UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON D.C. 20460

OFFICE OF THE ADMINISTRATOR
SCIENCE ADVISORY BOARD

August 4, 2011

EPA-SAB-11-012

The Honorable Lisa P. Jackson
Administrator
U.S. Environmental Protection Agency
1200 Pennsylvania Avenue, N.W.
Washington, D.C. 20460

Subject: SAB Review of EPA's Draft Hydraulic Fracturing Study Plan

Dear Administrator Jackson:

This Science Advisory Board (SAB) report responds to a request from EPA's Office of Research and Development (ORD) to review and provide advice on its February 2011 *Draft Plan to Study the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources* (draft Study Plan). Hydraulic fracturing (HF) generates fractures in underground geologic formations to facilitate extraction of natural gas (or oil) from low-permeability formations in the subsurface. The process involves the use of directional drilling to drill vertically to the formation of interest and then horizontally into the formation. After installation of a wellbore which is subsequently perforated along its horizontal extent, water-based hydraulic fracturing fluid is injected and the formation is subjected to high pressure to induce fracturing. This method of natural gas extraction has the potential to impact ground and surface water resources through water acquisition, mixing with the fracking fluid chemicals, well injection of the fracking fluid, flowback and post-fracturing produced water, and water treatment and waste disposal.

The draft Study Plan identifies research questions and proposes a research program to assess potential impacts of HF on drinking water resources and identify data gaps. The scope of the proposed research includes the full lifecycle of water in HF, from water acquisition through the mixing of chemicals and actual fracturing to the post-fracturing stage, including the management of flowback and produced water and its ultimate treatment and/or disposal. The SAB was asked to comment on the appropriateness of EPA's proposed water lifecycle framework, research questions, and research approach, activities, and outcomes.

In general, the SAB found EPA's approach for the Study Plan to be appropriate and comprehensive, and concludes that EPA has identified the necessary tools in its overall research approach to assess potential impacts of hydraulic fracturing on drinking water resources. EPA identified specific potential outcomes for the research related to each step in the HF water lifecycle. However, the SAB does not anticipate that all of these outcomes can be achieved given the time and cost constraints of the proposed research program. Further, the SAB identifies several areas of the Study Plan that can be better focused and suggests several additional important topics for further study to maximize impact within the time available until a report of interim research results is provided in 2012.

The SAB concludes that while EPA's use of the water lifecycle is an appropriate framework to characterize hydraulic fracturing and to identify potential impacts on drinking water, EPA should make certain adjustments to the framework, including consideration of water quantity impacts on the local watershed mass balance and consideration of the postclosure/well abandonment phase within the lifecycle. The SAB also finds that the Study Plan provides inadequate detail on how to address the overall research questions. EPA should develop more focused research questions that could be answered within the time and budget constraints of the project.

To help focus efforts, the SAB recommends that EPA consider the four steps of the risk assessment paradigm (i.e., hazard identification, exposure assessment, dose-response assessment, and risk characterization) to assess and prioritize research activities for each water lifecycle stage presented in the draft Study Plan, and to focus research questions. The SAB recommends that EPA first focus on hazard identification and potential human exposure in the current research effort. The SAB concludes that important routes of potential human health exposure include exposure to liquids that are brought back to the surface during hydraulic fracturing operations and to potential groundwater contamination. EPA will be obtaining information as the study progresses and should use its expertise to set priorities for these and other pathways as needed. The SAB further recommends that none of the proposed comprehensive toxicity testing be conducted at this time due to time and cost constraints. Rather, EPA should evaluate available databases to understand the toxicity of selected constituents determined to have a high potential for exposure.

The SAB has several additional suggestions to improve EPA's draft Study Plan. EPA should specify whether the research focus is strictly on hydraulic fracturing in shale gas production or will include fracturing in conventional natural gas production, coal bed methane production, or other types of natural gas and oil extraction activity. SAB is not suggesting that studies be limited to particular type of activity; rather, EPA should be careful with the realm of inference drawn in the report to different activities (i.e., results should not be generalized across all types of HF activity). EPA should also collect baseline hydrologic and water quality data in a given case study area before HF activity begins so that significant changes in water availability or water quality caused by HF activity can be more readily documented. Furthermore, the Study Plan should address the cumulative consequences of carrying out multiple HF operations in a single watershed or region.

In addition, EPA should gather currently available information on the composition of post-fracturing produced water from the hydraulic fracturing process, and proprietary information on all additives included in any injected water. EPA should include the following constituents in EPA's analysis of impacts of water acquisition and other HF processes on water quality: hydrogen sulfide, ammonium, radon, iron, manganese, arsenic, selenium, total organic carbon, and bromide, in addition to HF fluid constituents and formation chemicals. Further, EPA should assess the potential of constituents in HF-impacted waters to form disinfection by-products during drinking water treatment.

EPA should also include consideration of water quality parameters for which Maximum Contaminant Levels (MCLs) have not been established under the Safe Drinking Water Act, in addition to the proposed parameters for which MCLs have been established. Since MCLs have not been established for some of the chemicals used in the HF process, MCLs alone will not be sufficient for assessing all potentially significant impacts of hydraulic fracturing on drinking water quality. EPA should focus study of treatment of post-fracturing produced water constituents on literature searches of municipal and industrial wastewater management practices with similar waters, and assess the need for any special storage, handling, management, or disposal controls for solid residuals after treatment.

Lastly, EPA should develop one or more focused research outcomes related to the planned research pertaining to environmental justice issues. For the case studies, EPA should also assess demographic information, such as race, color, national origin, and income, to screen whether hydraulic fracturing disproportionately impacts some citizens near sites used for the case studies (e.g., identify whether more HF wells are near communities with lower incomes).

The SAB appreciates the opportunity to provide EPA with advice on this important subject. We look forward to receiving the Agency's response and to providing future advice on this topic.

Sincerely,

/signed/

Dr. Deborah L. Swackhamer, Chair
Science Advisory Board

/signed/

Dr. David A. Dzombak, Chair
SAB Hydraulic Fracturing Study Plan
Review Panel

Enclosures

NOTICE

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Abbreviations and Acronyms

BMP	Best Management Practices
BTEX	Benzene, Toluene, Ethylbenzene, and Xylenes
CWT	Centralized Waste Treatment
CWA	Clean Water Act
DOE	U.S. Department of Energy
DBP	Disinfection By-product
EPA	U.S. Environmental Protection Agency
HF	Hydraulic Fracturing
MCLs	Maximum Contaminant Levels
NETL	DOE's National Energy Technology Laboratory
O&M	Operation & Maintenance
ORD	EPA Office of Research and Development
POTW	Publicly Owned Treatment Works
PPRTVs	Provisional Peer-Reviewed Toxicity Values
PWSS	Public Water Supply Systems
QSAR	Quantitative Structure-Activity Relationships
Rn	Radon
SAB	EPA Science Advisory Board
TDS	Total Dissolved Solids
TOC	Total Organic Carbon
UIC	Underground Injection Control
USDW	Underground Sources of Drinking Water
USGS	U.S. Geological Survey

EXECUTIVE SUMMARY

In January 2010, EPA's Office of Research and Development (ORD) initiated planning for a study to assess the potential impacts of hydraulic fracturing on drinking water resources. EPA proposed a study scope in March 2010 that was reviewed by the Science Advisory Board (SAB) in an open meeting on April 7-8, 2010; SAB's Report on its review of the study scope was transmitted to the Administrator on June 24, 2010. Subsequently, EPA developed a draft *Hydraulic Fracturing Study Plan* and requested SAB review of the draft Plan. The charge questions for the review are provided in Appendix A. The SAB Hydraulic Fracturing Review Panel reviewed the draft Study Plan and background materials provided by ORD, considered public comments that were received on the draft Study Plan, held public meetings on March 7-8, 2011, and held public teleconferences on May 19 and May 25, 2011 to provide advice to EPA on the scientific adequacy, suitability and appropriateness of EPA's draft Study Plan. The Panel also considered oral statements that were received on the draft Study Plan during the public meetings and teleconferences. The external draft SAB Report on EPA's Draft Hydraulic Fracturing Study Plan dated June 14, 2011 was reviewed and approved by the Chartered SAB at a public teleconference on July 5, 2011.

The draft Study Plan assesses the potential impacts of hydraulic fracturing on drinking water resources, and identifies the driving factors that affect the severity and frequency of any potential impacts. A summary of the research questions upon which the draft Study Plan was formulated is provided in Appendix B (Table 2 from the Study Plan). The draft Study Plan proposes to assess potential impacts from five aspects of the water lifecycle associated with hydraulic fracturing: Water Acquisition, Chemical Mixing, Well Injection, Flowback and Produced Water, and Water Treatment and Waste Disposal. As noted in the draft Study Plan, EPA plans to conduct this lifecycle analysis through literature reviews, data gathering and analysis, modeling, laboratory investigations, and field investigations and case studies.

The SAB was asked to comment on various aspects of EPA's Study Plan, including EPA's proposed water lifecycle framework for the study plan, EPA's proposed research questions that would address whether or not hydraulic fracturing impacts drinking water resources, and EPA's proposed research approach, activities, and outcomes. The enclosed report provides the advice and recommendations of the SAB through the efforts of the SAB Hydraulic Fracturing Review Panel.

In general, the SAB found EPA's overall approach for the draft EPA Study Plan to be appropriate and comprehensive, and concludes that EPA has identified the necessary tools in its overall research approach to assess adequately potential impacts of hydraulic fracturing on drinking water resources. However, the SAB identified several areas of the Study Plan that can be better focused and recommends several additional important topics for study to maximize impact within the time available until a report of interim research results is provided in 2012. While a more detailed description of the technical recommendations is included in this SAB Report, the key points and recommendations are highlighted below.

Charge Question 1: Water Use in Hydraulic Fracturing

EPA has developed a Study Plan that identifies a set of proposed research activities associated with each stage of the hydraulic fracturing water lifecycle, from water acquisition through the mixing of chemicals and actual fracturing to post-fracturing production, including the management of post-fracturing produced water and ultimate treatment and disposal.

The SAB concludes that EPA's use of the water lifecycle depicted in Figure 7 of the draft Study Plan is an appropriate framework to characterize hydraulic fracturing and to identify the potential drinking water issues. Figure 7 is provided within this SAB report as Appendix C. The SAB also finds that the Study Plan adequately identifies and addresses the areas of concern identified for each stage of the hydraulic fracturing water lifecycle. However, the SAB concludes that the diagram is incomplete, and has several recommendations to strengthen the framework and provide an improved assessment of potential drinking water issues.

The SAB recommends that EPA make certain adjustments to the hydraulic fracturing lifecycle framework. EPA should assess water quantity impacts on the local watershed mass balance, and the framework depicted in Figure 7 should link water fluxes associated with hydraulic fracturing to water flows in the surrounding natural hydrological cycle. The water mass balance that accounts for waters entering and leaving the system is a critical issue, and EPA should initially focus the water mass balance assessment towards the case study efforts. EPA should also assess interbasin transfers of post-fracturing produced water in order to identify possible water quality and quantity issues associated with such transfers.

The SAB recommends that EPA also add a postclosure/well abandonment phase as a new component to Figure 7, and separately consider this phase in the Study Plan. SAB recognizes that potential risks for this new component may not be at the same level as potential risks in other phases of the lifecycle. EPA should determine if there is historical evidence to indicate if there are any differences regarding the postclosure/well abandonment phase of hydraulic fracturing wells when compared to the postclosure/well abandonment phase for other types of wells.

In addition to the water quality impacts indicated in Figure 9a, EPA should assess the potential release of volatile contaminants to the air, and their potential for subsequent deposition to surface water resources. Figure 9a is provided within this SAB report as Appendix D.

Charge Question 2: Research Questions

EPA has identified a comprehensive set of research questions to address the primary mechanisms and pathways that can allow hydraulic fracturing to impact drinking water resources (see Appendix B). The questions cover each step of the life cycle of a hydraulic fracturing process that can impact drinking water and are appropriately focused on the unique aspects of hydraulic fracturing that can lead to such impacts. EPA also proposes to conduct scenario evaluations that will assess the environmental futures and impacts of hydraulic fracturing operations at various spatial and temporal scales in the selected case study areas. The scenarios will include at least two futures: (1) average annual conditions in 10 years based on the full exploitation of non-conventional natural gas and (2) average annual conditions in 10 years based on sustainable water use in hydraulic fracturing operations.

As presented by EPA staff at the March 7, 2011 SAB meeting, EPA's budget for the research on HF impacts to drinking water resources is as follows:

Fiscal Year 2010 (Enacted): $1.9 million.
Fiscal Year 2011 (President's Request): $4.4 million.
Fiscal Year 2012 (President's Request): $6.1 million.

EPA's schedule for delivery of research products includes completion of a report of interim research results in 2012. This interim report will contain a synthesis of EPA's research to date and will include results from retrospective case studies and initial results from scenario evaluations. Since certain portions of the work described in the draft Study Plan, including prospective case studies and work performed under EPA's Science to Achieve Results (STAR) program, are longer-term activities that are not likely to be finished by 2012, additional reports of study findings will be published as these long-term activities progress, with a follow-up report on the study in 2014.

EPA's use of retrospective case studies will focus on investigating reported instances of drinking water resource contamination or other impacts in areas where hydraulic fracturing has already occurred. EPA will conduct retrospective case studies at three to five sites across the United States; these studies will use existing data and possibly field sampling, modeling, and/or parallel laboratory investigations to determine the potential relationship between reported impacts and hydraulic fracturing activities. EPA will also conduct prospective case studies that will involve sites where hydraulic fracturing will occur after the research is initiated. These case studies allow sampling and characterization of the site before, during, and after water extraction, drilling, hydraulic fracturing fluid injection, flowback, and gas production. EPA will work with industry and other stakeholders to conduct two to three prospective case studies in different regions of the United States.

The SAB finds that the Study Plan provides inadequate detail on how to address the overall research questions presented in Table 2 (see Appendix B) and that EPA should develop more focused research questions that could be answered within the budget and time constraints of the project. The SAB provides recommendations for supplementing and revising the existing questions. These recommendations are designed to recognize explicitly key issues that may not be adequately addressed in the current questions. The SAB also finds that the scenario evaluation does not, but should, cross all research questions. For example, the potential effects of water acquisition on drinking water quality are not included in scenario evaluation. SAB also notes that scenario evaluations beyond the case studies for water acquisition and flowback water, and their modeling, would particularly assist EPA's research effort.

SAB recommends that EPA clarify whether the research focus is on hydraulic fracturing in shale gas production, conventional natural gas production, coal bed methane production, and/or other types of hydraulic fracturing activity. SAB is not suggesting that studies be limited to particular type of activity; rather, EPA should be careful with the realm of inference drawn in the report to different activities (i.e., results should not be generalized across all types of HF activity). In addition, to the extent that the Study Plan is being designed to inform decision-making related to an EPA regulatory framework, the Study Plan should include specific research questions aimed at this objective.

Within the body of this Report, SAB provides comments that may affect the primary and secondary research questions and how they are answered at each life cycle stage. An important challenge facing the study is the diverse nature of hydraulic fracturing operations around the country. The geological setting, the hydrological setting, the community setting and the requirements and standard operating procedures at each stage of the hydraulic fracturing life cycle vary with geographical location. These differences can give rise to fundamental differences in the nature of the potential impacts to drinking water resources. The SAB recommends that EPA include several focused research questions associated with individual lifecycle stages. The SAB also concludes that the Study Plan should address the cumulative consequences of carrying out multiple HF operations in a single watershed or region. While detailed research on cumulative impacts may be beyond the scope of the current study, the incremental impacts of hydraulic fracturing operations should be well characterized in the current study and a framework for assessment of cumulative impacts should be established. This will provide the foundation for subsequent assessment of total environmental exposures and risks, and cumulative impacts.

The SAB recommends that EPA consider the four steps of the risk assessment paradigm (i.e., hazard identification, exposure assessment, dose-response assessment, and risk characterization) to assess and prioritize research activities for each water lifecycle stage presented in the draft Study Plan, and to focus research questions. At this time, EPA should focus on hazard identification and potential human exposure for the components of HF fluids in the current research effort. The SAB strongly recommends that none of the proposed toxicity testing of chemical constituents be conducted at this time due to time and cost constraints. Rather, EPA should evaluate the toxicity of selected constituents determined to have a high potential for exposure through literature sources and available databases. The SAB recommends that EPA explicitly recognize this in the framing of the secondary research questions.

The SAB does not agree that developing analytical methods for detecting chemicals associated with HF is an appropriate goal for the research. The SAB concludes that it may be difficult to develop analytical methods for specific constituents that do not have existing EPA-approved methods, and difficult to achieve a practical indicator approach, within the time and budget allotted for the study. If it is undertaken, such an effort could succeed for a limited number of chemicals, but at the cost of diverting resources from goals that should have higher priority.

SAB recommends that EPA conduct research in a few additional areas. EPA should assess the capacity of microseismic data to provide detailed information about extent of fracturing and to assist in the hydraulic fracturing modeling (see discussion under Charge Question 4c). In addition, potential impacts to drinking water may be the result of the hydraulic fracturing process or the result of the manner in which it is implemented (e.g., the particular manner in which site preparation and drilling are conducted). Potential impacts to drinking water resources that are the result of particular management practices should be identified as being linked to those management practices. This would be most useful if there are sufficient data available to compare various management practices.

The SAB recommends EPA include both prospective and retrospective case studies as planned because the studies address different questions and perspectives. In retrospective case studies there is concern that it may not be possible to obtain sufficient data to separate risks that may be associated with the various management practices employed.

In prospective case studies there is concern that the best management practices examined in these case studies will not necessarily be used at other sites, and that the water quality parameters that are analyzed before, during, and after injection of the HF fluids will probably undergo minimal change during the relatively short duration of the research program. Also, the number of retrospective and prospective case studies that can be evaluated in the given time will be limited, which will make it difficult to generalize from the data gathered. The SAB recommends that EPA take a long view, and consider what kind of data will be desired in ten years in order to design the data collection protocols for the prospective studies. Further, the SAB notes that the selected case study locations must be chosen based on reasonable, mechanistically possible contamination scenarios, incorporating uncertainty.

An additional issue is that EPA needs to view the environmental concerns and issues in the context of the local community. As noted in Section 9 of the Study Plan, to address these concerns, EPA plans to combine the data collected on the locations of well sites within the United States with demographic information (e.g., income and race) to screen whether hydraulic fracturing disproportionately impacts some citizens and to identify areas for further study. The SAB concludes this would effectively inform environmental justice discussions. The SAB recommends that EPA consider information such as race, color, national origin, and income in this analysis, identify metrics that would gauge the environmental justice impacts resulting from this analysis, and develop one or more specific research outcomes related to the planned research pertaining to environmental justice issues. For the case studies, EPA should also assess demographic information, such as race, color, national origin, and income, to screen whether hydraulic fracturing disproportionately impacts some citizens near sites used for the case studies (e.g., identify whether more HF wells are near communities with lower incomes). Also, EPA should conduct systematic interviews with local public health officers to identify potentially vulnerable subpopulations, the consideration of fairness in local decision-making, and the impacts of current operations associated with HF operations at case study locations.

Another issue is the importance of assessing uncertainty at each step in the research study. Given time and resource constraints, the studies will not be able to answer all questions with a high degree of certainty. The SAB recommends that EPA explicitly identify or estimate the uncertainty or confidence in all research conclusions, and in the assessment of cause and effect associated with potential HF impacts to drinking water supplies. The quality of the information on which the research was based as well as any uncertainties arising in the conduct of the research should be evaluated, at least in a preliminary manner.

The SAB has a number of specific concerns associated with the research questions at individual lifecycle stages. These are presented in the discussion associated with the subsequent charge questions.

Charge Question 3: Research Approach

EPA's research approach involves application of a broad range of scientific expertise in environmental and petroleum engineering, ground water hydrology, fate and transport modeling, and toxicology, as well as many other areas, and use of case studies and generalized scenario evaluations, to address the key questions associated with each of the five water cycle stages of hydraulic fracturing.

The SAB agrees that EPA has identified the necessary tools in its overall research approach as outlined in the Study Plan to adequately assess potential impacts of hydraulic fracturing on drinking water resources. However, the SAB concludes that EPA should conduct a well-focused study so that critical research questions are identified, approaches are designed that will enable answering those questions, and conclusions reached are supported by appropriate analysis.

The SAB finds that the Study Plan provides limited detail on anticipated data acquisition, analysis, management, and storage (including model simulation results), and recommends that EPA revise the draft Study Plan to include such details. The SAB recommends that EPA consider using existing data acquisition and analysis methods rather than develop new methods due to time and budget constraints. EPA should also carefully consider the quality of various types of data that would be used within the analysis (industry data, local and non-industry data), and consider archiving samples for later use.

The SAB finds that the Study Plan overemphasizes case studies in the study approach, and underemphasizes the review and analysis of existing data and the use of scenario analysis. The SAB concludes that the specific objectives of case studies are unclear and should be clarified, and that EPA should explain better the rationale for the selected case studies. The SAB concludes there is significant value to the synthesis of existing data, and that EPA should review all available data sources to learn from what is already known about the relationship of hydraulic fracturing and drinking water resources. The SAB also provides citations for additional literature that EPA should assess in order to ensure a comprehensive understanding of the trends in the hydraulic fracturing process and the potential impacts of hydraulic fracturing on drinking water resources.

Charge Question 4(a): Proposed Research Activities - Water Acquisition

To address the research questions listed in Table 2 (see Appendix B) for the Water Acquisition stage of the water lifecycle, EPA plans to conduct retrospective and prospective case studies, analyze and map water quality and quantity data, and assess impacts of cumulative water withdrawals. The SAB finds that these proposed activities will, in general, adequately address the research questions associated with this lifecycle stage as outlined in Table 2. However, the SAB recommends that the Study Plan include an additional research effort to collect baseline hydrologic and water quality data in a given area before HF activity begins, so that significant changes in water availability or water quality caused by HF activity can be more readily documented.

SAB also recommends that EPA consider developing a “vulnerability index” or a list of criteria that could be used to indicate situations where a water supply is vulnerable to adverse impacts on water quality or quantity, and where further evaluation may be warranted. SAB recognizes that, given EPA’s limits on available time and site-specific data, this activity could potentially be delayed until there is more experience and available data.

The SAB recommends that EPA’s list of analytes (provided in Table G1 of the draft Study Plan) that would be studied to assess the potential impacts of water acquisition and other HF activities on water quality should specifically include the following constituents: hydrogen sulfide, ammonium, radon, iron, manganese, arsenic, selenium, total organic carbon, and bromide, in addition to HF fluid constituents and likely formation or additive chemicals. EPA should also assess the potential of constituents in HF-impacted waters to form disinfection by-products (including trihalomethanes, haloacetic acids, total organic halogen, and other halogenated organic compounds) in drinking water treatment.

The SAB recommends that EPA include consideration of HF water quality parameters for which Maximum Contaminant Levels (MCLs) have not been established under the Safe Drinking Water Act, in addition to the proposed parameters for which MCLs have been established. Since MCLs have not been established for some of the chemicals used in the HF process, MCLs alone will not be sufficient for assessing all potentially significant impacts of hydraulic fracturing on drinking water quality. EPA should also examine trends in water quality associated with HF water acquisition and determine whether adverse impacts will result if these trends continue.

Advances in membrane desalination, increasing use of aquifer storage and recovery systems, and regional water shortages are changing perspectives on what constitutes a source of drinking water. The SAB recommends that EPA not automatically exclude from consideration potential impacts on a water source having more than 10,000 mg/L of total dissolved solids if it could reasonably be anticipated to be a viable source of water supply in the future.

<u>Charge Question 4(b): Proposed Research Activities - Chemical Mixing</u>

The SAB concludes that, overall, EPA has generally proposed a sound approach to address the research questions associated with this lifecycle stage as outlined in Table 2 (see Appendix B). The SAB has some recommendations for specific components of the research plan that could be strengthened as described further below.

SAB recommends that EPA gather both currently available information on the composition of post fracturing produced water from the hydraulic fracturing process, and proprietary information on all additives included in any injected water. The SAB supports EPA’s proposed approach to analyze existing data rather than collect samples to assess HF fluid composition and toxicity of fluid components, and concludes that EPA’s effort to gather data from nine hydraulic fracturing service companies will likely provide sufficient information on the composition of HF fluids. SAB recommends that EPA also gather HF fluid composition data from states collecting such data, and consider the role that recycling and reuse of HF fluids will play in influencing both quantity and composition of HF fluids. Also, while it would be helpful if EPA developed indicators of contamination, it may be difficult to achieve a practical indicator approach within the time allotted for the current study.

SAB generally supports EPA's plans to identify factors that influence the likelihood of contamination of drinking water resources as a result of chemical mixing activities. Although SAB agrees that EPA will identify a number of factors that influence the likelihood of contamination of drinking water resources as a result of chemical mixing activities, the list of factors may not be complete, the project time and budget may not allow time for a complete evaluation of the factors, and the results should not be generalized across all HF sites.

SAB does not conclude that case studies alone will provide sufficient information regarding effectiveness of mitigation approaches in reducing impacts to drinking water resources. SAB recommends that EPA analyze data from HF service companies and states in order to provide additional insight. The retrospective case studies may also be a source of useful information about approaches that failed to prevent or control impacts.

Charge Question 4(c): Proposed Research Activities - Well Injection

With the cooperation of service companies, full access to data, and careful selection of case studies, the SAB agrees that the proposed research can adequately address several fundamental questions associated with possible impacts of the injection and fracturing processes on drinking water resources. However, the SAB concludes it will not be possible to cover all facets of the proposed research within the time allotted for the research activities, and recommends that EPA narrow the scope of activities associated with specific case studies and site investigations and use a wide variety of sources available to EPA in order to increase the success of the research program. The SAB provides a number of specific recommendations for focusing EPA's fundamental and secondary research questions associated with this topic area.

As a starting point, the SAB recognizes that there are three primary opportunities during well injection for contaminants to affect drinking water resources: escape through the well, through the cement surrounding the well, and as a result of various steps of the hydraulic fracturing process itself. Assuming drilling and cementing practices for HF wells are not different from practices for other industry wells, the consensus of the Panel is that well drilling and cementing practices be researched separately from the hydraulic fracturing process itself. In doing so, the SAB finds the EPA can better focus on the question of the potential influence of the hydraulic fracturing process on drinking water resources and contamination of aquifers.

Charge Question 4(d): Proposed Research Activities - Flowback and Produced Water

The SAB concludes that, overall, EPA has generally proposed a sound approach to address the research questions associated with this lifecycle stage as outlined in Table 2 (see Appendix B). The SAB has some recommendations for specific components of the research plan that could be strengthened as described further below.

The handling, treatment and disposal of post-fracturing produced water represents an important route of exposure and has potential for adverse widespread impacts. Although flowback and produced water are sometimes mentioned independently, these distinctions are only operational as there is a continuous evolution of water quality for post-fracturing produced water. To the extent differentiation of flowback and produced water is desired by EPA, the SAB recommends that EPA clearly define flowback and produced water in the main body of the Study Plan.

The SAB supports EPA's plan to gather information on the composition of post- fracturing produced water from the hydraulic fracturing process as much as possible from currently available data, including proprietary information where possible. The SAB recommends the collection of water quality data before, during, and after injection, and from carefully selected locations, including the ongoing studies on the quality of surface waters in the regions with significant hydraulic fracturing activity. EPA should evaluate quality assurance/quality control (QA/QC) aspects of the studies that would be assessed or conducted by EPA.

The SAB recommends that EPA consider the use of a risk assessment framework analysis (i.e., hazard identification, exposure assessment, dose-response assessment, and risk characterization) to assess and prioritize research activities for the lifecycle stages of flowback and produced water. Specific comments on hazard identification, exposure assessment, toxicity testing, analytical methods, and indicators of contamination are included within this Report's response to Charge Question 2.

Charge Question 4(e): Proposed Research Activities - Wastewater Treatment and Waste Disposal

The SAB concludes that, overall, EPA has generally proposed a sound approach to address the research questions associated with this lifecycle stage as outlined in Table 2 (see Appendix B). The SAB has some recommendations for specific components of the research plan that could be strengthened as described further below.

The Panel strongly recommends the use of scenario modeling, in concert with both retrospective and prospective case studies, to "define the boundaries" for activities under this portion of the water lifecycle. Scenario modeling involving simple mass balances should be conducted as a first-order effort to determine if or when dilution constitutes adequate "treatment." Existing practice in some areas is to discharge return flows to wastewater treatment plants and to rely on dilution to "treat" a number of constituents not removed by conventional wastewater treatment processes, such as total dissolved solids (TDS), chloride, bromide, and non-biodegradable organic matter. For these constituents, simple calculations can be done to estimate effluent and downstream concentrations, which can then be evaluated for their potential to cause adverse impacts (not only to humans, via drinking water supplies, but also to other receptors in future studies).

Hydraulic fracturing return flows contain many constituents that are similar to those for which treatment technologies exist within the state of practice of industrial wastewater treatment. For those constituents, SAB finds that EPA should conduct a thorough literature review to identify existing treatment technologies that are currently being used to treat HF wastewater, identify knowledge relevant to hydraulic fracturing return flows, and identify constituents of HF return waters that might merit additional attention. SAB recommends that EPA review the documented data in the retrospective case studies to assess the efficacy and success of industrial wastewater treatment operations and pre-treatment operations for hydraulic fracturing return flows. Only a limited number of Publicly Owned Treatment Plants (POTWs) have the ancillary treatment technologies needed to remove the constituents in hydraulic fracturing return waters. SAB recommends that EPA focus its efforts towards literature searches on POTW and industry management practices that can minimize the adverse effects associated with certain constituents such as TDS, natural organic matter (NOM), bromide, and radioactive species. In addition, EPA should assess the need for any special storage, handling, management, or disposal controls for solid residuals after treatment. EPA should assess whether land application (e.g., for disposal, irrigation, or road application for dust suppression or deicing) of hydraulic-fracturing associated wastewaters or residuals from treatment of these wastewaters, which is mentioned in the Study Plan, has the potential to affect drinking water resources.

Charge Question 5: Research Outcomes

EPA has proposed to conduct certain research activities associated with all stages of the hydraulic fracturing water lifecycle shown in Figure 7 of the Study Plan in order to address the research questions posed in Table 2 of the Study Plan. Table 2 and Figure 7 are provided within this SAB report as Appendix B and Appendix C, respectively. EPA proposes to conduct the research using case studies and generalized scenario evaluations, which will rely on data produced by a combination of the tools listed in Section 5.3 of the Study Plan. In addition, EPA outlines a program of quality assurance that will be developed for all aspects of the proposed research. EPA's proposed research activities for each stage of the hydraulic fracturing water lifecycle are outlined in Figure 9 of the Study Plan, and EPA provides brief summaries of how the proposed research activities will answer the fundamental research questions. Figure 9a is provided within this SAB report as Appendix D.

The SAB focused on the potential research outcomes that EPA identified for each step in the HF water lifecycle. These potential research outcomes are identified in Chapter 6 of the draft Study Plan, at the end of the discussion of each stage of the water lifecycle. For each potential research outcome listed in the draft report, the SAB determined whether the outcome is likely to be achieved in whole, in part, or not at all, by the proposed research. In addition to comments on specific outcomes for steps in the HF water lifecycle, comments on environmental justice research outcomes are included within this report's response to Charge Question 2.

EPA identified specific potential outcomes for the research related to each step in the HF water lifecycle. However, the SAB does not anticipate that all of these outcomes can be achieved given the time and cost constraints of the proposed research program.

INTRODUCTION

Background

In January 2010, EPA's Office of Research and Development (ORD) initiated planning for a study to assess the potential impacts of hydraulic fracturing on drinking water resources. EPA proposed a study scope in March 2010 that was reviewed by the Science Advisory Board (SAB) in an open meeting on April 7-8, 2010; SAB's Report on its review of the study scope was provided to the Administrator in June 2010. In its response to EPA in June 2010, the SAB endorsed a lifecycle approach for the study plan, and recommended that: (1) initial research be focused on potential impacts to drinking water resources, with later research investigating more general impacts on water resources; (2) five to ten in-depth case studies be conducted at "locations selected to represent the full range of regional variability of hydraulic fracturing across the nation"; and (3) engagement with stakeholders occur throughout the research process.

Subsequently, EPA developed a draft *Hydraulic Fracturing Study Plan* and requested SAB review of the draft Plan. The draft *Study Plan* assesses the potential impacts of hydraulic fracturing on drinking water resources, and identifies the driving factors that affect the severity and frequency of any potential impacts. The draft *Study Plan* proposes to assess potential impacts from five aspects of the water lifecycle associated with hydraulic fracturing: Water Acquisition, Chemical Mixing, Well Injection, Flowback and Produced Water, and Water Treatment and Waste Disposal. As noted in the draft Study Plan, EPA plans to conduct this lifecycle analysis through literature reviews, data gathering and analysis, modeling, laboratory investigations, and field investigations and case studies.

The SAB was asked to comment on various aspects of EPA's approach for the Study Plan, including EPA's proposed water lifecycle framework for the study plan, EPA's proposed research questions that would address whether or not hydraulic fracturing impacts drinking water resources, and EPA's proposed research approach, activities, and outcomes. EPA identified the proposed research questions from stakeholder meetings and a review of the existing literature on hydraulic fracturing. Stakeholders also helped EPA to identify the potential case study sites discussed in the draft study plan.

The Panel reviewed the draft Study Plan and background materials provided by EPA, and considered public comments that were received on the draft Study Plan, held public meetings on March 7-8, 2011 to provide advice to EPA on its draft Study Plan. The Panel held follow-up public teleconference calls on May 19 and May 25, 2011, to discuss the external draft SAB Report dated April 28, 2011. The Panel considered oral statements that were received on the draft Study Plan during the public meetings and teleconferences.

The updated external draft SAB Report dated June 14, 2011, was submitted to the chartered SAB for discussion at the July 5, 2011, public teleconference. The external draft SAB Report was revised based on comments received from the Board.

The enclosed report provides the advice and recommendations of the SAB through the efforts of the SAB Hydraulic Fracturing Review Panel. EPA will consider the comments from the SAB during the development of its final plan to study the potential impacts of hydraulic fracturing on drinking water resources.

Charge Questions to the Panel

The Agency's Charge to the Panel (Appendix A) included a total of five questions, which were broken into nine total charge questions that were reviewed by the Panel:

Charge Question 1: Water Use in Hydraulic Fracturing

> EPA has used the water lifecycle shown in Figure 7 to characterize hydraulic fracturing and to identify the potential drinking water issues. Please comment on the appropriateness of this framework for the study plan. Within the context of the water lifecycle, does the study plan adequately identify and address the areas of concern?

Charge Question 2: Research Questions

> EPA has identified both fundamental and secondary research questions in Table 2. Has EPA identified the correct research questions to address whether or not hydraulic fracturing impacts drinking water resources, and if so, what those potential impacts may be?

Charge Question 3: Research Approach

> The approach for the proposed research is briefly described in Chapter 5. Please provide any recommendations for conducting the research outlined in this study plan, particularly with respect to the case studies. Have the necessary tools (i.e., existing data analysis, field monitoring, laboratory experiments, and modeling) been identified? Please comment on any additional key literature that should be included to ensure a comprehensive understanding of the trends in the hydraulic fracturing process.

Charge Question 4(a): Proposed Research Activities - Water Acquisition

> Proposed research activities are provided for each stage of the water lifecycle and summarized in Figure 9. Will the proposed research activities adequately answer the secondary questions listed in Table 2 for the Water Acquisition stage of the water lifecycle? Please provide any suggestions for additional research activities.

Charge Question 4(b): Proposed Research Activities - Chemical Mixing

> Proposed research activities are provided for each stage of the water lifecycle and summarized in Figure 9. Will the proposed research activities adequately answer the secondary questions listed in Table 2 for the Chemical Mixing stage of the water lifecycle? Please provide any suggestions for additional research activities.

Charge Question 4(c): Proposed Research Activities - Well Injection

Proposed research activities are provided for each stage of the water lifecycle and summarized in Figure 9. Will the proposed research activities adequately answer the secondary questions listed in Table 2 for the Well Injection stage of the water lifecycle? Please provide any suggestions for additional research activities.

Charge Question 4(d): Proposed Research Activities - Flowback and Produced Water

Proposed research activities are provided for each stage of the water lifecycle and summarized in Figure 9. Will the proposed research activities adequately answer the secondary questions listed in Table 2 for the Flowback and Produced Water stage of the water lifecycle? Please provide any suggestions for additional research activities.

Charge Question 4(e): Proposed Research Activities - Wastewater Treatment and Waste Disposal

Proposed research activities are provided for each stage of the water lifecycle and summarized in Figure 9. Will the proposed research activities adequately answer the secondary questions listed in Table 2 for the Wastewater Treatment and Waste Disposal stage of the water lifecycle? Please provide any suggestions for additional research activities.

Charge Question 5: Research Outcomes

If EPA conducts the proposed research, will we be able to:

a. Identify the key impacts, if any, of hydraulic fracturing on drinking water resources; and
b. Provide relevant information on the toxicity and possible exposure pathways of chemicals associated with hydraulic fracturing?

RESPONSE TO THE CHARGE QUESTIONS

Water Use in Hydraulic Fracturing

Charge Question 1: EPA has used the water lifecycle shown in Figure 7 to characterize hydraulic fracturing and to identify the potential drinking water issues. Please comment on the appropriateness of this framework for the study plan. Within the context of the water lifecycle, does the study plan adequately identify and address the areas of concern?

3.1.1. General Comments

EPA has developed a Study Plan that identifies a set of proposed research activities associated with each stage of the hydraulic fracturing water lifecycle, from water acquisition through the mixing of chemicals and actual fracturing to post-fracturing production, including the management of flowback and produced water and ultimate treatment and disposal.

In general, the SAB concludes that EPA's use of the water lifecycle depicted in Figure 7 (see Appendix C) of the draft study plan is an appropriate framework to characterize hydraulic fracturing and to identify the potential drinking water issues, and adequately identifies and addresses the areas of concern identified for each stage of the hydraulic fracturing water lifecycle. However, the SAB finds that the diagram is incomplete, and has several recommendations to strengthen the framework and provide an improved assessment of potential drinking water issues.

The SAB recommends that EPA make certain adjustments to the hydraulic fracturing lifecycle framework. EPA should assess water quantity impacts on the local watershed mass balance, and the framework depicted in Figure 7 should link water fluxes associated with hydraulic fracturing to water flows in the surrounding natural hydrological cycle. The water mass balance assessment is a critical effort, and EPA should initially focus the water mass balance assessment towards the case study efforts.

EPA should also add a postclosure/well abandonment phase as a new component to Figure 7, and SAB recommends that EPA separately consider this phase in the Study Plan. SAB recognizes that potential risks for this new component may not be at the same level as potential risks in other phases of the lifecycle. EPA should determine if there is historical evidence to indicate if there are any differences regarding the postclosure/well abandonment phase of hydraulic fracturing wells when compared to the postclosure/well abandonment phase for other types of wells.

EPA should also assess interbasin transfers of post-fracturing produced water in order to identify possible water quality and quantity issues associated with such transfers. In addition, EPA should assess additional sources of water quality impacts beyond those indicated in Figure 9a (see Appendix D).

3.1.2. Specific Comments

The SAB recommends that EPA make certain adjustments to the hydraulic fracturing lifecycle framework. First, EPA's framework depicted in Figure 7 should involve imbedding water fluxes associated with hydraulic fracturing within water flows in the surrounding natural hydrological cycle. To take this broader view, EPA should reformat Figure 7 to put a box around the block diagram that links to the hydrological cycle. Also, within the first block of the framework (i.e., the water acquisition block), EPA should change the wording from 'Water availability' to 'Water availability and environmental flows,' and also change the wording from 'Impact of water withdrawal on water quality' to 'Impact on environmental fluxes and water quality.'

The SAB agrees that assessing the water mass balance for any particular site or collection of sites is an important undertaking and supports EPA's efforts to conduct this analysis. The SAB concludes that EPA should initially focus this water mass balance assessment towards the case study efforts. A critical issue associated with water mass balance is assessing and accounting for the change in hydrologic/environmental flows. When assessing the water balance interconnection between natural flow and flow associated with hydraulic fracturing activities, a large water volume is removed and stored for hydraulic fracturing activities, and EPA should tie that water into the broad hydrological cycle on a regional scale.

In addition, SAB recommends that EPA include feedback loops that assess interbasin transfers of flowback and produced water, in order to identify possible water quality and quantity issues associated with such transfers.

Regarding water quality impacts, SAB concludes that some other sources of impacts beyond those indicated in the Figure 9a (see Appendix D) should be assessed. It is important to recognize that substantial credibility in the impact analysis for individual chemicals will result when complete mass balances (i.e., summations of transfers to air, water, soil, and other media) are assessed. EPA should also consider spatial (e.g., geographic locations of wells and their proximity to nearby drinking water resources) and temporal (e.g., length of time associated with operation of hydraulic fracturing wells within a watershed) issues relevant to assessing cumulative water quality impacts. The SAB recognizes that there are difficulties in incorporating spatial and temporal issues into the water quality impact assessment, but EPA should attempt to provide some boundaries for these issues to assist in determining what future work may be useful.

Research Questions

Charge Question 2: EPA has identified both fundamental and secondary research questions in Table 2. Has EPA identified the correct research questions to address whether or not hydraulic fracturing impacts drinking water resources, and if so, what those potential impacts may be?

3.2.1. General Comments

EPA has identified a comprehensive set of research questions to address the primary mechanisms and pathways that can allow hydraulic fracturing to impact drinking water resources. The questions cover each step of the life cycle of a hydraulic fracturing process that can impact drinking water and are appropriately focused on the unique aspects of hydraulic fracturing that can lead to such impacts. EPA has identified research questions to address whether or not hydraulic fracturing impacts drinking water resources.

As presented by EPA staff at the March 7, 2011 SAB meeting, EPA's budget for the research on HF impacts to drinking water resources is as follows:

Fiscal Year 2010 (Enacted): $1.9 million.
Fiscal Year 2011 (President's Request): $4.4 million.
Fiscal Year 2012 (President's Request): $6.1 million.

EPA's schedule for delivery of research products includes completion of a report of interim research results in 2012. This interim report will contain a synthesis of EPA's research to date and will include results from retrospective case studies and initial results from scenario evaluations. Since certain portions of the work described in the draft Study Plan, including prospective case studies and work performed under EPA's Science to Achieve Results (STAR) program, are longer-term activities that are not likely to be finished by 2012, additional reports of study findings will be published as these long-term activities progress, with a follow-up report on the study in 2014.

EPA's use of retrospective case studies will focus on investigating reported instances of drinking water resource contamination or other impacts in areas where hydraulic fracturing has already occurred. EPA will conduct retrospective case studies at three to five sites across the United States; these studies will use existing data and possibly field sampling, modeling, and/or parallel laboratory investigations to determine the potential relationship between reported impacts and hydraulic fracturing activities. EPA will also conduct prospective case studies that will involve sites where hydraulic fracturing will occur after the research is initiated. These case studies allow sampling and characterization of the site before, during, and after water extraction, drilling, hydraulic fracturing fluid injection, flowback, and gas production. EPA will work with industry and other stakeholders to conduct two to three prospective case studies in different regions of the United States.

The SAB finds that the Study Plan provides inadequate detail on how to address the overall research questions presented in Table 2 (see Appendix B) and discussed within the draft Study Plan, and that EPA should develop more specific research questions that could be answered within the budget and time constraints of the project. EPA should conduct a well-focused study so that critical research questions are identified, approaches are designed that will enable answering those questions, and conclusions reached are supported by appropriate analysis. At the same time, EPA's framework should take a broader view with regard to water quantity than depicted in Figure 7 (see Appendix C), and link water fluxes associated with hydraulic fracturing to water flows in the surrounding natural hydrological cycle. The SAB provides recommendations for supplementing and revising the existing questions. These recommendations are designed to recognize explicitly key issues that may not be adequately addressed in the current questions.

SAB provides comments that may affect the primary and secondary research questions and how they are answered at each life cycle stage. To the extent that the Study Plan is being designed to inform decision-making related to an EPA regulatory framework, the Study Plan should include specific research questions aimed at this objective. An important challenge facing the study is the diverse nature of hydraulic fracturing operations around the country. The geological setting, the hydrological setting, the community setting and the requirements and standard operating procedures at each stage of the hydraulic fracturing life cycle vary across the country. These differences can give rise to fundamental differences in the nature of the potential impacts to drinking water resources. For example, the limited availability of reinjection wells in the Marcellus Shale region gives rise to a completely different set of potential impacts to drinking water than in areas where reinjection of produced waters is routine.

EPA proposes to conduct scenario evaluations that will assess the environmental futures and impacts of hydraulic fracturing operations at various spatial and temporal scales in the selected case study areas. The scenarios will include at least two futures: (1) average annual conditions in 10 years based on the full exploitation of non-conventional natural gas and (2) average annual conditions in 10 years based on sustainable water use in hydraulic fracturing operations. The SAB finds that the scenario evaluation does not, but should, cross all research questions. See further discussion on this topic under this Report's response to Charge Question 3. The specific objectives of case studies are unclear and should be clarified. As the study moves forward, it is important for EPA to explain the rationale for the selected case studies.

SAB recommends that EPA clarify whether the research focus is on hydraulic fracturing in shale gas production, conventional natural gas production, coal bed methane production, or other types of hydraulic fracturing activity. SAB is not suggesting that studies be limited to particular type of activity; rather, EPA should be careful with the realm of inference drawn in the report to different activities (i.e., results should not be generalized across all types of HF activity).

The Study Plan should address the cumulative consequences of carrying out multiple HF operations in a single watershed or region. While the Study Plan includes proposed research activities in the context of water acquisition, considering the cumulative impacts of large water withdrawals, the panel notes that there are many other aspects to understanding cumulative effects of the hydraulic fracturing process. For example, considering the role of disturbing and revegetating many acres of land, the presence of multiple well pads on the landscape, and how these changes to the landscape in turn affect the water budget and downstream water quality. While detailed research on cumulative impacts may be beyond the scope of the current study, the incremental impacts of hydraulic fracturing operations should be well characterized in the current study and a framework for assessment of cumulative impacts should be established. This will provide the foundation for subsequent assessment of total environmental exposures and risks, and cumulative impacts.

SAB recommends that EPA conduct research in a few additional areas. EPA should assess the capacity of microseismic data to provide detailed information about extent of fracturing and to assist in the hydraulic fracturing modeling (see discussion under Charge Question 4c). In addition, potential impacts to drinking water may be the result of the hydraulic fracturing process or the result of the manner in which it is implemented (e.g., the particular manner in which site preparation and drilling are conducted). In retrospective case studies there is concern that it may not be possible to obtain sufficient data to separate risks that may be associated with the various management practices employed.

The SAB recommends EPA include both prospective and retrospective case studies as planned because the studies address different questions and perspectives. In retrospective case studies there is concern that it may not be possible to obtain sufficient data to separate risks that may be associated with the various management practices employed.

In prospective case studies there is concern that the best management practices examined in these case studies will not necessarily be used at other sites, and that the water quality parameters that are analyzed before, during, and after injection of the HF fluids will probably undergo minimal change during the relatively short duration of the research program. Also, the number of retrospective and prospective case studies that can be evaluated in the given time will be limited, which will make it difficult to generalize from the data gathered. The SAB recommends that EPA take a long view, and consider what kind of data will be desired in ten years in order to design the data collection protocols for the prospective studies. Further, the SAB notes that the selected case study locations must be chosen based on reasonable, mechanistically possible contamination scenarios, incorporating uncertainty.

An additional issue is that EPA needs to view the environmental concerns and issues in the context of the local community outcomes should be identified by EPA for environmental justice issues. As noted in Section 9 of the Study Plan, to address these concerns, EPA plans to combine the data collected on the locations of well sites within the United States with demographic information, such as race, color, national origin, and income, to screen whether hydraulic fracturing disproportionately impacts some citizens and to identify areas for further study. The SAB concludes this would effectively inform environmental justice discussions. The SAB recommends that EPA develop one or more specific research outcomes related to the planned research pertaining to environmental justice issues. For the case studies, EPA should also assess demographic information, such as race, color, national origin, and income, to screen whether hydraulic fracturing disproportionately impacts some citizens near sites used for the case studies (e.g., identify whether more HF wells are near communities with lower incomes). Also, EPA should conduct systematic interviews with local public health officers to identify potentially vulnerable subpopulations, the consideration of fairness in local decision-making, and the impacts of current operations associated with HF operations at case study locations.

Another issue is the importance of assessing uncertainty at each step in the research study. Given time and resource constraints, the studies will not be able to answer all questions with a high degree of certainty. The SAB recommends that EPA explicitly identify or estimate the uncertainty or confidence in all research conclusions, and in the assessment of cause and effect associated with potential HF impacts to drinking water supplies. The quality of the information on which the research was based as well as any uncertainties arising in the conduct of the research should be evaluated, at least in a preliminary manner. This is particularly true for case studies and evaluations of current practices in that it is expected that these portions of the research will be based upon grey literature sources that have not been peer reviewed or subject to the same quality constraints that will govern the proposed studies. The need to collect proprietary information may limit the quality of the research product.

The SAB has a number of specific concerns noted below associated with the research questions at individual lifecycle stages. Additional specific comments on each of the lifecycle stages are included within this report's responses to Charge Questions 4(a) through 4(e).

3.2.2. Specific Comments

Water acquisition

The potential impacts associated with water acquisition are clearly related to the volume of water required and the availability and quality of such water to the community impacted. EPA should assess the volume of water in context with the needs and availability of water to the surrounding community, and a series of secondary questions should be added to reflect this. For example: What are the depths of functional groundwater wells in the area of hydraulic fracturing and what is the potential relationship between these wells and hydraulic fracturing activities both on the surface and below ground?

The Study Plan proposes a sustainability analysis that will reflect minimum river flow requirements and aquifer drawdown for drought, average, and wet precipitation years. Minimum river flow requirements need to be determined as suggested, but also, more importantly, "What are the environmental flow requirements?" Minimum flows and environmental flows are quite different concepts. Environmental flow refers to the amount of water needed in a watercourse to maintain healthy ecosystems. Minimum flow is a level below which the amount of flow in a specified watercourse should not drop at a given time. This term is also used in law to denote water which is expressly dedicated to remain in the stream channel which should not be diverted for other purposes. These flow requirements should be determined based on hydrological processes in the region where hydraulic fracturing is being practiced.

The Study Plan also emphasizes the relationship between water acquisition (related to availability) and water quality. Additional questions should relate this relationship to different sources of water. For example: How different will impacts of water withdrawal be on different water sources, e.g., different stream types (perennial and intermittent) and lakes, and their water quality based on their different base geology?

The draft Study Plan should recognize the differences between acquiring low quality water that is not considered a valuable resource to the community as opposed to displacing agricultural or drinking water that could be used by the community. This is an area where the cumulative impacts of well field development as opposed to single well impacts will be important. For example, a secondary question addressing this might be: What are the cumulative effects of water acquisition for multiple well sites relative to the effects of one or limited well sites?

Chemical mixing

The fundamental question in this area is focused on accidental releases during the mixing process. The secondary questions appropriately emphasize the importance of the composition and potential toxicity of the fracturing fluids. Similarly, the total volumes and the physical and chemical properties of the constituents must be identified to address potential impacts at subsequent life cycle stages. The total quantities and physical and chemical properties can also be useful in subsequent evaluations of other issues not within the scope of the present study, for example, air emissions from the chemical mixing operations. The SAB recommends that the secondary question be expanded to explicitly recognize the need for information regarding volumes and physical and chemical properties of the mixing components.

The potential toxicity of the fracturing fluids will likely be addressed primarily through literature sources. The SAB strongly discourages using any of EPA's limited resources for toxicity studies of chemical constituents. SAB recommends that EPA explicitly recognize this in the framing of the secondary questions.

EPA should assess the likelihood of releases during chemical mixing and the relationship of the frequency and volume of releases to best management practices to the extent possible. SAB recommends that EPA add an explicit secondary question to address this need. For example: Have different practices for chemical mixing resulted in different frequencies of spills and different volumes of spills when they occur?

Well injection

This stage of the life cycle of hydraulic fracturing should be explicitly separated into well construction and well completion. Drilling and cementing are construction activities whereas fracturing is considered a completion activity. Well construction may lead to impacts on drinking water resources and any weaknesses or failures in construction will lead to subsequent problems during completion activities and/or operations. Well construction could be considered another life-cycle stage for hydraulic fracturing so that the potential impacts to drinking water resources could be addressed by specific research questions. Since subsequent well-bore failure is likely associated with problems during construction, a secondary question focused on the ability to detect and correct well-bore construction problems prior to or during injection may be appropriate. A secondary question on the influence of management practices, such as cementing casings all the way to the surface, should also be included. For example: What have been the management practices relative to cementing casings and what has been the history of failure of different practices? Re-fracturing a formation may put additional stresses on a well, particularly if re-fracturing is conducted years after initial construction. It may not be possible to address this in the proposed study, but any existing evidence of this practice as a possible mechanism for drinking water impacts should be reviewed.

The remaining secondary questions are appropriate for the well injection and operation portion of the life cycle. The secondary questions should explicitly recognize, however, that the fate and transport of substances of concern includes not only substances introduced by the fracturing fluids but other substances that might be mobilized or rendered more toxic by the introduction of the fracturing fluid. For example, will changes in redox conditions in the subsurface due to fracturing fluid injection lead to redox changes and mobilization of metals such as arsenic, selenium and chromium or encourage/discourage specific metabolic processes?

The volume and depth of injection relative to subsurface drinking water resources is an important factor in the potential impact of the injection of fracturing fluids. As indicated previously, placing these quantities in context (cumulative impacts of adjacent wells, differences in geology and water availability, quality and location) is difficult given time and resource constraints, but the study should attempt to do so to the extent possible. A specific factor in some areas that may influence injection behavior is the presence of unplugged abandoned wells. A secondary question is recommended that explicitly recognizes the need to place results in the context of the local geology and history. For example: What is the relationship between well injection depths and impacts of injection fluids, considering local geology and historic use as evidenced, for example, by unplugged wells?

Since hydraulic fracturing occurs in the deep subsurface environment where it is difficult to assess effects on ground water resources, the operation and injection life cycle of a hydraulically fractured well has significant uncertainties. This lifecycle analysis is a critical component of the proposed study.

Flowback and produced water

The SAB concludes that the draft Study Plan's secondary questions in this lifecycle stage correctly emphasize the importance of the composition of post-fracturing produced water and its variability. How the composition of the flowback and produced water may vary as a function of management practices and local geology is important but difficult to assess given time and resource constraints. EPA should address this question to the extent possible, including an assessment of the uncertainty in the conclusions. A secondary question explicitly identifying this as an area of concern may be appropriate. For example: What factors such as management and local geology can be identified as primary drivers of composition of flowback and produced water, and what is the uncertainty of this determination?

The SAB concludes that given the constraints of time and funding, EPA should attempt to identify the fate of fracturing fluid components that are deemed to be of highest priority that are introduced with the injection. A specific secondary question that asks "What fraction of the injected components are returned to the surface and what is the likely fate of any components not returned to the surface?" may be appropriate.

As with chemical mixing, EPA should identify the cause and likelihood of spills or releases of flowback or produced water, as well as management practices that reduce their likelihood or mitigate their impact. It may be appropriate for EPA to expand the existing secondary questions to explicitly identify the need for identifying the likelihood of spills or releases and the effectiveness of mitigation practices.

Wastewater treatment and disposal

The form and potential impacts of wastewater treatment and disposal vary significantly with local conditions and practices. The lack of available reinjection wells in the Marcellus Shale area creates substantially greater concern for wastewater treatment practices in this area. EPA should explicitly identify these variations across the country and include a secondary question that recognizes the need to assess these variations. For example: How does the potential for reinjection vary across the country and across geological formations where hydraulic fracturing is practiced?

Specific issues associated with wastewater treatment are not currently identified in the secondary questions. Inorganic species such as bromide and radionuclides, as well as bulk parameters such as salinity, for which conventional wastewater treatment is largely ineffective, are of major concern. The presence of these constituents has also led to concerns about potential ecological effects and effects on drinking water treatment downstream (e.g., formation of brominated disinfection by-products). The SAB recommends that EPA add a secondary question focusing on these contaminants of concern. For example: What is the potential for species for which conventional wastewater treatment is largely ineffective (e.g., salinity, bromide, radioactive inorganics) to enter drinking water resources downstream from industrial wastewater treatment facilities?

Postclosure/well abandonment

The SAB recommends that EPA add a postclosure/well abandonment phase as a new component to Figure 7, and separately consider this phase in the Study Plan. SAB recognizes that potential risks for this new component may not be at the same level as potential risks in other phases of the lifecycle. EPA should determine if there is historical evidence to indicate if there are any differences regarding the postclosure/well abandonment phase of hydraulic fracturing wells when compared to the postclosure/well abandonment phase for other types of wells.

In addition, SAB recommends that EPA consider adding the following drinking water issues, primary research questions, and secondary research questions to the second stage in Table 2 (see Appendix B) of the draft Study Plan relative to the suggested “post closure and well abandonment” life cycle stage:

Drinking Water Issues:

- Long-term water quality impacts to water quality of primary aquifers and secondary aquifer water resources.

Primary Questions:

- What is the long-term mechanical integrity of wells that have been hydraulically fractured?
- What monitoring schedule and types of monitoring are needed to better understand long-term integrity?

Secondary Questions:

- What field techniques are needed to assess long-term integrity of hydraulically fractured wells to ensure long-term mechanical integrity, particularly for casing and cementing?
- What modeling techniques are needed to predict integrity over long time horizons relative to material fatigue, seismic activity, and rock mechanics?

The SAB recommends that EPA consider the use of a risk assessment framework analysis (i.e., hazard identification, exposure assessment, dose-response assessment, and risk characterization) to assess and prioritize research activities for the lifecycle stages associated with hydraulic fracturing.

The SAB concludes it will be difficult for EPA to identify comprehensively the toxicity of chemical additives, apply tools to prioritize data gaps, and identify chemicals for further assessment. The SAB does not agree that it will be possible for EPA to collect and evaluate new data on human toxicity of HF chemical additives given the cost and time constraints of the current project. Therefore, SAB strongly recommends that none of the proposed toxicity testing of chemical constituents be conducted at this time.

At this time, EPA should focus on hazard identification and potential human exposure for the components of HF fluids in the current research effort. The SAB anticipates that an important opportunity for human health exposure is likely to be through exposure to liquids that are brought back to the surface during hydraulic fracturing operations, such as during surface water management of post-fracturing produced waters and during disposal of treated wastewater. In addition, since groundwater can potentially be contaminated by HF in a number of ways (including leakage from liquid storage areas; leakage from the injection wells; leakoff during hydraulic fracturing potentially along faults or up abandoned wells; seepage into the ground if hydraulic-fracturing associated wastewaters or residuals from treatment of these wastewaters are land applied; facilitated transport for natural gas; and other means), potential groundwater contamination is another important opportunity for human health exposure. EPA will be obtaining information as the study progresses and should use its expertise to set priorities for these and other pathways as needed. EPA should evaluate the toxicity of selected constituents determined to have a high potential for exposure for which toxicity is unknown through literature sources and available databases. The SAB recommends that EPA explicitly recognize this in the framing of the secondary questions.

EPA should collect and review pre-existing data on toxicity of HF additives, and conduct a limited effort to estimate toxicity (such as through toxicity estimates using quantitative structure-activity relationships, or QSARs, for HF additives for which no pre-existing toxicity data exist and a high potential for exposure is likely). The review of existing data and of the QSARs should be used to identify chemicals for further assessment.

The SAB finds the development of potential chemical indicators of contamination associated with hydraulic fracturing an appealing approach. However, SAB concludes that it may be difficult to achieve a practical indicator approach or identify a set of such contamination indicators within the time allotted for the study. The EPA can likely develop a list of possible indicators for which analytical methods exist that can be tested in the prospective case studies and scenario modeling. Tracers that can be added might be another tactic to consider but must take into consideration public and industry concerns about such an approach. SAB finds that EPA's consideration of inorganic salts and organic HF additives (for which analytical methods already exist) as contamination indicators can adequately support the research outcome related to toxicity assessment.

The SAB also recommends that development of analytical methods for specific constituents that do not have existing EPA-approved methods should be given a low priority due to cost and time constraints. The EPA should focus on existing methods for the near term effort and develop a list of priorities for future efforts based on the first-order hazard assessment.

Two other potential products of this research activity are to prioritize a list of chemicals requiring further toxicity study and to develop Provisional Peer-Reviewed Toxicity Values (PPRTVs) for chemicals of concern. The SAB also recommends that these activities have a low priority if exposure to a substance is not likely and/or levels of exposure are minimal (e.g., parts per trillion). For prioritizing chemicals for further study, EPA should review the process it used to develop its most recent Contaminant Candidate List (CCL) and apply any lessons learned. Toxicity testing of hydraulic fracturing fluids could perhaps be separately conducted as a long term research study, potentially through EPA's Science to Achieve Results (STAR) program, or through a CRADA (Cooperative Research and Development Agreement) with industry. EPA could develop a prioritized list of components requiring future studies relating to toxicity and human health effects. Scenario modeling may be useful in developing the list of priorities for future toxicity testing.

Research Approach

> *Charge Question 3: The approach for the proposed research is briefly described in Chapter 5. Please provide any recommendations for conducting the research outlined in this study plan, particularly with respect to the case studies. Have the necessary tools (i.e., existing data analysis, field monitoring, laboratory experiments, and modeling) been identified? Please comment on any additional key literature that should be included to ensure a comprehensive understanding of the trends in the hydraulic fracturing process.*

3.3.1. General Comments

EPA's research approach involves application of a broad range of scientific expertise in environmental and petroleum engineering, ground water hydrology, fate and transport modeling, and toxicology, as well as many other areas, and use of case studies and generalized scenario evaluations, to address the key questions associated with each of the five water cycle stages of hydraulic fracturing.

The SAB concludes that EPA has identified the necessary tools in its overall research approach as outlined in the Study Plan to adequately assess potential impacts of hydraulic fracturing on drinking water resources. However, the SAB provides several recommendations for improving the tools that have been identified and also offers recommendations for additional focused analyses. The SAB concludes that the Study Plan provides limited detail on anticipated data analysis, management, and storage (including model simulation results), and recommends that the Study Plan include such details. The SAB recommends that EPA consider using existing data analysis methods rather than developing new methods due to time and budget constraints. EPA should also carefully consider the quality of various types of data that would be used within the analysis (industry data, local and non-industry data). It is imperative for EPA to set a standard for use of data and prior research information that will support the present research effort. The SAB notes that while anecdotal information and publications that have not been peer reviewed may provide useful data, EPA should classify the data as such. Since the scientific value of grey literature can be uncertain, EPA should appropriately qualify any use of such literature within the draft report. As much as possible, peer reviewed information should be employed and complete citations should be provided for that information. The SAB also recommends that EPA consider archiving samples for later use.

The SAB finds that the Study Plan generally overemphasizes case studies in the study approach, and underemphasizes the review and analysis of existing data and the use of scenario analysis. However, the SAB recognizes that case studies will likely provide accurate information on hydraulic fracturing fluids and well operations, although difficulties associated with collecting proprietary information may limit the quality of the research product. The SAB agrees there is significant value to the synthesis of existing data, and that EPA should review all available data sources to learn from what is already known about the relationship of hydraulic fracturing and drinking water resources. The SAB also provides citations for additional literature that EPA should assess to ensure a comprehensive understanding of the trends in the hydraulic fracturing process and the potential impacts of hydraulic fracturing on drinking water resources.

3.3.2. Specific Comments

In addition to the general comments provided above, the SAB specifically considered issues of research approach including: partnering, the value of the case studies, the role of scenario evaluation, the analysis of existing data, and the methods described for the research. The SAB's recommendations for each of these topics are provided below.

Partnering

Table A2 lists a significant EPA role in the research and some collaborators within the federal agencies (U.S. Department of Energy National Energy Technology Laboratory, NETL, and U.S. Geological Survey, USGS). Table F1 includes extensive collaborators for the case study work. However, it is not clear what data may be available from collaborators involved in the analysis of existing data, as well as the extent of the existing data, the laboratory studies or the scenario development and analysis. While EPA has extensive expertise and the timeline is short on this study, the SAB recommends EPA consider expanding the research team to include researchers with experience in this area of investigation (especially those with experience in well construction and fracturing operations).

Case Studies

The SAB generally agrees that the case study approach would be a useful endeavor, since case studies could potentially provide high quality data from specific hydraulic fracturing sites related to the core research questions to be answered. However, the draft Study Plan does not provide adequate justification for the purpose of the case studies, link the expected results to the specific research questions, or explain how models will be integrated among the different research components. Thus, there was insufficient information to evaluate the likelihood of success from this research approach. The SAB recommends that Table 1 be revised to include an additional column indicating how case studies link to research questions.

There is concern that the number of case studies planned might be insufficient to span the range of geological and hydrological regimes where drilling is active or anticipated. There is concern that the case studies will ultimately be too limited in scope for results to be applied generally. Thus, the Panel discussed the total number of case studies needed to yield useful data for the research program, and whether a statistically acceptable number of case studies could be undertaken to meet the research objectives. The SAB did not reach consensus on this point because the specific objectives of these case studies are unclear. As the study moves forward, it is important for EPA to explain the rationale for the selected case studies.

The retrospective case studies described include three to five sites where possible drinking water contamination was observed related to hydraulic fracturing. All the sites described are in small geographic areas and represent potential groundwater contamination. No case study deals with the potential effects of large scale, basin-wide disposal practices on drinking water resources. The SAB recommends that EPA conduct at least one case study with this larger watershed-scale focus. The SAB specifically recommends that EPA consider conducting a case study in the Ohio River Basin of Southwestern Pennsylvania, since this is a location where such watershed-scale drinking water impacts are suspected.

The prospective case studies appear to be at small geographic scale and, similar to the retrospective case studies and, do not incorporate a watershed level approach. The SAB expresses concern that the prospective case studies do not have clearly defined boundaries. For example, it is unclear if waste disposal will be incorporated in the case studies. The SAB recommends a full life cycle approach, as EPA has proposed for this project, be applied to the prospective case studies, where life cycle includes the acquisition of water through to disposal of wastewater across multiple potential options. The case study plan describes monitoring, but insufficient detail is provided to assess the suitability of the target chemicals. The SAB recommends that the case study monitoring plan target specific measurements and not be developed as a general plan.

The SAB discussed the relative merit of prospective versus retrospective case studies, especially given the budget constraints. After extensive discussion of the importance of the different components of each type of case study, the Panel concluded that there is value in each. While the difficulties of completing both case study formats within the limits of time and budget was discussed, the SAB recommends EPA include both prospective and retrospective case studies as planned because the studies address different questions and perspectives. The SAB notes that retrospective studies conducted at sites with known environmental and health issues would provide information on sources, fate and transport of releases of hydraulic fracturing contaminants to the environment. The prospective studies will help identify limitations of existing studies and data, what data are needed for future studies, and situations where hydraulic fracturing would be less likely to present significant environmental or health problems. The prospective studies would also provide useful information on water mass balance, well drilling operations, treatment system performance, health and safety issues of chemical mixing, and other issues. The SAB notes that while prospective studies may not provide useful information on long term hydraulic fracturing performance in deep formations, such studies may be helpful and representative for assessing impacts from hydraulic fracturing operations that occur at the surface because techniques for assessing surface environments are much better developed. The SAB recommends that EPA take a long view, and consider what kind of data will be desired in ten years in order to design the data collection protocols for the prospective studies. Further, the SAB notes that the selected case study locations must be chosen based on reasonable, mechanistically possible contamination scenarios, incorporating uncertainty.

Scenario Evaluation

The SAB notes that the scenario evaluation component of the research plan was not as clearly articulated as the case studies. For example, it is unclear how “typical management and engineering practices in representative geological settings” will be selected for scenario generation or how system vulnerability will be incorporated into models. The Panel discussed using scenario evaluations to examine “worst case scenarios” and establish boundaries for subsequent research tasks. For example, if the worst case scenario in a given situation would lead to nondetectable levels of contamination, then monitoring for contaminants in that setting would waste precious resources. If scenario modeling shows that ground water contamination would occur only after a long period of time, then that scenario would use additional scenario modeling rather than monitoring wells to assess potential groundwater contamination. If scenario modeling shows that the greatest potential for contamination occurs only during “start up" operations in a given area, that given area may be a good location for a prospective study with the monitoring designed to coincide with the onset of HF operations.

The SAB notes that the scenario evaluation focus does not cross all research questions (according to the tables in the appendices of the EPA's draft Study Plan). For example, the potential effects of water acquisition on drinking water quality are not included in scenario evaluation. Since that potential effect is also not incorporated extensively in the case studies, the SAB is concerned that it might be neglected. Similarly, no scenario evaluation is proposed for research on flowback and produced water and its disposal. The SAB recommends that modeling to evaluate scenarios be used across all research questions identified. Further, the SAB notes the central role that modeling studies play in designing monitoring, laboratory work and even what is addressed in the case studies. Scenario evaluation can be a unifying driver for the study by integrating the different approaches to focus on a key set of answerable questions.

EPA should assess EPA's 2009 guidance on application of models (U.S. EPA, 2009) to help identify factors that should be assessed when selecting which environmental models to use in the study.

Analysis of Existing Data

Although the draft Study Plan describes analysis of existing data as a key starting point for the research plan, the details of this approach are unclear. Chapter 5 provides only brief details, while Figure 9a (see Appendix D) shows this as a significant part of the draft Study Plan. The SAB agrees there is significant value to the synthesis of existing data, and that EPA should review all available data sources to learn from what is already known about the relationship of hydraulic fracturing and drinking water resources. EPA's 2004 study clearly documented the lack of existing data and thus EPA should identify what new data are available and better articulate applicability of the new data to the research questions. In the response below, SAB provides citations for additional literature that EPA should assess in order to ensure a comprehensive understanding of the trends in the hydraulic fracturing process and the potential impacts of hydraulic fracturing on drinking water resources. The Panel discussed at length the limitations of the small data set that will be generated from the limited number of case studies that will be conducted in the available time and budget. These limitations suggest the analysis of all existing available data will be even more critical to answer the research questions identified. The SAB recommends EPA more carefully consider the nature and extent of existing data in this field, and provide details of the planned analysis of these data. For example, the SAB recommends looking at (1) data on existing source water conditions and the water quantity and quality needed for ecological ("environmental") flows, (2) data on existing well technologies, and (3) data on existing disposal technologies.

Field and Laboratory Methods

Overall the draft Study Plan inadequately describes the field and laboratory methods that will be utilized and thus provides insufficient information to allow full evaluation by the SAB. Field monitoring is not well described, and the laboratory scale experimentation and analysis was only briefly described in the draft Study Plan. The modeling components do not fully address the physical mechanisms that could be encountered, such as density-dependent flows, thermally-induced flows, and surface-water–groundwater interactions. The use of isotopic analysis is mentioned for both gas and water analysis but the SAB concludes that more detail is needed to assess this approach.

In several sections of the Study Plan, EPA recommends the development of separate analytical methods for detecting chemicals associated with hydraulic fracturing events. The SAB concludes that there is insufficient time or resources to develop new analytical methods during this study. The SAB recommends EPA employ known methods and use scenario modeling and mass balances to identify worst case outcomes. It would be helpful if EPA identified conservative or persistent indicator chemicals common to most or all fracturing fluids to narrow the analytical focus.

3.3.3. Additional Literature

Additional literature that EPA should assess to ensure a comprehensive understanding of the trends in the hydraulic fracturing process, and the potential impacts of hydraulic fracturing on drinking water resources, include the following:

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Proposed Research Activities - Water Acquisition

Charge Question 4(a): Proposed research activities are provided for each stage of the water lifecycle and summarized in Figure 9. Will the proposed research activities adequately answer the secondary questions listed in Table 2 for the Water Acquisition stage of the water lifecycle? Please provide any suggestions for additional research activities.

3.4.1. General Comments

To address the research questions listed in Table 2 (see Appendix B) and summarized in Figure 9 (see Appendix D) for the Water Acquisition stage of the water lifecycle, EPA plans to conduct the following activities:

- Conduct retrospective and prospective case studies.
- Analyze and map water quality and quantity data.
- Assess impacts of cumulative water withdrawals.

The SAB finds that the proposed activities will, in general, adequately address the research questions associated with this lifecycle stage as outlined in Table 2. However, the SAB recommends that the draft Study Plan include an additional desired research outcome to collect baseline hydrologic and water quality data in each prospective case study before HF activity begins, so that significant changes in water availability or water quality caused by HF activity can be more readily documented. EPA should develop a "vulnerability index" or a list of criteria that could be used in the future to indicate situations where a water supply is vulnerable to adverse impacts on water quality or quantity, and identify where further evaluation may be warranted.

Further, the SAB recommends that EPA provide more details or broaden the scope of work aimed at understanding the cumulative effects of water withdrawals on water availability. The proposed work uses only scenario analysis and modeling to provide a first approximation of the effects of large water withdrawals. Attention should be given to quantifying the role of this water use on both surface water and groundwater, and to quantify thresholds of change that would lead to transient and permanent effects on water availability. Though the proposed modeling includes scenarios under wet through dry conditions, the use of frequency analysis with data from existing streamflow monitoring stations should be expanded in this context. For example, EPA should use flow duration curves and flood frequency curves to help understand the natural variability in flows. This can help to quantify the role of both the timing and magnitude of small and large water withdrawals in the context of probable hydrological variability. Also, this can be used to highlight the fact that water withdrawals can adversely affect even wetter regions of the country (e.g., Pennsylvania) during periods when rainfall is significantly less than normal.

The SAB recommends that EPA's list of analytes (provided in Table G1 of the draft Study Plan) that would be studied to assess the potential impacts of water acquisition and other hydraulic fracturing activities on water quality should specifically include the following constituents: hydrogen sulfide, ammonium, radon, iron, manganese, arsenic, selenium, total organic carbon, and bromide. In addition, EPA should also assess the potential of constituents in HF-impacted waters to form disinfection by-products (including trihalomethanes, haloacetic acids, other halogenated organic compounds and disinfection by-products formed by other disinfecting agents such as ozone and chloramines) in drinking water treatment.

The SAB recommends that EPA include consideration of HF water quality parameters for which Maximum Contaminant Levels (MCLs) have not been established under the Safe Drinking Water Act, in addition to the proposed parameters for which MCLs have been established. Since MCLs have not been established for some of the chemicals used in the HF process, MCLs alone will not be sufficient for assessing all potentially significant impacts of hydraulic fracturing on drinking water quality. EPA should also examine trends in water quality associated with HF water acquisition and determine whether adverse impacts will result if these trends continue.

The SAB has a number of specific comments noted below associated with this lifecycle stage. Additional specific comments on the research questions for this lifecycle stage are included within this Report's response to Charge Question 2.

Advances in membrane desalination, increasing use of aquifer storage and recovery systems, and regional water shortages are changing perspectives on what constitutes a source of drinking water. The SAB recommends that EPA not automatically exclude from consideration potential impacts on a water source having more than 10,000 mg/L of total dissolved solids if it could reasonably be anticipated to be a viable source of water supply in the future.

3.4.2. Specific Comments

The draft Study Plan does not explicitly address the obstacles private well owners and small public water supply systems (PWSSs) may encounter if they experience adverse impacts on water availability or water quality that they believe are related to HF activities. Unlike larger users, private well owners and small PWSSs will generally lack the financial resources to hire experts to prove that their water resources have been adversely impacted. This problem is related to both management practices and environmental justice (as discussed in Section 9 of the draft Study Plan), and is an issue for anyone whose private well is impacted. The SAB recommends that the draft Study Plan include an additional desired research outcome to develop a recommended protocol for collecting baseline hydrogeologic and water quality data in each prospective study area before HF activity begins, so that significant changes in water availability or water quality caused by HF activity can be more readily documented. EPA should develop a "vulnerability index" or a list of criteria that could be used to indicate situations where a water supply is vulnerable to adverse impacts on water quality or quantity, , and identify where further evaluation may be warranted.

EPA's list of analytes to be considered in studying the potential impacts of water acquisition (and other HF activities) on water quality (Table G1) should explicitly include: 1) hydrogen sulfide, a toxic and corrosive substance that also imparts a strongly offensive odor to air and water, exerts an oxygen demand in streams, and exerts a high oxidant demand (e.g., chlorine demand) when present in a public water supply; 2) ammonium, a compound naturally present in many alluvial aquifers and some deeper formation that exerts a large chlorine demand and is also toxic to many aquatic organisms; 3) radon, a radioactive gas that could potentially be released into drinking water by HF activities; 4) iron, manganese, arsenic, and selenium, constituents that may be mobilized by HF activities, including water withdrawal; and 5) total organic carbon (TOC), bromide and potential disinfection by-product precursors that can form trihalomethanes, haloacetic acids, and other halogenated organic compounds when present in source waters that are treated with chlorine-based disinfectants.

The SAB concludes that since proprietary and/or new chemicals are used in the HF process for which no Maximum Contaminant Levels (MCLs) under the Safe Drinking Water Act have been established, MCLs are not sufficient for assessing all potentially significant impacts on drinking water quality. For example, changes in nutrient or carbon loading to a stream that do not directly cause an MCL to be exceeded can still cause changes in water quality, such as increased production of taste- and odor-causing compounds or disinfection by-product (DBP) precursors, resulting in increased treatment costs or degradation of drinking water quality. An increase in bromide in source waters may cause an increase in cancer risk (if more carcinogenic brominated species are preferentially formed) even if the MCLs for DBPs are not exceeded. A significant increase in the chloride concentration can cause considerable economic loss to a community even if the secondary MCL for TDS of 500 mg/L is not exceeded. Therefore, the SAB recommends that EPA include in its analysis parameters for which MCLs have not been established, in addition to the proposed parameters for which MCLs have been established. EPA should also include potential impacts on water quality that do not involve MCL exceedances.

When assessing the fate and mass balance of potential contaminants associated with hydraulic fracturing operations, EPA should assess the potential release of contaminants to the air, in order to close the mass balance. Such releases, with subsequent deposition to surface water resources, could potentially result in contamination of water supply sources, and thus their magnitude should be estimated to determine if further study is warranted. Further, it is important to note that unhealthy exposures can result from breathing air containing chemicals volatilized from potable water (such as in the shower), as well as through consumption and potentially other exposure routes. These indoor air exposures associated with potable water are within the scope of traditional drinking water research and should be considered.

EPA should also examine trends in water quality associated with HF water acquisition and determine whether adverse impacts will result if these trends continue, e.g., if HF water acquisition activities continue to increase in the area up to the maximum level that can be reasonably expected.

The draft Study Plan states (p. 1) notes that for EPA's study, EPA defines "drinking water resources" to be any body of water, ground or surface, that could currently, or in the future, produce an appropriate quantity and flow rate of water to serve as a source of drinking water for public or private water supplies. This includes both underground sources of drinking water (USDWs) and surface waters. USDWs are defined in the glossary as aquifers capable of supplying a public water system and having a TDS concentration of 10,000 mg/L or less. It is reasonable to consider very deep, highly saline aquifers isolated from drinking water resources as potential sites for waste injection, but shallower brackish waters are increasingly being considered as potential sources of supply, especially in more arid areas of the U.S. Due to advances in membrane desalination, even seawater is now considered as a potential source of water supply, as exemplified by the membrane desalination plant operated by Tampa Bay Water and similar plants being planned or designed in California, Texas, and other locations . Furthermore, some relatively saline aquifers may be suitable for use in future "aquifer storage and recovery" operations. The SAB recommends that EPA not automatically exclude from consideration potential impacts on a water source having more than 10,000 mg/L of total dissolved solids if it could reasonably be anticipated to be a viable source of water supply in the future. The SAB is not proposing that EPA expand the scope of the study to intentionally look for opportunities to evaluate such cases.

Proposed Research Activities - Chemical Mixing

> *Charge Question 4(b): Proposed research activities are provided for each stage of the water lifecycle and summarized in Figure 9. Will the proposed research activities adequately answer the secondary questions listed in Table 2 for the Chemical Mixing stage of the water lifecycle? Please provide any suggestions for additional research activities.*

3.5.1. General Comments

To address the research questions listed in Table 2 (see Appendix B) and summarized in Figure 9 (see Appendix D) for the Chemical Mixing stage of the water lifecycle, EPA plans to conduct the following activities:

- Conduct retrospective and prospective case studies.
- Compile a list of chemicals used in HF fluids.
- Identify possible chemical indicators and analytical methods.
- Develop additional analytical methods.
- Review scientific literature on surface chemical spills.
- Identify known toxicity of HF chemicals.
- Predict toxicity of unknown chemicals
- Develop Provisional Peer-Reviewed Toxicity Values (PPRTVs) for chemicals of concern.

The SAB concludes that, overall, EPA has generally proposed a sound approach to address the research questions associated with this lifecycle stage as outlined in Table 2. The SAB has some recommendations for specific components of the research plan that could be strengthened as described further below.

The SAB supports EPA's proposed approach to analyze existing data rather than collecting samples for analysis to assess HF fluid composition and toxicity of fluid components, and agrees that EPA's effort to gather data from nine hydraulic fracturing service companies will likely provide sufficient information on the composition of HF fluids. Appendix C of the Draft Plan indicated that all companies have agreed to comply with the request and that information would be submitted by January 2011. Nearly all the information received by EPA was designated as confidential business information (CBI). EPA is currently reviewing the CBI claims. Information that was not claimed to be CBI has been made available to the public in the EPA Docket, at the following website address: http://www.regulations.gov, and the docket number is: EPA-HQ-ORD-2010-0674. SAB recommends that EPA also gather HF fluid composition data from states collecting such data, and consider the role that recycling and reuse of HF fluids will play in influencing both quantity and composition of HF fluids.

Specific comments on exposure analyses, hazard identification , toxicity testing, analytical methods, and indicators of contamination are included within this Report's response to Charge Question 2. The SAB finds that EPA should give low priority to development of analytical methods for specific components for which there are no existing EPA-approved methods due to time and budget limitations.

The SAB generally supports EPA's plans to identify factors that influence the likelihood of contamination of drinking water resources as a result of chemical mixing activities. Although SAB agrees that EPA will identify a number of factors that influence the likelihood of contamination of drinking water resources as a result of chemical mixing activities, the list of factors may not be complete, the project time and budget may not allow time for a complete evaluation of the factors, and the results should not be generalized across all HF sites.

The SAB does not agree that case studies alone will provide sufficient information regarding effectiveness of mitigation approaches in reducing impacts to drinking water resources. SAB recommends that EPA analyze data from HF service companies and states in order to provide additional insight. The retrospective case studies may also be a source of useful information about approaches that failed to prevent or control impacts.

The SAB has a number of specific comments noted below associated with this lifecycle stage. Additional specific comments on the research questions for this lifecycle stage are included within this Report's response to Charge Question 2.

3.5.2. Specific Comments

<u>What is the composition of hydraulic fluids and what are the toxic effects of these constituents?</u>

The draft Study Plan indicated that the approach to be used in answering the question about composition of HF fluids and toxicity of the components will be to analyze existing data. The SAB agrees that EPA's effort to gather data from nine hydraulic fracturing service companies is an approach that is likely to answer the question on composition of HF fluids. The SAB supports the analysis of existing data rather than reverse engineering of collected samples of fluids in order to assess HF fluid composition and toxicity of fluid components. Given the size of the companies and their geographic coverage, a comprehensive list of the composition of HF fluids is anticipated. The level of detail requested should provide the EPA with data adequate to answer the question. The SAB notes that a few states are collecting relevant data either as a requirement of permitting (e.g., Wyoming) or on a voluntary basis (e.g., Pennsylvania) that can be of use to the EPA for this question. The SAB also recommends that EPA consider the role that recycling and reuse of HF fluids will play in composition. SAB recommends that EPA consider assessing how to reduce the potential adverse effects of additive chemicals, and options to encourage development of 'greener' HF additives and HF methods, perhaps through partnership with the U.S. Department of Energy (DOE).

Specific comments on hazard identification, exposure assessment, toxicity testing, analytical methods, and indicators of contamination are included within this Report's response to Charge Question 2. The SAB finds the development of potential chemical indicators of contamination an appealing approach. The consensus of the SAB is that it may be difficult to achieve a practical indicator approach within the time allotted for the study. The EPA can likely develop a list of possible indicators for which analytical methods exist that can be tested in the prospective case studies and scenario modeling. Tracers that can be added might be another tactic to consider but must take into consideration public and industry concerns about such an approach.

The SAB also recommends that development of analytical methods for specific components for which there are no existing EPA-approved methods should be given a low priority due to cost and time constraints. The EPA should focus on existing methods for the near term effort and develop a list of priorities for future efforts based on the first-order hazard assessment.

The U.S. House of Representatives Committee on Energy and Commerce Minority Staff provided a recent document (U.S. House of Representatives, 2011) on 'Chemicals used in Hydraulic Fracturing' which lists a large number of chemicals used in HF fluid reported by a number of drilling companies.

This report indicates that companies using these fluids purchase them from third party suppliers and the proprietary information belongs to those suppliers, and may provide important detailed information about chemical constituents of HF fluids. .

In addition, the Ground Water Protection Council (GWPC) and the Interstate Oil and Gas Compact Commission (IOGCC), with funding support from the DOE, unveiled a web-based national registry on April 11, 2011, disclosing the chemical additives used in the hydraulic fracturing process on a well-by-well basis (www.fracfocus.org). EPA should assess these data when assessing the composition and toxicity of HF fluids. The information on the web site covers wells drilled starting in 2011. A fact sheet on the effort is available from the State of Oklahoma (http://www.iogcc.state.ok.us/national-registry-provides-public-and-regulators-access-to-information-on-chemical-additiv).

What factors may influence the likelihood of contamination of drinking water resources?

The SAB concludes that the EPA will be able to identify a number of factors that influence the likelihood of contamination of drinking water resources as a result of chemical mixing activities, but the list of factors may not be complete and should not be generalized across all HF sites. The EPA indicated that it will analyze existing data and use the retrospective case studies to answer this question. The SAB expresses support in general for the planned approach to answering this question. The information request to the nine HF services companies will likely provide input on some of the factors (e.g., total quantities used, chemical and physical properties of components, etc.). The EPA will also search the existing literature for research about potential contamination of drinking water resources using the list of chemicals supplied through the information request. The states may provide information about the spills that may have affected drinking water resources. The SAB supports EPA's plan to develop a list of the knowledge gaps about factors influencing the contamination of drinking water resources as a result of chemical mixing activities for future research efforts. The SAB is concerned that several factors will be site specific and difficult to generalize across the range of geographical areas that are involved in HF activities. The SAB recommends that the EPA will need a full understanding of all the activities involved such as the cleaning of mixing vessels or tanker trucks and handling of the wash water. The SAB notes that the prospective case studies are potentially useful in answering this question; however, the SAB also notes that the best management practices examined in these case studies will not necessarily be used at other sites. The number of retrospective and prospective case studies that can be evaluated in the given time will be limited, which will not allow for generalization from the data gathered.

How effective are mitigation approaches in reducing impacts to drinking water resources?

The SAB expresses concern that the prospective case studies alone will not provide adequate answers for this question. The partners involved in the prospective case studies will likely follow best management practices and take extra precautions, the impact of which will be difficult to assess. There is concern that the number of case studies planned might be insufficient to span the range of geological and hydrological regimes where drilling is active or anticipated. There is concern that the case studies may ultimately be too limited in scope for results to be applied generally. Thus, the Panel discussed the total number of case studies needed to yield useful data for the research program, and whether a statistically acceptable number of case studies could or should be undertaken to meet the research objectives. The SAB did not reach consensus on this point because the specific objectives of these case studies are unclear. As the study moves forward, it is important for EPA to explain the rationale for the selected case studies. The analysis of data supplied by the HF service companies and states may be helpful in providing additional insight. The retrospective case studies may be a source of useful information about approaches that failed to reduce impacts. However, overall the SAB is not convinced that this question can be adequately addressed through the Study Plan.

Proposed Research Activities - Well Injection

> *Charge Question 4(c): Proposed research activities are provided for each stage of the water lifecycle and summarized in Figure 9. Will the proposed research activities adequately answer the secondary questions listed in Table 2 for the Well Injection stage of the water lifecycle? Please provide any suggestions for additional research activities.*

3.6.1. General Comments

In order to address the research questions listed in Table 2 (see Appendix B) and summarized in Figure 9 (see Appendix D) for the Well Injection stage of the water lifecycle, EPA plans to conduct the following activities:

- Conduct retrospective and prospective case studies.
- Analyze well files
- Test well failure and existing subsurface pathway scenarios
- Study reactions between HF fluids
- Identify known toxicity of naturally occurring substances
- Predict toxicity of unknown chemicals
- Develop Provisional Peer-Reviewed Toxicity Values (PPRTVs) for chemicals of concern.

The SAB does not agree it will be possible to cover all facets of the proposed research within the time allotted for the research activities and recommends that EPA narrow the scope of activities associated with specific case studies and site investigations and use a wide variety of sources available to EPA in order to increase the success of the research program. With the cooperation of service companies, full access to data, and careful selection of case studies, the SAB concludes that the proposed research can adequately address most of the fundamental questions associated with possible impacts of the injection and fracturing processes on drinking water resources, even with this more narrow scope. The SAB provides a number of specific recommendations for focusing EPA's fundamental and secondary research questions associated with this topic area. The SAB recommends that EPA should research well drilling and cementing practices separately from the hydraulic fracturing process.

The SAB has a number of specific comments noted below associated with this lifecycle stage. Additional specific comments on the research questions for this lifecycle stage are included within this Report's response to Charge Question 2.

3.6.2. Specific Comments

<u>Fundamental Research Question</u>

The fundamental research question addressed under the topic of well injection is "What are the possible impacts of the injection and fracturing process on drinking water resources?" Addressing this fundamental question involves establishing different degrees of risk. There are different risks dependent on different geologic and hydrogeologic conditions requiring a prioritization of research to be conducted. By conducting retrospective and prospective case studies as outlined in the draft Study Plan the various risk factors and their interdependence can be evaluated. While not totally encompassing and thus unable to cover all possible impacts, the research will aid in addressing the fundamental research question pertaining to possible impacts.

As a starting point, the SAB recognizes that there are three escape mechanisms during well injection such that contaminants might affect drinking water: escape through the well, through the cement surrounding the well, and as a result of various steps of the hydraulic fracturing process itself. Assuming drilling and cementing practices for HF wells are not different from practices for other industry wells, the consensus of the Panel is that well drilling and cementing practices be researched separately from the hydraulic fracturing process itself. In doing so, the SAB concludes the EPA can better focus on the question of the potential influence of the hydraulic fracturing process on drinking water resources and contamination of aquifers.

Since groundwater can potentially be contaminated by HF during well injection (including leakage from the injection wells, leakoff during hydraulic fracturing along faults or up abandoned wells), the possibility of exposures through potential groundwater contamination should be assessed. The SAB also recognizes that while discharges to surface water can also lead to exposures, they tend to be transient. Groundwater contamination is more likely to lead to long-term contamination and long-term exposure. In addition, groundwater is preferentially used as a source of supply by smaller utilities and communities (including rural communities) and by the majority of non-community water systems. Many such supplies are only minimally monitored, and their owners often lack the resources for independent protection of the aquifers from which their supplies are drawn. Unlike surface waters, groundwater is susceptible to contamination by methane and radon, and groundwater is more susceptible to contamination by volatile organic contaminants, including the Benzene, Toluene, Ethylbenzene, and Xylenes (BTEX) compounds that have reportedly been used at times to prepare HF fluids or may come from the formation itself. EPA will be obtaining information as the study progresses and should use its expertise to set priorities for these and other pathways as needed.

<u>Secondary Research Questions</u>

Discussion under item 4(c) focused on four secondary research questions:

1) *How effective are well construction practices at containing gases and fluids before, during and after fracturing?*

The SAB concludes that EPA's research activities regarding well construction practice should be split into two categories – the drilling, cementing and completion practices (i.e., well bore integrity during construction) versus the fracturing process itself. Regulatory agencies in some states may have access to data on well bore integrity that can enable the EPA to address specific examples of well bore and well failure. The SAB suspects that the data will be 'spotty', however, and may vary from state to state. The value of 'mining' such data may be in the retrospective case studies to evaluate risk. It will be area and site dependent. In addition, there are thousands of underground injection wells currently that are controlled by the Underground Injection Control Program (UIC) that can shed light on the general topic of well bore and well integrity. The Study Plan should define the data that would be collected to assess well failure and relate relevant factors particularly associated with HF operations into a risk assessment model. The Study Plan should also be specific about how the frequency of well failures will be determined because the method to be used is not obvious in the draft Study Plan. The well architecture itself is shifting away from vertical wells to highly deviated wells with multi-zone completions. EPA may have to specifically focus and direct its research activities based on well type in order to adequately evaluate the effectiveness of well construction practices and the risk of contamination of groundwater resources.

The hydraulic fracturing process needs to be addressed separately. The SAB recommends that EPA conduct research on factors such as depth of the hydraulic fracturing and proximity to underground aquifers, the geology of the subsurface, the hydrogeologic framework, stresses in the subsurface, the fluids and their amendments used in the process, and the interaction with the rock and fluids in the subsurface. By addressing these factors in a systematic manner through the use of case studies, modeling and laboratory analyses, risk assessment modeling may be undertaken to prioritize risk related to the HF process itself.

In the case studies EPA could provide special focus on the key factors necessary in establishing a risk assessment model. A shortcoming of this approach is that typical risk assessments do not include the potential for catastrophic failure (e.g., earth motions competent to break water supply lines). EPA should assess the potential for catastrophic failure within the scenarios assessed within the case studies, since treating end members within a risk assessment model can aid in creating transparency and hazard preparedness. Modeling the hydraulic fracture process through finite difference or finite element mathematical modeling may give insights into criteria for establishing risk.

Finally, EPA should be sure to include case study sites where hydraulic fracturing is being conducted in relatively shallow environments in proximity to drinking water aquifers. Microseismic monitoring, if available, could be used to help create appropriate fracture models. In areas of variable topography, underground mining, or in karst regions within the subsurface, stress variances can induce a variation in fracture growth.

2) *What are the potential impacts of pre-existing artificial or natural pathways/features on contaminant transport?*

The SAB generally agrees that geologic and hydrogeologic characterization is necessary, but notes this is a difficult task to undertake and complete with sufficient detail to inform subsurface transport models especially within the limits on budget and time for the study. The SAB recommends that EPA's first step should be to focus on specific areas where the most complete data on these topics are available. The SAB also recommends that EPA use the resources of other governmental agencies such as the U.S. Geological Survey to address subsurface characterization and to establish analogous injection sites (e.g., carbon dioxide sequestration projects). Site characterization is an essential ingredient of determining the viability of sites to store carbon dioxide. The DOE may be able to provide EPA with information on stresses in the subsurface, which is a significant factor to consider. It is also essential for EPA to establish stress profiles and determine the mechanical stratigraphy and hydrological properties of the case study areas. Generally, the data are available to engage in site characterization as part of the case studies that will be selected and undertaken.

The SAB concludes that a major concern to be addressed is the presence of faults in the subsurface. Not all faults are transmissive in nature, and numerous studies have documented faults as seals or sealing faults. The SAB notes that a key concern is what happens when there is injection near a fault. Generally, it is industry practice to avoid faults by conducting reflection seismic profiling to identify faults. These studies are often conducted for purposes of geosteering to avoid faults and drilling out of zone. However, sub-seismic faults exist, making it difficult to avoid faults altogether. Microseismic monitoring can assist in determining what happens if a hydraulic fracture is conducted near a fault. EPA should gather available seismic profile data to assist in evaluating the potential for releases to underground sources of drinking water. Whether or not the fault is transmissive requires other forms of study including transient pressure testing.

The SAB recommends that EPA identify a shallow site known to have faults as one of the prospective case studies. The SAB expresses concern about fracture fluids propagating in fault and fracture zones. These fluids can occur in gaseous or liquid state and have different mobility and flow characteristics. Mobile gases can move along fault and fractures zones in a relatively short time; liquids will take longer to move than gases. Different fluids create different potential problems and a variety of scenarios needs to be investigated. The SAB recommends that EPA focus additional research on the different fluids associated with the hydraulic fracturing process. The SAB recommends that EPA conduct soil geochemistry studies which may shed light on the question of vapor transport associated with the hydraulic fracturing process.

The SAB recognizes that the use of a chemical tracer may aid the monitoring effort, but notes that the tracer would have to be carefully and judiciously chosen. The tracer design must be unique, unambiguously related to the hydraulic fracturing process, uniquely identifiable, readily measurable at substantial dilutions, non-toxic and non-reactive.

The SAB concludes that long term monitoring is preferred over short term monitoring with respect to monitoring of HF impacts on water resources. The SAB recognizes that EPA may have difficulty in precisely determining cause and effect associations within the monitoring networks, for various reasons. If fractures are only opened during the hydraulic fracturing process, a very short time period for mobilization can occur. In low permeability formations, however, it may take considerable time for pressure to abate. Fluid flow in these low permeability reservoirs is non-Darcy flow involving diffusion. Upon production, pressure drawdown occurs and fractures usually close over time. EPA should assess the seismic conditions that create changes in subsurface geology of the formation (e.g. Marcellus Shale) which are created by the perforated gun-shoot holes through the casing and the application of pressure. Long term monitoring is a key aspect to assuring that these fractures do not cause contamination to groundwater and preferential flow pathways into and for ground water migration and contamination. In addition, abandoned wells and mines are potential primary conduits to near surface aquifers as well as surface waters. The identification of abandoned wells is problematic, and the SAB recommends that EPA assess the role these wells and old mine workings play in certain parts of the country relative to hydraulic fracturing operations.

The SAB encourages EPA to consider expanding its emphasis on hydraulic fracture mapping. There are many local issues tied to formation geology, vertical depth between aquifers and formations being fractured, and the existence of karst formations or naturally occurring regional-fracture systems that may enhance hydrogeologic communication after fracturing is completed. Much work has taken place in the private sector on this. Advances are being made in micro-seismic testing and interpretation, use of tiltimeters, and fracture network mapping and modeling. The SAB recommends that EPA carefully examine this issue as it develops its case studies. EPA should also consider collaborating with DOE and the U.S. Geological Survey to convene workshops on advanced hydrofracture mapping technology development and new technology applications, to help increase the knowledge base on such new geophysical techniques and hydrogeologic testing methods.

3) *What chemical/physical/biological processes could impact the fate and transport of substances in the subsurface?*

The SAB highly recommends that EPA pursue efforts to identify the chemicals used in the hydraulic fracturing process and their chemical and physical properties. Biological processes and the details regarding how the biological impact will be investigated are unclear in the draft Study Plan.

A major concern is the reaction of the injected chemicals within the formations and whether these reactions increase the potential for contamination of water resources in a given area. This information would aid in the determination of risk factors and assist the development of a risk assessment process. The primary composition of the chemicals used in the hydraulic fracturing process and their interaction with the natural compounds in the subsurface need to be addressed in this study. Research should also address the potential transformations of products formed from reactions of HF fluids with formation materials.

The Study Plan implies that this research would only involve laboratory studies. The SAB finds that the results may not be representative of what happens in the field. SAB recommends that analysis of samples collected in conjunction with the case studies be included in answering this question in addition to the laboratory studies. SAB also recommends that modeling be conducted to assist in answering this question, if there are models available that can predict the decomposition products from reactions of HF fluids with formation materials.

4) *What are the toxic effects of naturally occurring substances?*

EPA's proposed research activities can answer the question about the known toxic effects of naturally occurring substances that have been evaluated previously (e.g., radon, hydrogen sulfide, and selenium) by compiling existing toxicity information. As discussed in this Report's response to Charge Question 2, the SAB cautions EPA on spending resources on evaluating the toxicities of substances unless EPA knows that the probability of exposure to a particular substance is high. The SAB also notes that Table 5 is fairly general and does not include radon or ammonia and that Table D2 should be included in the discussion in Section 6.3.5. Specific comments on hazard identification, exposure assessment, toxicity testing, analytical methods, and indicators of contamination are included within this Report's response to Charge Question 2. The SAB also recommends that EPA consider hazard broadly and include risks that these substances may have (explosions) that are not due to toxicity. EPA should also acknowledge importance of any aesthetic impacts that both naturally occurring and well-injection derived substances may have on drinking water quality.

Recommendations for Additional Research Activities

The SAB provides the following recommendations for additional research activities:

1) Conduct a case study involving seismic and groundwater monitoring in a highly stressed area involving faults within 1000 feet of wells undergoing hydraulic fracture treatment. The purpose of this recommendation is to emphasize the complex interplay between natural fractures within a formation and its response to hydraulic fracture treatment. In shales in particular, the stress-dependence of the permeability of natural fractures, as well as the permeability generated by shear fracturing that may develop, are the dominant features that control fluid flow and potential fluid mobility pathways. See Maxwell et al. (2011).

2) Identify and characterize common and best practices for well construction (e.g., casing design, construction under different scenarios, settings, failure rates, life expectancies, and performance of cements under a variety of hydraulic fracturing conditions) and monitoring, and determine whether such practices meet minimum standards from a public water supply perspective. Exploration wells represent permanent establishment of potential means of hydrogeologic communication between formations and aquifers and the incidence of well completion failure, especially around annulus cementing through the aquifer, and such incidences need to be well understood. EPA should gather available information on this topic from the American Petroleum Institute and the National Ground Water Association.

3) Research fluids and fluid movements associated with hydraulic fracturing in terms of mobility. There are gaseous and liquid states, and potentially even "hybrid" states and phases, different flow paths, and different flow mechanisms under different temperature and pressure regimes.

4) Review Tables 5, D2 (needs to be included in section 6.3.5), and D3 for completeness (e.g., radon is not included). In the future, as discussed in specific comments in this Report's response to Charge Question 2, toxicity studies, if exposure is likely, may need to be undertaken.

Proposed Research Activities – Flowback and Produced Water

Charge Question 4(d): Proposed research activities are provided for each stage of the water lifecycle and summarized in Figure 9. Will the proposed research activities adequately answer the secondary questions listed in Table 2 for the Flowback and Produced Water stage of the water lifecycle? Please provide any suggestions for additional research activities.

3.7.1. General Comments

In order to address the research questions listed in Table 2 (see Appendix B) and summarized in Figure 9 (see Appendix D) for the Flowback and Produced Water stage of the water lifecycle, EPA plans to conduct the following activities:

- Conduct retrospective and prospective case studies
- Compile list of chemicals found in flowback and produced water
- Identify or develop analytical methods
- Review scientific literature on surface chemical spills
- Investigate scenarios involving contaminant migration up the well
- Identify known toxicity of HF wastewater constituents
- Predict toxicity of unknown chemicals
- Develop Provisional Peer-Reviewed Toxicity Values (PPRTVs) for chemicals of concern.

The SAB concludes that, overall, EPA has generally proposed a sound approach to address the research questions associated with this lifecycle stage as outlined in Table 2. The SAB has some recommendations for specific components of the research plan that could be strengthened as described further below.

The handling, treatment and disposal of post-fracturing produced water represents an important route of exposure and has potential for adverse widespread impacts. Although sometimes flowback and

produced water are mentioned independently, these distinctions are only operational as there is a continuous evolution of water quality for post-fracturing produced water. To the extent differentiation of flowback and produced water is desired by EPA, the SAB recommends that EPA clearly define flowback and produced water in the main body of the Study Plan.

EPA should gather both currently available information on the composition of post-fracturing produced water from the hydraulic fracturing process, and proprietary information on all additives included in any injected water. The SAB recommends the collection of water quality data before, during, and after injection, and from carefully selected locations, including the ongoing studies on the quality of surface waters in the regions with significant hydraulic fracturing activity. EPA should evaluate quality assurance/quality control (QA/QC) aspects of the studies that would be assessed or conducted by EPA.

Specific comments on hazard identification, exposure assessment, toxicity testing, analytical methods, indicators of contamination, and on the research questions for this lifecycle stage, are included within this Report's response to Charge Question 2. The SAB has a number of specific comments noted below associated with this lifecycle stage.

3.7.2. Specific Comments

The SAB recommends the handling of liquids that are brought back to the surface during hydraulic fracturing operations, such as during surface water management of flowback and produced waters and during disposal of treated wastewater, represents an important route of exposure and has potential for adverse widespread environmental impacts from the development of unconventional gas resources. This is particularly true in situations where Class II Underground Injection Control (UIC) wells are not the main disposal alternative. A lifecycle approach is an important component of this study, and this lifecycle must be correctly characterized. In addition, since groundwater can potentially be contaminated by hydraulic fracturing in a number of ways (including leakage from liquid storage areas; leakage from the injection wells; leakoff during hydrofracking potentially along faults or up abandoned wells; seepage into the ground if hydraulic-fracturing associated wastewaters or residuals from treatment of these wastewaters are land applied; facilitated transport for natural gas; and other means), potential groundwater contamination is another important opportunity for human health exposure. EPA will be obtaining information as the study progresses and should use its expertise to set priorities for these and other pathways as needed.

The SAB agrees with EPA that it is very important to gather information on the composition of flowback and produced water from the hydraulic fracturing process, to the extent these data are currently available. EPA should contact Publicly Owned Treatment Works (POTWs) who accept this water for treatment, accessing the Colorado Oil and Gas Commission database, and assessing ongoing DOE National Energy Technology Laboratory projects, particularly since the sampling and analysis to be conducted as part of this study would be rather limited. Within the human exposure assessment, EPA should assess which chemicals are of primary concern and their probability for transport in groundwater and air. The SAB recommends that water quality data be collected before, during, and after injection, and from carefully selected locations, including the ongoing studies on the quality of surface waters in the regions with significant hydraulic fracturing activity. In cases where actual concentrations of contaminants are needed to assess potential environmental impacts, including toxic effects, it would be necessary to validate QA/QC aspects of the studies that collected these data. It is expected that the prospective case studies would follow requisite QA/QC protocols. Development of new analytical techniques may be beyond the capability of the proposed study in terms of time and budget; there is likely sufficient information in the literature to utilize when conducting sample collection and analysis as part of this study.

The Study Plan appears to emphasize the focus of study and research towards shale formations, but also notes that coal bed methane and other types of hydraulic fracturing are to be considered (Section 2.3). The Study Plan should clarify and specify the research focus for this lifecycle stage (i.e., whether the focus for gathering information is on hydraulic fracturing in shale units, natural gas production, coal bed methane production, other types of hydraulic fracturing activity, or a combination of the above).

The SAB recommends a number of specific research questions under the response to Charge Question 2, and provides a few additional recommended specific research questions:

- Inventory types of water being used in hydraulic fracturing to answer questions regarding how much high quality water is being used (e.g., water less than 10,000 mg/L TDS) vs. lower quality waters.

- Inventory post-fracturing produced water quality for different geographic regions and by HF product used to facilitate specific environmental monitoring and improve reporting outcomes as well as to inform first responders in the case of spills and leaks and to develop necessary management (treatment) approaches as a function of ultimate disposal alternatives.

- Consider normal industrial practices at coal bed methane hydraulic fracturing facilities. These facilities have documented best management approaches for produced waters, and also have identified boundaries for use of and expectations associated with produced water quality and hazard scenarios and spills.

- Assess industry practices on containment technologies and releases from pits and liners with leaky seals, and describe the "best management practices" for handling flowback and produced water during storage and transport of HF materials.

- The SAB recommends that identification of potential for leaks and spills during storage and transport should be based on documented events in the past, which can serve to assess the probability for the release of contaminants during different stages of flowback and produced water management provided that trends in management practices are taken into consideration.

- Assess potential adverse environmental impacts associated with buried pits and impoundments through evaluating the quality of soils and groundwater near such structures.

- The SAB recommends that the disposal of post-fracturing produced water to existing POTWs and Centralized Waste Treatment (CWT) facilities needs to be evaluated in terms of the fate of key constituents (e.g., chloride, bromide, radium) that may be relevant for drinking water treatment facilities downstream of these wastewater treatment plants.

Proposed Research Activities - Wastewater Treatment and Waste Disposal

> *Charge Question 4(e): Proposed research activities are provided for each stage of the water lifecycle and summarized in Figure 9. Will the proposed research activities adequately answer the secondary questions listed in Table 2 for the Wastewater Treatment and Waste Disposal stage of the water lifecycle? Please provide any suggestions for additional research activities.*

3.8.1. General Comments

In order to address the research questions listed in Table 2 (see Appendix B) and summarized in Figure 9 (see Appendix D) for the Wastewater Treatment and Waste Disposal stage of the water lifecycle, EPA plans to conduct the following activities:

- Conduct retrospective and prospective case studies
- Assess existing data on treatment and/or disposal of HF wastewaters
- Identify HF chemical constituents that create disinfection byproducts
- Evaluate potential impacts of high chloride concentrations on drinking water utilities

The SAB concludes that, overall, EPA has generally proposed a sound approach to adequately address the research questions associated with this lifecycle stage as outlined in Table 2. The SAB has some recommendations for specific components of the research plan that could be strengthened as described further below.

The Panel strongly recommends the use of scenario modeling, in concert with both retrospective and prospective case studies, to "define the boundaries" for activities under this portion of the water lifecycle. If dilution is potentially inadequate, then adverse impacts are possible and additional treatment may be needed. Scenario modeling involving simple mass balances should be conducted as a first-order effort to determine if or when dilution constitutes adequate "treatment." Existing practice in some areas is to discharge return flows to wastewater treatment plants and to rely on dilution to "treat" a number of constituents not removed by conventional wastewater treatment processes, such as TDS, chloride, bromide, and non-biodegradable organic matter. For these constituents, simple calculations can be done to estimate effluent and downstream concentrations, which can then be evaluated for their potential to cause adverse impacts (not only to humans, via drinking water supplies, but also to other receptors in future studies).

Hydraulic fracturing return flows contain many constituents that are similar to those for which treatment technologies exist within the state of practice of industrial wastewater treatment. For those constituents, SAB concludes that EPA should conduct a thorough literature review to identify existing treatment technologies that are currently being used to treat HF wastewater, identify knowledge relevant to hydraulic fracturing return flows, and identify constituents of HF return waters that might merit additional attention. SAB recommends that EPA review the documented data in the retrospective case studies to assess the efficacy and success of industrial wastewater treatment operations and pre-treatment operations for hydraulic fracturing return flows. Only a limited number of Publicly Owned Treatment Plants (POTWs) have the ancillary treatment technologies needed to remove the constituents in hydraulic fracturing return waters.

SAB recommends that EPA focus its efforts towards literature searches on POTW and industry management practices that can minimize the adverse effects associated with certain constituents such as TDS, natural organic matter (NOM), bromide, and radioactive species. In addition, EPA should assess the need for any special storage, handling, management, or disposal controls for solid residuals after treatment. EPA should assess whether land application (e.g., for disposal, irrigation, or road application for dust suppression or deicing) of hydraulic-fracturing associated wastewaters or residuals from treatment of these wastewaters, which is mentioned in the Study Plan, has the potential to affect drinking water resources.

The SAB encourages EPA to consider measures of pollution prevention associated with treatment of hydraulic fracturing wastewaters, and consider developing research questions that are built around how to develop technologies and strategies that reduce and eliminate the need for treatment and disposal. In addition, in some cases the HF wastes might be reused by injection into new wells, and the changes in water quality associated with such reinjection should be considered when assessing the composition of the wastes needing treatment. EPA should develop proposed research activities related to how the presence of hydraulic fracturing fluids impacts issues (social and technological) related to water reuse. Several recent publications of the WateReuse Association and WateReuse Foundation may be useful to EPA regarding this topic (See Huang and Li, 2009; Salveson, 2009; and Davis, 2009).

In addition, surface impoundments, holding ponds, and other strategies used for recycling, temporary storage, and disposal of HF wastes should be constructed with the best available technologies for surface impoundments. EPA's Surface Impoundment Study highlighted best practices for these types of temporary storage scenarios. See U.S. EPA, 2001. EPA's surface impoundment regulations also provide requirements on surface impoundment construction and operation/maintenance. See 40 CFR Parts 264/265, Subpart K.

The SAB has a number of specific comments noted below associated with this lifecycle stage. Additional specific comments on the research questions for this lifecycle stage are included within this Report's response to Charge Question 2.

3.8.2. Specific Comments

The SAB recommends that the research question itself be reworded to "Are treatment processes that are commonly used in water and wastewater treatment plants effective at removing constituents of hydraulic fracturing (HF) wastewater, and how do these constituents affect the performance of such treatment processes?"

Hydraulic fracturing return flows contain many constituents that are similar to those for which treatment technologies exist within the state of practice of industrial wastewater treatment. For those constituents, a thorough literature review should be conducted to match treatability studies and treatment technologies that are currently being used to treat HF wastewater to hydraulic fracturing return flows, and to identify constituents of HF wastes that might merit additional attention. The EPA retrospective case studies should review the documented data to assess the efficacy and success of industrial wastewater treatment operations and pre-treatment operations for hydraulic fracturing wastewater (return flows). Such studies need to critically assess characteristics of: volumes and flowrates; influent and effluent concentrations; the fate of the treated water; management practices, and the disposal of solid residuals. Rather than just a handful of retrospective studies as proposed, the full richness of available data should be explored. In addition, facilities maintenance (aspects, requirements, frequency, etc.) and cost factors (capital, operation and maintenance) at different stages of the life-cycle) need documentation.

Few POTWs are designed to remove many of the contaminants of the hydraulic fracturing process. Dissolved solids are not removed in such systems, and in high concentrations they can disrupt some unit operations. This phenomenon has been well-studied, so the research on this topic should focus on industry management practices that can minimize the adverse effects. All POTWs that now accept hydraulic fracturing return flows should be included in the retrospective studies in the assessment of the potential impacts of TDS. Similarly, the effects of increased NOM and bromide concentrations on disinfection byproducts formation in drinking water treatment processes and on corrosion of water distribution networks can be assessed based on a thorough literature review and information that the service companies likely have on the salt content of the wastewaters. Radioactive species also deserve special attention. Therefore, once again, the research should focus on management options to avoid concentrations that lead to adverse effects, rather than on studying effects that have already been well characterized.

The EPA effort should include studying the impact on water treatment plants of the potential increased burden of analyzing for contaminants in the treated effluent from any plants (POTWs or industrial) that treat hydraulic fracturing wastewater and discharge the treated effluent upstream of water treatment plants. Controlled release and dilution of the wastewater is one such management method and deserves discussion and investigation. If specific contaminants in hydraulic fracturing return flows are identified as posing a significant risk to a drinking water supply source, then pre-treatment options for those contaminants should be investigated. Also, POTW life cycle costs in light of this new stream of wastewater should be addressed. Pilot scale testing objectives are in need of articulation.

Solid residuals from POTWs are typically taken to landfills, incinerated, or applied to land (there may be some intermediate steps). If some hydraulic fracturing wastewater contaminants are collected in the POTW residuals stream, then the need for any special storage, handling, management, or disposal controls should be assessed. The EPA retrospective studies need to investigate this issue. In states that allow land application of POTW residuals, there is a large data set on sludge quality and chemistry. The prospective studies might be designed to assess the ability to predict treatment performance, and then predict the real time genesis of outflow and residuals composition from the POTWs.

The draft Study Plan should address the cumulative consequences of carrying out multiple HF operations in a single watershed or region. Examples of such consequences include causing a water body to exceed its total maximum daily load limit, which may cause the waterbody to be considered impaired and placed on the “303(d) list” of impaired waters (stream segments, lakes) that the Clean Water Act requires all states to submit for EPA approval. The SAB notes that an important impact of the cumulative HF wastewater discharges in a region might be missed if the focus is entirely on discharges from individual developments. This is especially true given the fact that entire regions are now under development or consideration for development of these hydrocarbon resources. Some example study questions include: “What is the assimilative capacity of natural systems (wetlands, lakes, streams) to accommodate hydraulic fracturing treated wastewaters?”; “Is this the best expenditure of ecosystem services?”; and “Is this an equitable expenditure of environmental services?”

The DOE collaboration associated with treatment technologies should be more clearly articulated and defined, as well as the anticipated collaboration with any other entities mentioned in the draft Study Plan.

Research Outcomes

Charge Question 5: If EPA conducts the proposed research, will we be able to:

a. *Identify the key impacts, if any, of hydraulic fracturing on drinking water resources; and*
b. *Provide relevant information on the toxicity and possible exposure pathways of chemicals associated with hydraulic fracturing?*

3.9.1. General Comments

EPA has proposed to conduct certain research activities associated with all stages of the hydraulic fracturing water lifecycle shown in Figure 7 of the Study Plan in order to address the research questions posed in Table 2 and summarized in Figure 9 of the Study Plan. Table 2 and Figures 7 and 9 are provided within this report as Appendix B, Appendix C, and Appendix D, respectively. EPA proposes to conduct the research using case studies and generalized scenario evaluations, which will rely on data produced by a combination of the tools listed in Section 5.3 of the Study Plan. In addition, EPA outlines a program of quality assurance that will be developed for all aspects of the proposed research. EPA's proposed research activities for each stage of the hydraulic fracturing water lifecycle are outlined in Figure 9 of the Study Plan, and EPA provides brief summaries of how the proposed research activities will answer the fundamental research questions.

To respond to this Charge Question, the SAB focused on the potential research outcomes that EPA identified for each step in the HF water lifecycle. These potential research outcomes are identified in Chapter 6 of the draft Study Plan, at the end of the discussion of each stage of the water lifecycle. For each potential research outcome listed in the draft report, the SAB determined whether the outcome is likely to be achieved in whole, in part, or not at all, by the proposed research.

The two charge sub-questions are inherently very broad, primarily because of the heterogeneity of hydraulic fracturing operations. For example, the potential 'key impacts' of hydraulic fracturing are likely to depend strongly on local geological and hydrological conditions, and the magnitude of those impacts is likely to depend on the site-specific details of the fracturing operation and the management practices that are in place, both for routine operation and for dealing with emergency situations such as flooding and spills. For this reason, the short (but not particularly helpful) response to the charge question is: "Yes" at some sites and under certain conditions, and "No" at other sites or under other conditions. While one could try to identify the most important conditional factors that influence the potential impacts of HF at different sites and then prepare a response to the charge question for each of the corresponding contingencies, the SAB concludes that such an approach would lead to a large and unwieldy matrix of conditional contingencies that would not be particularly valuable to EPA or the stakeholders.

In responding to these two charge sub-questions, the SAB reiterates the importance of assessing uncertainty at each step in the research study. Given time and resource constraints, the studies will not be able to answer all questions with a high degree of certainty. The SAB recommends that EPA explicitly identify or estimate the uncertainty or confidence in all research conclusions, and in the assessment of cause and effect associated with potential HF impacts to drinking water supplies. The quality of the information on which the research was based as well as any uncertainties arising in the conduct of the research should be evaluated, at least in a preliminary manner.

The SAB focused on the potential research outcomes that the EPA identified for each step in the HF water lifecycle. These potential research outcomes are identified in Chapter 6 of the draft Study Plan, at the end of the discussion of each stage of the water lifecycle. For each potential research outcome listed in the draft report, the SAB attempted to determine whether the outcome is likely to be achieved in whole, in part, or not at all, by the proposed research. The SAB recognizes that the ability to achieve a particular potential outcome is contingent on local conditions and therefore cannot be assessed for all sites in a limited research program. Nevertheless, the potential research outcomes are much more specific than the charge question and the SAB finds this specificity allows for more focused evaluation.

The SAB recognizes that the EPA did not claim that the listed potential research outcomes were comprehensive, or that the lists comprised the most important outcomes that the research would achieve. However, the potential research outcomes appeared as the final entry in the sections describing the various steps in the HF water life cycle, and the SAB concludes that EPA intended the lists to capture most of the key outcomes that EPA hoped would be achieved. The SAB considered whether other, non-listed research outcomes might affect SAB's response to the charge question, but did not identify any non-listed outcomes that would significantly alter this SAB assessment.

As described further below, the SAB concludes that: 1) all of the potential water acquisition research outcomes identified by EPA can be achieved; 2) approximately 50% of the potential chemical mixing research outcomes identified by EPA can be achieved; 3) approximately 40% of the potential well injection research outcomes identified by EPA can be achieved; 4) approximately 40% of the potential flowback and produced water research outcomes identified by EPA can be achieved; and 5) approximately 33% of the potential wastewater treatment and waste disposal research outcomes identified by EPA can be achieved.

The SAB concludes that all of the potential water acquisition research outcomes identified by EPA can be achieved. EPA can identify possible impacts on water availability and quality associated with large-volume water withdrawals for hydraulic fracturing. Also, EPA could determine the cumulative effects of large volume water withdrawals within a watershed and aquifer, and develop metrics that can be used to evaluate the vulnerability of water resources. While the SAB agrees that these research outcomes can be accomplished at HF sites that are carefully characterized in the case studies, the potential for extrapolation of these findings to other sites will be limited. Regarding the assessment of current water resource management practices related to hydraulic fracturing, the SAB concludes that EPA can accomplish this task through collection of data on water management practices from a representative cross-section of the industry. However, it is unclear whether the "assessment" referred to in this outcome would comprise only data-gathering about existing `management practices or a more in-depth analysis of the effectiveness of the practices.

With respect to the chemical mixing life-cycle stage, the SAB concludes that EPA can summarize available data on the identity and frequency of use of many (but not all) hydraulic fracturing chemicals, the concentrations at which the chemicals are typically injected, and the total amounts used, assuming cooperation from the HF service companies is forthcoming. The goal of identifying the toxicity of chemical additives can be achieved for those additives whose toxicity has been studied previously, and the goal of identifying data gaps can also be achieved. The SAB finds that the outcome of identifying chemical indicators for HF fluids is a worthy goal, but is skeptical that this outcome can be achieved. The SAB concludes that the outcome of determining the likelihood that surface spills will result in the contamination of drinking water resources is too broad to achieve in a general sense, but that it will be possible to achieve that outcome for a few chemicals that can be selected based on their potential to pose significant risk to human and environmental health. The SAB agrees that an assessment of management practices related to on-site chemical storage and mixing is achievable as part of the proposed research, assuming full cooperation of the HF service companies.

With respect to the well injection life-cycle stage, the frequency and severity of well failures, as well as the factors that contribute to them, can be assessed, if the relevant data are supplied by the HF service companies and if EPA determines the number of hydraulically fractured wells in a defined period for which well failure data are also available. The goal of identifying the key conditions that determine the extent of interaction of existing pathways with hydraulic fractures is excessively broad and is unlikely to be achieved in a way that is of significant practical value. However, significant progress toward achieving this goal might be made in cases where appropriate modeling has been carried out by the HF service companies, if those companies make their data available to the EPA. The SAB concludes that while EPA could identify the key conditions that increase or decrease the likelihood of the interaction of existing pathways with hydraulic fractures through modeling, the simulated outcomes will be dependent on assumptions and choices made about how to represent the physical system. These assumptions and choices may not be well constrained by reliable data. The outcome of analyzing water quality of a potentially affected water body before, during, and after injection can certainly be achieved. However, implicit in this outcome is the expectation that any impacts of HF activities could be inferred based on changes in water quality. The SAB is skeptical that such impacts could be detected in the relatively short time frame of the proposed research. While the SAB agrees that EPA can evaluate water quality before, during, and after injection, the evaluation might have to be continued substantially beyond the end of the initial research before the outcome can be established with reasonable confidence. The goal of quantifying the mobility and fate of HF additives and of naturally occurring substances that are mobilized by HF activities (e.g., formation fluid, gases, trace elements, radionuclides, organic material), and other substances that might be mobilized or rendered more toxic by the introduction of the fracturing fluid, is too broad to be achieved by the proposed research, but this goal might be achieved for a limited number of high-priority chemicals. Specific comments on analytical methods are included within this Report’s response to Charge Question 2.

With respect to the flowback and produced water (i.e., post-fracturing produced water), the SAB concludes that the outcomes of compiling existing data on the identity, quantity, and toxicity of flowback and produced water, and the preparation of a prioritized list of components for future investigation with respect to toxicity and human health effects are achievable. EPA plans to determine the likelihood that surface spills will result in the contamination of drinking water resources. The outcome of determining the likelihood that surface spills will result in the contamination of drinking water resources is too broad to be achievable in any meaningful way. The SAB finds that this likelihood will be highly site specific and will not be quantifiable with a simple, generalized equation, and thus the SAB does not agree that the outcome can be achieved or quantified by some generalized equation. However, procedures can be developed for assessing the likelihood that surface spills will lead to significant contamination of drinking water, when the procedures are applied to specific spill scenarios in specific hydrogeologic settings. The description of the data that will be collected in order to evaluate the risks to drinking water resources posed by current methods for on-site management of HF wastes is vague. A thorough analysis of on-site management practices could be useful for evaluating those risks, but the SAB is unable to assess whether the data that will be collected and the analysis that will be conducted will achieve that goal.

With respect to wastewater treatment and waste disposal, the SAB concludes that the research will achieve the outcome of identifying the fate and effects of inorganic constituent of HF wastes in
wastewater treatment and drinking water treatment plants with minimal or no new laboratory research (largely, but not exclusively, by literature surveys and information generated in an ongoing DOE study; see U.S. Department of Energy, 2011). This goal is unlikely to be achieved for organic constituents of HF wastes, especially those that will be present in trace concentrations after mixing with other water entering the treatment plants. The SAB agrees that EPA may be able to achieve an outcome of assessing some short- and long-term effects of the constituents resulting from inadequate treatment of hydraulic fracturing wastewaters on water and wastewater treatment processes, and on the water quality of the treated water. However, this potential outcome can be achieved only for a very limited range of potential effects.

In addition to the research outcomes identified in the draft research plan, the SAB recommends that EPA include as an outcome the generation of new research ideas for reducing the potential adverse effects of HF activities (for example, ways to reduce water usage, identify BMPs, or develop ‘greener’ HF additives).

An additional issue is that EPA needs to view the environmental concerns and issues in the context of the local community. Specific comments on environmental justice issues are included within this Report’s response to Charge Question 2.

3.9.2. Specific Comments

Potential Research Outcomes: Water Acquisition (Section 6.1)

The potential research outcomes related to water acquisition identified in the draft Study Plan were:

a) Identify possible impacts on water availability and quality associated with large volume water withdrawals for hydraulic fracturing.

b) Determine the cumulative effects of large volume water withdrawals within a watershed and aquifer.

c) Develop metrics that can be used to evaluate the vulnerability of water resources.

d) Provide an assessment of current water resource management practices related to hydraulic fracturing.

SAB's response to these outcomes is as follows:

a) The SAB considers Outcome 6.1a to be largely a conceptual outcome that can be achieved by understanding the steps involved in hydraulic fracturing and the environment in which it is conducted. The phrase "possible impacts" suggests that the task can be accomplished by brainstorming among a broad and representative group of technical experts and stakeholders. A significant amount of such brainstorming has already occurred, and most of the possible impacts of HF have probably been identified. Continued attention should be paid to this task throughout the project to increase the chance of identifying other, less obvious potential impacts, based on data collected and observations made as the research progresses. Thus, the SAB agrees that Outcome 6.1a can be achieved.

b, c) The possible cumulative effects of large volume withdrawals from a watershed have been documented in many prior water resource investigations unrelated to HF (see U.S. Army Engineer Waterways Experiment Station, 1999; Prudic, D.E., 2007; and Alberta Environment, 2007). These effects are highly site-specific, and many studies on withdrawal do not address impacts on water quality. Most large withdrawals are tied to either high density areas or agriculture, and HF activities can be within low density non-agricultural areas. The outcome of determining the cumulative effects of large volume water withdrawals will be accomplished at HF sites that are carefully characterized in case studies, and the potential for extrapolation of the findings to other sites will be limited due to the unique site-specific ecological and developmental factors associated with the locations for each case study.

The situation is largely the same with respect to establishment of metrics for evaluating the vulnerability of water resources to withdrawal of large volumes of water. It might be possible to establish metrics that relate specifically to HF environments and activities, such as the presence of pre-existing hydraulic interconnections in the underground (e.g., from mines) or the generation of such pathways during the HF process. However, while these metrics might be categorized as generally applicable, the data needed to apply them are detailed and site-specific, so it is unclear whether simply identifying the metrics represents a valuable outcome.

d) It is unclear to the SAB whether the "assessment" referred to in this outcome would comprise only data-gathering about existing management practices or a more in-depth analysis of the effectiveness of the practices. If the former, then the task can be accomplished by collection of data on water management practices from a representative cross-section of the industry. If the latter, then the metrics for evaluating the practices need to be carefully developed, and it is not clear that the EPA has paid sufficient attention to this effort to allow it to succeed.

Potential Research Outcomes: Chemical Mixing (Section 6.2)

The potential research outcomes related to chemical mixing identified in the draft Study Plan were:

a) Summarize available data on the identity and frequency of use of various hydraulic fracturing chemicals, the concentrations at which the chemicals are typically injected, and the total amounts used.

b) Identify the toxicity of chemical additives, and apply tools to prioritize data gaps and identify chemicals for further assessment.

c) Identify a set of chemical indicators associated with hydraulic fracturing fluids and associated analytical methods.

d) Determine the likelihood that surface spills will result in the contamination of drinking water resources.

e) Assess current management practices related to on-site chemical storage and mixing.

SAB's response to these outcomes is as follows:

a) SAB concludes that Potential Outcome 6.2a is achievable, assuming cooperation from the HF service companies is forthcoming. The Panel noted that a state agency in Wyoming is currently collecting data on chemical use in HF, and the EPA should take maximum advantage of that effort, as well as any similar efforts undertaken by other state, federal, or non-governmental agencies.

b) The SAB does not agree that it is possible, within the cost and time constraints of the proposed research, to collect and evaluate new data on human toxicity of HF chemical additives. Specific comments on hazard identification, exposure assessment, toxicity testing, analytical methods, and indicators of contamination are included within this Report's response to Charge Question 2.

c) The logical potential chemical indicators of HF fluids are the HF additives themselves and, in some cases, specific salt ions or aggregate measures of salt concentration (e.g., specific conductivity, TDS). The HF additives are usually added at low concentrations into the injected water, and they are likely to be partially modified (e.g., by microbial action), volatilized, and/or diluted substantially before entering a drinking water resource. Development of analytical methods for detecting low concentrations of such chemicals can be very time-consuming and costly. On the other hand, in situations where the concentration of salts (or the relative concentration of specific ions) can serve as an indicator of HF fluids, no research is needed to choose the specific indicator (either chloride or TDS is likely to be as good as any other choice), and no methods development is required. Therefore, the SAB recommends that during this project, inorganic salts and, possibly, organic HF additives for which analytical methods already exist be used as chemical indicators of the presence of HF fluids in water resources. If it is determined, based on other components of the research, that some HF chemicals might be particularly valuable indicators of the presence of HF fluids, then efforts to develop analytical methods for those chemicals can be undertaken subsequently.

It should be noted that, if a chemical that is present in the formation water (e.g., chloride) is chosen as the indicator and is found at elevated concentrations in a nearby water resource, the possibility can be raised that the concentration increase would have occurred even in the absence of HF activity. Barring the unlikely possibility that a direct pathway for the chemical from the HF environs to the water resource can be established, this issue falls more in the legal than the scientific domain (i.e., what is the burden of proof needed to attribute the higher concentration to HF activity?). In addition, establishing that an increase in concentration has occurred at a site where HF activity has been ongoing for several years would require some historical record of the concentration of the indicator prior to HF activity; at a site where HF activity is starting (i.e., the site of a prospective case study), it would require that the indicator appear in the water resource within one or at most two years for the potential outcome to be achieved during this research program. Neither of these scenarios can be assured, even if an appropriate indicator is selected. Use of HF additives as indicators does not suffer from this drawback but, as noted above, it is likely to be considerably more difficult to detect such additives in the water resource. For these reasons, although the SAB is supportive of the search for an indicator chemical as part of this project, it is not convinced that an appropriate indicator will be found (i.e., this outcome is a worthy goal, but it might not be achieved).

d) There is no question that surface spills of HF fluids are potential sources of contamination to shallow aquifers or surface waters. The likelihood that such contamination will actually occur depends strongly on the management practices for the HF liquid waste stream and on the local geology and hydrology, as well as the magnitude of the spill and the types of retardation and/or transformations to which the chemicals are susceptible. Useful information on the possible modes of transport and transformation of HF chemicals can be obtained in laboratory studies, but such studies also depend on the hydrogeological conditions and are often costly to conduct. The SAB finds that a general question about "the likelihood that surface spills will result in the contamination of drinking water resources" is unanswerable, but that it can be answered once site-specific and contaminant-specific information is available. Because of the cost of obtaining the necessary contaminant-specific information, it is appropriate for the EPA to identify the chemicals that pose the greatest risk to human and environmental health before initiating such studies. To the extent that those chemicals can be identified, and their transport and transformation characterized, as part of this research program, the outcome can be achieved for those chemicals. If these tasks cannot be completed as part of the current research program, then the research will still generate a useful outcome, but the goal of determining the likelihood of contamination of drinking water resources will not be achieved.

e) Assuming that HF service companies are forthcoming with information about their chemical storage and mixing management practices, and that a broad data-gathering effort is undertaken, an assessment of management practices related to on-site chemical storage and mixing is achievable as part of the proposed research. It should be noted that chemical storage and mixing in HF are not obviously and fundamentally different from the corresponding activities in many other industrial settings. The implicit question that is being addressed by this potential outcome is whether the management practices are appropriate for the risks and challenges that exist for chemical storage and mixing at HF sites. Data regarding current practices, when combined with an assessment of the risks associated with chemical storage and mixing, should help answer this question.

Potential Research Outcomes: Well Injection (Section 6.3)

The potential research outcomes related to well injection identified in the draft Study Plan were:

a) Determine the frequency and severity of well failures, as well as the factors that contribute to them.

b) Identify the key conditions that increase or decrease the likelihood of the interaction of existing pathways with hydraulic fractures.

c) Evaluate water quality before, during, and after injection.

d) Determine the identity, mobility, and fate of potential contaminants, including fracturing fluid additives and/or naturally occurring substances (e.g., formation fluid, gases, trace elements, radionuclides, organic material) and their toxic effects.

e) Develop analytical methods for detecting chemicals associated with hydraulic fracturing events.

SAB's response to these outcomes is as follows:

a) Outcome 6.3a is achievable if thorough historical data on well failures are provided by the HF service companies and if EPA determines the number of hydraulically fractured wells in the country. The draft Study Plan indicates that "EPA will select a representative sample of sites and request the complete well files for the sites" and "will analyze the well files to assess the typical causes, frequency, and severity of well failures." From these statements, it is clear that EPA anticipates full cooperation from service companies. If that cooperation is forthcoming, then this task will be achievable and could yield valuable information.

b) EPA proposes to achieve potential Outcome 6.3b primarily or exclusively via computer modeling of contaminant transport under various "hydraulic fracturing well injection scenarios," taking into account features of both the engineering systems and the local geology. Such modeling will undoubtedly shed some light on the potential contamination of drinking water sources during the well injection phase of HF operations. However, the simulated outcomes will be strongly dependent on assumptions and choices made about how to represent the physical system, and the SAB has concerns that these assumptions and choices are not well constrained by reliable data. As a result, converting the modeling outcomes to useful interpretive or predictive outcomes may be problematic if the modeling assumptions and choices are not well constrained by reliable data. The SAB is unable to determine if sufficient data exist to constrain modeling choices, and thus cannot determine if this outcome can be met.

As currently phrased, the claimed potential outcome is excessively broad and is unlikely to be achieved in a way that is of significant practical value. For example, the presence of many pre-existing interconnected fractures is likely to facilitate interaction of existing pathways with hydraulic fractures, but that conclusion is intuitive. Modeling could probably be carried out to identify some details of pre-existing fractures that pose especially high risk for interaction with hydraulic fractures. The effort required for such modeling is large, but in many cases much of the modeling might already have been completed as part of the pre-drilling analysis. EPA should request any geophysical data, well logs, etc., that the developers of sites have accumulated and use that information to the extent possible in this portion of the research

c) The SAB assumes that the water quality referred to in potential Outcome 6.3c was the water quality of the drinking water source that might be at risk of contamination as a result of HF activities. The plan to evaluate water quality before, during, and after injection of the HF fluids indicates that this potential outcome applies primarily or exclusively to the prospective case studies. While there is no doubt that such an evaluation can be carried out, the water quality parameters that are analyzed will probably undergo minimal change during the relatively short duration of the research program. In addition, the need to rely on inorganic salts as tracers for the HF fluids (because analytical methods for the organic additives are either not available at all, or not yet proven for the concentrations and matrices of interest) will complicate the interpretation of the data, because it will raise the question of whether hydraulic fracturing was truly the cause of any observed change in chemical composition.

The SAB has some concern that the absence of a strong contaminant signal could be misinterpreted as support for the null hypothesis (i.e., that the contaminants cannot migrate to the water body), when in fact it simply reflects a time lag between the initiation of HF activities and the appearance of HF fluids in the water source that is longer than the observation period. The SAB concludes that the water quality evaluation that will be carried out is a worthwhile effort, but that it might have to be continued substantially beyond the end of the initial research before the outcome can be established with reasonable confidence.

d) Potential Outcome 6.3d is written in a way that suggests that the identity, mobility, fate, and toxicity of all potentially significant contaminants will be determined as part of the project, and that outcome is clearly not achievable. As noted elsewhere in this report, the SAB recommends that none of the proposed toxicity testing be carried out as part of the current research. If that recommendation is accepted, the determination of toxic effects will be limited to those contaminants for which the toxicity has already been assessed. However, the goal of quantifying the mobility and fate of the contaminants that are deemed to be of highest priority is achievable. Given the plethora of HF additives and naturally occurring substances of potential interest, the SAB recommends that the contaminants of primary concern be identified based on an initial investigation of their usage rates, physical/chemical properties, and potential routes of human exposure, and that transport-and-fate studies be carried out only on those contaminants, by a combination of laboratory, field, and computer modeling experiments.

e) Specific comments on hazard identification, exposure assessment, toxicity testing, analytical methods, and indicators of contamination are included within this Report’s response to Charge Question 2.

Potential Research Outcomes: Flowback and Produced Water (Section 6.4)

The potential research outcomes related to flowback and produced water identified in the draft Study Plan were:

a) Compile information on the identity, quantity, and toxicity of flowback and produced water components.

b) Develop analytical methods to identify and quantify flowback and produced water components.

c) Provide a prioritized list of components requiring future studies relating to toxicity and human health effects.

d) Determine the likelihood that surface spills will result in the contamination of drinking water resources.

e) Evaluate risks posed to drinking water resources by current methods for on-site management of wastes produced by hydraulic fracturing.

SAB's response to these outcomes is as follows:

a) The compilation of existing data relating to the identity, quantity, and toxicity of flowback and produced water components is achievable as part of the research, and the SAB finds that successful completion of this step is critical. The SAB wishes to reiterate its belief that the toxicity data collected as part of this effort should be restricted to data that are already in the scientific literature.

b) Specific comments on hazard identification, exposure assessment, toxicity testing, analytical methods, and indicators of contamination are included within this Report’s response to Charge Question 2.

c) The likelihood that surface spills will result in contamination of drinking water resources depends on the volume of the spill, the identities and concentrations of the contaminants in the spillage, and the details of the potential pathways from the site of the spill to the water resource. Therefore, this likelihood is highly site specific and cannot be quantified by some generalized equation. The SAB agrees that the EPA understands and appreciates this site-specificity, but the wording of potential outcome 6.4d does not reflect that understanding; therefore, if the potential outcome is interpreted literally, it cannot be achieved. The SAB recommends that EPA consider revising this potential outcome so that it refers to development of procedures that can be used to assess the likelihood that various types of surface spills will lead to significant contamination of drinking water resources, when the procedures are applied to specific spill scenarios in specific hydrogeologic settings.

d) The data that the EPA anticipates collecting with regard to on-site management of HF wastes are vague. The draft plan indicates the data will be collected from literature reviews, retrospective case studies, and prospective case studies, but it is unclear exactly what information will be sought. Statements such as, "it will be informative to compare the typical management practices to unexpected situations that may lead to impacts…on drinking water resources" and "information will also be collected on the ways in which wastewater is transported for treatment or disposal" suggest that the research will, at best, generate a list of some management (and probably some mismanagement) practices. However, it is difficult to see how such data will be translated into a useful, generalized evaluation of the risks associated with on-site management of HF wastes.

Potential Research Outcomes: Wastewater Treatment and Waste Disposal (Section 6.5)

The potential research outcomes related to wastewater treatment and waste disposal identified in the draft Study Plan were:

a) Evaluate treatment and disposal methods that are currently being used to treat flowback and produced water resulting from hydraulic fracturing activities.

b) Assess the short- and long-term effects resulting from inadequate treatment of hydraulic fracturing wastewaters.

SAB's response to these outcomes is as follows:

a) The SAB interpreted potential outcome 6.5a as comprising both the effectiveness with which components of HF wastes can be removed from the waste stream using treatment and disposal methods that are currently being used to treat HF wastewater, and the effect of such wastes on the performance of treatment processes with respect to removal and/or degradation of other (non-HF) waste components. It should be noted that, in some cases, the HF wastes might be reused by injection into new wells, and the changes in water quality associated with such reinjection should be considered when assessing the composition of the wastes needing treatment. The draft Study Plan identifies pre-treatment of HF wastewaters prior to direct land application or prior to discharge to a community wastewater treatment system, as well as discharge directly to a community wastewater treatment system (without pre-treatment) as potential treatment/disposal methods. The draft Study Plan notes that substantial work that addresses these issues has been completed by DOE NETL, and that only research to fill in the remaining knowledge gaps will be carried out as part of the proposed project. It is not clear that an assessment of the effectiveness of pre-treatment for solutions that will be re-injected is an important research activity for this project.

The monovalent inorganic constituents in HF wastes can be removed from the solution only by desalination processes such as reverse osmosis, and the effectiveness of these processes is relatively well-established. Some of the organic constituents of HF wastes might be removed by biodegradation, volatilization, or adsorption, but few studies have attempted to track these compounds as they pass through a treatment plant, and the feasibility of doing so in situations where the HF fluids are discharged to a POTW is complicated by the low concentrations of those compounds that are expected to be present once the HF fluids have been diluted by other influents to the plant.

The effects of the major inorganic contaminants in HF waste fluids on wastewater treatment processes and on soils have been extensively studied in other contexts, and the results of that research should be taken into account, along with the results of the DOE research. The effects of the organic contaminants on process performance will be more difficult to evaluate, other than anecdotally, for the same reasons that make the fate of the compounds themselves difficult to assess.

Based on the above considerations, the SAB concludes that potential outcome 6.5a is likely achievable with respect to the inorganic constituents of HF wastes, with minimal or no new laboratory research. However, the same cannot be said for the organic constituents. For the organic constituents, it is unlikely that this potential outcome will be achieved in situations where the HF wastes are a small portion of the total waste stream entering the treatment plant. The outcome might be achieved in a scenario where the HF wastes account for the majority of the influent to the treatment process (e.g., in a treatment or pre-treatment facility treating only HF fluid or wastewater consisting primarily of HF fluid).

b) Taken in conjunction with the research plan for topic 6.5, it appears that potential outcome 6.5b is referring primarily to the effects that components of HF wastewaters might have on drinking water quality (e.g., TDS in drinking water, DBP formation during disinfection of drinking water) and the infrastructure of wastewater and drinking water treatment systems (e.g., increasing corrosion rates). Although the potential outcome is written as though a wide (or even comprehensive) range of such effects will be investigated, in truth only a couple will be explored. Furthermore, even those effects are probably better studied by combining mass balance calculations with existing literature on DBP formation and corrosion. The SAB's assessment is that this potential outcome can be achieved for a very limited range of effects, and that very little new laboratory research is required to do so.

APPENDIX A: EPA's CHARGE TO THE PANEL

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Development
February 9, 2011

MEMORANDUM

SUBJECT: Request for review of the *Draft Plan to Study the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources*

FROM: Fred S. Hauchman, Director ***/Signed/***
Office of Science Policy (8104R)

TO: Edward Hanlon, Designated Federal Officer
EPA Science Advisory Board Staff (1400R)

This memorandum requests that the Science Advisory Board (SAB) review and comment on the EPA Office of Research and Development's (ORD) *Draft Plan to Study the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources.* The purpose of this draft study plan is to identify research activities that will answer the following questions:

- Can hydraulic fracturing impact drinking water resources?
- If so, what are the conditions associated with the potential impacts on drinking water resources?

Background

Hydraulic fracturing, which involves the pressurized injection of water, chemical additives, and proppants into geological formations, induces fractures in the formation that stimulate the flow of natural gas or oil, thus increasing the volume of gas or oil that can be recovered from coalbeds, shales, and tight sands. As natural gas production has increased, so have concerns about the potential environmental and human health impacts of hydraulic fracturing in the U.S., particularly with respect to drinking water resources. In its Fiscal Year 2010 Appropriation Conference Committee Directive to EPA, the U.S. House of Representatives urged EPA to conduct a study of hydraulic fracturing and its relationship to drinking water, specifically:

> "*The conferees urge the Agency to carry out a study on the relationship between hydraulic fracturing and drinking water, using a credible approach that relies on the best available science, as well as independent sources of information. The conferees expect the study to be conducted through a transparent, peer-reviewed process that will ensure the validity and accuracy of the data. The Agency shall consult with other Federal agencies as well as appropriate State and interstate regulatory agencies in carrying out the study, which should be prepared in accordance with the Agency's quality assurance principles.*"

In March 2010, EPA asked the SAB to review an initial research scoping document related to hydraulic fracturing.[1] This document outlined the initial approach for determining the scope of the study, potential research questions, and an initial approach for conducting the study. In its response to EPA[2] in June 2010, the SAB endorsed a lifecycle approach for the study plan, and recommends that: (1) initial research be focused on potential impacts to drinking water resources, with later research investigating more general impacts on water resources; (2) five to ten in-depth case studies be conducted at "locations selected to represent the full range of regional variability of hydraulic fracturing across the nation"; and (3) engagement with stakeholders occur throughout the research process.

Following the receipt of the SAB comments in June 2010, EPA developed the attached *Draft Plan to Study the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources.* The draft plan focuses on the full lifecycle of water in the hydraulic fracturing process, from water acquisition, through the mixing of chemicals and actual fracturing, to the post-fracturing stage, including the management of flowback and produced water and its ultimate treatment and/or disposal. The research questions outlined in the study plan address how activities in each of these stages may impact drinking water resources. EPA has identified these research questions from stakeholder meetings and a review of the existing literature on hydraulic fracturing. Stakeholders have also helped EPA to identify the potential case study sites discussed in the draft study plan.

Specific Request

ORD requests that the SAB comment on the scope, proposed research questions, research approach, research activities, and research outcomes outlined in the *Draft Plan to Study the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources*. Comments from the SAB will be considered during the development of the final plan to study the potential impacts of hydraulic fracturing on drinking water resources.

We appreciate the efforts of the SAB to prepare for the upcoming review of the *Draft Plan to Study the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources*, and we look forward to discussing the plan in detail on March 7-8, 2011. Questions regarding the enclosed materials should be directed to Susan Burden at burden.susan@epa.gov or 202-564-6308.

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[1] http://yosemite.epa.gov/sab/sabproduct.nsf/0/3B745430D624ED3B852576D400514B76/$File/Hydraulic%20Frac%20Scoping%20Doc%20for%20SAB-3-22-10%20Final.pdf

[2] http://yosemite.epa.gov/sab/sabproduct.nsf/0/CC09DE2B8B4755718525774D0044F929/$File/EPA-SAB-10-009-unsigned.pdf

Charge to the SAB

We ask the SAB to focus on the questions below during the review of the *Draft Plan to Study the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources:*

1. **Water Use in Hydraulic Fracturing**

   EPA has used the water lifecycle shown in Figure 7 to characterize hydraulic fracturing and to identify the potential drinking water issues. Please comment on the appropriateness of this framework for the study plan. Within the context of the water lifecycle, does the study plan adequately identify and address the areas of concern?

2. **Research Questions**
   EPA has identified both fundamental and secondary research questions in Table 2. Has EPA identified the correct research questions to address whether or not hydraulic fracturing impacts drinking water resources, and if so, what those potential impacts may be?

3. **Research Approach**
   The approach for the proposed research is briefly described in Chapter 5. Please provide any recommendations for conducting the research outlined in this study plan, particularly with respect to the case studies. Have the necessary tools (i.e., existing data analysis, field monitoring, laboratory experiments, and modeling) been identified? Please comment on any additional key literature that should be included to ensure a comprehensive understanding of the trends in the hydraulic fracturing process.

4. **Proposed Research Activities**
   Proposed research activities are provided for each stage of the water lifecycle and summarized in Figure 9. Will the proposed research activities adequately answer the secondary questions listed in Table 2 for each stage of the water lifecycle? Please provide any suggestions for additional research activities.

5. **Research Outcomes**
   If EPA conducts the proposed research, will we be able to:
   a. Identify the key impacts, if any, of hydraulic fracturing on drinking water resources; and
   b. Provide relevant information on the toxicity and possible exposure pathways of chemicals associated with hydraulic fracturing?

Attachment: *Draft Plan to Study the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources*

APPENDIX B: Table 2 From EPA's February 2011 Draft Hydraulic Fracturing Study Plan

TABLE 2. HYDRAULIC FRACTURING RESEARCH QUESTIONS

Water Lifecycle Stage	Fundamental Research Question	Secondary Research Questions
Water acquisition	How might large volume water withdrawals from ground and surface water impact drinking water resources?	• What are the impacts on water availability? • What are the impacts on water quality?
Chemical mixing	What are the possible impacts of accidental releases of hydraulic fracturing fluids on drinking water resources?	• What is the composition of hydraulic fracturing fluids and what are the toxic effects of these constituents? • What factors may influence the likelihood of contamination of drinking water resources? • How effective are mitigation approaches in reducing impacts to drinking water resources?
Well injection	What are the possible impacts of the injection and fracturing process on drinking water resources?	• How effective are well construction practices at containing gases and fluids before, during, and after fracturing? • What are the potential impacts of pre-existing artificial or natural pathways/features on contaminant transport? • What chemical/physical/biological processes could impact the fate and transport of substances in the subsurface? • What are the toxic effects of naturally occurring substances?
Flowback and produced water	What are the possible impacts of accidental releases of flowback and produced water on drinking water resources?	• What is the composition and variability of flowback and produced water and what are the toxic effects of these constituents? • What factors may influence the likelihood of contamination of drinking water resources? • How effective are mitigation approaches in reducing impacts to drinking water resources?
Wastewater treatment and waste disposal	What are the possible impacts of inadequate treatment of hydraulic fracturing wastewaters on drinking water resources?	• How effective are treatment and disposal methods?

APPENDIX C: Figure 7 From EPA's February 2011 Draft Hydraulic Fracturing Study Plan

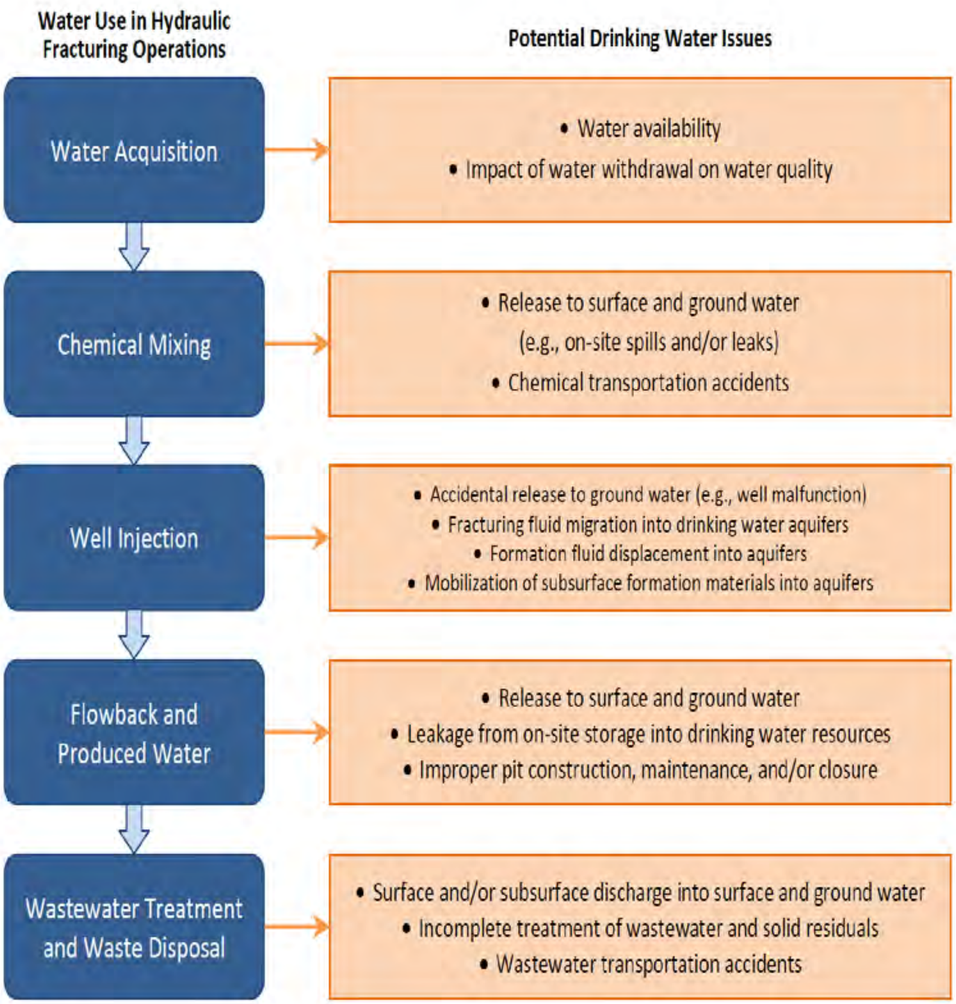

FIGURE 7. WATER USE IN HYDRAULIC FRACTURING OPERATIONS

APPENDIX D: Figures 9a and 9b From EPA's February 2011 Draft Hydraulic Fracturing Study Plan

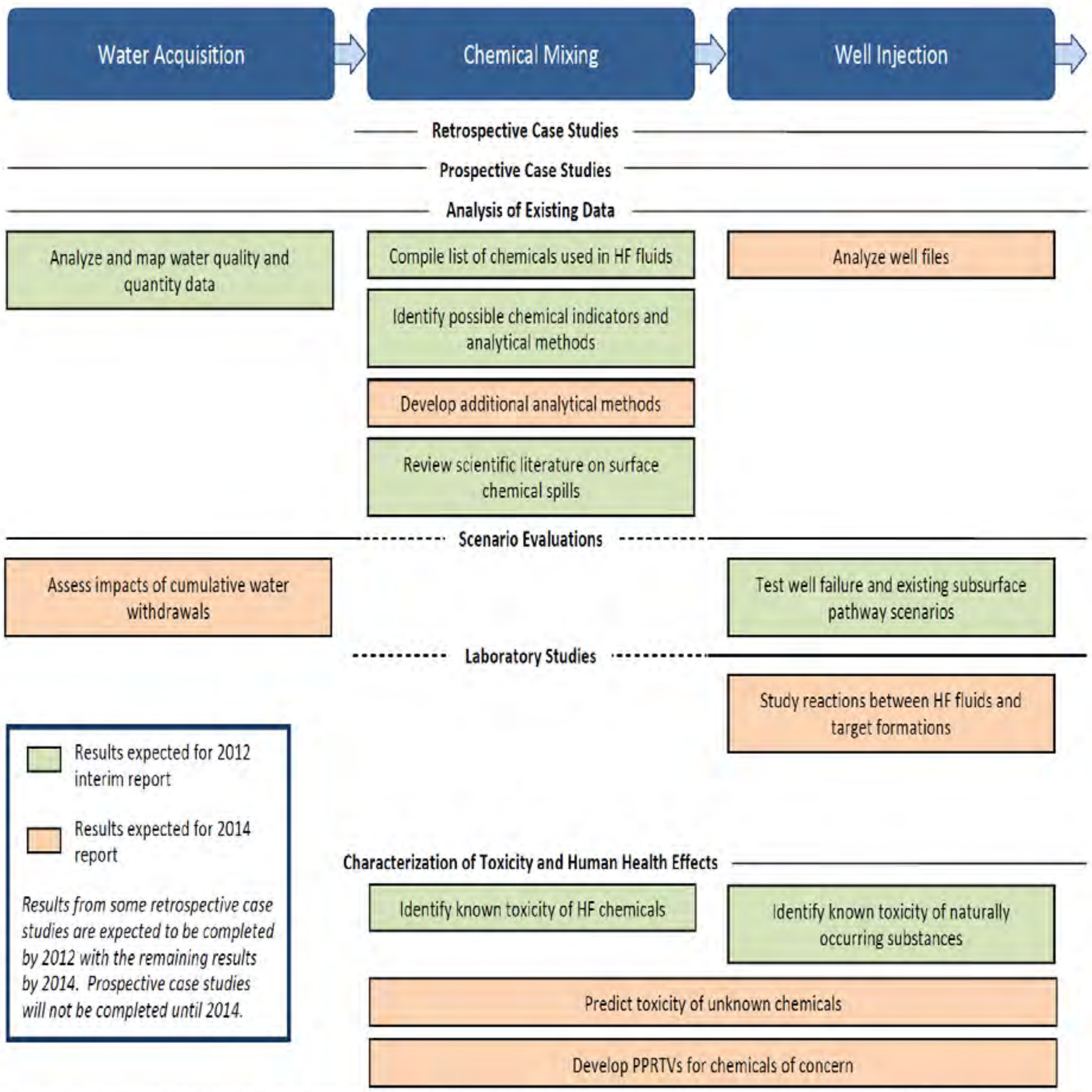

FIGURE 9a. SUMMARY OF RESEARCH PROJECTS PROPOSED FOR THE FIRST THREE STAGES OF THE HYDRAULIC FRACTURING WATER LIFECYCLE

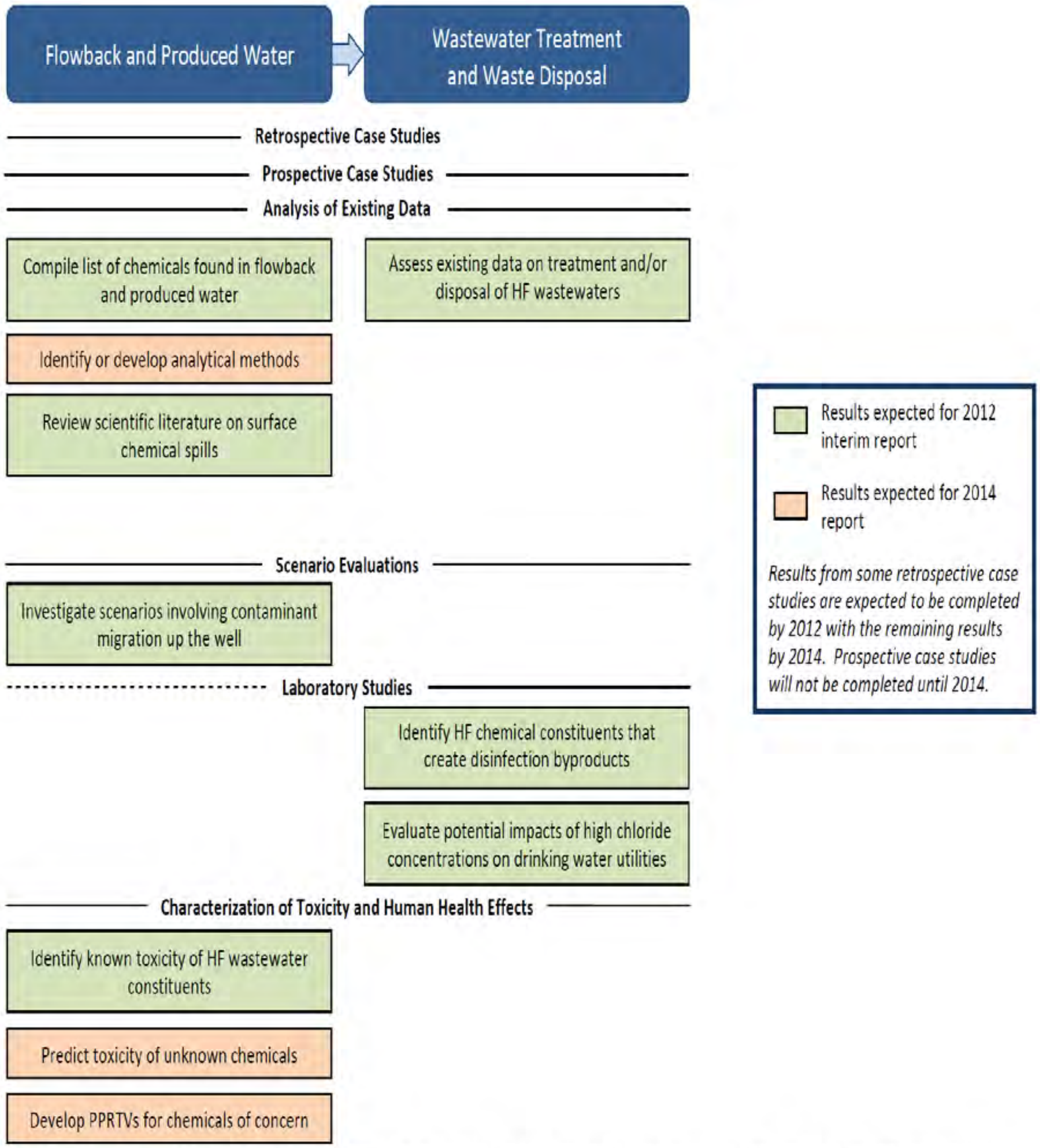

FIGURE 9b. SUMMARY OF RESEARCH PROJECTS PROPOSED FOR THE LAST TWO STAGES OF THE HYDRAULIC FRACTURING WATER LIFECYCLE