Appendix B

Quality Assurance Plan: Evaluation of Impacts to Underground Sources of Drinking Water by Hydraulic Fracturing of Coalbed Methane Reservoirs

The U.S. Environmental Protection Agency (EPA), bases environmental protection efforts on the best available scientific information and sound science. The credibility of the resulting policy decision depends, to a large extent, on the strength of the scientific evidence on which it is based. Sound science can be described as organized investigations and observations conducted by qualified personnel using documented methods and leading to verifiable results and conclusions (SETAC, 1999).

This Quality Assurance Plan for data collection and evaluation describes the procedures the Agency used for a systematic and well-documented, graded approach to realizing the goal for the "Evaluation of Impacts to Underground Sources of Drinking Water by Hydraulic Fracturing of Coalbed Methane Reservoirs." The goal of Phase I of EPA's hydraulic fracturing study was to assess the potential for contamination of USDWs due to the injection of hydraulic fracturing fluids into CBM wells and to determine based on these findings, whether further study is warranted. This Quality Assurance Plan (developed following the guidelines of EPA publication 240/B-01/003) guides the production of a set of data and scientific findings that are sound, with conclusions supported by the data.

1.0 Project Management

This section of the Quality Assurance Plan addresses the basic area of project management, including the project history and objectives, and roles and responsibilities of the participants.

1.1 Project and Task Organization

Overall project management was provided by the EPA's Office of Water, Groundwater and Drinking Water (OGWDW), Groundwater Protection Division. Data was gathered by an EPA OGWDW contractor.

The contractor compiled the gathered data into a draft summary report, reviewed the draft report, and submitted the draft report to EPA and other federal agencies for review. After the contractor addressed comments from EPA and other federal agencies, EPA submitted the draft report to a Peer Review Panel for their comments (see Table B-1 for a list of the members of the Peer Review Panel). Following receipt of comments from the Peer Review Panel, EPA and its contractors responded to those comments. The availability of the report for stakeholder review and comment was announced in the *Federal Register* on August 28, 2002.

Table B-1: Peer Review Panel

Name	Affiliation	Education	Experience
Morris Bell	Engineer, Colorado Oil and Conservation Commission	Engineering Degree, University of Oklahoma	Closely involved with coalbed methane development in the San Juan and Raton Basins. Has investigated water well complaints and directed projects to test water wells. Worked for Amoco as a production engineer, drilling and completing tight gas wells. Also worked as a consultant, specializing in the completion and evaluation of coalbed methane wells.
Peter E. Clark	Associate Professor, Dept. of Chemical Engineering and Material Science, University of Alabama	Ph.D., University of Oklahoma State University	Specializes in complex fluid flows and hydraulic fracturing. Has taught several courses in the Chemical Engineering, Mineral Engineering, Engineering Mechanics, and Civil Engineering Departments. These courses included fluid mechanics, petroleum rock and fluids, well completion, drilling, and natural gas engineering.
David Hill	Manager, Engineering Resources, Gas Technology Institute (GTI)	MBA, Northwestern University; BS, Marietta College, Petroleum Engineering	Expertise includes unconventional reservoirs (e.g., coalbed methane, gas shales, tight sands); hydraulic fracturing; and reservoir evaluation in technical, managerial, and marketing aspects of technology development, deployment, and commercialization. Has authored and co-authored over 40 articles about oil- and gas-related research and development, and field-based operations.

Table B-1: Peer Review Panel			
Name	**Affiliation**	**Education**	**Experience**
Buddy McDaniel	Technical Advisor for Production Enhancement Technology, Halliburton	B.S., Chemical Engineering, University of Oklahoma	Specializes in applications for highly deviated and horizontal wellbores and understanding of reservoir response to fracturing applications. Conducted research related to laboratory measurement of fracture conductivity of proppants under simulated reservoir conditions. Was actively involved in design and application of hydraulic fracturing treatments in soft chalks, deviated and horizontal wellbores, gas storage wells, geothermal wells, and conventional hydrocarbon reservoirs.
Jon Olson	Asst. Professor, Dept. of Petroleum and Geosystems Engineering, University of Texas at Austin	Ph.D., Stanford University, Applied Earth Sciences	Worked in the areas of fracture mechanics and coal geology and has published several papers on these subjects. Was employed by Mobil Exploration for several years as research engineer in the areas of rock mechanics, structural geology, and well performance.
Ian Palmer	Senior Petroleum Engineer, BP Amoco	Ph.D., University of Adelaide in Australia	Has worked extensively in coalbed methane extraction, including fracture design and prediction, rock mechanisms of coal, and openhole cavity completions. Also developed hydraulic fracturing models.
Norm Warpinski	Distinguished Member of Technical Staff, Sandia Laboratories	Ph.D., University of Illinois, Mechanical Engineering	Authority on hydraulic fracturing, geomechanics, poroelasticity, in situ stresses, and production mechanisms. Has expertise ranging from theoretical modeling and laboratory testing to field and in situ mineback experiments. Serves as project manager and lead scientist for a program to develop hydraulic fracture diagnostic technology for use in industry fracturing applications. Has published extensively on subject of hydraulic fracturing.

1.2 Problem Definition and Background

Hydraulic fracturing is a half century-old technology used in oil and natural gas production. The hydraulic fracturing process uses very high hydraulic pressures to initiate a fracture. A hydraulically induced fracture acts as a conduit in the rock or coal formation that allows the oil or coalbed methane to travel more freely from the rock pores (where the oil or methane is trapped) to the production well that can bring it to the surface.

After a well is drilled into a reservoir rock that contains oil, natural gas, and water, every effort is made to maximize the production of oil and gas. One way to improve or maximize the flow of fluids to the well is to connect many pre-existing fractures and flow pathways in the reservoir rock with a larger fracture. This larger, man-made fracture starts at the well and extends out into the reservoir rock for as much as several hundred feet. To create or enlarge fractures, a thick fluid, typically water-based, is pumped into the coal seam at a gradually increasing rate and pressure. Eventually the coal seam is unable to accommodate the fracturing fluid as quickly as it is injected. When this occurs, the pressure is high enough that the coal fractures along existing weaknesses within the coal. Along with the fracturing fluids, sand (or some other propping agent or "proppant") is pumped into the fracture so that the fracture remains "propped" open even after the high fracturing pressures have been released. The resulting proppant-containing fracture serves as a conduit through which fracturing fluids and groundwater can more easily be pumped from the coal seam.

To initiate coalbed methane production, groundwater and some of the injected fracturing fluids are pumped out (or "produced" in the industry terminology) from the fracture system in the coal seam. As pumping continues, the pressure eventually decreases enough so that methane desorbs from the coal, flows toward, and is extracted through the production well.

EPA is conducting a study to assess the potential for contamination of underground sources of drinking water (USDWs) due hydraulic fracturing fluid injection into coalbed methane wells. The study focuses on hydraulic fracturing used specifically for enhancing coalbed methane production. EPA, through its contractors and subcontractors, gathered information on the hydraulic fracturing process and requested comment from the public on contamination allegedly due to hydraulic fracturing practices. In this Phase I effort, EPA did not incorporate new, scientific fact finding, but used existing sources of information, and consolidated pertinent data in a summary report to serve as the basis for the study. EPA decided if additional research was required based on the findings from this effort.

1.3 Project and Task Description

The purpose of this project is to assist EPA in assessing the potential for contamination of USDWs from the injection of hydraulic fracturing fluids into coalbed methane wells, and to determine based on these findings if further study is warranted. EPA will use the information from this study in any regulatory or policy decisions regarding hydraulic fracturing. The first step in investigating the potential for hydraulic fracturing to affect the quality of USDWs was to define mechanisms by which contamination could occur.

EPA defined two hypothetical mechanisms by which hydraulic fracturing of coalbed methane wells could potentially impact USDWs:

1. Direct injection of fracturing fluids into a USDW in which the coal is located, or injection of fracturing fluids into a coal seam that is already in hydraulic communication with a USDW (e.g., through a natural fracture system).

2. Creation of a hydraulic connection between the coalbed formation and an adjacent USDW.

The objective of the project is to consider these two mechanisms, based on existing literature and data, when evaluating whether hydraulic fracturing fluid injection into coalbed methane wells could contaminate USDWs.

Information was collected regarding the geology and hydrogeology of the coalbed methane production regions, the processes used to hydraulically fracture coalbed methane production wells, and the fluids used in the fracturing process. EPA also evaluated water supply incidents possibly related to hydraulic fracturing of coalbed methane production wells. EPA relied on currently available literature and data as the primary source of information for project efforts.

1.4 Quality Objectives and Criteria

To ensure that findings are valid, the following quality assurance questions will be addressed for all sources of data:

- What was the purpose of the study?
- Whose data are they?
- What is their source?
- Are the data reliable?
- Is the interpretation biased?

This Quality Assurance Plan establishes a set of guidelines and general approaches to assess available data and information in a clear, consistent, and explicit manner. Data collection and review according to this process will make conclusions more transparent, and thus more readily understood and communicable to stakeholders.

The objectives of the systematic expert review of data and information are transparency, avoidance of bias, validity, replicability, and comprehensiveness. Following a data and information review protocol can ensure a common understanding of the task and adherence to a systematic approach. The components of this Quality Assurance Plan are as follows:

- Specification of the hypotheses to be addressed;
- Justification of the expertise represented in the expert investigators team;
- Specification of the methods to be used for identification of relevant studies, assessment of evidence of the individual studies, and interpretation of the entire body of available evidence (WHO, 2000);
- Review process; and
- Communication of findings.

Revisions to the Quality Assurance Plan may be necessary as new aspects of the task emerge during the study development process.

1.5 Special Training and Certification

To provide authoritative assessments of data and information, it is important to rely on expert investigators to evaluate the evidence, draw conclusions on the existence of actual and/or potential hazard, and estimate the magnitude of the associated risk. The team of expert investigators, that evaluated the evidence associated with this study, possesses the following qualifications:

- Formal training in basic scientific principles applicable to the project;
- Basic knowledge of the subject or the body of technical information pertaining to it;
- Experience in scientific review of technical data and information;
- Ability to use descriptive and analytical tools appropriately;
- Ability to design studies to test hypotheses;
- Ability to communicate results accurately to decision-makers and stakeholders; and
- Experience coordinating multiple tasks and disciplines to ensure timely and accurate delivery of study components.

The above-listed qualifications ensure that the project team was able to fulfill the objectives of this project.

1.6 Documents and Records

Documents produced for the project and submitted to EPA included the draft and final summary reports (hard copy and digital format). Information and records included in the data report package following completion of the project included:

- Maps (hard copies);
- Scientific literature (hard copies);
- Books (hard copies);
- Database search results (hard copies);
- Logbooks (hard copies); and
- Site visit notes and photographs (hard copies).

All the above-listed materials are maintained by the EPA OGWDW.

2.0 Data Generation and Acquisition

Processes and methods used to collect the data and information must be clear, explicit, and based on valid practice. It is important to adhere to a rigorous and thorough approach to the processes of data collection and data logging.

In Phase I, EPA did not incorporate new, scientific fact finding, but instead used existing sources of information, and consolidated pertinent data in a summary report to serve as the basis for the study. EPA decided if additional research is required based on the findings from this effort. As such, this Quality Assurance Plan does not cover areas of sampling process design, sampling methods, sample handling and custody, analytical methods, quality control, instrument/equipment testing, inspection, and maintenance, instrument/equipment calibration and frequency, and inspection/acceptance of supplies and consumables.

2.1 Non-Direct Measurements

All information summaries and conclusions developed during the course of this project were based on non-direct measurements. Available literature and data were used as the primary source of information for the summary report. An extensive literature search was conducted using the Engineering Index and GeoRef on-line reference databases. Searches will be guided by subject topics and key words within the following areas:

- Hydrogeology of the coalbed methane basins;
- Hydraulic fracturing practices;
- Fracture behavior;
- Hydraulic fracturing fluids and additives; and
- Information regarding water quality incidents.

All search results were printed, catalogued, and surveyed for pertinent journal articles, books and conference proceedings that may contain information meeting the specific data needs of the summary report. Most pertinent articles were acquired from the University of Texas Library in Austin, Texas, as this library's holdings include an extensive collection of oil and gas-related publications. References from the articles were researched and documents relevant to the study were acquired. All papers collected for the study were archived by topic for future reference.

To verify facts extracted from the literature, state regulatory agencies, geological surveys, gas companies, service companies and other relevant organizations were contacted by telephone. Dated telephone logs were used to document all communications. Personal conversations with the employees of the various organizations yielded additional information in the form of literature, figures and maps. These were collected and referenced in conjunction with literature identified in the literature searches.

Internet-based searches were used to locate additional information. Relevant web sites were located using various search engines such as Google™, Yahoo®, and Alta Vista®. More specialized search engines, such as those provided on state geological survey web sites, also were searched. All relevant web sites were logged and referenced appropriately. Efforts were made to acquire the most recent literature. EPA offered state drinking water agencies and the public an opportunity to provide information to EPA on any impacts to groundwater believed to be associated with hydraulic fracturing by a request for public comment. Submissions were reviewed by EPA staff for information pertinent to this report. In addition, a request to provide information and comments regarding incidents of public and private well impacts that could potentially be associated with hydraulic fracturing was published in the July 30, 2001 *Federal Register* (*Federal Register*: July 30, 2001; Volume 66; Number 146; Page 39395-39397).

Details on specific methods used to collect information for each of the major report chapters is included in Chapter 2 of this report.

2.2 Data Management

Gathered information and data was managed to facilitate finding any one piece of gathered data. To achieve this goal, the following data management procedures were used:

- All telephone interviews were recorded in labeled log books;
- All scientific literature, published maps, existing water quality data, conference proceedings, and trade journal articles were filed by coal basin;
- Material safety data sheets and product literature were filed separately;
- Trip folders (to contain notes and photographs) were generated for each site visit;
- Computer database searches were filed separately; and
- Internet websites were referenced in the summary report.

Most data was stored in hard copy format. Wherever possible, data was stored digitally on compact disc.

3.0 Assessment and Oversight

The quality assurance review process provides a means to examine if the results and conclusions are verifiable. The review process results in a determination of whether the conclusions are directly supported by the data or evidence gathered and can be independently validated by others. This quality assurance review process is hierarchical and includes four review levels:

- Weighted emphasis on data based on source;
- Cross referencing of data sources when possible;
- EPA and other federal agencies review; and
- Review by a Peer Review Panel.

EPA's review was accomplished by the Work Assignment Manager in conjunction with other EPA headquarter offices and with other EPA Underground Injection Control regional offices involved with coalbed methane or hydraulic fracturing. Other federal agencies asked to review work products produced by this project, included the United States Geological Survey and the Department of Energy.

EPA assembled a peer review panel consisting of experts in hydraulic fracturing or associated subjects. The panelists provided comments to EPA regarding the sources of data used in the study, the data themselves, and the conclusions drawn from those data.

Comments were requested to assist the investigators in making the study as sound as possible and to ensure that the study met EPA standards for objectivity, evidence, and responsiveness to the study charge. Reviewer comments and objections were preserved and made a part of the record for the study. Issue papers were written containing detailed explanations of responses to comments and objections. Reasons for proceeding or not proceeding with the study were clearly explained.

4.0 Data Validation and Usability

This section describes activities that occurred after the initial collection of data. These activities determined whether or not the gathered data were useful and helpful to the project.

4.1 Data Review, Verification, and Validation

Subsequent to the data logging process, those reports potentially providing useful information underwent a selection process to evaluate quality of the information and usefulness to the study. Systematic evaluation of the validity of individual studies, data, and information included assessment of the following:

- Source of the data and information;
- Qualitative review of the literature;
- Qualitative review of data and information collected;
- Scientific strength of the data and information;
- Geographical, geological, geochemical, spatial, and temporal relevance;
- Relevance to determining baseline conditions;
- Validity of extrapolation to the scope of the study;
- Characteristics of associations, plausibility, alternative explanations;
- Consistency and specificity of the results;
- Scientific uncertainties, limitations, and confounding variables; and

- Other evaluation parameters, as appropriate.

A scale or rating of the data and information with respect to a level of proof required to support conclusions is specifically not proposed as part of this quality assurance process. Establishing a specific level of scientific evidence required to justify a subsequent conclusion would generate significant controversy. Instead, expert judgment was used to evaluate and weigh available data and information.

A variety of technical methods and tools were utilized to sort through the pertinent information and decipher the meaning of the data. These data analysis methods may include:

- Quantitative review of selected data and information collected;
- Tabulating valid data and information;
- Constructing geologic cross sections;
- Evaluating current and historical site operations;
- Review of consistencies between studies;
- Review of sources of discrepancies between studies and information; and
- Other methods/tools as appropriate.

All assumptions were explicitly documented, the basis for the use of any models explained, lack of evidence noted, and scientific uncertainties described as precisely as possible.

4.2 Reconciliation with User Requirements

This sub-section describes how the gathered and validated data and information were used to meet the requirements of this project and EPA.

4.2.1 Drawing Conclusions

Drawing conclusions from evaluated, analyzed, and summarized data and information involve judgment as to whether observations are consistent with the study hypotheses/objectives, or, whether some alternative is suggested. The expert investigators drew upon all evaluated and appropriately summarized data and information; however, no checklist or formula was applied to arrive at conclusions. Instead, critical scientific reasoning and judgment was used to draw conclusions. The process of scientific reasoning and judgment was made explicit by describing and documenting how investigators:

- Assessed completeness of data and information;
- Accounted for lack of evidence and limitations, and impacts on the conclusions;
- Assessed and accounted for bias in original data and/or information;
- Used applicable guidelines and rationales;
- Used any ranges of estimates to arrive at conclusions, where appropriate and;
- Incorporated assumptions into assessments and accounted for the implications of those assumptions in their conclusions.

Conclusions were drawn within the boundaries of the data and the scope of the study. Lack or absence of evidence was addressed. The relative strength or weakness of available information to support conclusions, limitations on where a conclusion may apply, and alternative interpretations of data, was recognized. Any qualification on the use of the data and factors that contribute to uncertainty was conveyed.

Much of the information obtained from public response to the *Federal Register* Notice or from other sources cannot be confirmed through review of peer-reviewed publications or other data sources. However, the information was reviewed and contrasted to evaluate the extent of complaints received and any trends in the complaints within and between individual coalbed methane production basins.

4.2.2 Communication of Findings

This Quality Assurance Plan is reflected in the communication of scientific findings in a clear, accurate, and complete manner to interested parties. Investigators communicated:

- The body of technical information that was considered;

- The manner for evaluating, and drawing conclusions from, collected data and information; and

- Conclusions that address the hypotheses/objectives, supported by the results of data evaluation and analysis.

The use of presentation tools such as charts, diagrams, and computer-generated displays was based on sufficient, valid, and defensible data.

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