential biodegradation reactions inferred from geochemical indicators. The relative importance of methanogenesis could not be assessed as methane concentrations in groundwater are not routinely measured at contaminated sites. Estimated biodegradation rates tended to be near the low end of the range of values reported in the literature for U.S.-based studies. Possible causes include cooler temperatures in Western Canada and the common presence of hydrocarbon and inorganic co-contaminants in plumes associated with upstream oil and gas sites.

3.2 Biological Activity Reaction Test (BART™) Results

The BART™ test was evaluated at six sites with a variety of geologic and PHC or mixed PHC-inorganic contaminant conditions. The BART™ results were compared to evidence of natural attenuation derived from contaminant trend and geochemical indicator distributions. Evidence of bacterial activity was typically identified in all locations except in one monitoring well with high salinity (chloride = 20,000 mg/L). Tests conducted at 12 °C showed a longer lag time than room temperature tests (22°C), but had similar responses indicating microbial activity.

The BART™ test results generally correlated well with other lines of evidence for hydrocarbon biodegradation related to sulphate reduction (*i.e.*, greatest observed activity at sites with known hydrocarbon and sulphate depletion). In contrast, activity levels for the other three biological activity indicators did not correlate with the other corresponding lines of evidence (*i.e.*, no link between test result and corresponding geochemical indicators and hydrocarbon depletion).

The BART™ method is therefore considered to provide evidence of potential sulphate reducing reactions, but not to generally identify the presence of hydrocarbon degrading bacteria. The main value of the BART™ tests is their simplicity, allowing relatively

untrained personnel to screen quickly a range of microbial activities. These tests may help assess potential biodegradation reactions supporting natural attenuation (*i.e.*, focus on more definitive microbial testing) or corroborate other lines of microbial and geochemical evidence.

3.3 Low Flow Sampling Results

The main reason for focussing on sampling methods is that spatial and temporal trends in monitoring data often form the main lines of evidence supporting MNA (University of Alberta, 2002). The study to evaluate sampling methods in low hydraulic conductivity soils and their effect on data collected to support MNA at upstream oil and gas sites was conducted in two phases. The first phase involved an evaluation of current and developing practices and equipment for groundwater sampling in low flow situations. The second phase involved sampling at three sites to assess how conventional purging and sampling methods influence geochemical indicator data used to support MNA. Future work will entail using the most promising technique(s) identified in the first phase.

The first phase of the study reviewed three topics concerned with sampling to support MNA: well purging and low-flow sampling; groundwater sampling equipment; and, field analytical equipment for site characterization. The review suggested that there is no simple, definitive method for obtaining high quality, representative samples for natural attenuation studies in low recharge soils. Current research suggests that low flow sampling is the best approach for minimizing changes in groundwater geochemistry due to sampling. This method has an added benefit of minimizing disturbance such as enhanced colloidal movement when wells are purged aggressively. The method is considered limited to sites where recharge rates exceed approximately 0.1 to 0.3 L/minute.

Under slow recharge conditions, diffusion type samplers provide an attractive option for sampling volatile and semi-volatile organic compounds. Methods are being developed to expand this approach to obtain representative samples for other geochemical parameters of interest. Direct push technologies appear to provide an excellent opportunity for faster source characterization in soil without many cobbles or boulders that would hinder probe installation. Direct push groundwater sampling systems permit rapid acquisition of a large number of samples for preliminary characterization, but monitoring wells must be properly completed for long-term monitoring. Field portable gas chromatography for on-site analysis provides the capability to analyze direct-push samples, with a variety of separation and detector systems now widely available. Fiber optic sensors are not well developed yet, but as the technology evolves it may provide excellent new data acquisition opportunities.

In the second phase of the study, three monitoring wells with dissolved hydrocarbon impacts were selected at each of three sites in an area northwest of Edmonton, Alberta (Komex, 2002). At each well, three groups of replicate samples were collected before, immediately after, and one day after purging. The samples were analyzed for major ions and general water quality parameters, target dissolved hydrocarbons (benzene, toluene, ethylbenzene, xylenes and total purgeables, BTEX/TPH), and selected gases (oxygen, nitrogen, carbon dioxide, and methane).

Some variability was noted in the replicate samples particularly in the samples taken immediately after purging. Dissolved gas concentrations of oxygen and nitrogen increased after purging due to atmospheric contact. The combination of well construction and hydrogeology appeared to have a greater influence on analytical variation than either purging the well or the sampling method used. In some cases a seasonal trend was evident, but only for some analytes such as sulphate, calcium and bicarbonate. Some analytes appeared to vary with water table fluctuations either directly or inversely. In other cases, no satisfactory explanation was developed to address the variability.

4.0 MNA STEERING COMMITTEE

AENV formed a steering committee to assist with guideline development and to ensure that government, public, and industry concerns and issues regarding evaluation and implementation of MNA were adequately addressed. The committee consists of members from the Canadian Association of Petroleum Producers, the Canadian Chemical Producers Association, the Canadian Petroleum Products Institute, other government agencies such as the Energy and Utilities Board, public advocacy groups such as the Pembina Institute and the Farmer's Advocate, as well as consulting company and academic representatives involved in MNA research.

The steering committee has met twice since its inception in May 2002. During the first meeting MNA issues relevant to each committee stakeholder were reviewed and recommendations for topics to be incorporated into a guideline were formalized. Specific issues included:

1. Make the guideline workable
2. Make it as simple/clear as possible
3. Build it on existing knowledge
4. Include minimal technical content (less may be better)
5. Address the regulatory context for contaminated sites
6. Clearly formalize responsibilities for reporting, review, *etc.*
7. Clarify/define proponent notification requirements
8. Include links to necessary technical documentation

9. Make guideline compatible with risk management practices advocated by AENV.

In addition to these issues, stakeholders wanted to be sure that the requirements for regulatory acceptance of MNA were clearly spelled out in the guideline and that details of post-implementation monitoring and reporting requirements were included. The guideline would deal mainly with hydrocarbons but should be left open-ended so that other contaminants could be included as research continued. Actions related to offsite contamination would be based on the identified risk to receptors.

Based on the input from the first meeting, a draft outline was prepared to initiate discussion at the next committee meeting. The purpose of this second meeting was to finalize the outline so that a draft guideline could be completed by early fall 2002. The outline presented to the committee at the second meeting was based on the UK Environment Agency MNA guideline. In keeping with that guideline, the draft outline provided for a staged review of the conceptual model developed to evaluate MNA feasibility. The first step involves a screening process to determine if MNA might be applied to a site. The screening process is essential to allow the proponent and regulator to decide whether the further potential for MNA should be evaluated prior to entering into an expensive and comprehensive site investigation. A checklist is to be provided to assist the proponent and regulator with the screening process. If MNA appears to be feasible, further data collection to support the appropriate lines of evidence could proceed followed by assessment and acceptance of MNA implementation by the regulator and post-implementation monitoring and reporting. The regulator would review the site assessment reports and require additional data collection as necessary. A contingency plan would also form part of the site assessment report.

In keeping with the committee's directions, much of the technical information on sampling and data evaluation will be provided in appendices to the guideline. Generalised case studies will be included to provide guidance on data collection, regulatory evaluation, and report preparation.

In the second meeting, concerns regarding the timing of regulatory review were expressed. Stakeholders were concerned about potential delays between preparation, implementation and regulatory acceptance of MNA proposals. Therefore, the guideline would need to clearly spell out the regulatory commitment to reviewing MNA submissions. There was also a suggestion to use a Code of Practice for registering contaminated sites where MNA would be applied. This optional approach puts the onus on the proponent to collect and compile the necessary data. Regulators would retain the right to spot-check and review any file at any time. As a result, this approach would require that proponents maintain strict control over the quality of the site investigation, monitoring and data collection, and reporting aspects of MNA proposals.

The timeframe for post-implementation monitoring also was an issue for committee members. Three scenarios based on existing practice were discussed. In the first scenario, monitoring would continue until remediation objectives were met. The second scenario involves reviewing monitoring results against model-based target predictions for concentration reduction. Monitoring would cease if results matched predictions of a downward concentration trend. The last scenario would be to continue monitoring for a set time period after remediation objectives were met to ensure that MNA had been effective. The committee supported the last option particularly in cases where offsite contamination existed.

5.0 GUIDELINE COMPLETION SCHEDULE

The first draft of the new guideline is scheduled for completion by September 30, 2002. Once completed, the draft will be circulated to committee members for comment. Formal presentation of the guidelines will be made during the next committee meeting scheduled for October. After comments have been received, the second draft will be prepared and presented for broader stakeholder input. The presentation may take one or both of two forms: placement on AENV's website; and/or formal guideline presentation at public information/instructional forums held in various venues across Alberta. The guideline will be finalized once public comments are received and reviewed.

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