2/16/16 Draft

The Honorable Gina McCarthy
Administrator
U.S. Environmental Protection Agency
1200 Pennsylvania Avenue, N.W.
Washington, D.C. 20460

Subject: SAB Review of the EPA's draft Assessment of the Potential Impacts of Hydraulic Fracturing for Oil and Gas on Drinking Water Resources

Dear Administrator McCarthy:

The EPA Science Advisory Board (SAB) is pleased to transmit its response to a request from the U.S. Environmental Protection Agency (EPA) Office of Research and Development (ORD) to review and provide advice on scientific charge questions associated with the EPA's June 2015 draft *Assessment of the Potential Impacts of Hydraulic Fracturing for Oil and Gas on Drinking Water Resources (External Review Draft, EPA/600/R-15/047, June 2015).* The draft Assessment Report synthesizes available scientific literature and data on the potential impact of hydraulic fracturing for oil and gas development on drinking water resources, and identifies possible operational events during the life cycle of hydraulic fracturing for oil and gas operations that potentially could result in an impact to drinking water. The SAB was asked to comment on various aspects of the EPA's draft Assessment Report, including the descriptions of hydraulic fracturing activities and their relationship to drinking water resources, the individual stages in the hydraulic fracturing water cycle (HFWC), and the identification and hazard evaluation of hydraulic fracturing chemicals. The specific charge questions to the Panel from the EPA are provided as Appendix A to the SAB report.

The EPA developed the draft Assessment Report in response to the U.S. Congress, which urged the EPA in late 2009 to examine the relationship between hydraulic fracturing and drinking water resources. In response, the EPA developed a research Study Plan which was reviewed by the SAB in 2011. An EPA Progress Report on the study detailing the EPA's research approaches, activities, and remaining work was released in late 2012. Subsequently, a consultation was conducted in May 2013 with individual expert members of SAB's Hydraulic Fracturing Research Advisory Panel convened under the auspices of the SAB. The EPA's assessment includes original research, and those results were considered in the development of the EPA's draft Assessment Report.

In general, the SAB finds the EPA's overall approach to assess the potential impacts of hydraulic fracturing for oil and gas production on drinking water resources, focusing on the individual stages in the HFWC, to be appropriate and comprehensive. The SAB also finds that the agency provided a generally comprehensive overview of the available literature that describes the factors affecting the relationship of hydraulic fracturing and drinking water, and adequately described the findings of such published data in the draft Assessment Report. However, the SAB has concerns regarding various aspects of the draft Assessment Report and has several recommendations for changes to its text and follow-on activities to address gaps that the SAB has identified. The enclosed report provides detailed comments and recommendations for improving the draft Assessment Report, as well as recommendations that the agency may consider longer-term activities that may be conducted after the draft Assessment Report is finalized. Also included, as Appendix B, is a dissenting view from one member of the Panel mainly on the major findings of the EPA, on the adequacy of spill assessment by the EPA, and on the need for prospective studies. The SAB's key findings and recommendations are summarized below.

Prospective Case Studies: The SAB is concerned that the EPA had planned to but did not conduct various assessment, field studies, and other research, and the SAB recommends that the EPA delineate these planned activities within the draft Assessment Report and discuss why they were not conducted. The lack of prospective case studies as originally planned by the EPA and described in the research 2011 Study Plan is a major limitation of the draft Assessment Report.]

Clarity of and Support for Major Findings: The SAB has concerns regarding the clarity and adequacy of support for several major findings presented within the draft Assessment Report that seek to draw national-level conclusions regarding the impacts of hydraulic fracturing on drinking water resources. The SAB is concerned that these major findings as presented within the Executive Summary are ambiguous and appear inconsistent with the observations, data, and levels of uncertainty presented and discussed in the body of the draft Assessment Report. Of particular concern in this regard is the high-level conclusion statement on page ES-6 that "We did not find evidence that these mechanisms have led to widespread, systemic impacts on drinking water resources in the United States." The SAB finds that this statement does not clearly describe the system(s) of interest (e.g., groundwater, surface water) nor the definitions of "systemic" and "widespread". The SAB agrees that the statement has been interpreted by members of the public in many different ways, and concludes that the statement requires clarification and additional explanation.

The SAB recommends that the EPA revise the major statements of findings in the Executive Summary and elsewhere in the draft Assessment Report to be more precise, and to clearly link these statements to evidence provided in the body of the draft Assessment Report. The SAB also recommends that the EPA discuss the significant data limitations and uncertainties, as documented in the body of the draft Assessment Report, when presenting the major findings.

The draft Assessment Report should make clear that the hydraulic fracturing industry is rapidly evolving, with changes in the processes being employed, whereas the Assessment necessarily was developed with the data available at a point in time.

Recognition of Local Impacts: The SAB finds that EPA's initial goal of assessing the HFWC using national-level analyses and perspective was appropriate. The draft Assessment Report should recognize that most stresses to surface or groundwater resources associated with stages of the HFWC are localized. For example, the impacts of water acquisition will predominantly be observed locally at small space and time scales. These local-level hydraulic fracturing impacts, when they occur, can be severe, and the draft Assessment Report needs to recognize better the importance of local impacts. In this regard, the SAB recommends that the agency should include and critically analyze the status, data on potential releases, and any available findings from the EPA and state investigations conducted in Dimock, Pennsylvania; Pavillion, Wyoming; and Parker County, Texas where hydraulic fracturing activities are perceived by many members of the public to have caused significant local impacts to drinking water resources. Examination of these high-visibility cases is important so that the public can understand the status of investigations in these areas, conclusions associated with the investigations, lessons learned if any for the different stages of the hydraulic fracturing water cycle, what additional work should be done to improve the understanding of these sites and the HFWC, plans for remediation if any, and the degree to which information from these case studies can be extrapolated to other locations.

Accessibility of the Assessment to a Broad Audience: The SAB recommends that sections of the draft Assessment Report be revised to make these sections more suitable for a broad audience. It is important that the Assessment Report, and especially the Executive Summary, be understandable to the general public. The SAB makes specific recommendations about opportunities to define terms, provide illustrations, clarify ambiguities and be more precise in the presentation of major findings.

Approach for Assessing Water Quality and Quantity Impacts: The SAB provides several suggestions to improve the agency's approach for assessing the potential for hydraulic fracturing for oil and gas production to change the quality or quantity of drinking water resources. While the draft Assessment Report comprehensively summarizes the available information concerning the sources and quantities of water used from surface water, groundwater, and treated wastewaters, the SAB finds that the potential for water availability impacts on drinking water resources is greatest in areas with high hydraulic fracturing water use, low water availability, and frequent drought. The SAB finds that there are important gaps in the data available to assess water use that limit understanding of hydraulic fracturing potential impacts on water acquisition.

Definition of Proximity: The draft Assessment Report should discuss the selection of a one-mile radius to define proximity of a drinking water resource to hydraulic fracturing operations, and the potential need to consider drinking water resources at greater than one mile distance from a hydraulic fracturing operation. The EPA should also present more information regarding the vertical distance between surface-water bodies and the target zones being fractured, and the depths of most aquifers compared to the depths of most hydraulically fractured wells.

Probability and Risk of Well Failure Scenarios: The EPA should also clearly describe the probability and risk associated with hydraulic fracturing for the various life cycle operations associated with oil and gas wells, including well injection-related failure scenarios and mechanisms, to help the reader understand the most significant failure mechanisms regarding the stages in the HFWC. The agency should provide more information regarding the extent or potential extent of the effects of chemical mixing processes from hydraulic fracturing operations to drinking water supplies. The EPA should provide additional detail describing the extent and duration of the impacts of spilled liquids and releases of flowback and produced waters when they occur.

The agency should include additional major findings associated with the higher likelihood of impacts to drinking water resources associated with hydraulic fracturing well construction, well integrity, and well injection problems. These findings should discuss factors and effects regarding the severity and frequency of potential impacts from poor hydraulic fracturing cementation techniques, hydraulic fracturing operator error, migration of hydraulic fracturing chemicals from the deep subsurface, and abandoned hydraulically fractured wells.

The agency should also include additional major findings associated with the effects on drinking water resources of large spill events that escape containment, and sustained, undetected leaks.

Chemical Toxicity and Hazard: The agency should compile toxicological information on chemicals employed in hydraulic fracturing in a more inclusive manner, and not limit the selection of hydraulic fracturing chemicals of concern to those that have formal noncancer oral reference values (RfVs) and cancer oral slope factors (OSFs). The agency should use a broad range of toxicity data, including information pertinent to subchronic exposures from a number of reliable sources cited by the SAB in addition to those used in the draft Assessment Report to conduct hazard evaluation for hydraulic fracturing chemicals. As the agency broadens inclusion of toxicological information to populate missing toxicity data, the EPA can expand the tiered hierarchy of data described in the draft Assessment Report to give higher priority to chemicals with RfVs without excluding other quality toxicological information that is useful for hazard and risk assessment purposes.

Also, an important limitation of the agency's hazard evaluation of chemicals across the HFWC is the agency's lack of breadth in its analysis of most likely exposure scenarios and hazards associated with hydraulic fracturing activities. To help prioritize future research and risk assessment efforts, the agency should identify the most likely exposure scenarios and hazards and obtain toxicity information relevant to the exposure scenarios. The EPA provides a wide range of possible scenarios along the HFWC, but more emphasis is need on identifying the most likely durations and routes of exposures of concern so that EPA can determine what toxicity information is most relevant and focus research and monitoring efforts on the most important and/or likely scenarios. The SAB concludes that this should be based on consideration of findings in prospective and retrospective site investigations, as well as case studies of public and private wells and surface water supplies impacted by spills or discharges of flowback, produced water or treated or partially treated wastewater. Furthermore, the EPA developed a multi-criteria decision analysis (MCDA) approach to analyze hydraulic fracturing chemicals and identify/prioritize those of most concern. In light of the limitations described in the SAB's response to Charge Question 7, and given that the EPA applied this approach to very few chemicals, the EPA should explicitly state that these MCDA results (based only on chemicals with RfVs) should not be used for prioritization of chemicals of most concern nationally nor to direct future toxicity testing research needs.

Characteristics of HF Fluids: For the sake of clarity, the draft Assessment Report should distinguish between hydraulic fracturing chemicals injected into a hydraulic fracturing well vs. constituents, chemicals and hydrocarbons that come back out of the hydraulic fracturing well in produced fluids, and between those chemical constituents and potential impacts unique to hydraulic fracturing oil and gas extraction from those that also exist as a component of conventional oil and gas development, or those chemicals/constituents that are naturally occurring in the formation waters of the zone being produced. The agency should also clarify whether compounds identified as being of most concern in produced water are products of the hydraulic fracturing activity, flowback, or late-stage produced water, or are chemicals of concern derived from oil and gas production activities that are not unique to hydraulic fracturing activity or are naturally occurring in the formation water. This will help inform the public about the different characteristics of HF injection flowback and produced waters and in-situ subsurface brines relative to formation water produced in conventional oil and gas development.

Best Management Practices: The SAB recommends that the agency describe best management practices used by industry regarding operations associated with each stage of the HFWC, in order to better inform the public on available processes, methods and technologies that can minimize hydraulic fracturing potential impacts to drinking water resources. The EPA should also discuss state standards and regulations implemented with the aim of improving hydraulic fracturing operations, and the evolution of oilfield and state regulatory practices that are relevant to HFWC activities.

Baseline Water Quality Data: The EPA should also include additional discussion on background and pre-existing baseline chemistry of surface and groundwater in order to better understand the impacts of hydraulic fracturing-related spills and leaks. A major public concern is the appearance of contaminated or degraded drinking water wells in areas where hydraulic fracturing occurs. Since naturally occurring contaminants and degraded wells can occur from issues not related to hydraulic fracturing, the EPA should also include additional discussion on how background and pre-existing baseline chemistry of surface and groundwater data is used in order to better understand the impacts of hydraulic fracturing-related spills and leaks. The scientific complexity of baseline sampling and data interpretation should be described.

Treatment of Hydraulic Fracturing Wastewater: The agency should also provide clearer information on certain wastewater hydraulic fracturing treatment process fundamentals, and the occurrence and removal of disinfection by-product precursors other than bromide. The agency should describe the basis for nationwide estimates of hydraulic fracturing-related wastewater production, various aspects of hydraulic fracturing-waste disposal, the locations of wastewater treatment and disposal facilities relative to downstream public water supply intakes and wells, the impacts of water recycling on pollutant concentrations and their potential impacts on drinking water quality should spills of recycled water occur, and trends in wastewater disposal methods.

In the enclosed report, the SAB provides a number of specific recommendations to improve the clarity and scientific basis of the EPA's analyses within the EPA's draft Assessment Report, as well as recommendations that the agency may consider longer-term activities that may be conducted after the draft Assessment Report is finalized.

The SAB appreciates the opportunity to provide the EPA with advice on this important subject. We look forward to receiving the agency's response.

Sincerely,

Enclosure

NOTICE

U.S. Environmental Protection Agency
Science Advisory Board
Hydraulic Fracturing Research Advisory Panel

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Acronyms and Abbreviations

ATSDR	Agency for Toxic Substances and Disease Registry
BMP	Best Management Practices
BTEX	Benzene, Toluene, Ethylbenzene, and Xylenes
CBM	Coal Bed Methane
COGCC	Colorado Oil and Gas Conservation Commission
CWA	Clean Water Act
CWT	Centralized Wastewater Treatment
CWTFs	Centralized Wastewater Treatment Facilities
DOE	U.S. Department of Energy
DBP	Disinfection By-Product
EPA	U.S. Environmental Protection Agency
FDA	U.S. Food and Drug Administration
GIS	Geographic Information System
HAA	Haloacetic Acid
HF	Hydraulic Fracturing
HFWC	Hydraulic Fracturing Water Cycle
K_{ow}	Octanol-Water Partition Coefficient
MCDA	Multi-Criteria Decision Analysis
MCLs	Maximum Contaminant Levels
MRLs	Minimal Risk Levels
NDMA	N-Nitrosodimethylamine
NGO	Non-Governmental Organization
NPDES	National Pollutant Discharge Elimination System
OECD	Organisation for Economic Co-operation and Development
ORD	EPA Office of Research and Development
POTW	Publicly Owned Treatment Works
PWS	Public Water Supply
PWSS	Public Water Supply Systems
RCRA	Resource Conservation and Recovery Act
RfDs	Chronic Reference Doses
RfV	Reference Value
SAB	EPA Science Advisory Board
TDS	Total Dissolved Solids
THM	Trihalomethane
TLVs	Threshold Limit Values
TOC	Total Organic Carbon
TOX	Total Organic Halide
UIC	Underground Injection Control
USGS	U.S. Geological Survey
VOCs	Volatile Organic Compounds

1. EXECUTIVE SUMMARY

Overview

The EPA's Office of Research and Development (ORD) requested that the Science Advisory Board (SAB) conduct a peer review and provide advice on scientific charge questions associated with the EPA's June 2015 draft *Assessment of the Potential Impacts of Hydraulic Fracturing for Oil and Gas on Drinking Water Resources (External Review Draft, EPA/600/R-15/047, June 2015)* (hereafter, the "draft Assessment Report"). The draft Assessment Report synthesizes available scientific literature and data on the potential for hydraulic fracturing for oil and gas production to change the quality or quantity of drinking water resources, and identifies factors affecting the frequency or severity of any potential changes.

The EPA developed the draft Assessment Report in response to the U.S. Congress, which urged the EPA in late 2009 to examine the relationship between hydraulic fracturing and drinking water. In response, the EPA first developed a Research Scoping document (U.S. EPA, 2010), followed by a detailed research Study Plan (U.S. EPA, 2011), both of which were reviewed by the SAB, in 2010 and in 2011, respectively. A Progress Report (U.S. EPA, 2012) on the study describing the EPA's research approaches, activities, and remaining work was released in late 2012, and was followed by a consultation with individual expert members of SAB's Hydraulic Fracturing Research Advisory Panel (SAB HF Panel) convened under the auspices of the SAB in May 2013. The EPA used literature and the results from the EPA's research projects to develop the draft Assessment Report.

The EPA examined over 3,500 individual sources of information, and cited over 950 of these sources in the draft Assessment Report. The sources of data that the EPA evaluated included articles published in science and engineering journals, federal and state reports, non-governmental organization reports, oil and gas industry publications, other publicly available data and information, including confidential and non-confidential business information, submitted by industry to the EPA. The draft Assessment Report also includes citation of relevant literature developed as part of the EPA's research Study Plan (U.S. EPA, 2011).

At a series of public meetings held in the last quarter of 2015 and the first quarter of 2016, the SAB HF Panel reviewed the draft Assessment Report and considered public comments to develop advice on the scientific adequacy of the EPA's draft Assessment Report. The chartered SAB deliberated on the SAB HF Panel's draft report in ***[Insert Month/Year]*** and ***[Insert chartered SAB disposition of the draft Panel Report]***. The body of this report provides the advice and recommendations of the SAB.

The SAB was asked to provide advice and comment on various aspects of the EPA's draft Assessment Report through responses to eight charge questions. The multi-part charge questions were formulated to follow the structure of the assessment, including the introduction, the descriptions of hydraulic fracturing activities and drinking water resources, the individual stages in the hydraulic fracturing water cycle (HFWC), the identification and hazard evaluation of hydraulic fracturing chemicals, and the overall synthesis of the materials presented in the assessment.

The enclosed report provides detailed comments and recommendations for improving the draft Assessment Report, as well as recommendations that the agency may consider longer-term activities that may be conducted after the draft Assessment Report is finalized. Also included, as Appendix B, is a dissenting view from one member of the Panel mainly on the major findings of the EPA, on the adequacy of spill assessment by the EPA, and on the need for prospective studies. The SAB's key findings and recommendations are summarized below.

In general, the SAB finds the EPA's overall approach to assess the potential impacts of hydraulic fracturing for oil and gas production on drinking water resources, focusing on the individual stages in the HFWC, to be appropriate and comprehensive. The SAB also finds that the agency provided a generally comprehensive overview of the available literature that describes the factors affecting the relationship of hydraulic fracturing and drinking water, and adequately described the findings of such published data in the draft Assessment Report. However, the SAB has concerns regarding various aspects of the draft Assessment Report and has several recommendations for changes to its text and follow-on activities to address gaps that the SAB has identified. The SAB is also concerned that the EPA had planned to but did not conduct various assessment, field studies, and other research, and the SAB recommends that the EPA delineate these planned activities within the draft Assessment Report and discuss why they were not conducted. The SAB concludes that the lack of prospective case studies as originally planned by the EPA and described in the research Study Plan (U.S. EPA, 2011) is a major limitation of the draft Assessment Report.

The SAB recognizes that there are a large number of recommendations included in this SAB report. The SAB has identified SAB recommendations that the agency may consider longer-term future activities that may be conducted after the draft Assessment Report is finalized. If there are recommendations that the EPA is unable to fully address before finalizing the draft Assessment Report, the SAB recommends that the EPA describe the additional research needed to adequately assess the topic and include this in the Chapter 10 or a chapter that the EPA would add to the draft Assessment Report on ongoing research, and data and research needs.

Thematic Areas for Improving the Draft Assessment Report

The SAB identified several thematic areas for improvement of the draft Assessment Report.

<u>Revisions to Statements on Major Findings</u>

In its draft Assessment Report, the Agency sought to draw national-level conclusions regarding the impacts of hydraulic fracturing on drinking water resources. The SAB finds that several major summary findings do not clearly, concisely, and accurately describe the findings as developed in the chapters of the draft Assessment Report, and that these findings are not adequately supported with data or analysis from within the body of the draft Assessment Report. The SAB is concerned that these major findings are presented ambiguously within the Executive Summary and appear inconsistent with the observations, data, and levels of uncertainty presented and discussed in the body of the text.

Most SAB Panel members expressed particular concern regarding the draft Assessment Report's high-level conclusion on page ES-6 that "We did not find evidence that these mechanisms have led to widespread, systemic impacts on drinking water resources in the United States." Most SAB Panel members find that this statement does not clearly describe the system(s) of interest (e.g., groundwater, surface water) nor the definitions of "systemic" and "widespread," agree that the statement has been interpreted by members of the public in many different ways, and conclude that the statement requires clarification and additional explanation. A Panel member finds that this statement is acceptable as written and that the EPA should have provided a more robust discussion on how the EPA reached this conclusion (e.g., through a comparison of the number of wells drilled vs. reported spills, or analysis on reported potable wells shown to be impacted by HFWC). Further details regarding this Panel member's concerns are noted in Attachment 1 to this Report.

The Agency should strengthen the Executive Summary and Chapter 10 Synthesis by linking the stated findings more directly to evidence presented in the body of the draft Assessment Report. The EPA should more precisely describe each of the major findings of the draft Assessment Report, in both the Executive Summary and Chapter 10 Synthesis, and provide a full accounting of all available information, including specific cases of drinking water impacts, that relate to these major findings. The synthesis discussion in Chapter 10 should be revised to present integrated conclusions, rather than a summary of findings from Chapters 4-9. These integrated conclusions should include those hydraulic fracturing practices demonstrated to be effective in safeguarding drinking water resources. Chapter 10 should also be revised to discuss methods to reduce uncertainties related to the HFWC, including research, data, and research needs.

<u>More Attention to Local Impacts</u>

The SAB finds that EPA's initial goal of assessing the HFWC using national-level analyses and perspective was appropriate. The draft Assessment Report should recognize that most stresses to surface or groundwater resources associated with stages of the HFWC are localized. For example, the impacts of water acquisition will predominantly be felt locally at small space and time scales. These local-level hydraulic fracturing potential impacts can be severe, and the draft Assessment Report needs to better characterize and recognize the importance of local impacts, especially since locally important impacts are unlikely to be captured in a national-level summary of impacts.

In the context of the need for more attention to local impacts, the SAB finds that the Agency should include and explain the status, data on potential releases, and findings if available, for the EPA and state investigations conducted in Dimock, Pennsylvania; Pavillion, Wyoming; and Parker County, Texas, where hydraulic fracturing activities are perceived by many members of the public to have caused impacts to drinking water resources. Examination of these high-visibility cases is important so that the public can more fully understand the status of investigations in these areas; conclusions associated with the investigations; lessons learned, if any, for the different stages of the hydraulic fracturing water cycle; what additional work should be done to improve the understanding of these sites with respect to the HFWC; plans for remediation, if any; and the degree to which information from these case studies can be extrapolated to other locations.

The Panel was not unanimous on the subject of prospective case studies to examine the effects on HF on the HFWC. The SAB agrees that EPA should evaluate lessons learned from its initial attempts to develop the prospective case studies, including how these lessons could inform design of future prospective case studies. The draft Assessment Report should identify ongoing and future needs for research, assessments, and field studies. The SAB agrees that draft Assessment Report should discuss its plans for conducting prospective studies and other research that EPA had planned but did not conduct, including the prospective case studies as originally described in the research Study Plan (U.S. EPA, 2011).For the majority of Panelists, this lack of prospective case studies is a major limitation of the draft Assessment Report. The SAB agrees that prospective studies would allow the EPA to monitor the potential impacts of HF activities on the HFWC to a level of detail not routinely practiced by industry or required by most state regulation. Such detailed new data would enable EPA to reduce current uncertainties and research gaps regarding the relationship between hydraulic fracturing and drinking water, particularly for localized stresses to surface or groundwater resources as associated with different stages of the HFWC. The SAB agrees that the Agency may consider the issue of prospective case studies as an item for longer-term future activity. One Panel member concluded that this prospective study work is not needed and should not be conducted.

The draft Assessment Report provided limited information on the magnitude of hydraulic fracturing spills from all available sources and used information from two states – Pennsylvania and Colorado – to estimate the frequency of on-site spills nationwide. The SAB recognizes that these two states likely have the most complete datasets on spills available to the EPA. However, the Panel notes that geologies vary between states and this limits extrapolation. The Panel encourages the agency to contact state agencies and review state databases in order to enable a broader analysis and to update the draft Assessment Report to reflect this. Although the SAB recognizes that state database systems vary, the databases should be incorporated into the EPA's reporting of metrics within the draft Assessment Report. As written, the SAB finds that the draft Assessment Report's analysis of spill data cannot confidently be extrapolated across the entire U.S. The SAB recommends that the Agency revisit a broader grouping of states and "refresh" the draft Assessment Report with updated information on the reporting of spills associated with HFWC activities. The draft Assessment Report does not provide a robust discussion regarding the information yielded from available data on HFWC spills, and SAB recommends that the EPA assess and discuss the current status of data reporting on spills, the nature of hydraulic fracturing fluids, and a more thorough presentation and explanation of the frequency and types of data reported by the hydraulic fracturing industry. In addition, the SAB finds that it is essential to have more extensive and reliable information on type, intensity, and duration of human exposures to HFWC constituents and chemicals in order to determine whether hydraulic fracturing activities in different locales pose health risks.

The SAB agrees there are important gaps and uncertainties in publicly available data on sources and quantities of water used in hydraulic fracturing. To address these gaps and uncertainties, the agency should, as a longer-term future activity: 1) synthesize information that is collected by the states but not available in mainstream databases, such as well completion reports, permit applications, and the associated water management plans; and 2) assess whether there are specific local and regional aquifers that are particularly impacted by HFWC activities, and if so, provide quantifiable information on this topic. In the draft Assessment Report the agency should describe the scale of the task for gathering and organizing data collected by states its efforts to investigate data available from state agencies, the scale of its efforts to conduct this investigation, and the critical lessons learned from the effort.

<u>Data Needs Regarding Chemicals of Concern</u>

Throughout the draft Assessment Report, within discussions for each stage of the HFWC, the EPA notes that there are data limitations that prevented the EPA from doing analyses that the EPA desired to conduct. Within these discussions, the EPA should outline the level of data that the EPA would desire in order for it to conduct an appropriate assessment of that topic area.

The Panel finds that EPA could improve its use of publicly available databases, including the FracFocus Chemical Disclosure Registry database and the Water Use in the United States database. Regarding the

FracFocus database, the SAB agrees that it may not be sufficient because it does not include certain proprietary, confidential business information (CBI) and because it lacks information on the identity, properties, frequency of use, and magnitude of exposure for approximately 11% of hydraulic fracturing chemicals used in HF operations (which are considered CBI; see EPA draft Assessment Report, p. 5-73).The Agency should acknowledge the limited information on the fluids being injected, and should describe its concerns regarding its reliance on the February 2013 FracFocus version 1.0 for its findings in the draft Assessment Report. The agency should also revise the draft Assessment Report, to characterize in some fashion data on proprietary compounds that the EPA may have, and information provided in FracFocus on chemical class and concentration (% mass of hydraulic fracturing fluid). Since the FracFocus data that the agency assessed was current up to February 2013, the SAB also recommends that the draft Assessment Report discuss the current status, use and changes to the FracFocus platform, and outline what follow-on analyses should be done with the FracFocus database. For example, analyses on trends in green chemical usage in HF could be conducted. As feasible, the EPA should consider conducting some preliminary analyses of trends. Further, the EPA should discuss the current status of FracFocus and changes that have been made to the FracFocus platform and system, and articulate needs for information that is collected and available from individual states and that could help with assessment yet is not readily accessible. In addition, the agency should note that the current version of FracFocus also provides some additional insights into the CBI associated with chemicals used during HF operations. Finally, potential limitations and uncertainties of the Water Use in the United States dataset should be discussed. There are limitations and uncertainties associated with the spatial and temporal scale of the information presented (by county and state, in five-year intervals), and with the categories of data (e.g., with data definitions changing over time, and with water used for hydraulic fracturing reported as part of a larger overall category of water use associated with mining). The EPA should, as a longer-term future activity, update the study results with the latest information from the current versions of these databases.

The SAB commends the EPA for conceiving and designing the Multi-Criteria Decision Analysis (MCDA) presented in Chapter 9, and for formulating a logical approach for assessing the scope and potential impacts of hydraulic fracturing on national drinking water resources, given that the available information is limited and fragmented. However, the SAB finds that the agency should not restrict the criteria for selection of hydraulic fracturing chemicals of concern to solely chemicals that have formal non-cancer oral reference values (RfVs) and cancer oral slope factors (OSFs). The agency should expand the criteria for identifying hydraulic fracturing chemicals of concern through use of peer-reviewed toxicity data, including information pertinent to sub-chronic exposures available from a number of reliable sources. The draft Assessment Report should explicitly indicate what fraction of the compounds identified in hydraulic fracturing fluid and/or produced waters have some hazard information (e.g., toxicity data available from or used by U.S. or state governments or international non-governmental organizations for risk assessment purposes, or publicly available peer-reviewed data), and what fraction have no available information.

The SAB recommends that the EPA outline a plan for analyzing organic compounds in HF flowback and produced waters, in collaboration with state agencies. Flowback water composition data are limited and the majority of available data are for inorganics. In addition, data are needed on the formation of disinfection by-products in drinking water treatment plants downstream from Centralized Wastewater Treatment Facilities (CWTFs) and from Publicly Owned Treatment Works (POTWs) receiving hydraulic-fracturing-related wastewater.

For the sake of clarity, the draft Assessment Report should distinguish between hydraulic fracturing chemicals injected into a hydraulically fractured well vs. compounds that come back out of the well in produced fluids. It should also distinguish between those chemical constituents and potential impacts unique to hydraulic fracturing oil and gas extraction and from those that also exist as a component of conventional oil and gas development. The draft Assessment Report should also clarify whether compounds identified as being of most concern in produced water are products of the hydraulic fracturing activity, flowback, or late-stage produced water, or are chemicals of concern derived from oil and gas production activities that are not unique to hydraulic fracturing activity. This will help inform the public about the different characteristics of HF injection flowback and produced waters and in-situ subsurface brines as compared to formation water produced in conventional oil and gas development.

<u>Best Management Practices and Improvements in Hydraulic Fracturing Operations</u>

The SAB recommends that the agency describe best management practices used by industry regarding operations associated with each stage of the HFWC, in order to better inform the public on available processes, methods and technologies that can minimize hydraulic fracturing potential impacts to drinking water resources. Also, the draft Assessment Report should summarize improvements, changes or accomplishments that have occurred since 2012 in hydraulic fracturing operations related to the HFWC. Since 2012, many significant technological and regulatory oversight improvements have occurred related to well construction, well integrity, well injection, and other aspects of the HFWC. Within the draft Assessment Report, the EPA should discuss state standards and regulations that have been implemented with the aim of improving hydraulic fracturing operations, and the evolution of oilfield and state regulatory practices that are relevant to HFWC activities. The EPA should consider hydraulic fracturing-related standards and regulations within a few key states such as Pennsylvania, Wyoming, Texas, Colorado and California who all have implemented new hydraulic fracturing-related regulations since 2012.

<u>Transparency and Clarity of the Assessment</u>

The SAB recommends that sections of the draft Assessment Report should be revised to make these sections more suitable for a broad audience. As currently written, the Executive Summary is understandable to technical experts in geoscience and engineering, but will be less clear to a general audience. It is important that the general public be able to understand the Assessment Report and especially the Executive Summary. The SAB makes specific recommendations about opportunities to define terms, provide illustrations, clarify ambiguities, and be more precise in the presentation of major findings. Clearer statements are needed on the goals and scope of the assessment and on specific descriptions of hydraulic fracturing activities. Well-designed diagrams and illustrations should be added to enhance the public's understanding of hydraulic fracturing activities and operations. Technical terms should be used sparingly and should always be defined, and graphics should be introduced to illustrate and clarify key concepts and processes. To improve the clarity of the document, the EPA could also consider developing questions that could be answered to summarize findings throughout the draft Assessment Report. For example, the text could provide discussion of what is a likely scenario based upon "x" and what is a possible scenario based upon "y" to show a range of possibilities with the technical backup that supports any generalizations. The technical backup could be specific cases, for example.

Highlights of Responses to Specific Charge Questions

The SAB provides a number of additional suggestions to improve the agency's approach for assessing the potential for HFWC activities to change the quality or quantity of drinking water resources. Among these is a recommendation that the Assessment Report should identify critical data and research needs for reducing uncertainties. A more detailed description of the technical recommendations is included in this SAB report, and the responses to specific charge questions are highlighted below.

<u>Goals, Background and History of the Assessment (Charge Question 1)</u>

> *The goal of the assessment was to review, analyze, and synthesize available data and information concerning the potential impacts of hydraulic fracturing on drinking water resources in the United States, including identifying factors affecting the frequency or severity of any potential impacts. In Chapter 1 of the assessment, are the goals, background, scope, approach, and intended use of this assessment clearly articulated? In Chapters 2 and 3, are the descriptions of hydraulic fracturing and drinking water resources clear and informative as background material? Are there topics that should be added to Chapters 2 and 3 to provide needed background for the assessment?*

The SAB was asked whether the opening chapters of the draft Assessment Report were clearly articulated and informative, and whether additional topics should be added. Chapters 1, 2, and 3 provide a generally well written overview of the assessment and descriptions of hydraulic fracturing, the HFWC, and drinking water resources. However, Chapter 1 could be improved by including and highlighting a concise statement of the goals of the assessment, and by incorporating a more careful statement of its scope. The description of hydraulic fracturing in Chapter 2 is clear and informative, but needs to give more emphasis to some aspects of hydraulic fracturing that distinguish it from conventional well development. The description of drinking water resources in Chapter 3 is also clear and informative, but also could be improved, in particular by paying more attention to the local geology, hydrogeology, and to the physical properties (thickness, porosity, permeability, fracture density) of the rock layers overlying target horizons, and including more discussion of the characteristics and proximity of aquifers.

As the intended users of the draft Assessment Report range from policy makers and regulators to the industry and the public, the EPA should include illustrative material (illustrations, diagrams, and charts) in these chapters so that non-technical readers have visuals to facilitate understanding of this technical material. Within Chapters 2 and/or 3, the draft Assessment Report should also include discussions of new hydraulic fracturing technologies. Within Chapter 1 or an appendix, the draft Assessment Report should include an overview discussion of federal and state standards and regulations that pertain to hydraulic fracturing activities for oil and gas development, and mechanisms for enforcement of the laws with respect to protection of surface water quality, groundwater quality, municipal water supplies, and private wells. The overview should provide a description of organizations responsible for monitoring and regulation of HFWC activities.

The EPA should add more information regarding groundwater resources in hydraulically fractured areas (e.g., typical depths to aquifers, confined or unconfined aquifers, aquifer thicknesses, and aquifer continuity). The draft Assessment Report should present more information regarding the vertical distance between surface-water bodies and the target zones being fractured, and the depths of most aquifers compared to the depths of most hydraulically fractured wells. The draft Assessment Report should include text to describe why the EPA assessed certain HF-related topics and issues within the draft Assessment Report, and why certain hydraulic fracturing topics, issues and activities were considered to be beyond the scope of this assessment (e.g. contamination from drilling fluids and cuttings).

It should be emphasized that the EPA-conducted research was integrated with a large amount of additional information and research. The EPA should explicitly explain what it did in terms of its own research in developing the assessment. The EPA should also discuss the temporal characteristics and differences in temporal characteristics for the HFWC stages in Chapter 2 (e.g. the differences in duration of the actual hydraulic fracturing of the rock versus the duration of production). In addition, the EPA should assess whether there are specific local and regional aquifers that are particularly impacted by hydraulic fracturing activities, and if so, provide quantifiable information on this topic within the draft Assessment Report.

The draft Assessment Report should make clear that the hydraulic fracturing industry is rapidly evolving, with changes in the processes being employed, whereas the Assessment necessarily was developed with the data available at a point in time.

<u>Water Acquisition Stage in the HFWC (Charge Question 2)</u>

> *The scope of the assessment was defined by the HFWC, which includes a series of activities involving water that support hydraulic fracturing. The first stage in the HFWC is water acquisition: the withdrawal of ground or surface water needed for hydraulic fracturing fluids. This is addressed in Chapter 4.*
>
> *a. Does the assessment accurately and clearly summarize the available information concerning the sources and quantities of water used in hydraulic fracturing?*
> *b. Are the quantities of water used and consumed in hydraulic fracturing accurately characterized with respect to total water use and consumption at appropriate temporal and spatial scales?*
> *c. Are the major findings concerning water acquisition fully supported by the information and data presented in the assessment? Do these major findings identify the potential impacts to drinking water resources due to this stage of the HFWC? Are there other major findings that have not been brought forward? Are the factors affecting the frequency or severity of any impacts described to the extent possible and fully supported?*
> *d. Are the uncertainties, assumptions, and limitations concerning water acquisition fully and clearly described?*
> *e. What additional information, background, or context should be added, or research gaps should be assessed to better characterize any potential impacts to drinking water resources from this stage of the HFWC? Are there relevant literature or data sources that should be added in this section of the report?*

The SAB was asked whether Chapter 4 of the draft Assessment Report comprehensively, accurately and clearly summarized potential impacts associated with the water acquisition stage of the HFWC, whether uncertainties and limitations were fully described, and whether additional information or topics should be added. An enormous amount of available information about the quantities of water used in hydraulic fracturing was synthesized in Chapter 4 of the draft Assessment Report. The agency concludes Chapter 4 with a statement that the quantity of water withdrawn for hydraulic fracturing represents a small proportion of freshwater usage at regional or state-wide levels. While the draft Assessment Report comprehensively summarizes the available information concerning the sources and quantities of water used from surface water, groundwater, and treated wastewaters, the SAB finds that EPA's statistical extrapolation to describe average conditions at the national scale masks important regional and local differences in water acquisition impacts. Stresses to surface or groundwater resources associated with water acquisition and hydraulic fracturing are localized and temporary in time.

The SAB finds that water withdrawals for hydraulic fracturing can contribute significantly to groundwater depletion, particularly in arid environments. Further, the SAB concurs with the EPA's findings that water withdrawals for hydraulic fracturing are capable of altering the flow regimes of streams, even in regions of rainfall abundance, and that the potential for water availability impacts on drinking water resources is greatest in areas with high hydraulic fracturing water use, low water availability, and frequent drought. While the SAB concurs with these findings, the agency should include additional clarifications in the draft Assessment Report on the regulatory frameworks in which the HFWC activities are managed that aim to minimize the potential for these negative impacts.

The SAB agrees there are important gaps and uncertainties in publicly available data on sources and quantities of water used in hydraulic fracturing. At local scales, where the greatest impacts are most likely to occur, reliable data are generally lacking. These reported gaps limit the understanding of potential impacts of water acquisition of HFWC activities on drinking water resources. To address these gaps and uncertainties, the agency should, as a longer-term future activity: 1) synthesize information that is collected by the states but not available in mainstream databases, such as well completion reports, permit applications, and the associated water management plans; and 2) assess whether there are specific local and regional aquifers that are particularly impacted by HFWC activities, and if so, provide quantifiable information on this topic. The EPA should describe best management practices being implemented by the states or other regulatory agencies (e.g., the Susquehanna River Basin Commission) that have well established programs in permitting, collecting, monitoring and managing water resources. In the draft Assessment Report the agency should describe the scale of the task for gathering and organizing data collected by states its efforts to investigate data available from state agencies, the scale of its efforts to conduct this investigation, and the critical lessons learned from the effort.
The SAB recommends that the EPA conduct further work to explore how hydraulic fracturing water withdrawals affect short-term water availability at local scales. The SAB concludes that the agency should continue efforts, for the long term, to do the work proposed in the prospective studies that were in the EPA's research Study Plan (U.S. EPA, 2011) but which were subsequently not conducted. The EPA should enhance the understanding of localized impacts by providing more focus and analysis on the Well File Review and on examination of other information not in literature and common databases in order to provide information about actual hydraulic fracturing water acquisition and its relationship to drinking water.

The SAB concludes that the lack of prospective case studies as originally planned by the EPA and described in the research Study Plan (U.S. EPA, 2011) is a major limitation of the draft Assessment Report. The SAB finds that such studies would allow the EPA to monitor conditions prior to drilling, during drilling and completion (aka fracturing) and production to a level of detail not routinely practiced by industry or required by most state regulation. These detailed new data would allow the EPA to reduce current uncertainties and research gaps about the relation between hydraulic fracturing water acquisition and drinking water. The SAB concludes that the EPA should continue research, as a longer-term future activity on expanded case studies and long-term prospective studies. One Panel member concluded that this prospective study work is not needed and should not be conducted.

There are several additional major findings that the EPA should identify within this chapter. First, it should be more clearly noted that the stresses on water resources are expected to be local and temporary, and the agency should not understate the potential for localized problems associated with such stresses. Second, the draft Assessment Report should consider further exploring and describing how water acquisition and associated potential impacts on lowered streamflow and water table drawdown could affect the availability of drinking water. Third, the EPA draft Assessment Report should expand on the discussion of the evolution and utilization of technologies that are being used to facilitate reuse of produced water or other non-drinking sources of water.

<u>Chemical Mixing Stage in the HFWC (Charge Question 3)</u>

The second stage in the HFWC is chemical mixing: the mixing of water, chemicals, and proppant on the well pad to create the hydraulic fracturing fluid. This is addressed in Chapter 5.

a. Does the assessment accurately and clearly summarize the available information concerning the composition, volume, and management of the chemicals used to create hydraulic fracturing fluids?
b. Are the major findings concerning chemical mixing fully supported by the information and data presented in the assessment? Do these major findings identify the potential impacts to drinking water resources due to this stage of the HFWC? Are there other major findings that have not been brought forward? Are the factors affecting the frequency or severity of any impacts described to the extent possible and fully supported?
c. Are the uncertainties, assumptions, and limitations concerning chemical mixing fully and clearly described?
d. What additional information, background, or context should be added, or research gaps should be assessed, to better characterize any potential impacts to drinking water resources from this stage of the HFWC? Are there relevant literature or data sources that should be added in this section of the report?

The SAB was asked whether Chapter 5 of the draft Assessment Report comprehensively, accurately and clearly summarized potential impacts associated with the chemical mixing stage of the HFWC, whether uncertainties and limitations were fully described, and whether additional information or topics should be added. The chemical mixing stage of the HFWC, addressed in Chapter 5 of the draft Assessment Report, includes a series of above-ground, engineered processes involving complex hydraulic fracturing fluid pumping and mixing operations, and the potential failure of these processes, including near-site containment, poses a potentially significant risk to drinking water supplies. The SAB finds that the data presented by the EPA within this chapter indicates that spills occur at hydraulic fracturing sites; that there are varying causes, composition, frequency, volume, and severity of such spills; and that little is known about certain hydraulic fracturing chemicals and their safety. While the EPA conducted a large effort in developing this chapter, most members of the SAB Panel are concerned that two fundamental, underlying questions have not been answered: (1) What is the potential that spills occurring during the chemical mixing process affect drinking water supplies? and (2) What are the relevant concerns associated with the degree to which these spills impact drinking water supplies? These Panel members are also concerned that the EPA's major finding "None of the spills of hydraulic fracturing fluid were reported to have reached groundwater" is supported only by an absence of evidence rather than by evidence of absence of impact. A Panel member finds that the draft Assessment Report provided a thorough description of the variables associated with a spill (i.e., amount, duration, soils, weather, groundwater, surface water, constituents released, and other spill aspects), and noted that the Report should provide more granularity on how states respond to spills.

There are three major findings that the EPA should present in this chapter of the draft Assessment Report:

(1) There is significant uncertainty regarding which hydraulic fracturing chemicals are currently in use.

(2) There is significant uncertainty regarding the identity of chemicals used in particular hydraulic fracturing operations, and this uncertainty is compounded by limited knowledge about on-site storage of hydraulic fracturing chemical.

(3) There is significant uncertainty regarding the frequency, severity, and type of hydraulic fracturing-related spills and their associated impacts.

Chapter 5, as it stands, provides little knowledge of the magnitude of hydraulic fracturing spills and it does not adequately describe either the uncertainty or the lack of understanding of such spills. The SAB notes that the EPA's estimates on the frequency of on-site spills were based upon information from two states. While the SAB recognizes that the states of Pennsylvania and Colorado likely have the most complete datasets on this topic that the EPA could access, the SAB notes that geologies vary between states and encourages the agency to contact the state agencies and review state databases and update the draft Assessment Report to reflect a broader analysis. While the SAB recognizes that state database systems vary, the databases should be incorporated into the EPA's reporting of metrics within the draft Assessment Report. As written, the SAB finds that the draft Assessment Report's analysis of spill data cannot confidently be extrapolated across the entire U.S. The SAB recommends that the agency revisit a broader grouping of states and "refresh" the draft Assessment Report with updated information on the reporting of spills associated with HFWC activities. The SAB finds that the uncertainties, assumptions, and limitations concerning chemical mixing are not fully and clearly described, and that data limitations compromise the ability to develop definitive, quantitative conclusions within the draft Assessment Report regarding the frequency and severity of spilled liquids. The SAB also concludes that the retrospective case studies that are reported in the draft Assessment Report do not provide sufficient clarity on the potential severity of spilled liquids, pre-existing conditions of groundwater, causation for the issue (e.g., well integrity), or current regulatory status with the relevant agencies associated with the sites. The EPA provided incomplete data on chemical mixing process spill frequency and the potential severity of effects of such spills on drinking water resources. The SAB finds that the EPA's interpretation of these limited data in its conclusion that the risk to drinking water supplies from this stage of the HFWC is not substantial is not supported or linked to data presented in the body of the draft Assessment Report, and the EPA should revise this interpretation of these limited data;

The SAB recommends that the EPA revise its assessments associated with the chemical mixing stage of the HFWC to address these concerns. The agency should:

- Revise Chapter 5 of the draft Assessment Report to provide more information regarding the extent or potential extent of the effects of spills associated with chemical mixing processes from hydraulic fracturing operations to drinking water supplies.
- Describe the type of data needed to provide a meaningful assessment of the extent, severity and potential impact of spills. The assessment needs to be critical and based on the relevant factors

contributing to spill severity, including the mass of chemicals spilled, the total volumes and duration of the spills.
- Describe clearly the efforts that the EPA made, or barriers that the EPA encountered, to using the data that was available.
- Include within the draft Assessment Report a more thorough presentation and explanation of the frequency and types of data that the hydraulic fracturing industry reports, some of which may not be readily accessible (i.e., not in an electronic format that is 'searchable').
- Provide improved analysis on the current state of data reporting on spills and the nature of hydraulic fracturing fluids.
- Define "severity" in a way that is amenable to quantitative analysis and clearly delineate those factors contributing to spill severity within the draft Assessment Report.
- Investigate at least one state as a detailed example for scrutinizing the available spill data (since a number of states have spill reporting requirements and processes).

<u>Well Injection Stage in the HFWC (Charge Question 4)</u>

The third stage in the HFWC is well injection: the injection of hydraulic fracturing fluids into the well to enhance oil and gas production from the geologic formation by creating new fractures and dilating existing fractures. This is addressed in Chapter 6.

a. Does the assessment clearly and accurately summarize the available information concerning well injection, including well construction and well integrity issues and the movement of hydraulic fracturing fluids, and other materials in the subsurface?
b. Are the major findings concerning well injection fully supported by the information and data presented in the assessment? Do these major findings identify the potential impacts to drinking water resources due to this stage of the HFWC? Are there other major findings that have not been brought forward? Are the factors affecting the frequency or severity of any impacts described to the extent possible and fully supported?
c. Are the uncertainties, assumptions, and limitations concerning well injection fully and clearly described?
d. What additional information, background, or context should be added, or research gaps should be assessed, to better characterize any potential impacts to drinking water resources from this stage of the HFWC? Are there relevant literature or data sources that should be added in this section of the report?

The SAB was asked whether Chapter 6 of the draft Assessment Report comprehensively, accurately and clearly summarized potential impacts associated with the well injection stage of the HFWC, whether uncertainties and limitations were fully described, and whether additional information or topics should be added. The hydraulic fracturing well injection stage of the HFWC is described in Chapter 6 of the draft Assessment Report. The well injection stage has an important role in the HFWC's potential influence on drinking water resources. The chapter covers a wide range of topics and raises many potential issues regarding the potential effects of hydraulic fracturing on drinking water resources. While Chapter 6 provides a comprehensive overview of the well injection stage in the HFWC, the chapter is very densely written and is potentially inaccessible to the nontechnical reader. The SAB recommends that the EPA include additional, clearer diagrams and illustrations in this chapter to help the general public better understand the concepts and the most significant failure scenarios and mechanisms regarding this stage in the HFWC. The EPA should also include discussions of new technologies and state standards and regulations that have improved hydraulic fracturing operations.

Chapter 6 provides a comprehensive list of possible hydraulic fracturing-related failure scenarios and mechanisms related to this stage in the HFWC. The draft Assessment Report should not make definitive statements regarding whether some or all hydraulically fractured wells are or are not leaking because the chapter's conclusions regarding how many hydraulically fractured wells are or are not leaking are not well supported by analyses or other information presented. Before drawing conclusions on water quality impacts associated with this HFWC step, the agency should:

- More clearly describe the probability, risk, and relative significance of potential hydraulic fracturing-related failure mechanisms, and the frequency of occurrence and most likely magnitude and/or probability of risk of water quality impacts, associated with this stage in the HFWC.
- Include a discussion of recent state hydraulic fracturing well design standards, required mechanical integrity testing in wells, new technologies and fracture fluid mixes, and state regulatory standards that have changed the probability of risk of water quality impacts associated with this stage in the HFWC.
- Include an analysis and discussion on low frequency, high severity hydraulic fracturing case studies and example situations.

Important lessons from carbon capture and storage studies, such as those conducted under the U.S. Department of Energy (DOE), have shown that well construction and integrity issues are a primary concern with potential releases of chemicals into the environment associated with subsurface storage. The SAB notes that these carbon capture and storage studies have relevance to assessments regarding potential releases from hydraulic fracturing activities. The SAB recommends that the agency examine DOE data and reports on risks of geological storage of CO_2 to water resources and include relevant information in the Assessment Report.

The SAB also recommends that the agency include and explain the status, data on potential releases, and findings if available for the EPA and state investigations conducted in Dimock, Pennsylvania; Pavillion, Wyoming; and Parker County, Texas where hydraulic fracturing activities are perceived by many members of the public to have caused impacts to drinking water resources. Examination of these high-visibility, well-known cases is important so the public can more fully understand the status of investigations in these areas, conclusions associated with the investigations, lessons learned if any for the different stages of the hydraulic fracturing water cycle, what additional work should be done to improve the understanding of these sites and the HFWC, plans for remediation if any, and the degree to which information from these case studies can be extrapolated to other locations.

In the descriptions of the models for fracture propagation and fluid migration introduced and discussed in this chapter, the EPA should clarify that these model predictions and results are not evidence, and clearly describe the limitations of such models.

The draft Assessment Report should include some discussion about the ongoing work associated with induced seismicity in HFWC activities and potential impacts on drinking water resources associated with hydraulic fracturing activity. Induced seismicity from well injection for hydraulic fracturing should be distinguished from induced seismicity associated with hydraulic fracturing wastewater disposal via Class II deep well injection. Detailed discussion of induced seismicity from wastewater disposal should be reserved for Chapter 8 which is focused on wastewater treatment and disposal.

A key aspect of reducing impacts from HFWC operations to drinking water supplies is responsible well construction and operation, and isolation of potable water from hydraulic fracturing operations. To accomplish this, the agency should recognize in the draft Assessment Report that the following activities are required: inspection, testing and monitoring of the tubing, tubing-casing annulus and other casing annuli; and monitoring and testing of the potable groundwater through which the tubing, tubing-casing annulus and other casing annuli pass. The SAB also notes that the EPA can reduce uncertainties associated with hydraulic fracturing cement and casing integrity by examining and assessing more of the 20,000 well files referenced in the draft Assessment Report. This would be a longer-term, future activity. The SAB also recommends that the EPA communicate more fully the statistical analyses that were conducted and perform these analyses on any future expanded Well File Review, and develop graphs or tables associated with such analyses.

The SAB recommends that when estimated percentages are quoted from the Well File Review, the EPA should accompany them with the relevant confidence intervals, and indicate whether they are found in the text of the Review or are inferred from graphs. The EPA should also discuss whether the relatively low percentage of horizontal well completions covered by the Review limits its relevance to current practice.

The agency should include additional major findings associated with the higher likelihood of impacts to drinking water resources associated with hydraulic fracturing well construction, well integrity, and well injection problems. These findings should discuss factors and effects regarding the severity and frequency of potential impacts from poor hydraulic fracturing cementation techniques, hydraulic fracturing operator error, migration of hydraulic fracturing chemicals from the deep subsurface, and abandoned hydraulically fractured wells.

<u>Flowback and Produced Water Stage in the HFWC (Charge Question 5)</u>

> *The fourth stage in the HFWC focuses on flowback and produced water: the return of injected fluid and water produced from the formation to the surface and subsequent transport for reuse, treatment, or disposal. This is addressed in Chapter 7.*
>
> *a. Does the assessment clearly and accurately summarize the available information concerning the composition, volume, and management of flowback and produced waters?*
> *b. Are the major findings concerning flowback and produced water fully supported by the information and data presented in the assessment? Do these major findings identify the potential impacts to drinking water resources due to this stage of the HFWC? Are there other major findings that have not been brought forward? Are the factors affecting the frequency or severity of any impacts described to the extent possible and fully supported?*
> *c. Are the uncertainties, assumptions, and limitations concerning flowback and produced water fully and clearly described?*
> *d. What additional information, background, or context should be added, or research gaps should be assessed, to better characterize any potential impacts to drinking water resources from this stage of the HFWC? Are there relevant literature or data sources that should be added in this section of the report?*

The SAB was asked whether Chapter 7 of the draft Assessment Report comprehensively, accurately and clearly summarized potential impacts associated with the flowback and produced water stage of the HFWC, whether uncertainties and limitations were fully described, and whether additional information or topics should be added. Overall, the discussion on hydraulic fracturing flowback and produced water within Chapter 7 of the draft Assessment Report provides a clear and accurate summary of the available information concerning composition, volume, and management of flowback and produced waters. Chapter 7 also provides an overview of fate and transport of spilled liquids and the various components necessary to evaluate migration of a spill (i.e., amount of material released, timing of the release, response efforts, timing of response measures, soils, geology, and receptors).

However, the EPA should provide additional detail describing the extent and duration of the impacts of spilled liquids and releases of flowback and produced waters when they occur, and conduct various activities including those described below to reduce uncertainties associated with conclusions regarding such impacts:

- While Chapter 7 summarizes many types of incidents regarding the management of flowback and produced waters and refers to case studies that describe leaks and spills, the chapter should provide additional detail describing the extent and duration of the impacts associated with these incidents, including details on the impact of spilled liquids and releases when they occur. To understand the likely probability of these events, Chapter 7 should quantify in text and in a figure the frequency of the different types of release events, including whether the spilled material impacts groundwater or surface water.
- While the major findings on hydraulic fracturing flowback and produced water presented in Section 10.1.4 of the draft Assessment Report are supported by the analysis presented in Chapter 7, the major findings should be more explicitly quantified and clearly identified within the chapter.
- The agency should also include additional major findings associated with the effects on drinking water resources of large spill events that escape containment, and sustained, undetected leaks.
- The draft Assessment Report should discuss what is known about what happens to un-recovered fracture fluids that are injected into hydraulically fractured wells, and where these fluids go if they do not come back to the surface. The EPA should describe the challenge of monitoring and modeling the fate of injected fracture fluids over time.

- Chapter 7 emphasizes the horizontal and vertical distance between spill and receptor without adequately indicating that certain subsurface geologic conditions and hydraulic gradient scenarios in the shallow subsurface can allow spilled liquids to migrate a considerable distance from the point of release. While such long-distance travel incidents have only been rarely reported, the draft Assessment Report should describe the frequency and severity of such events and recognize that such events occur.
- While data gaps have been identified in Chapter 7, especially with respect to baseline conditions and individual incidents, the draft Assessment Report should clarify whether there are data gaps because the data are non-existent or just not easily (i.e., electronically) available.
- The draft Assessment Report should also include additional analysis and discussion on how recycled hydraulic fracturing produced water that is reused onsite at hydraulic fracturing facilities without treatment might affect the severity or frequency of potential contamination of surrounding drinking water resources, in the event of a spill or release.
- The EPA should significantly expand and clarify the discussion provided in Chapter 7 on the use by industry of tracers for injection fluids, as well as the efforts made by the EPA to develop tracers, and describe how tracers might be an approach that could allow assessment of releases of contamination and interpretation of the source of contamination if it occurs. The agency should summarize what compounds or metals are used currently for chemical and radioactive tracers,

the degree to which tracers are used, where tracers are used, what concentrations are in use, and what concentrations are measured for these tracers in the flowback or produced waters.

- Regarding compounds of concern in flowback and produced waters:
  - The agency should clarify whether compounds identified as being of most concern in produced water are products of the hydraulic fracturing activity, flowback, or late-stage produced water, or are chemicals of concern derived from oil and gas production activities that are not unique to hydraulic fracturing activity. These efforts may require the development of analytical methods.
  - The SAB recommends that the EPA should outline a plan for analyzing organic compounds in HF flowback and produced waters, in collaboration with state agencies, since flowback water composition data are limited and the majority of available data are for inorganics.
  - The agency should present additional information on changes in flowback and produced waters chemistry over time.
  - The agency should include more information and discussion in Chapter 7 regarding radionuclides associated with hydraulic fracturing flowback and produced water (including the Pennsylvania Department of Environmental Protection research on this topic), bromide concentrations in hydraulic fracturing flowback and produced water and wastes and in surface waters, best management practices (BMPs) for hydraulic fracturing surface impoundments, and the natural occurrence of brines in the subsurface.
  - The draft Assessment Report should also include additional discussion on background and pre-existing baseline chemistry of surface and groundwater in order to better understand the impacts associated with flowback and produced water. A major public concern is the appearance of contaminated or degraded drinking water wells in areas where hydraulic fracturing occurs. Since naturally occurring contaminants and degraded wells can occur from issues not related to hydraulic fracturing, the EPA should also include additional discussion on how background and pre-existing baseline chemistry of surface and groundwater data is used in order to better understand the impacts of hydraulic fracturing-related spills and leaks. The scientific complexity of baseline sampling and data interpretation should be described.

<u>Wastewater Treatment and Waste Disposal Stage in the HFWC (Charge Question 6)</u>

The fifth stage in the HFWC focuses on wastewater treatment and waste disposal: the reuse, treatment and release, or disposal of wastewater generated at the well pad. This is addressed in Chapter 8.

a. Does the assessment clearly and accurately summarize the available information concerning hydraulic fracturing wastewater management, treatment, and disposal?

b. Are the major findings concerning wastewater treatment and disposal fully supported by the information and data presented in the assessment? Do these major findings identify the potential impacts to drinking water resources due to this stage of the HFWC? Are there other major findings that have not been brought forward? Are the factors affecting the frequency or severity of any impacts described to the extent possible and fully supported?

c. Are the uncertainties, assumptions, and limitations concerning wastewater treatment and waste disposal fully and clearly described?

d. What additional information, background, or context should be added, or research gaps should be assessed, to better characterize any potential impacts to drinking water resources *from this stage of the HFWC? Are there relevant literature or data sources that should be added in this section of the report?*

The SAB was asked whether Chapter 8 of the draft Assessment Report comprehensively, accurately and clearly summarized potential impacts associated with the wastewater treatment and waste disposal stage of the HFWC, whether uncertainties and limitations were fully described, and whether additional information or topics should be added. Overall, Chapter 8 clearly and accurately summarizes a large amount of existing information on the rapidly evolving topic of treatment, reuse, and disposal of wastewater associated with hydraulic fracturing, and recognizes the significant data and information gaps associated with this stage of the HFWC. The chapter's summary of water quality characteristics of wastewaters from various sites clearly indicates that spills or discharges of inadequately treated wastewater could potentially result in significant adverse impacts on drinking water quality.

While Chapter 8 adequately summarizes many aspects related to hydraulic fracturing wastewater treatment based upon literature analysis, it provides little new or original findings – such as those anticipated based on the EPA's November 2011 final Hydraulic Fracturing Research Study Plan. (U.S. EPA, 2011), and has other limitations. The chapter does not adequately address the potential frequency and severity of impacts of hydraulic fracturing wastewaters on drinking water quality, nor potential scenarios in the near future that could influence such impacts (e.g., reduced access to deep well injection due to restrictions associated with seismic activity). In addition, major findings concerning wastewater treatment and disposal, including the conclusion in the chapter that *"there is no evidence that these contaminants have affected drinking water facilities,"* are not fully supported by the information and data presented in Chapter 8, and Chapter 8 should clearly and accurately describe the basis for this statement. To address these concerns, the EPA should conduct further analyses and activities, including the following:

- The draft Assessment Report should more clearly describe the potential frequency and severity of impacts associated with this stage in the HFWC, before drawing conclusions on water quality impacts associated with this HFWC step.
- The chapter describes unit processes used in CWTFs, but many of these descriptions are very general and sometimes incorrectly describe such unit processes; the chapter should be revised to address this issue.
- The agency should further assess impacts on public drinking water supplies that rely upon intakes from surface waters located in watersheds downstream of hydraulic fracturing activities or discharges of hydraulic fracturing fluids.
- The chapter should clearly summarize the regulatory framework around CWTFs and publicly owned treatment works (POTWs) receiving wastewater discharges associated with hydraulic fracturing-related oil and gas production.
- While the chapter notes that treated hydraulic fracturing wastewater discharges can increase formation of brominated and iodinated disinfection by-products (DBPs) at downstream drinking water treatment plants, Chapter 8 should also discuss other DBPs that could form at downstream water treatment plants (and water resource reclamation facilities) impacted by wastewater discharges associated with hydraulic fracturing.
- Chapter 8 should clearly and accurately summarize available information regarding the impacts of water recycling on pollutant concentrations and their potential impacts on drinking water quality should spills of recycled water occur.

- Chapter 8 should be revised to adequately describe the composition and disposal methods of residuals from CWTFs (including residuals from zero-liquid discharge facilities), and whether and to what extent those residuals may impact drinking water sources now and in the future.
- Chapter 8 should further consider temporal trends or costs of hydraulic fracturing water purification technologies over the past decade, trends in wastewater disposal methods including the scientific, regulatory and economic drivers of these changes and their potential impacts on drinking water resources, and potential future trajectories associated with these trends (e.g., if deep well injection of wastewater is reduced because of regulatory changes driven by public concerns about seismic activity and its associated costs).
- The SAB agrees that the chapter does not adequately assess other waste disposal issues such as disposal of cuttings and drilling muds and disposal of residuals from drinking water treatment plants and POTWs impacted by wastewater discharges associated with hydraulic fracturing, and disposal of soils, pond sediments, and other solid media contaminated by hydraulic fracturing chemicals; the chapter should be revised to include some level of assessment on these topics, and outline data gaps that should be addressed in longer-term future activity.
- Chapter 8 should also describe the potential impacts of induced seismicity associated with hydraulic fracturing wastewater disposal activity on water quality and drinking water resources, and on oil and gas production and public water supply infrastructure (e.g., damage to wells, storage vessels, and pipelines transporting water and wastewater).

<u>Chemicals Used or Present in Hydraulic Fracturing Fluids (Charge Question 7)</u>

The assessment used available information and data to identify chemicals used in hydraulic fracturing fluids and/or present in flowback and produced waters. Known physicochemical and toxicological properties of those chemicals were compiled and summarized. This is addressed in Chapter 9.

a. Does the assessment present a clear and accurate characterization of the available chemical and toxicological information concerning chemicals used in hydraulic fracturing?
b. Does the assessment clearly identify and describe the constituents of concern that potentially impact drinking water resources?
c. Are the major findings fully supported by the information and data presented in the assessment? Are there other major findings that have not been brought forward? Are the factors affecting the frequency or severity of any impacts described to the extent possible and fully supported?
d. Are the uncertainties, assumptions, and limitations concerning chemical and toxicological properties fully and clearly described?
e. What additional information, background, or context should be added, or research gaps should be assessed, to better characterize chemical and toxicological information in this assessment? Are there relevant literature or data sources that should be added in this section of the report?

The SAB was asked whether Chapter 9 of the draft Assessment Report comprehensively, accurately and clearly summarized available chemical and toxicological information concerning chemicals used in the HFWC, whether uncertainties and limitations were fully described, and whether additional information or topics should be added. The EPA clearly articulates its approach for characterizing the available physicochemical and toxicological information. However, Chapter 9 of the draft Assessment Report should characterize toxicological information on chemicals employed in hydraulic fracturing in an inclusive manner, and not restrict the criteria for selection of hydraulic fracturing chemicals of concern to solely chemicals that have formal noncancer oral reference values (RfVs) and cancer oral slope factors (OSFs). The agency should use a broad range of toxicity data, including information pertinent to subchronic exposures from a number of reliable sources, in expanding the criteria for hydraulic fracturing chemicals of concern. As the EPA broadens inclusion of toxicological information to populate missing toxicity data, the EPA can expand the tiered hierarchy of data described in the EPA report to give higher priority to chemicals with RfVs without excluding other quality toxicological information that is useful for hazard and risk assessment purposes.

The draft Assessment Report should explicitly indicate what fraction of the compounds identified in hydraulic fracturing fluid and/or produced waters have some hazard information (e.g., toxicity data available from or used by federal. or state agencies or international non-governmental organizations for risk assessment purposes, or publicly available peer-reviewed data), and what fraction have no available information. In addition, the EPA should summarize potential hazards from methane (physical hazard), bromide and/or chloride-related disinfection by-products formed in drinking water, and naturally occurring constituents and compounds (e.g. metals, radionuclides) in hydraulic fracturing wastewater that were discussed in earlier chapters. An important limitation of the EPA's hazard evaluation of chemicals across the HFWC is the agency's lack of breadth in its analysis of most likely exposure scenarios and hazards associated with hydraulic fracturing activities. To help prioritize future research and risk assessment efforts, the agency should identify the most likely exposure scenarios and hazards and obtain toxicity information relevant to the exposure scenarios.

The EPA uses FracFocus 1.0 as the primary source of information on the identity and frequency of use of chemicals in hydraulic fracturing processes. The SAB expresses concern that the FracFocus database may not be complete or sufficient because it does not include certain confidential business information (CBI) which is proprietary in nature, and lacks information on the identity, properties, frequency of use, and magnitude of exposure for approximately 11% of hydraulic fracturing chemicals used in HF operations (which are considered CBI; see EPA draft Assessment Report, p. 5-73). Although the agency acknowledged limitations of the FracFocus data, the EPA can do more to address them by characterizing in some way the toxicology data on proprietary compounds that the EPA may have, and by using information provided in updated versions of FracFocus on chemical class and concentration (% mass of hydraulic fracturing fluid). Based on this information, the agency should assess and clearly describe how gaps in knowledge about proprietary compounds affect the uncertainty regarding conclusions that can be drawn on potential impacts of hydraulic fracturing on drinking water resources. The agency should also revise the draft Assessment Report to characterize in some fashion data on proprietary compounds that the EPA may have, and information provided in FracFocus on chemical class and concentration (% mass of hydraulic fracturing fluid). Since the FracFocus data that the agency assessed was current up to February 2013, the SAB also recommends that the draft Assessment Report discuss the current status, use and changes to the FracFocus platform, and outline what follow-on analyses should be done with the FracFocus database. For example, analyses on trends green chemical usage in HF could be conducted. As feasible, the EPA should consider conducting some preliminary analyses of trends. Further, the EPA should discuss the current status of FracFocus and changes that have been made to the FracFocus platform and system, and articulate needs for information that is collected and available from individual states and that could help with assessment yet is not readily accessible. In addition, the agency should note that the current version of FracFocus also provides some additional insights into the CBI associated with chemicals used during HF operations.

Absent additional information, it is not feasible to conclude which constituents—each differing in occurrence, concentration, and volume during the various phases of hydraulic fracturing gas and oil extraction—are of greatest concern. While additional field studies should be given a high priority in order to better understand the intensity and duration of exposures to constituents of flowback and produced water, the recommendations for additional field studies may be considered a longer term future activity.

To help prioritize future research and risk assessment efforts, the agency should identify the most likely exposure scenarios and hazards and obtain toxicity information relevant to the exposure scenarios. The EPA provides a wide range of possible scenarios along the HFWC, but more emphasis is need on identifying the most likely durations and routes of exposures of concern so that EPA can determine what toxicity information is most relevant and focus research and monitoring efforts on the most important and/or likely scenarios. The SAB agrees that this should be based on consideration of findings in prospective and retrospective investigations, as well as case studies of public and private wells and surface water supplies impacted by spills or discharges of flowback, produced water or treated or partially treated wastewater.

The SAB commends the EPA for formulating a conceptual approach for assessing the scope and potential impacts of hydraulic fracturing on national drinking water resources when there is limited data on exposure (e.g. concentration, volume and duration in different parts of the water cycle.) While the SAB agrees in principle that toxicological and physicochemical information could approximate hazard potential under certain exposure scenarios, the SAB does not agree with specific elements and limited selection of data illustrating the MCDA approach. The MCDA outlined by the EPA gives equal weight to information on physicochemical scores, occurrence and toxicity. This may place undue emphasis on physiochemical score. While useful in judging a chemical's likelihood of occurrence in drinking water, this value may be a relatively poor surrogate for actual exposure. As an example, compounds may not be addressed that tend to remain at their original deposition site and serve as a reservoir for prolonged release. In light of the limitations described above and in the SAB's response to Charge Question 7a (e.g., the EPA limited toxicological information to government reviewed reference values), and given that the EPA applied this approach to only 37 chemicals used in hydraulic fracturing fluids and 23 chemicals detected in flowback or produced water, the EPA's MCDA results should be considered for preliminary hazard evaluation purposes only, as the EPA originally intended. In addition, the agency should suggest use of an MCDA approach on a regional or site-specific basis where more complete constituent identity, concentrations and toxicity information is available for the specific case being analyzed.

For the sake of clarity, the draft Assessment Report should distinguish between chemicals injected into a hydraulic fracturing well vs. constituents, chemicals and hydrocarbons that come back out of the well in produced fluids. The SAB suggests that if no chemicals are added to a hydraulic fracturing well, there is still a potential for impacts to drinking water resources from compounds present naturally in the subsurface which could also be present in produced water. In Chapter 9 and throughout the draft Assessment Report, chemical constituents and potential impacts unique to hydraulic fracturing oil and gas extraction should be clearly distinguished from those that also exist as a component of conventional oil and gas development. The agency should clarify whether compounds identified as being of most concern in produced water are products of the hydraulic fracturing activity, flowback, or late-stage produced water, or are chemicals of concern derived from oil and gas production activities that are not unique to hydraulic fracturing activity. These efforts may require the development of analytical methods. Such activities will help inform the public about the different characteristics of HF injection flowback and produced waters and in-situ subsurface brines relative to formation water produced in conventional oil and gas development.

<u>Synthesis of Science on Potential Impacts of Hydraulic Fracturing on Drinking Water Resources, and Executive Summary (Charge Question 8)</u>

The Executive Summary and Chapter 10 provide a synthesis of the information in this assessment. In particular, the Executive Summary was written for a broad audience.

a. Are the Executive Summary and Chapter 10 clearly written and logically organized?
b. Does the Executive Summary clearly, concisely, and accurately describe the major findings of the assessment for a broad audience, consistent with the body of the report?
c. In Chapter 10, have interrelationships and major findings for the major stages of the HFWC been adequately explored and identified? Are there other major findings that have not been brought forward?
d. Are there sections in Chapter 10 that should be expanded? Or additional information added?

The SAB was asked whether the Executive Summary and Chapter 10 of the draft Assessment Report comprehensively, accurately and clearly synthesized information and described major findings in the assessment, and explored and identified interrelationships between stages of the HFWC. The SAB was also asked whether additional information or topics should be added. The EPA should significantly modify the form and content of the Executive Summary and Chapter 10 Synthesis of the draft Assessment Report. The Executive Summary is unlikely to be understandable by a large segment of its readership, and should be revised to make this section more suitable for a broad audience. Clearer statements are needed on the goals and scope of the assessment and on specific descriptions of hydraulic fracturing activities, and additional diagrams and illustrations should be provided to enhance the public's understanding of hydraulic fracturing activities and operations. Technical terms should be used sparingly and should always be defined, and graphics should be introduced to illustrate and clarify key concepts and processes.

Several major findings presented in both the Executive Summary and Chapter 10 Synthesis are ambiguous and require clarification, and/or are inconsistent with observations presented in the body of the draft Assessment Report. These major findings include:

- "*We did not find evidence that these mechanisms have led to widespread, systemic impacts on drinking water resources in the United States.*"
- "*High fracturing water use or consumption alone does not necessarily result in impacts to drinking water resources.*"
- *"None of the spills of hydraulic fracturing fluid were reported to have reached groundwater."*
- "*The number of identified cases, however, was small compared to the number of hydraulically fractured wells.*"
- "*According to the data examined, the overall frequency of occurrence [of hydraulically fractured geologic units that also serve as a drinking water sources] appears to be low."*
- "*Chronic releases can and do occur from produced water stored in unlined pits or impoundments, and can have long-term impacts.*"

The SAB is concerned that these major findings do not clearly, concisely, and accurately describe the findings developed in the chapters of the draft Assessment Report, and that the EPA has not adequately supported these major findings with data or analysis from within the body of the draft Assessment

Report. Most SAB Panel members expressed particular concern regarding the draft Assessment Report's high-level conclusion statement on page ES-6 that "We did not find evidence that these mechanisms have led to widespread, systemic impacts on drinking water resources in the United States." Most members of the SAB find that this statement does not clearly describe the system(s) of interest (e.g., groundwater, surface water) nor the definitions of "systemic" and "widespread"." Most Panel members agree that the statement has been interpreted by members of the public in many different ways, and conclude that the statement requires clarification and additional explanation. A Panel member finds that this statement is acceptable as written and that the EPA should have provided a more robust discussion on how the EPA reached this conclusion (e.g., through a comparison of the number of wells drilled vs. reported spills, or analysis on reported potable wells shown to be impacted by HFWC). Further details regarding this Panel member's concerns are noted in Attachment 1 to this Report.

The agency should strengthen the Executive Summary and Chapter 10 Synthesis by linking the stated findings more directly to evidence presented in the body of the draft Assessment Report. The EPA should more precisely describe each of the major findings of the draft Assessment Report in both the Executive Summary and Chapter 10 Synthesis, and provide a full accounting of all available information, including specific cases of drinking water impacts, that relate to these major findings.

The synthesis discussion in Chapter 10 should be revised to present integrated conclusions, rather than a summary of findings from Chapters 4-9. These integrated conclusions should include those hydraulic fracturing practices demonstrated to be effective in safeguarding drinking water resources. Chapter 10 should also be revised to discuss methods to reduce uncertainties related to the HFWC, including research, data, and research needs.

The Executive Summary focuses on national- and regional-level generalizations of the potential effects of hydraulic fracturing-related activities on drinking water resources. Although these generalizations are often desirable and useful, the EPA should make these conclusions cautiously, and clearly qualify these conclusions through acknowledgement of the substantial heterogeneity existing in both natural and engineered systems. Furthermore, the EPA should provide more emphasis in the Executive Summary on the importance of local hydraulic fracturing potential impacts. These local-level hydraulic fracturing impacts may occur infrequently, but they can be severe and the Executive Summary should more clearly describe such impacts. Further, the local important impacts are unlikely to be captured in a national level summary of impacts.

The draft Assessment Report should also identify ongoing research and needs for future research, assessment and field studies. The SAB concludes that the EPA include in that discussion the EPA's future plans for conducting prospective studies and other research that the EPA had planned to conduct but did not conduct. One Panel member concluded that this prospective study work is not needed and should not be conducted.

2. INTRODUCTION

2.1. Background

In its Fiscal Year 2010 Appropriation Conference Committee Directive to the EPA, the U.S. House of Representatives urged the agency 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."*

Hydraulic fracturing (HF) is a well stimulation technique used by oil and gas producers to explore and produce natural gas from sources such as coalbed methane and shale gas formations. The gas extraction process includes: site exploration, selection and preparation; equipment mobilization-demobilization; well construction and development; mixing and injecting fracturing fluids; hydraulic fracturing of the formation; produced water and waste management, transport, treatment, and/or disposal; gas production (infrastructure for storage and transportation); and site closure.

In June 2015, the EPA's Office of Research and Development (ORD) released a draft assessment report (U.S. EPA, 2015), entitled *Assessment of the Potential Impacts of Hydraulic Fracturing for Oil and Gas on Drinking Water Resources*. ORD requested the EPA SAB conduct a peer review of the EPA's draft Assessment report through which the SAB would develop an advisory report of consensus advice for the EPA Administrator.

The draft Assessment Report synthesizes available scientific literature and data on the potential for hydraulic fracturing for oil and gas production to change the quality or quantity of drinking water resources, and identifies factors affecting the frequency or severity of any potential changes. The draft Assessment Report follows the hydraulic fracturing water cycle (HFWC) described in the Study Plan (U.S. EPA, 2011) and Progress Report (U.S. EPA, 2012). The HFWC includes five stages: (1) water acquisition for hydraulic fracturing fluids; (2) chemical mixing to form fracturing fluids; (3) well injection of fracturing fluids; (4) flowback and produced water; and (5) wastewater treatment and disposal. Potential impacts on drinking water resources are considered at each stage in this cycle.

2.2. SAB Review

In response to the U.S. Congress, the EPA developed a study scope (U.S. EPA, 2010) in March 2010 that was reviewed by the SAB Environmental Engineering Committee and additional members of the SAB in an open meeting on April 7-8, 2010. The SAB's Report on its review of the study scope was provided to the Administrator in June 2010. In its response to the EPA in June 2010, the SAB endorsed a lifecycle approach for the research study plan (U.S. EPA, 2011), 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 (SAB, 2010).

EPA then developed a research Study Plan (U.S. EPA, 2011) that was reviewed by the SAB HF Panel in an open meeting on March 7-8, 2011. In its response to the EPA in August 2011, the SAB found the EPA's approach for the research Study Plan to be appropriate and comprehensive, and concluded that the EPA has identified the necessary tools in its overall research approach to assess impacts of hydraulic fracturing on drinking water resources (SAB, 2011). The EPA's research Study Plan identified specific potential outcomes for the research related to each step in the HFWC, and the SAB did not anticipate that all of these outcomes could be achieved given the time and cost constraints of the proposed research program. Further, the SAB identified several areas of the research Study Plan that could be better focused and suggested several additional topics for further study.

In late 2012, the EPA released a Progress Report (U.S. EPA, 2012) on the study detailing the EPA's research approaches and next steps. Peer-review input on the Progress Report was provided through a consultation with individual members of the SAB HF Panel convened under the auspices of the SAB in an open meeting on May 7-8, 2013. At the May 2013 consultation meeting, ORD briefed the SAB HF Panel on the current status of its research, and the SAB HF Panel members individually addressed 12 charge questions spanning each of the five components of the hydraulic fracturing lifecycle, including water acquisition, chemical mixing, well injection, flowback and produced water, and wastewater treatment and waste disposal. Members discussed the charge questions and also developed written responses. The written comments of the individual experts on the SAB HF Panel were posted on the SAB May 2013 meeting webpage.

On June 4, 2015, ORD released its draft Assessment Report and requested the EPA SAB to conduct a peer review on the draft Assessment Report. On September 30, 2015, the SAB HF Panel conducted a public teleconference to receive a briefing on the EPA's draft Assessment Report and to discuss the EPA's charge questions. On October 28-30, 2015, the SAB HF Panel conducted an advisory meeting to develop consensus advice in response to charge questions associated with the research described in the EPA's draft Assessment Report. The charge questions are listed below and in Appendix A.

The SAB HF Panel held a public teleconference call on December 3, 2015 to complete agenda items from the October 28-30, 2015 SAB HF Panel meeting and further develop preliminary key points in response to charge questions on the agency's draft assessment. The SAB HF Panel then held public teleconferences on February 1, February 2, March 7 and March 10, 2015, to discuss substantive comments from SAB HF Panel members on this draft SAB report. On a public teleconference on ***[Insert Month/Year],*** the chartered SAB deliberated on the SAB HF Panel's draft report and ***[Insert chartered SAB disposition of the draft Panel Report]***.

The Executive Summary highlights the SAB's major findings and recommendations. The SAB's full responses to the charge questions are detailed in Section 3.

3. RESPONSES TO THE EPA'S CHARGE QUESTIONS

3.1. Goals, Background and History of the Assessment

Question 1: The goal of the assessment was to review, analyze, and synthesize available data and information concerning the potential impacts of hydraulic fracturing on drinking water resources in the United States, including identifying factors affecting the frequency or severity of any potential impacts. In Chapter 1 of the assessment, are the goals, background, scope, approach, and intended use of this assessment clearly articulated? In Chapters 2 and 3, are the descriptions of hydraulic fracturing and drinking water resources clear and informative as background material? Are there topics that should be added to Chapters 2 and 3 to provide needed background for the assessment?

Chapter 1 provides an introductory section and a discussion on the background, scope, approach and organization of the draft Assessment Report. Chapter 2 provides a discussion on hydraulic fracturing, oil and gas production, and the U.S. energy sector. It defines hydraulic fracturing, discusses how widespread hydraulic fracturing is, and describes the trends and outlook for the future of hydraulic fracturing. Chapter 3 describes drinking water resources in the U.S., and discusses current and future drinking water resources and the proximity of drinking water resources to hydraulic fracturing activity.

3.1.1. Goals and Scope of the Assessment

In Chapter 1 of the assessment, are the goals, background, scope, approach, and intended use of this assessment clearly articulated?

Chapter 1 is well written, and introduces the background and intended use of the assessment clearly and understandably. However, it needs a clear and explicit statement of the goals and objectives of the assessment; a concise statement of the goals in nontechnical language will provide a coherent framework for the entire document. Chapter 1 also needs to better distinguish the goals from the approach. For instance, the review, synthesis, and analysis of scientific literature and information provided by stakeholders, and of research conducted, should be stated as part of the approach rather than a goal of the study.

It should be emphasized that the EPA-conducted research was integrated with a large amount of additional information and research. The EPA should explicitly explain what it did in terms of its own research in developing the assessment. The use of the EPA-sponsored research projects, technical input from agencies, industries, Non-Governmental Organizations (NGOs) and other stakeholders should be highlighted as part of the approach.

As stated on page 1-2 of the draft Assessment Report, the scope of the assessment is "defined by the HFWC" and it is desirably broad, in particular not limiting it solely to the actual hydraulic fracturing step. The draft Assessment Report should provide additional explanation of the rationale for its choice to use the HFWC to assess impacts of hydraulic fracturing on drinking water resources. The EPA should discuss in the draft Assessment Report all of the ways in which hydraulic fracturing and related activities might impact the quality or quantity of drinking water resources in one of the five HFWC stages. The EPA should include text to describe why the EPA assessed certain HF-related topics and issues within the draft Assessment Report, and why certain hydraulic fracturing topics, issues and activities were considered to be beyond the scope of this assessment (e.g. contamination from drilling fluids and cuttings). Also, the EPA should consistently revise text throughout the draft Assessment Report when referring to hydraulic fracturing to note the EPA is referring to the entire HFWC, consisting of the five stages defined in this assessment.

As noted in Chapter 1, the definition of the study scope was broad but not all inclusive, and some aspects of oil and gas production are stated to be outside the scope of the draft Assessment Report. However, Chapter 1's statement about aspects of the draft Assessment Report that are outside of the scope of the assessment is not entirely consistent with the rest of the draft Assessment Report. For example, hydraulic fracturing well closure is explicitly excluded in Chapter 1, and yet Chapter 2 contains a section on "Site and Well Closure." Also, hydraulic fracturing imposes unique stresses on well structure, such as casing and cement, and hence well integrity, even post production, is within the scope (e.g., concerns about the integrity of inactive or orphaned wells are discussed in Chapter 6). The EPA should correct these statements in Chapter 1 to be more inclusive of situations and analyses that the EPA did include later in the draft Assessment Report, or if appropriate to the draft Assessment Report's goals, exclude this from later discussion.

The intended users of the draft Assessment Report range from policy makers and regulators to the industry and the public; however, parts of Chapters 1-3 are overly technical for many of those users. The technical details are important, and should not be diluted. The EPA should include illustrative material (illustrations, diagrams, and charts) in these chapters so that non-technical readers have visuals to facilitate understanding of this technical material. Where appropriate, the EPA should move some technical details to an appendix of the draft Assessment Report, replaced by graphical material. The SAB recognizes that many readers of the draft Assessment Report will read only the Introduction and Executive Summary, and thus recommends that the EPA should not put all such details in appendices.

Considerable public interest associated with hydraulic fracturing and the HFWC in general in this assessment is generated by experiences at individual sites. Chapter 1 should acknowledge the importance of these experiences, and the needs associated with public outreach and education related to drinking water quality. The Assessment Report should include (not necessarily with all detail in Chapter 1) explicit updated summaries of studies that have been or are being conducted in Dimock, Pennsylvania; Pavillion, Wyoming; and Parker County, Texas, including the status of those studies and the currently responsible government bodies associated with monitoring of hydraulic fracturing activities in these areas.

Chapter 1 should provide a general overview discussion of the relevant federal, state and tribal laws and requirements pertaining to hydraulic fracturing activities for oil and gas development, and mechanisms for enforcement of the laws and requirements with respect to protection of surface water quality, groundwater quality, municipal water supplies, and private wells. The overview should provide a description of organizations responsible for monitoring and regulation of HFWC activities.

The draft Assessment Report should make clear that the hydraulic fracturing industry is rapidly evolving, with changes in the processes being employed, whereas the Assessment necessarily was developed with the data available at a point in time.

3.1.2. Descriptions of Hydraulic Fracturing and Drinking Water Resources

In Chapters 2 and 3, are the descriptions of hydraulic fracturing and drinking water resources clear and informative as background material?

The description of hydraulic fracturing in Chapter 2 is clear and informative. Regarding time scale, the EPA should emphasize the relatively short time span of the actual hydraulic fracturing operation within Chapter 2, and place this emphasis in perspective with the time frames of the other parts of the HFWC. The SAB agrees that the section on site identification and well development should include some discussion noting that the new geological source rock targets being produced by hydraulic fracturing and horizontal drilling require closer well spacing that, compared to conventional drilling methods, can have significantly greater potential impacts on drinking water resources (Zobackand Arent, 2014). In addition, the EPA should recognize in Chapter 2 that some oil and gas resources being developed with the aid of hydraulic fracturing are located in close proximity to large populations.

The description of drinking water resources in Chapter 3 is informative and generally clear. However, the chapter should include more description and depiction (including diagrams and photographs) of the natural geologic framework into which the engineered hydraulic fracturing systems are incorporated. Chapter 3 could also be improved by paying more attention to the local geology and to the physical properties (thickness, porosity, permeability, fracture density) of the rock layers overlying target horizons, and including more discussion of the characteristics and proximity of aquifers. Chapter 3 should also include more discussion about potential issues associated with future hydraulic fracturing water supplies and sources (e.g., the chapter should discuss potential issues such as overpumping or ground subsidence associated with the deeper aquifers in the West if such aquifers are considered potential future hydraulic fracturing water sources).

The SAB is also concerned that parts of Chapters 2 and 3 are overly technical for many of the intended users. While the technical details are important and should not be diluted, these chapters should include illustrative material (illustrations, diagrams, and charts) so that non-technical readers have visuals to facilitate understanding of this technical material. Where appropriate, the EPA should move some technical details to an appendix, replaced by graphical material.

3.1.3. Topics to be Added

Are there topics that should be added to Chapters 2 and 3 to provide needed background for the assessment?

The EPA should discuss the temporal characteristics and differences in temporal characteristics for the HFWC stages in Chapter 2 (e.g. the differences in duration of the actual hydraulic fracturing of the rock versus the duration of production). In Section 3.2 of Chapter 3, references to “co-location” of hydraulic fracturing with surface and groundwater should be clarified.

Within Chapters 2 and 3, the EPA should also include discussions of new hydraulic fracturing technologies, best management practices and standards and regulations that have improved hydraulic fracturing operations associated with each stage of the HFWC.

Although aquifers are presented on the first page of Chapter 3 as part of the drinking water resources of the United States, aquifers are only superficially mentioned in the body of the chapter. The EPA should add more information regarding groundwater resources in hydraulically fractured areas (e.g., typical depths to aquifers, confined or unconfined aquifers, aquifer thicknesses, and aquifer continuity). All of this information is available from the U.S. Geological Survey (USGS, 1996; and USGS, 2000).

The draft Assessment Report should discuss the selection of a one mile radius to define proximity of a drinking water resource to hydraulic fracturing operations, and the potential need to consider drinking water resources at greater than one mile distance from a hydraulic fracturing operation (e.g., in the case of undetected leakage from an impoundment and subsequent long-distance transport in a transmissive subsurface feature). The EPA should present more information regarding the vertical distance between surface-water bodies and the target zones being fractured, and the depths of most aquifers compared to the depths of most hydraulically fractured wells.

The SAB suggests that the EPA consider including discussions of the following topics in Chapter 3:

- A discussion highlighting communities experiencing water constraints that are or might be related to hydraulic fracturing activities in those regions;
- and
- Whether there are specific local and regional aquifers that are particularly impacted by hydraulic fracturing activities, and if so, whether the EPA could include quantifiable information on this topic. The EPA should consider including maps of aquifers similar to the county-specific maps that the EPA provided within Chapter 3.

3.2. <u>Water Acquisition Stage in the HFWC</u>

Question 2: The scope of the assessment was defined by the HFWC, which includes a series of activities involving water that support hydraulic fracturing. The first stage in the HFWC is water acquisition: the withdrawal of ground or surface water needed for hydraulic fracturing fluids. This is addressed in Chapter 4.

- *a. Does the assessment accurately and clearly summarize the available information concerning the sources and quantities of water used in hydraulic fracturing?*
- *b. Are the quantities of water used and consumed in hydraulic fracturing accurately characterized with respect to total water use and consumption at appropriate temporal and spatial scales?*
- *c. Are the major findings concerning water acquisition fully supported by the information and data presented in the assessment? Do these major findings identify the potential impacts to drinking water resources due to this stage of the HFWC? Are there other major findings that have not been brought forward? Are the factors affecting the frequency or severity of any impacts described to the extent possible and fully supported?*
- *d. Are the uncertainties, assumptions, and limitations concerning water acquisition fully and clearly described?*
- *e. What additional information, background, or context should be added, or research gaps should be assessed to better characterize any potential impacts to drinking water resources from this stage of the HFWC? Are there relevant literature or data sources that should be added in this section of the report?*

Chapter 4 presents a discussion on water acquisition, in particular the withdrawal of ground or surface water needed for hydraulic fracturing fluids. The chapter examines the sources, quality and provisioning of water used during hydraulic fracturing, water use per hydraulic fracturing well (including factors affecting such use and national patterns associated with that use), cumulative water use and consumption at national, state and county scales, and a chapter synthesis of major findings, factors affecting the frequency or severity of impacts, and associated uncertainties.

3.2.1. Summary of Available Information on Sources and Quantities of Water Used in HF

a. Does the assessment accurately and clearly summarize the available information concerning the sources and quantities of water used in the hydraulic fracturing process?

The assessment regarding the water acquisition stage in the HFWC clearly summarizes the available information concerning the sources and quantities of water used from surface water, groundwater, and treated wastewaters. The SAB agrees there are gaps in the data available to assess water use.

Chapter 4 of the draft Assessment Report focuses on the water acquisition stage within the HFWC. The EPA collected, analyzed, and clearly and accurately summarized an enormous amount of available information about the quantities of water used in hydraulic fracturing. The analysis of water acquisition for hydraulic fracturing is, from a geographical standpoint, the most comprehensive to date. Information on water use from surface water, groundwater, and treated wastewater sources is nicely characterized. References are included regarding the use or reuse of wastewater, as well as brackish waters not currently used as drinking water sources which lessens the impacts by reducing the demands on fresh drinking water sources. The analysis and discussion of potential impacts of water acquisition is focused at large scales, and needs to better address local-scale potential impacts. This should be considered by the agency for a longer-term future activity. The EPA should improve the clarity of its summary of sources and quantities in water acquisition for hydraulic fracturing by using clearer, more consistent, and technically accurate wording in regard to discussion of potential impacts. The EPA should also bring findings from the body of the draft Assessment Report on local scale impacts into the executive summary.

The EPA compared water use in hydraulic fracturing to information on water use for other purposes. The chapter concludes that withdrawals for hydraulic fracturing represent a small proportion of freshwater usage at regional or state-wide levels. The chapter points out that in a small percentage of areas, in particular at the county and sub-county scale, there is potential for combined impacts from all uses of these sources. At local scales, water withdrawals can contribute significantly to groundwater depletion, particularly in arid environments. Further, water withdrawals for hydraulic fracturing are also capable of altering the flow regimes of small streams, even in regions of rainfall abundance. While the SAB concurs with these two findings, the agency should include additional clarifications into the draft Assessment Report on the regulatory frameworks in which the HFWC activities are managed that aim to minimize the potential for these negative impacts. The EPA has produced very informative graphics and tables that substantially improve the public availability of information characterizing the sources and quantities of water used in hydraulic fracturing, and the relationship between that use and drinking water. This information is also useful for focusing future efforts to fill information gaps on sources and quantities of water used in hydraulic fracturing.

There are important gaps in the data available to assess water use that limit understanding of hydraulic fracturing potential impacts on water acquisition, which were identified and discussed in the draft Assessment Report in the context of sources of uncertainties. The EPA summarized many databases, journal articles, technical reports, and other information describing sources and quantities in water acquisition for hydraulic fracturing. Some of this information (especially technical reports, media reports, and presentations at conferences) has not been peer reviewed, as noted in the draft Assessment Report. The data gaps need to be addressed, as a longer-term future activity.

The draft Assessment Report relied heavily on two publicly available databases that provide only limited capability to assess the sources and quantities of water used in the hydraulic fracturing process: a) the FracFocus Chemical Disclosure Registry database, where major limitations include questions regarding data completeness (e.g., including information from all wells in an area); and b) the Water Use in the United States database from the USGS, where major limitations are associated with limitations of the spatial and temporal scale of the data (e.g., information not available at sub-county scales, and information on water used in hydraulic fracturing reported as part of larger categories of mining water use).

3.2.2. Total Water Use at Appropriate Temporal and Spatial Scales

b. Are the quantities of water used and consumed in hydraulic fracturing accurately characterized with respect to total water use and consumption at appropriate temporal and spatial scales?

The draft Assessment Report comprehensively characterizes the quantities of water used and consumed for hydraulic fracturing at multiple temporal and spatial scales. Though the national scale images of how water use is distributed across the country are useful and informative, the SAB finds that EPA's statistical extrapolation to describe average conditions at the national scale masks important regional and local differences in water acquisition impacts. The SAB concludes that the analyses at local scales (e.g., case studies) that were used to quantify how hydraulic fracturing water withdrawals affect short-term water availability are more relevant to spatial and temporal scales for assessing impacts of water acquisition. The draft Assessment Report should discuss regulatory mechanisms that are in place to address this issue.

The draft Assessment Report comprehensively characterizes the quantities of water used and consumed for hydraulic fracturing with respect to total water use at multiple temporal and spatial scales. The EPA determined values for the average volume of water used per well using data from broad geographic areas, and estimated total water use and consumption at national, state, and county scales. The EPA compared the quantity of water used for hydraulic fracturing to quantities of water used for domestic purposes, and to total water use for all purposes. The SAB recommends that the EPA expand this comparison, put water use for hydraulic fracturing into a broader context by including all other primary categories of water use from the U.S. Geological Survey classification, and update this comparison by including contemporary values as possible. Further, the EPA should summarize the amounts of water withdrawn for all uses relative to total annual streamflow.

The potential for the withdrawal of large volumes of water used in the hydraulic fracturing process to affect water resources is characterized over broad geographic areas, in fifteen individual states where hydraulic fracturing currently occurs. This information is used to scale up the results to consider average conditions across the nation. Though information on water used in hydraulic fracturing at large spatial and temporal scales is useful and informative, these are not the most appropriate or relevant scales to consider the potential problem of water acquisition impacts. Typically, the amount of water used in hydraulic fracturing would be very small compared to water availability over any large geographic region (e.g., state or nation) or over any long time frame (e.g., annually), given the short duration of the water use activity. The large volumes of water required in the hydraulic fracturing process are used infrequently, during initial well completions and re-stimulation operations. The draft Assessment Report should explicitly state that stresses to surface or groundwater resources associated with water acquisition and hydraulic fracturing are localized in space, and temporary in time.

The discussion of quantities of water used and consumed in hydraulic fracturing is hampered by the lack of information on water use and availability at local scales, as noted in the draft Assessment Report. The SAB finds that the EPA should use case studies to quantify the effect of hydraulic fracturing water withdrawals on short-term water availability since they are the most relevant and appropriate spatial and temporal scales discussed in the draft Assessment Report for assessing the impacts of water acquisition. While the draft Assessment Report discusses the difficulties associated with assessing impacts at local scales where the greatest impacts are likely to occur, reliable data are generally lacking at local scales, and site-specific factors strongly influence both water use and water management decisions. The SAB recommends that the EPA conduct further work, as a longer-term future activity, to explore how hydraulic fracturing water withdrawals affect short-term water availability at local scales. The SAB concludes that the EPA should discuss its plans for performing the water use impact monitoring proposed for the prospective studies described in the Study Plan (U.S. EPA, 2011) but which were subsequently not conducted. The SAB recommends that as a future activity the EPA should collect data available from state agencies such as the PA DEP on this topic. The EPA should clarify if any information of the Well File Review included descriptions of water acquired for hydraulic fracturing at local and site specific scales.

The EPA should include timeframes associated with time of impact and time of response at a water system in its analyses in order to put numeric values in the proper time perspective. The SAB has concerns with the EPA's use of the term "cumulative impacts" and notes that the EPA assessed total use rather than cumulative use. The EPA should consider reviewing the units of volume and flowrate used in each section the draft Assessment Report (including Chapters 3 and 4 and Appendix B, which pertain to water acquisition) and consider whether alternate units, or supplemental units in parentheses, would improve clarity. Further, the EPA should check whether the volumes or flowrates presented in the draft Assessment Report were accurately presented as percentages of other volumes or flowrates, in order to make sure the information is accurately conveyed.

3.2.3. Major Findings

c.1 Are the major findings concerning water acquisition fully supported by the information and data presented in the assessment?

The major findings concerning water acquisition for hydraulic fracturing (from surface waters, groundwaters, and treated wastewaters) were generally supported by the information and data presented in the assessment. However, the finding that there were no cases where water use for hydraulic fracturing alone caused a stream or well to run dry is not appropriate in order to determine severity of impacts, since, for example, a stream with substantially decreased water availability, or a well experiencing regional water-level decline as a result of water acquisition, may be impacted. The SAB recommends that the EPA characterize imbalances between water supply and demand, and localized effects, especially water quality effects, as affected by many interactive factors. This characterization would provide an improved assessment of impacts and benefits.

The major findings regarding the sources of water acquisition, the range of amounts of water used in hydraulic fracturing, and the conditions where potential for impacts may occur are supported by the data that are presented in the draft Assessment Report. One conclusion was that the amount of water used in hydraulic fracturing is very small compared with total water use and consumption at county or statewide spatial scales. The chapter should explicitly state that stresses to surface or groundwater resources associated with water acquisition for hydraulic fracturing are localized in space, and temporary in time. The impacts of water acquisition would predominantly be felt locally at small space and time scales, which are not well represented in the draft Assessment Report. The draft Assessment Report should include additional emphasis noting that the potential for impacts on drinking water resources is greatest in areas with high hydraulic fracturing water use, low water availability, and frequent drought. This is illustrated within the draft Assessment Report through examples from case studies. For example, in a study in southern Texas in the Eagle Ford Shale region where there is a dense array of natural gas wells, there is not much water supply available to support the needs for water acquisition, and groundwater use there is causing change in water storage and drawdown of the local water table.

c.2 Do these major findings identify the potential impacts to drinking water resources due to this stage of the HFWC?

Several case studies were used to explore how hydraulic fracturing water withdrawals affect short-term water availability. Given the emphasis on local conditions, these case studies are the most relevant to spatial and temporal scales that were used in the draft Assessment Report for considering potential impacts to drinking water resources due to hydraulic fracturing water acquisition. These case studies illustrate how hydraulic fracturing water withdrawals may affect short- and long-term water availability in areas experiencing high rates of hydraulic fracturing. Results suggest that water imbalances from hydraulic fracturing operations have not occurred in either the Susquehanna River basin or the upper Colorado River basin. These studies demonstrated that many local factors and local heterogeneity explain whether water imbalances occur. However, the SAB finds that since the EPA conducted case studies on only a few river basins, the role of factors such as climate, geology, water management, and water sources could not be fully explored.

The EPA should improve the clarity of its major findings regarding the potential impacts to drinking water resources from water acquisition, and use less ambiguous, more consistent, and technically accurate wording. For example, the draft Assessment Report states that *"Detailed case studies in western Colorado and northeastern Pennsylvania* ***did not show impacts****, despite indicating that streams could be vulnerable to water withdrawals from hydraulic fracturing."* (emphasis added). However, the case study report that is cited concludes: *"****Minimal impacts*** *to past or present drinking water supplies or other water users resulting from hydraulic fracturing water acquisition* ***were found*** *in either study basin due to unique combinations of these factors in each area."* (emphasis added). Since "Minimal impacts" is not the same as "no impacts," the EPA should clarify these findings and results.

c.3. Are there other major findings that have not been brought forward?

There are several other major findings that the EPA should consider bringing forward. First, it should be more clearly noted that the stresses on water resources from water acquisition for hydraulic fracturing are expected to be local and temporary, taking care not to understate the potential for localized problems. Several of the public commenters, for example, expressed concern with surface waters taken from small rivers or streams. In such cases the timing of water withdrawals with relation to flow conditions is important, since withdrawals during low flow periods may result in dewatering and severe impacts on small streams. More attention needs to be given to describing the potential impacts on water resources at "hot spots" in space (e.g., headwater streams) and in time (e.g., seasonally, and/or under low flow conditions). The draft Assessment Report should discuss regulatory mechanisms that are in place to address this issue.

Second, the EPA should consider further exploring and describing how water acquisition and associated potential impacts on lowered streamflow and water table experiencing regional water-level decline could affect the quality of drinking water, and assess whether such impacts would be short-term (e.g., a few days)- or long-term (e.g., weeks or months). For example, if streamflow is reduced, the draft Assessment Report should describe what might be the effects on chloride or total dissolved solids in streamflow, and how this might affect water supply and treatment costs. The recommendations in this paragraph may be considered longer-term future activity.

Third, the reuses of wastewater and produced formation water are described in the draft Assessment Report, and the EPA should expand on the discussion of the evolution and utilization of technologies that are being used to facilitate reuse of produced water or other non-drinking sources of water. While most geographic areas show a very low percentage of reuse as a source of water for hydraulic fracturing, the reuse percentages in some regions can be high. The EPA should consider exploring and describing within the draft Assessment Report how and why the Garfield County region in Colorado (Piceance Basin) is able to use 100% wastewater for hydraulic fracturing (as indicated in Table 4-1 of the draft Assessment Report). This situation may be due to a combination of the wastewater quality in this area, that the area has been unitized (with all operators sharing infrastructure to produce the fields), and that the area is mature (having been one of the early areas of unconventional oil and gas development). These combined factors together may have allowed time for the technology to develop for reuse of produced wastewater. Even though this is a local-scale occurrence, this could be a major finding that might inform development of this technology in other areas.

3.2.4. Frequency or Severity of Impacts

c.4. Are the factors affecting the frequency or severity of any impacts described to the extent possible and fully supported?

The description of the frequency of impacts is highly generalized and qualitative. Though the statements about factors affecting the frequency and severity of impacts are reasonable, the SAB recommends that the EPA strengthen and clarify the general statements within the draft Assessment Report by adding more specific and quantitative results. The draft Assessment Report explains thoroughly the potential for impacts and the types of conditions that warrant caution with respect to both water quantity and quality impacts at local scales. The draft Assessment Report proposes that proper water management in these areas may be able to reduce the potential impacts, which may include adding the use of non-drinking sources, and examples of this are shown in the draft Assessment Report.

The draft Assessment Report noted that there were no cases where water use for hydraulic fracturing alone caused a stream or well to run dry, yet the SAB finds that this is not necessarily an appropriate metric to consider severity of impacts. Even if streams or wells have not dried up, streams experiencing substantially decreased water availability as a result of water acquisition, and wells experiencing significant water-level decline as a result of water acquisition, are impacted by this stage of the HFWC. The SAB recommends that the EPA characterize imbalances between water supply and demand, and localized effects, especially water quality effects, as affected by many interactive factors. This characterization would provide an improved assessment of impacts and benefits.

3.2.5. Uncertainties, Assumptions and Limitations

d. Are the uncertainties, assumptions, and limitations concerning water acquisition fully and clearly described?

The draft Assessment Report fully and clearly describes the uncertainties, assumptions, and limitations about water acquisition for hydraulic fracturing. There are important gaps in the data and information available to assess water use that the EPA acknowledges. The EPA summarizes a vast quantity of information from databases, journal articles, technical reports, and other sources of information that describes sources and quantities in water acquisition for hydraulic fracturing. Some of this information (especially technical reports, media reports, and presentations at conferences) has not been peer reviewed, as noted in the draft Assessment Report.

The FracFocus Chemical Disclosure Registry database platform (http://fracfocus.org) is managed by the Groundwater Protection Council (GWPC) and the Interstate Oil and Gas Compact Commission (IOGCC). This database includes information on water and chemical use, as reported by the oil and gas industry. Potential limitations and uncertainties of this dataset for this assessment stem from incomplete information on all oil and gas wells, and from the reliability of the unverified information. Second is Water Use in the United States database (http://water.usgs.gov/watuse/), compiled by the U.S. Geological Survey. This includes data on water used by source and category, as reported by local, state, and federal environmental agencies. Potential limitations and uncertainties of this dataset are associated with the spatial and temporal scale of the information presented (by county and state, in five-year intervals), the categories of data (e.g., with data definitions changing over time, and with water used for hydraulic fracturing reported as part of a larger overall category of water use associated with mining). The EPA should update, as a longer-term future activity, the study results with the latest information from the current versions of these databases.

An additional source of uncertainty is the poor quality and sparse information on specific water withdrawals from groundwater, streams, and surface-water reservoirs. Although data on locations and volumes of water withdrawal are available for some regions (e.g., Pennsylvania's Susquehanna River Basin), this sort of information is reportedly not recorded, or is at least inaccessible, for several states included in the EPA's analysis. The availability or absence of data may reflect differences in regulations and regulatory oversight. The SAB recommends that the EPA include within Chapter 4 a review of the regulatory landscape governing water withdrawals for hydraulic fracturing. The SAB also recommends that the EPA evaluate, as a longer-term future activity, the various regulatory approaches for their efficacy in safeguarding against freshwater depletion at local scales.

At local scales, where the greatest impacts are most likely to occur, data are reported as generally lacking, as pointed out in the draft Assessment Report. The case studies included in the draft Assessment Report demonstrate that local heterogeneity and site-specific factors determine water imbalances at local sites, and that results cannot be extrapolated to entire river basins. The EPA should, as a longer-term future activity, enhance the understanding of localized impacts by providing more focus and analysis on the Well File Review and on examination of other information not in the archival scientific literature and common databases in order to provide updated information about actual hydraulic fracturing water acquisition and its relationship to drinking water, and about water availability compared to other users of the resource including agricultural, recreational, and industrial, and less focus on hypothetical scenarios and modeling.

3.2.6. Additional Information, Background or Context to be Added

e.1. What additional information, background, or context should be added, or research gaps should be assessed to better characterize any potential impacts to drinking water resources from this stage of the HFWC?

Given limitations in the reported availability of water consumption and use data, especially at local scales, and in the representativeness of the case studies used, many interactive factors contributing to understanding effects of hydraulic fracturing on water availability and quality (e.g., climate, geology, water management, and multiple water sources) could not be fully characterized.

The SAB concludes that in the future the EPA should continue research on expanded case studies and long-term prospective studies. The recommendation in the previous sentence may be considered a longer term future activity. The EPA should also collaborate with state and regional regulatory agencies involved with this issue. One Panel member concluded that this prospective study work is not needed and should not be conducted.

One of the key limitations toward understanding the potential impacts of hydraulic fracturing water acquisition on drinking water is the availability and reliability of data. The EPA should articulate what data sets were requested and reviewed as part of this report, what future needs are recommended for reliable, independent data on water use and consumption that may better facilitate assessment of potential impacts to drinking water resources, and which agencies are excelling in data base management. Another area for improvement is the EPA's reliance on the publicly available databases for this draft Assessment Report, including the FracFocus Chemical Disclosure Registry database and the Water Use in the United States database. The SAB identifies concerns regarding the EPA's reliance on an early version of the FracFocus database, and provides suggestions for acknowledging and addressing these concerns within the Executive Summary of this SAB Report.

The EPA could potentially reduce gaps in understanding the relationship between water acquisition for hydraulic fracturing and drinking water by using available information from the Well File study database. The EPA's 2012 Progress Report identified the Well File Review as a key data source for many aspects of the relationship between hydraulic fracturing and drinking water, including water acquisition, yet the 2015 Well File Review Report does not contain any information about water acquisition, and that report is not cited in Chapter 4 of the draft assessment. The SAB recommends that the EPA add at least a brief summary of the information about water acquisition that was provided by the Well File Review into the draft Assessment Report, and explain why that information was not included in the draft Assessment Report.

The case studies are limited in terms of the sites and associated environmental conditions that they represent and the results are not readily transferrable to other areas. Therefore, many interactive factors that need to be considered toward understanding effects of the HFWC on water availability and quality (e.g., climate, geology, water management, and multiple water sources) could not be fully characterized. The agency should, as a longer-term future activity, continue to explore how hydraulic fracturing water withdrawals affect short-term water availability at local scales. The SAB concludes that the EPA should continue the work proposed in the prospective studies that were in the Study Plan (U.S. EPA, 2011) but which were subsequently not conducted. The SAB agrees that the lack of prospective studies remains a major limitation of the draft Assessment Report. Such studies would allow the EPA to monitor water conditions prior to drilling, during drilling and completion (aka fracturing) and production to a level of detail not routinely practiced by industry or required by most state regulation. These detailed new data would allow the EPA to reduce current uncertainties and research gaps about the relation between hydraulic fracturing water acquisition and drinking water.

The EPA could, as a longer-term future activity, articulate how reported (or purported) cases of water acquisition impacts on drinking water actually occurred, and to what extent the factors controlling the frequency and extent of these impacts are being addressed by improved operator practices, and regulatory oversight. Controversial or contentious sites should not be ignored, but addressed directly. The draft Assessment Report does not focus adequate attention on local experiences of water impacts actually experienced prior to and during the study period that have been described in local newspapers, media coverage, agency reports, and/or publications. Such attention in future efforts would provide more information on the frequency and severity of impacts based on actual experiences.

To address these gaps and uncertainties, the agency should, as a longer-term future activity: 1) synthesize information that is collected by the states but not available in mainstream databases, such as well completion reports, permit applications, and the associated water management plans; and 2) assess whether there are specific local and regional aquifers that are particularly impacted by HFWC activities, and if so, provide quantifiable information on this topic. For example, as noted in the draft Assessment Report, water use management in the Susquehanna River Basin and other areas is credited with minimizing the impact of hydraulic fracturing withdrawals on stream flow.

The EPA should describe best management practices being implemented by the States or other regulatory agencies (i.e. Susquehanna River Basin Commission, SRBC) that have well established programs in permitting, collecting, monitoring and managing water resources. The SRBC holds the regulatory authority in this basin. The EPA could present more detail, using monitoring data from industry and from the SRBC, in order to develop a better understanding how hydraulic fracturing could have impacted the drinking water due to temporal dynamics. The agency should also describe SRBC regulations for low-flow conditions of streams during which operators are prohibited from withdrawing water. The EPA should consider exploring these dynamics at local scales by examination of these and other water use management events.

The EPA should describe the scale of the task in gathering and organizing data collected from the states. Within the draft Assessment Report, the EPA is encouraged to describe its efforts to investigate data available from state agencies, the scale of its efforts to conduct this investigation, and what critical lessons were learned from the effort.

e2. Are there relevant literature or data sources that should be added in this section of the report?

The SAB encourages the EPA to use additional available information from the Well File study database to characterize potential water acquisition impacts, as planned in the 2012 Progress Report.

The EPA also should review the following additional literature and data sources related to water acquisition for potential inclusion in this section of the draft Assessment Report:

Barth-Naftilan, E., N. Aloysius, and J. E. Saiers. 2015. Spatial and temporal trends in freshwater appropriation for natural gas development in Pennsylvania's Marcellus Shale Play. *Geophys. Res. Lett.* 42, doi:10.1002/2015GL065240.

Entrekin, S.A., K.O. Maloney, K.E. Kapo A.W. Walters, M.A. Evans-White, and K.M. Klemow. 2015. Stream Vulnerability to Widespread and Emergent Stressors: A Focus on Unconventional Oil and Gas. PLoS ONE 10(9): e0137416. doi:10.1371/journal.pone.0137416

Freyman, M. 2014. Hydraulic fracturing and water stress: Water demand by the numbers. Shareholder, lender & operator guide to water sourcing. Ceres report. Online URL: http://www.ceres.org/issues/water/shale-energy/shale-and-water-maps/hydraulicfracturing-water-stress-water-demand-by-the-numbers

Hildenbrand, Z.L., D.D. Carlton Jr., B.E. Fontenot, J.M. Meik, J.L. Walton, J.T. Taylor, J.B. Thacker, S. Korlie, C.P. Shelor, D. Henderson, A.F. Kadio, C.E. Roelke, P.F. Hudak, T Burton, H.S. Rifai, and K.A. Schug. 2015. A comprehensive analysis of groundwater quality in the Barnett Shale Region. *Environ. Sci. Technol.* 49(13), p. 8254–8262. DOI: 10.1021/acs.est.5b01526.

Jackson, R.B., E.R. Lowry, A. Pickle, M. Knag, D. DiGiulio, and K. Zhao. 2015. The depths of hydraulic fracturing and accompanying water use across the United States. *Environ. Sci. Technol.* 49(15), p. 8969-8976. doi: 10.1021/acs.est.5b01228.

Rahm, B.G., & S.J. Riha. 2012. Toward strategic management of shale gas development: Regional, collective impacts on water resources. *Environ. Sci. & Pol.* 17, p. 12-23. March 2012. doi: 10.1016/j.envsci.2011.12.004.

Rahm, B.G., J.T. Bates, L.R. Bertoia, A.E. Galford, D.A. Yoxtheimer, and S.J. Riha. 2013. Wastewater management and Marcellus Shale gas development: trends, drivers, and planning implications. *J. Environmental Management* 120, p. 105-113. May 15, 2013. doi: 10.1016/j.jenvman.2013.02.029. Online URL: http://dx.doi.org/10.1016/j.jenvman.2013.02.029.

Reig, P., T. Luo, and J.N. Proctor, World Resources Institute, Global Shale Gas Development: Water Availability & Business Risks, September 2014.

Shank, M. K., and J. R. Stauffer Jr. 2014. Land use and surface water withdrawals effects on fish and macroinvertebrate assemblages in the Susquehanna River basin, USA. *J. Freshwater Ecol.* 13. doi:10.1080/02705060.2014.959082.

Vengosh, A.; R.B. Jackson, N. Warner, T.H. Darrah, and A. Kondash. 2014. A critical review of the risks to water resources from unconventional shale gas development and hydraulic fracturing in the United States. *Environ. Sci. Technol.* 48(15), p. 8334–8348. March 7, 2014. DOI: 10.1021/es405118y.

3.3. Chemical Mixing Stage in the HFWC

Question 3: The second stage in the HFWC is chemical mixing: the mixing of water, chemicals, and proppant on the well pad to create the hydraulic fracturing fluid. This is addressed in Chapter 5.

a. Does the assessment accurately and clearly summarize the available information concerning the composition, volume, and management of the chemicals used to create hydraulic fracturing fluids?

b. Are the major findings concerning chemical mixing fully supported by the information and data presented in the assessment? Do these major findings identify the potential impacts to drinking water resources due to this stage of the HFWC? Are there other major findings that have not been brought forward? Are the factors affecting the frequency or severity of any impacts described to the extent possible and fully supported?

c. Are the uncertainties, assumptions, and limitations concerning chemical mixing fully and clearly described?

d. What additional information, background, or context should be added, or research gaps should be assessed, to better characterize any potential impacts to drinking water resources from this stage of the HFWC? Are there relevant literature or data sources that should be added in this section of the report?

Chapter 5 presents a discussion on chemical mixing, in particular the mixing of water, chemicals, and proppant on the well pad to create the hydraulic fracturing fluid. The chapter examines the chemical mixing process, provides an overview of hydraulic fracturing fluids including discussions on water-based fluids, alternative fluids, and proppants (granular additives such as fine sand injected to hold open microfractures), and discusses the frequency and volume of hydraulic fracturing chemical use, including descriptions of the frequency with which hydraulic fracturing chemicals are used at the national scale, national oil versus gas usage of chemicals, and a state-by-state discussion on the frequency of hydraulic fracturing chemical use. Chapter 5 also examines chemical management and spill potential associated with hydraulic fracturing operations, chemical storage, hoses and lines, blending operations, manifolding (bringing together multiple fluid flow lines), high-pressure pumps, and surface wellhead fracture stimulation. In addition, Chapter 5 presents a discussion on spill prevention, containment, and mitigation associated with hydraulic fracturing operations, fate and transport of hydraulic fracturing chemicals, trends in chemicals used in hydraulic fracturing, and a chapter synthesis of major findings, factors affecting the frequency or severity of impacts, and uncertainties.

3.3.1. Summary of Available Information on the Composition, Volume and Management of Hydraulic Fracturing Chemicals

a. Does the assessment accurately and clearly summarize the available information concerning the composition, volume, and management of the chemicals used to create hydraulic fracturing fluid.

The chemical mixing stage of the HFWC includes a series of above-ground, engineered processes involving complex fluid pumping and mixing operations, and the potential failure of these processes, including near-site containment, poses a potential risk to drinking water supplies. The draft Assessment Report does not accurately and clearly summarize the available information concerning the composition, volume, and management of the chemicals used to create hydraulic fracturing fluid. Chapter 5, as it stands, provides little knowledge of the magnitude of hydraulic fracturing spills and it does not adequately describe either the uncertainty or the lack of understanding of such spills, and the EPA should revise its assessments associated with this stage of the HFWC to address these concerns. An accurate assessment would detail data gaps, provide quantitative uncertainties and an overall evaluation of the actual state of knowledge. The chapter is a general, mostly qualitative, description of industrial mixing processes and fluid compositions. Many public commenters expressed the view that a substantial fraction of chemical additives are unknown, either by identity or behavior. This chapter does little to alleviate the basic concern regarding the understanding of the composition of hydraulic fracturing fluids and, by extension, how they would behave after a spill. The agency should revise Chapter 5 of the draft Assessment Report to provide more information regarding the extent or potential extent of the effects of chemical mixing processes associated with hydraulic fracturing operations to drinking water supplies.

HF fluids: The draft Assessment Report's discussion of hydraulic fracturing fluids and their properties is primarily based upon the FracFocus 1.0 database. A lack of verification of the accuracy and completeness of the FracFocus information (page 5-73) makes conclusions regarding the data that are reported uncertain. The SAB identifies issues with the EPA's reliance on the FracFocus version 1.0 database, and provides suggestions for acknowledging and addressing these concerns.

The draft Assessment Report broadly describes the extent of the chemical data record but should be critical of what is not known and the consequences of this uncertainty. As such, the SAB does not recommend that the EPA make generalizations regarding how chemicals will behave. Since the majority of hydraulic fracturing fluids are aqueous-based, concentrations in this report are calculated based on water as the carrier fluid. However, the SAB finds that the description of concentrations becomes confusing, and likely inaccurate, when non-aqueous-carrier phases such as methanol are the dominant liquid. To address these concerns, the SAB recommends that the draft Assessment Report provide a more rigorous explanation of volume, concentration, mass and chemical activity as it relates to the carrier fluid. The draft Assessment Report should provide a critical analysis of the type of data needed to provide a meaningful assessment of spill severity and impact, including description of the type of data that are available state by state. If the appropriate data are not currently available (e.g., the masses of chemicals spilled have not been reported), then the draft Assessment Report needs to detail the data that must be acquired by states so that critical assessments can be made.

Chemical mixing and delivery processes: The section on chemical mixing and delivery processes provides a broad overview of the steps involved (i.e., 'phases'; Fig. 5-3) as well as a description of the actual 'mechanical' actions involved, such as types of pumping equipment and hose operations. The fluid transfer steps of chemical mixing and delivery are key potential sources of spilled liquids to containment structures or directly to the environment. The SAB recommends that the EPA explain/assess the efficiency (i.e., failure rates) of these operations, and provide more information on: 1) the potential of spilled liquids during routine operations; and 2) actions that can improve spill prevention. For example, Figure 5.13 indicates that approximately 1/3 of spilled liquids are sourced to 'equipment' or 'hose or line' failure. The EPA should describe whether these spills are the consequence of many small leaks or substantial ones. Additionally, the agency should discuss if these spills are within "containment" or "off of containment" Page 5-43, line 17, notes that 60% of spilled liquids in Colorado were caused by equipment failure, and the EPA should describe what is the source of the variability in the origin of these spills within the draft Assessment Report, with an emphasis on what was spilled "off of containment".

Another source of uncertainty is the behavior of mixed chemicals. To a certain extent the sub-text of the discussion is that the various additives behave 'conservatively' (i.e., non-reactive) upon mixing. The

EPA should describe what occurs when an acid comes into contact with some of the organic additives, and whether chemical behavior depends on the carrier phase (i.e., water or methanol). Similarly, the agency should improve this section by including practical information on spill mitigation practices such as secondary containment, berm construction to prevent surface transport, and barriers to prevent spilled hydraulic fracturing fluids from reaching the ground surface, subsurface, and groundwater.

Chemical and spill management and potential impacts on the environment: Within the Chapter 5 discussion on chemical and spill management and potential impacts on water resources, the data sets for spills are incomplete, at least those that are readily available in electronic format. The SAB notes that the EPA's estimates on the frequency of on-site spills were based upon information from two states. While the SAB recognizes that the states of Pennsylvania and Colorado likely have the most complete datasets on this topic that the EPA could access, the SAB notes that geologies vary between states and encourages the agency to contact the state agencies and review state databases and update the draft Assessment Report to reflect a broader analysis. While the SAB recognizes that state database systems vary, the databases should be incorporated into the EPA's reporting of metrics within the draft Assessment Report. As written, the SAB finds that the draft Assessment Report's analysis of spills data cannot confidently be extrapolated across the entire U.S. The SAB recommends that the agency revisit a broader grouping of states and "refresh" the draft Assessment Report with updated information on the reporting of spills associated with HFWC activities. The EPA should address this significant 'completeness' issue in this section of Chapter 5, and describe the extent and types of spill reporting to states. The SAB also recommends that the draft Assessment Report include a more thorough presentation and explanation of the frequency and types of data that the hydraulic fracturing industry reports, some of which may not be readily accessible (i.e., not in electronic format that is 'searchable'). For example, Reference [5] (noted below under the 'additional types of data sources to consider' section of this response to charge question 3) documents that a substantial number of uncontained spills have occurred during North Dakota oil field operations. The SAB notes that while many of these spills may not be strictly part of the chemical mixing step, these spills provide information on the integrity of fluid management operations in general. The EPA over-interpreted this limited data in its conclusion that the risk to drinking water supplies from this stage of the HFWC is not substantial, and the EPA should revise this interpretation of these limited data.

Trends in chemical use in hydraulic fracturing operations: Section 5.9 describes ongoing changes in the hydraulic fracturing industry in the form of developing hydraulic fracturing chemical additives that the EPA considers to be 'safer' to the environment. The SAB notes that this section is not a critical review of such efforts. However, the SAB also notes that little is known about certain hydraulic fracturing chemicals and their safety. The SAB recommends that the EPA clarify in this section of the draft Assessment Report that many issues may play an important role in the hydraulic fracturing industry's substitution of hydraulic fracturing chemical additives for currently used additives. The SAB also recommends that the agency expand this chapter to include a more critical evaluation of this trend in hydraulic fracturing and how the industry has further limited the number of chemicals used in the completion process.

3.3.2. Major Findings

b1. Are the major findings concerning chemical mixing fully supported by the information and data presented in the assessment?

The EPA's major finding and conclusion described in Section 5.10.1 of the draft Assessment Report that there were 'no documented impacts to groundwater' for the 497 spills evaluated by the EPA, and in Section 10.1.2., on page 10-8, and on page ES-13, where the EPA notes that "*None of the spills of hydraulic fracturing fluid were reported to have reached groundwater*," is not supported by the information and data presented in the draft Assessment Report, due to the EPA's incomplete assessment of spilled liquids and consequences. The SAB is concerned that this major finding is supported only by an absence of evidence rather than by evidence of absence of impact. The 'available information' has been broadly summarized in the draft Assessment Report but the limitations of the data sources (e.g., FracFocus) have led to an incomplete record associated with the potential impacts associated with such spills. The SAB identifies issues regarding the EPA's reliance the FracFocus version 1.0 database, and provides suggestions for acknowledging and addressing these concerns. Further, there is a lack of a critical assessment of the data presented in this chapter in a number of instances, and the SAB concludes that the EPA needs to conduct such critical assessment to support conclusions that the EPA may make on such data. For example, while the EPA considers spill volume to be an indicator of potential severity, spill volume is not necessarily an indicator of potential severity because the composition of spilled fluids, including chemical species and concentrations, plays an important role in determining the severity of a potential environmental threat resulting from a spill.

Relationship between the chemical mixing step of the HFWC and drinking water quality: A secondary conclusion of the draft Assessment Report is that there is reportedly insufficient information to assess the relationship between the chemical mixing step of the HFWC and drinking water quality (Section 5.10.3). The SAB finds that the data presented by the EPA within Chapter 5 supports an occurrence of spilled liquids at hydraulic fracturing sites, and that there are varying causes, composition, frequency, volume, and severity of such spills. The SAB agrees that a substantial problem with the synthesis presented in this chapter is the lack of a full and accurate description of the uncertainty surrounding the issues regarding this conclusion. An example of this problem is the statement provided on page 5-71, line 14 of the draft Assessment Report noting: "The EPA analysis of 497 spills reports found no documented impacts to groundwater from those chemical spills, *though there was little information on post-spill testing and sampling.*" The EPA should summarize efforts made to review spill files from the states on each of these cases to determine what "post remedial sampling" was conducted. At the same time, the EPA cites Gross *et al.* (2013), which examined the Colorado Oil and Gas Conservation Commission (COGCC) spill database for a year's time in 2010-2011. Gross *et al.* (2013; reference [4]) noted below under the 'additional types of data sources to consider' section of this response to charge question 3) write in the abstract:

> "We analyzed publically available data reported by operators to the COGCC regarding *surface spills that impacted groundwater*. From July 2010 to July 2011, we noted *77 reported surface spills impacting the groundwater* in Weld County, which resulted in surface spills associated with less than 0.5% of the active wells."

The SAB is concerned that this information raises questions regarding how the agency actually analyzed spills as part the draft Assessment Report. The SAB recommends that the EPA clarify its statements in the draft Assessment Report on this topic in light of these comments, and also clarify whether the reported apparent lack of data is reflective of non-existent data or data that are reported somewhere but are not readily available. The SAB also recommends that the agency expand this chapter of the draft Assessment Report to provide improved analysis on the current state of data reporting on spills and the nature of hydraulic fracturing fluids.

An additional point is that the draft Assessment Report conflates spill frequency and spill volume with spill severity. The draft Assessment Report should define "severity" in a way that is amenable to some sort of quantitative analysis and clearly delineate those factors contributing to spill severity (e.g., the mass of a spilled chemical that has the potential to reach an environmental receptor, and the toxicity of spilled chemicals). Additionally, a number of states have spill reporting requirements, and processes, that may not be readily available in electronic, searchable form. The SAB recommends that the EPA investigate at least one state as a detailed example for scrutinizing the spill data (e.g., North Dakota, Reference [6] noted below under the 'additional types of data sources to consider' section of this response to Charge Question 3).

FracFocus 1.0: The EPA primarily used FracFocus version 1.0 during its study period to support most of the data assessment associated with EPA's development of the draft Assessment Report. The EPA outlines limitations of FracFocus data within the draft Assessment Report, and the SAB agrees with those observations and expresses additional questions regarding the use of these data. The SAB finds that a central problem regarding use of the FracFocus 1.0 data set is that it does not represent the full suite of hydraulic fracturing operations taking place within the U.S. during the study period. A lack of verification of the accuracy and completeness of the FracFocus information makes conclusions regarding the data that are reported uncertain. The SAB identifies a number of additional concerns regarding the EPA's reliance on the FracFocus version 1.0 database, and provides suggestions for acknowledging and addressing these concerns.

b2. Do these major findings identify the potential impacts to drinking water resources due to this stage of the HFWC?

The major findings presented in Chapter 5 of the draft Assessment Report do not identify the potential impacts to drinking water resources due to the chemical mixing stage of the HFWC. The SAB concludes that 'potential impacts' is inherently an issue of severity, and as described further under the response to sub-question b.4 of this charge question, the chapter does not provide the basis for understanding the potential for spills affecting drinking water supplies. The SAB finds that a conclusion on potential impact is a quantitative function of (at least) spill composition, frequency, containment probability, response adequacy, and the transport of chemical constituents to the environmental receptor. The SAB finds that the EPA does not adequately evaluate any of these factors in a manner to provide sufficient quantitative assessment of potential impacts and severity.

b3. Are there other major findings that have not been brought forward?

There are three other major findings that should be presented in Chapter 5 of the draft Assessment Report:

1. <u>Uncertainty regarding undetected and unmonitored hydraulic fracturing chemicals.</u> There is significant uncertainty regarding which hydraulic fracturing chemicals are currently in use. A crucial oversight within the draft Assessment Report is the lack of discussion on the degree of undetected, unmonitored hydraulic fracturing chemicals and analytical assessment of the many uncommon chemicals used in hydraulic fracturing. The SAB recommends that the EPA assess impacts and the underlying uncertainty associated with these undetected, unmonitored hydraulic fracturing chemicals and incorporate such an assessment into this chapter of the draft Assessment Report. This

assessment should also consider how many hydraulic fracturing chemicals that are in use do not have analytical methods, and are not undergoing monitoring.

2. Uncertainty regarding the identity of hydraulic fracturing chemicals used in particular hydraulic fracturing operations, as compounded by limited knowledge about on-site storage of chemicals. There is significant uncertainty regarding the identity of chemicals used in particular hydraulic fracturing operations, and this uncertainty is compounded by limited knowledge about on-site hydraulic fracturing chemical stockpiles. These stockpiles may change markedly over the time period of a hydraulic fracturing operation. Container failure is a primary source of hydraulic fracturing spills, and the effectiveness of spill containment is of interest in understanding response measures, sampling and closure. The reports of most spills discussed in the draft Assessment Report included little or no field investigation of the impacts of the release, or any documented after-spill investigation of suspected chemical contamination. The EPA should bring such information, either by direct EPA study or analogue studies, into the draft Assessment Report.

3. Uncertainty regarding spills and their associated impacts. There is significant uncertainty regarding the frequency, severity, and type of HFWC-related spills, and the agency should address this uncertainty in this chapter of the draft Assessment Report. The EPA should conduct, or at least include a plan for, a detailed study of state reports on spills (perhaps one example target state) with a full statistical analysis. This future study should include: a) the state of practice by the industry in spill monitoring and reporting; b) an assessment of state records regarding spills; and c) a more rigorous scientific description of potential severity of spilled liquids (e.g., type of spill, concentration of constituents, and volume).

3.3.3. Frequency or Severity of Impacts

b4. Are the factors affecting the frequency or severity of any impacts described to the extent possible and fully supported?

The factors affecting the frequency or severity of any impacts associated with HFWC-related spills are not described to the extent possible nor are they fully supported. While the EPA conducted a large effort in developing Chapter 5, the SAB is concerned that two fundamental, underlying questions have not been answered: What is the potential that spills occurring during the chemical mixing process affect drinking water supplies, and what are the relevant concerns associated with the degree to which these spills impact drinking water supplies? A Panel member finds that the draft Assessment Report provided a thorough description of the variables associated with a spill (i.e., amount, duration, soils, weather, groundwater, surface water, constituents released, and other spill aspects), and noted that the Report should provide more granularity on how states respond to spills.

This chapter addresses five linked topics: 1) chemical mixing and delivery processes; 2) description of hydraulic fracturing fluid components and their properties; 3) the potential impacts of hydraulic fracturing fluids on the environment, including spill volume and frequency; 4) principles of environmental fate and transport of potentially-spilled hydraulic fracturing fluids; and 5) trends in chemical use in hydraulic fracturing operations. In order to conduct a 'severity' analysis, the EPA must assess each of the above factors in such a way that a quantitative assessment of likelihood can be derived. By these criteria, the SAB finds that the EPA's assessment towards each of these linked topics is in need of substantial improvement.

The SAB recommends that the EPA substantially modify the discussion in Section 5.8 on fate and transport of spilled hydraulic fracturing chemicals. The SAB finds that this section portrays that more is known about fate and transport of hydraulic fracturing chemicals than is actually known. This section's discussion is not useful to this chapter because it does not describe the uncertainty about severity of hydraulic fracturing spills. The SAB finds EPA's descriptions of the classes of chemicals and their range of uses as useful information. However, the SAB recommends that the EPA combine detailed chemical property information with similar information provided elsewhere in the draft Assessment Report (e.g., Chapter 9). In Chapter 5, the SAB recommends that it is sufficient for the EPA to note that these hydraulic fracturing chemicals "fully occupy" the chemical property space. The SAB also recommends that the EPA minimize the value of the speculative transport scenarios that the EPA assessed and reported on in this chapter. The SAB concludes that there are too many factors affecting the fate of hydraulic fracturing chemicals in the environment for the EPA to use Octanol-Water Partition Coefficient (K_{ow}) as a proxy for relative mobility. These other factors include, for example, fate issues associated with chemicals in mixtures, chemicals in non-aqueous phases, and the nature of the environmental media into which these hydraulic fracturing chemicals may be released.

3.3.4. Uncertainties, Assumptions and Limitations

c. Are the uncertainties, assumptions, and limitations concerning chemical mixing fully and clearly described?

The SAB finds that the uncertainties, assumptions, and limitations concerning chemical mixing are not fully and clearly described. Data limitations compromise the ability to develop definitive, quantitative conclusions within the draft Assessment Report regarding the frequency and severity of spilled liquids. Data limitations do not constitute evidence that water resources are unaffected; rather, these limitations indicate the lack of inclusion of monitoring information from hydraulic fracturing sites described within the draft Assessment Report, and the lack of a thorough assessment of the uncertainties of each chemical mixing section of Chapter 5 of the draft Assessment Report. The details of the monitoring required to assess severity (and not simply what monitoring has already been conducted) is not and should be included in Chapter 5. A further complication is that analytical protocols for many chemicals used in hydraulic fracturing operations do not exist, and the lack of detection of such chemicals does not mean they are not present in the environment. To address these concerns, although the draft Assessment Report is not intended to be a risk analysis, the SAB recommends that the EPA include in this chapter a detailed analysis of the failure rates of the fluid handling equipment and the efficiency of containment measures. Furthermore, within each section of this chapter, the EPA should include a critical assessment of data gaps, statements of what is needed to close those gaps, and an explicit statement of uncertainty associated with the topics covered within these sections.

3.3.5. Additional Information, Background or Context to be Added

d1. What additional information, background, or context should be added, or research gaps should be assessed, to better characterize any potential impacts to drinking water resources from this stage of the HFWC?

Various data, analysis, and reporting gaps occur within this chapter of the draft Assessment Report. The EPA should address each of the following gaps as it revises the draft Assessment Report:

- What qualifies as a 'spill' is not defined clearly in the draft document. The draft Assessment Report should include a section on requirements for reporting spills, and the EPA should highlight differences, as they may exist, between state and Federal agencies. For example, the EPA should describe: a) whether there is a spill volume below which a report is not required; and b) whether a report is required if a spill is contained by on-site mitigation measures, and is deemed to not reach the 'environment'.
- A primary gap in understanding on the potential impact of the HFWC on drinking water involves the requirement for monitoring of water resources, including analysis of the potentially-affected environmental receptors prior to the initiation of hydraulic fracturing operations. Industry reports spills but the spill data are not all easily accessible, nor is industry-conducted monitoring readily available in a convenient electronic format. The reported spill data are likely a subset of all spills (varying by region, and the definition of what constitutes a spill.) and, when reported, the spill data may not be easily accessible or may not constitute the needed range of data to assess the impact on water quality compared to conditions prior to hydraulic fracturing operations. The SAB recommends that the draft Assessment Report include a summary of currently-required state regulatory specifications for monitoring requirements before, during and after hydraulic fracturing operations, including types of monitoring wells (i.e., construction specifications), analytical protocols for chemicals, and sampling intervals that would provide the data needed to assess the impact of hydraulic fracturing on water quality (e.g., [see References [1,2] (noted below under the 'additional types of data sources to consider' section of this response to charge question 3). The draft Assessment Report should also describe the current monitoring that is occurring during hydraulic fracturing operations and identify gaps in such monitoring.

The EPA should conduct each of the following efforts as it revises the draft Assessment Report:

- The draft Assessment Report should identify future research and assessment needs and future field studies. The agency should outline its plans for collaborating with regulatory agencies and research groups (e.g., at universities) and for conducting prospective studies and other research that the EPA had planned to conduct but did not conduct.
- A quantitative assessment of the frequency and type of equipment failure (e.g., as described further in the response to sub-question 5a, subpoint 2, in this SAB Report).
- A quantitative assessment of containment failure.
- An emphasis on the *mass* of chemicals potentially released, not volumes (as indicated in Fig. 5-5).
- An analysis of the *mass* of chemicals released in spills reported.
- A clear distinction between spill volume, frequency, severity; and identification of what are the target parameters and how will their values be determined.
- A clearer discussion of the chemical additives, including: concentrations, behavior in mixture; the effect of uncertainties in additive identity on potential severity; and limitations of property estimation methods.
- A well-documented case of a spill (perhaps an analogue) that is illustrative of actual risk and consequence.
- Extension of the chapter's analysis to updated versions of FracFocus and state reporting systems.
- An analysis of state response to spills, including: how spills are handled, who responds, the state and federal required actions on spills, and penalties for not reporting.

- A discussion of the principles of monitoring, with a recognition that specific monitoring campaigns will of necessity be site-specific.

In addition, once hydraulic fracturing fluids enter the environment, their transport and fate can become highly complex, costly, and in some cases difficult to assess and remediate. The EPA should update the chapter's discussion to emphasize efforts to contain and prevent hydraulic fracturing spills.

Also, the discussion in Section 5.8 on fate and transport provides little realistic assessment of the transport of hydraulic fracturing fluids to a drinking water receptor. The complexities involved in fate and transport are not covered in depth in Section 5.8. Hydraulic fracturing spills are not monolithic in type or potential severity, and this section gives the false impression that the transport of spilled fluids through complex earth materials is well understood. The SAB recommends that the EPA include some analogue cases that can provide illustrative examples of a spill and its likely fate in the environment. For example, a spill that would exemplify potential impacts of hydraulic fracturing fluid spills could be included to illustrate key ideas about environmental fate and transport and link it to the types of monitoring systems that could be installed to assess and evaluate potential impacts to drinking water from hydraulic fracturing sites. The SAB also suggests that the EPA consider studies from Superfund sites or many of the documented Leaking Underground Storage Tank (LUST) cases as examples of such example spills that the EPA could consider for such an assessment.

d2. Are there relevant literature or data sources that should be added in this section of the report?

The SAB recommends that the EPA consider the following additional literature sources within this chapter of the draft Assessment Report:

Monitoring: The following references are examples of publications that discuss approaches to monitoring schemes that are necessarily site-specific. The second reference, a journal, focuses on the topic:

1. Bunn, A.L., D.M. Wellman, R.A. Deeb, E.L. Hawley, M.J. Truex, M. Peterson, M.D. Freshley, E.M. Pierce, J. McCord, M.H. Young, T.J. Gilmore, R. Miller, A.L. Miracle, D. Kaback, C. Eddy-Dilek, J. Rossabi, M.H. Lee, R.P. Bush, P. Beam , G.M. Chamberlain, J. Marble, L. Whitehurst, K.D. Gerdes, and Y. Collazo. 2012. Scientific opportunities for monitoring at environmental remediation sites (SOMERS): integrated systems-based approaches to monitoring. *U.S. DOE (U.S. Department of Energy)* DOE/PNNL-21379. Prepared for Office of Soil and Groundwater Remediation, Office of Environmental Management, U.S. DOE, Washington, D.C., by Pacific Northwest National Laboratory, Richland, WA.

2. National Groundwater Association, *Groundwater Monitoring and Review*, various articles.

Spills: The following are examples of specific reports of spilled liquids. The article written by Gross, S.A. *et al*., is referenced within Chapter 5 of the draft Assessment Report; the SAB recommends that the EPA discuss this publication within Chapter 5.

3. Drollette, B.D., K. Hoelzer, N.R. Warner, T.H. Darrah, O. Karatum, M.P. O'Connor, R.K. Nelson, L.A. Fernandez, C.M. Reddy, A. Vengosh, R.B. Jackson, M. Elsner, and D.L. Plata. 2015. Elevated levels of diesel range organic compounds in groundwater near Marcellus gas operations are derived

from surface activities. *Proceedings of the National Academy of Sciences* 112(43), p. 13184-13189. October 27, 2015. doi/10.1073/pnas.1511474112.

4. Gross, S.A., H.J. Avens, A.M. Banducci, J. Sahmel, J. Panko, and Tvermous, B.T. 2013. Analysis of BTEX groundwater concentrations form surface spills associates with hydraulic fracturing operations. *J. Air Waste Manag. Assoc.* 63(4), p. 424-432.

5. New York Times. 2014. Reported Environmental Incidents in North Dakota's Oil Industry. An interactive database by spill type can be found here:
http://www.nytimes.com/interactive/2014/11/23/us/north-dakota-spill-database.html

Reporting: Although most State databases are not electronically searchable and thus create a substantial problem in finding and using hydraulic fracturing data, the SAB recommends that Chapter 5 of the draft Assessment Report be revised to include an assessment of state-level reporting efforts, and that the following references be considered by the EPA in this assessment:

6. North Dakota Department of Health. 2015. Reporting requirements for spills can be found here: http://www.ndhealth.gov/EHS/Spills/

7. Groundwater Protection Council. 2014. *State Oil and Gas Regulation Designed to Protect Water Resources.* Groundwater Protection Council.

Frequency: the SAB recommends that Chapter 5 of the draft Assessment Report be revised to substantially update the analysis on the relative frequency of chemical mixing spills compared to other types of spilled liquids. The following reference provides information that may support this analysis:

8. U.S. Environmental Protection Agency. 2000. *National Water Quality Inventory: 2000 Report*. Chapter 6: Groundwater quality. *United States Environmental Protection Agency Office of Water*, Washington DC 20460. EPA-841-R-02-001. August 2002.

3.4. Well Injection Stage in the HFWC

Question 4: The third stage in the HFWC is well injection: the injection of hydraulic fracturing fluids into the well to enhance oil and gas production from the geologic formation by creating new fractures and dilating existing fractures. This is addressed in Chapter 6.

a. *Does the assessment clearly and accurately summarize the available information concerning well injection, including well construction and well integrity issues and the movement of hydraulic fracturing fluids, and other materials in the subsurface?*
b. *Are the major findings concerning well injection fully supported by the information and data presented in the assessment? Do these major findings identify the potential impacts to drinking water resources due to this stage of the HFWC? Are there other major findings that have not been brought forward? Are the factors affecting the frequency or severity of any impacts described to the extent possible and fully supported?*
c. *Are the uncertainties, assumptions, and limitations concerning well injection fully and clearly described?*
d. *What additional information, background, or context should be added, or research gaps should be assessed, to better characterize any potential impacts to drinking water resources from this stage of the HFWC? Are there relevant literature or data sources that should be added in this section of the report?*

Chapter 6 presents a discussion on well injection, in particular the injection of hydraulic fracturing fluids into the well to enhance oil and gas production from a geologic formation by creating new fractures and dilating existing fractures. The chapter examines fluid migration pathways within and along hydraulic fracturing production wells, includes an overview of well construction, and discusses hydraulic fracturing fluid movement including fluid migration associated with induced fractures within subsurface formations. It also provides an overview of subsurface fracture growth, discussion on the migration of fluids through pathways related to fractures/formations, and a chapter synthesis of major findings, factors affecting the frequency or severity of impacts, and uncertainties.

3.4.1. General Comments

This is a dense and technically complex chapter. The EPA should include more accurate and frequent illustrations, photos, maps, and diagrams in this chapter to help the public better understand the complex issues and technologies discussed.

A key aspect of minimizing impacts to drinking water resources from the well injection stage of hydraulic fracturing operations is responsible well construction and operation, and isolation of potable water from hydraulic fracturing operations. To accomplish this, the agency should recognize in the draft Assessment Report that the following activities are required in order to conduct HFWC activities in a responsible manner: inspection, testing and monitoring of the tubing, tubing-casing annulus and other casing annuli; and monitoring and testing of the potable groundwater through which the tubing, tubing-casing annulus and other casing annuli pass.

In Chapter 4 of the draft Assessment Report, the EPA used text boxes and case study summaries to illustrate concepts which may be new or unknown to the public. The SAB recommends that the EPA include similar boxes and summaries in Chapter 6 and perhaps other chapters as well, in order to improve the chapter's explanation to the public on what has happened and why, and to help address concerns that have been raised by the public. Furthermore, to understand the issues discussed in this chapter, the general public needs more information regarding borehole construction, geologic parameters and well integrity issues in language that the general public can understand.

The SAB also provides a general comment regarding this and other chapters of the draft Assessment Report: the chapter should summarize improvements, changes or accomplishments that have occurred since 2012 in hydraulic fracturing operations related to the HFWC. Since 2012, many significant technological and regulatory oversight improvements have occurred related to well construction, well integrity and well injection. These improvements should be examined in the draft Assessment Report.

Important lessons from carbon capture and storage studies, such as those conducted by and with support of the U.S. Department of Energy (DOE), have shown that well construction and integrity issues are a primary concern with potential releases of chemicals into the environment associated with subsurface storage. The SAB notes that these carbon capture and storage studies have relevance to assessments regarding potential releases from hydraulic fracturing activities. The SAB recommends that the agency examine DOE data and reports on risks of geological storage of CO_2 to water resources and include relevant information in the Assessment Report.

3.4.2. Summary of Available Information on Hydraulic Fracturing Well Injection

a. Does the assessment clearly and accurately summarize the available information concerning well injection, including well construction and well integrity issues and the movement of hydraulic fracturing fluids, and other materials in the subsurface?

In order to better characterize any potential impacts to drinking water resources from the well injection stage of the HFWC, the EPA should further assess available information that will support activities recommended by the SAB within the responses below to sub-questions 4a, 4b and 4c.

The description of available data and information regarding well construction, injection and well integrity in Chapter 6 is generally well documented, but is geared toward a professional audience. The EPA should revise the text of this chapter of the draft Assessment Report so that the general public can better understand the intricacies of hydraulic fracturing well design and of well integrity issues.

The chapter's well construction discussion should discuss state regulatory oversight (including recent improvements and developments which have helped make operations safer), mechanical integrity testing of cement and wells, well integrity testing at the time of initial completion, and subsequent monitoring after the many fractures are placed.

Chapter 6 should include meaningful, accurate and properly scaled diagrams and charts to accompany the text. The relevant appendices linked to this chapter should be expanded to include more well construction, injection and well integrity design information. The EPA should strengthen the chapter's presentation of technical concepts by including clearer geologic illustrations and improved figures to help the general public understand heterogeneity (e.g., fractures, rock properties, and geologic layering) of the subsurface. The EPA should also fully explain any acronyms that are being used in this chapter since the acronyms are often confusing and presented without elaboration.

3.4.3. Major Findings

b1. Are the major findings concerning well injection fully supported by the information and data presented in the assessment?

b2. Do these major findings identify the potential impacts to drinking water resources due to this stage of the HFWC?

While most major findings presented by the EPA in Chapter 6 are generally supported by the information and data provided by the EPA, and the major findings presented by the EPA in this chapter identify almost every conceivable potential impact to drinking water associated with this stage in the HFWC, the chapter's conclusions regarding how many hydraulically fractured wells are or are not leaking are not well supported by analyses or other information presented and should be revised. The EPA should also state more clearly the findings of this chapter, and the chapter's conclusions should flow clearly from those specific findings. Before drawing conclusions on water quality impacts associated with this HFWC step, the EPA should:

- Clarify the description of the probability, risk, and relative significance of potential hydraulic fracturing-related failure mechanisms, and the frequency of occurrence and most likely magnitude and/or probability of risk of water quality impacts, associated with this stage in the HFWC.
- Include a discussion of recent state hydraulic fracturing well design standards, required mechanical integrity testing in wells, new technologies and fracture fluid mixes, and state regulatory standards that have changed the probability of risk of water quality impacts associated with this stage in the HFWC.
- Include an analysis and discussion on low frequency, high severity hydraulic fracturing case studies and example situations.

To improve the presentation and identification of major findings in Chapter 6, the EPA should improve the chapter's discussion and provide a hierarchy and prioritization regarding what are the most important first order factors and effects vs. second and third order factors and effects associated with the potential impacts of hydraulic fracturing well construction, well integrity and well injection on drinking water resources. For example, the EPA should discuss first and second order factors and effects regarding the severity and frequency of potential impacts from poor hydraulic fracturing cementation techniques, hydraulic fracturing operator error, migration of hydraulic fracturing chemicals from the deep subsurface, and abandoned hydraulically fractured wells (including likelihood of impacts, number of abandoned wells, and plugging issues associated with such wells). The SAB recommends that the EPA prioritize and improve the discussion of conclusions regarding frequency and severity of impacts, and describe high vs. low probability of impacts, and what the EPA considers high vs. low probability impacts. The EPA should include a summary figure that includes axes of probability vs. impact within this analysis.

On pages 6-56 and 6-57 of this chapter, the EPA includes the following major finding: "*Given the surge in the number of modern high-pressure hydraulic fracturing operations dating from the early 2000s, evidence of any fracturing-related fluid migration affecting a drinking water resource (as well as the information necessary to connect specific well operation practices to a drinking water impact) could take years to discover.*" The EPA should provide additional information regarding this finding, and further describe the basis for making this statement.

Also, the last sentence of the conclusory discussion in Section 6.4.4. on page 6-57 states: *"Evidence shows that the quality of drinking water resources may have been affected by hydraulic fracturing fluids escaping the wellbore and surrounding formation in certain areas, although conclusive evidence is currently limited."* The SAB recommends that the EPA revise this sentence since this conclusory sentence is internally contradictory and describes situations where actual effects have occurred in certain areas that should not be extrapolated to the nation or world as a whole.

b3. Are there other major findings that have not been brought forward?

While the major findings for Chapter 6 are supported by the information and data and do identify almost every conceivable impact to drinking water resources, the EPA did not bring forward assessments of the likelihood and commonality of possible impacts to drinking water resources associated with hydraulic fracturing well construction, well integrity and well injection. Also, there are several issues regarding cement and casing, spatial and temporal considerations, and stray gas that are critical to ensuring hydraulic fracturing well integrity that the EPA should further assess; these issues are further described below. The EPA's further assessment on these issues may result in additional major findings within this chapter of the draft Assessment Report.

<u>Cement and Casing</u>

The SAB finds that cement integrity, initially and over time, is critical to ensuring hydraulic fracturing well integrity, and hydraulic fracturing cement integrity and issues surrounding such integrity have not been well defined in Chapter 6 of the draft Assessment Report. Also, design principles associated with hydraulic fracturing cement integrity are absent from the draft Assessment Report and should be included to help the public better understand the issues surrounding hydraulic fracturing cement integrity.

The highest priority for improving the EPA's hydraulic fracturing cement and casing discussion in the draft Assessment Report is for the EPA to rewrite and better describe recommendations and requirements for mechanical integrity testing in wells prior to, during and after the hydraulic fracturing process has been completed. While these tests are mentioned in the footnotes of Chapter 6, the draft Assessment Report should specifically discuss the importance of conducting these tests in the text of Chapter 6, or highlight these tests in a text box that the EPA could include in this chapter. The SAB recommends that the draft Assessment Report mention that: a) these tests are vitally important to conduct in order to ensure hydraulic fracturing well integrity; b) that monitoring of well integrity during the life of the producing well is important; c) that these tests, along with cement bond log analyses, should be conducted before a well is hydraulically fractured and also on a periodic basis through the life of the hydraulic fracturing well to ensure hydraulic fracturing well integrity; and d) if these tests indicate a compromise of the well integrity, remedial activity should be conducted before further hydraulic fracturing operations can proceed. The SAB also suggests that the EPA include a figure in the draft Assessment Report that depicts a cement bond log that indicates good cement bonding, no cement bonding, and partial bonding. The SAB suggests that the EPA consider use of a diagram published by the Society of Petroleum Engineers on this topic (Society of Petroleum Engineers, 2013).

Since the quality, placement and type of cement is critical towards ensuring hydraulic fracturing cement integrity, the EPA should improve the draft Assessment Report's discussion on the various classes of cements used as well as different types of casings for hydraulically fractured wells. The EPA should include a diagram that illustrates typical cementation practices both in active as well as in abandoned wells. Regarding abandoned wells, the EPA should provide a diagram of an abandoned well with typical placement of cement, and include discussion on the frequency and requirements the cementing of abandoned wells. The EPA should also describe how abandoned wells of questionable integrity can provide a conduit to freshwater sources, and note that such wells are abundant, not routinely characterized, and in many instances not even identified.

The EPA should also include more information on aging hydraulically fractured wells, how wells may be re-completed (i.e., re-fracturing previously hydraulically fractured wells) and use of acids in old wells (and whether use of such acids degrades old cement), and include statements on whether these wells and hydraulic fracturing activities result in potential impacts to drinking water resources. The EPA should also improve the discussion and emphasis regarding the use of evaluation methodologies (e.g., cement bond logs, temperature logs, acoustic and circumferential bond logs, and pressure testing) and limitations of such methodologies in assessing hydraulic fracturing cement and casing integrity.

The SAB finds that databases and data exist for cement and casing integrity in hydraulic fracturing, and that while these databases have not generally been readily accessible this situation appears to be improving. The EPA should note in Chapter 6 the benefits to be gained through industry disclosure and sharing of specific data on cement and casing integrity to increase transparency on issues associated with this topic.

The SAB also notes that the EPA can reduce uncertainties associated with cement and casing integrity in hydraulic fracturing by examining and assessing more or all of the 20,000 well files referenced in the draft Assessment Report. The SAB also recommends that the EPA conduct full statistical analyses on such an expanded Well File Review, and include graphs or tables associated with such analyses into the draft Assessment Report. The recommendations in this paragraph may be considered longer-term future activities.

The SAB recommends that when estimated percentages are quoted from the Well File Review, the EPA should accompany them with the relevant confidence intervals, and indicate whether they are found in the text of the Review or are inferred from graphs. The EPA should also discuss whether the relatively low percentage of horizontal well completions covered by the Review limits its relevance to current practice.

Within Chapter 6 of the draft Assessment Report, the EPA should also describe available new research and technology that has been developed since 2010 with respect to cements, low thermal gradient setting times, swellable elastomers and flexible cements. The EPA should describe how available and widespread are the uses of these technologies, whether the availability and use of these technologies affects the temporal variation of occurrence of problems associated with cement and well integrity, and whether any, some, or most of the identified impacts associated with cement and well integrity have been or could be mitigated by such technologies.

The EPA should also better explain how pressure diffusion in karst limestone formations and in porous zones adjacent to shales can be critical in diffusing migration pathways associated with installation and cementing practices of hydraulically fractured wells. The EPA should improve the discussion to note that these pathways are complex and that porous zones can help diffuse pressures. This discussion should also describe the various difficulties associated with cementing hydraulically fractured wells in such zones.

The EPA should discuss the potential effects of natural and induced seismicity on cementing integrity and the challenges of studying this phenomenon.

Furthermore, within Chapter 6 the EPA should avoid the use of words such as "conduits" to describe minute cracks and fissures, since mechanical discontinuities occur on a range of scales and not all cracks/fissures are as large-scale as implied by words such as "conduits."

Spatial and Temporal Issues

Within Chapter 6 of the draft Assessment Report, the EPA should improve the discussion on how the manner by which hydraulically fractured wells are completed may affect how gas escapes from the hydraulic fracturing well, and how methods for hydraulically fracturing a well have improved over time to further mitigate such gas release incidences. The EPA should include a summary of temporal and spatial variations associated with hydraulic fracturing-related gas release incidences that have occurred, and the SAB concludes that such information would help to address many public concerns on this topic. The SAB recommends that at a minimum, the EPA should report the dates of such incidences (which may be noted on the collected data and from the literature review) so that such temporal conclusions may be drawn or inferred.

The EPA describes many timeframes in Chapter 6 but does not adequately differentiate or discuss these timeframes. The period of fluid injection to fracture the source rock may be hours or days for each fractured well segment; in contrast, the flow of oil and/or gas back into the well lasts for the entire production life of the well, which can be many years. Since hydraulic fracturing has a short time duration (hours/days) and post-fracturing produced water collection and disposal are performed over many years, the EPA should consider including and discussing a bar graph that summarizes the duration of different events in the "life-cycle" of a well. Such a summary would provide clarity on the difference in the duration of these stresses and the difference in the duration of fluid flow directions oriented away from and into the well. To this end, the EPA should consider including and discussing a graph such as the one suggested by SAB HF Panel member Dr. Scott Bair in his preliminary individual Panel member comments for Charge Question 4.[1]

The EPA should include information regarding the spatial proximity of wells to each other and to water sources and to known geologic faults to help the public better understand the physical situation in which hydraulic fracturing well injection is conducted. In addition, the SAB notes that statistical information on hydraulic fracturing well data summaries is generally not available, and the EPA should provide more information on the three-dimensional nature and aspects of well injection in the HFWC. The recommendations in this paragraph may be considered longer term future activity.

[1] See SAB's October 28-30, 2015 meeting website for these posted individual SAB Panel member comments, at the following website address: http://yosemite.epa.gov/sab/sabproduct.nsf/a84bfee16cc358ad85256ccd006b0b4b/26216d9fbba8784385257e4a00499ea0!OpenDocument&Date=2015-10-28.

<u>Stray Gas</u>

The EPA should expand the stray gas migration discussion in Chapter 6 on techniques that can be used to identify the source of stray gas such as noble gas tracers, and more clearly describe the pathways for such migration. While the draft Assessment Report accurately describes the general state of the art of these techniques, and describes variations in stray gas with respect to different types of oil and gas production (e.g., coal bed methane), the science of stray gas migration and analysis is described only briefly and should be rewritten to include greater clarification on the topic. For example, in its descriptions of situations where hydraulically fractured wells may not be properly cased and cemented, the EPA should distinguish between fracture-related gas vs. stray gas that may migrate naturally through formations.

3.4.4. Frequency or Severity of Impacts

b4. Are the factors affecting the frequency or severity of any impacts described to the extent possible and fully supported?

The SAB finds that Chapter 6 could be improved if the draft Assessment Report clarified the probabilities associated with the frequency and severity of impacts to drinking water resources associated with various stages of the hydraulic fracturing well injection process. The chapter generally does an excellent job of explaining the various possible situations that may occur and result in a release from the well injection process that may impact drinking water resources. However, the chapter should provide a more focused, improved discussion on the likelihood, frequency, magnitude, and severity of such impacts. The text, if not modified, would leave the reader to deduce or make incorrect inferences regarding such impacts. The EPA should clarify in Chapter 6 what is known about the frequency and the severity of such impacts, and should not state that the EPA is unable to assess such impact or severity.

As recommended in the following paragraphs, the EPA should further assess data that are available to improve the discussion on likelihood, frequency, magnitude, and severity of such impacts. While the anecdotal data on this topic are well described and very fully documented within the draft Assessment Report, the data are not statistical in nature, and therefore conclusions on severity of impact are difficult to assess. Conclusions as to severity and risk based on such data should be developed after these and other data are assessed. The chapter's discussion on this topic leaves the reader with high uncertainty on the frequency and severity of impacts, and whether any impacts can happen at any location at any time. The SAB notes that there are hydraulic fracturing-related issues that have arisen that should be identified, prioritized and described within this chapter to reduce uncertainties and help identify methods to minimize impacts of the well injection stage of the HFWC and minimize the uncertainties associated with abandoned wells.

Chapter 6 does not quantify the number of impacts described in the literature associated with the well injection stage of the HFWC. While the draft Assessment Report states that there are inadequate data to quantify the frequency or severity of such impacts, available literature and research presented in the draft Assessment Report did uncover a limited number of impacts. In addition, the EPA's Well File Review that is described in Text Box 6.1 on page 6-6 of the draft Assessment Report statistically examined a number of well files selected from over 20,000 wells. The SAB notes that the EPA can reduce uncertainties associated with hydraulic fracturing cement and casing integrity by examining and assessing more or all of the 20,000 well files referenced in the draft Assessment Report, as a longer-term future activity, and use this information to help assess the frequency of impacts relative to the number of hydraulically fractured wells. The SAB also recommends that the EPA conduct full statistical analyses on such an expanded Well File Review, and develop graphs or tables associated with such analyses.

The SAB recommends that when estimated percentages are quoted from the Well File Review, the EPA should accompany them with the relevant confidence intervals, and indicate whether they are found in the text of the Review or are inferred from graphs. The EPA should also discuss whether the relatively low percentage of horizontal well completions covered by the Review limits its relevance to current practice.

The EPA should distinguish studies that "presume" that impacts are caused anthropogenically, since the actual causes of such impacts may be natural (fault seepage) or due to historical events (such as releases from old, abandoned wells). The SAB recommends that the EPA rely on scientifically sound peer-reviewed papers (e.g., the paper by Darrah et al., 2014, that is cited in the draft Assessment Report) that identify sources of migrated gases based on isotopic and compositional analysis of the gas to identify the actual causes of such impacts, and that do not attempt to eliminate natural pathways based on assumptions that are not scientifically justified.

Section 6.4.1.3 of the draft Assessment Report describes several cases of documented impacts, and clarifies that the causes may be inconclusive. The SAB recommends that the EPA describe the frequency of such impacts relative to the number of wells. Some of these documented impacts were not documented to have occurred from hydraulic fracturing activities, and the reasons for such inconclusive documentation should also be described.

The EPA should expand the stray gas migration discussion in Chapter 6 on techniques used to identify the source of stray gas such as noble gas tracers, and to describe more clearly the pathways for such migration. The draft Assessment Report should discuss publications describing cases of such migration, and evaluate the veracity of conclusions drawn in these studies. The EPA provided a good discussion on Page 6-2 of the complexity and challenges associated with differentiating stray gas migration due to hydraulic fracturing activities from numerous potential natural and anthropogenic processes of gas, and the many potential natural occurring or man-made routes that may exist for such migration.

Distinguishing sources and pathways for gas resulting from casing failure, from natural migration in faults or shallow formations, or from unknown abandoned wells is typically difficult, and assessments of source and migration path often result in conflicting expert opinions. Beginning on page 6-16 in Section 6.2.2.1 in Text Box 6-2, the draft Assessment Report states that new noble gas and hydrocarbon stable isotope data can be used to further distinguish these sources and pathways. The SAB agrees that clear evidence of the existence of these pathways is needed in order to make sound conclusions on those sources and pathways.

It is stated in Chapter 6 that methane occurs naturally in many aquifers and that methane from different sources (i.e., significantly different formations and/or depths) can often be distinguished isotopically or compositionally. The text should be modified to clarify that the increase of methane alone in an aquifer or a nearby, domestic/residential or commercial potable well is not a good indicator of a release from a hydraulic fracturing well due to the potential release of naturally occurring methane in that aquifer from pumping or sampling disturbances in the water well. The text should also note that the best method for confirming cause and effect of methane releases is pre-drilling baseline sampling and post-drilling sampling of well fluids, combined with use of isotope and compositional analysis of dissolved gases, anions and cations and knowledge of the existing or perturbed natural pathways. However, as noted in the previous paragraph, interpretation of these data is complicated and often results in conflicting expert opinions.

<u>Modeling (Fluid Flow and Induced Seismicity)</u>

The EPA should improve the description and presentation in Chapter 6 of the objectives, designs, limitations and conclusions of the models and simulations that support analysis of the well injection stage of the HFWC. The EPA's modeling assessment report associated with this stage of the HFWC only studied the injection of fluid over a short period of time under hydrostatic conditions. The draft Assessment Report should describe additional project modeling work that is forthcoming. The SAB is concerned that the draft Assessment Report presents a confusing description regarding how the agency uses actual data (e.g., pressure data, water chemistry data or other measured parameters) to describe situations where hydraulic fracturing fluids reach drinking water resources, vs. how the EPA uses modeling predictions of such occurrences to describe these situations. In the descriptions of the models and simulation results the EPA should clarify that the models are interpretive and are based on a generic geologic system, generic fracturing stress, a specified hydraulic gradient, and generic physical rock properties.

Section 6.2.2 of the draft Assessment Report inappropriately uses the word "evidence" with regard to modeling. In the descriptions of the models for fracture propagation and fluid migration introduced and discussed in this chapter, the EPA should clarify that these model predictions and results are not evidence, and fully and clearly describe the limitations of such models. The EPA should state that the interpretation of such model predictions is not evidence, and that predictive models try to match natural physical and/or chemical properties that can be measured in the field or in the laboratory. The EPA should fully and clearly describe the limitations of such models, and note that the modeling results do not represent actual sites nor do they contain all combinations of stresses, hydraulic gradients, rock properties, typical geologic settings, and natural heterogeneity (e.g., fractures, rock properties, and geologic layering). Regarding typical geology, the SAB recommends that the EPA include a discussion on the importance of understanding the regional geology of an area prior to embarking on installing a hydraulic fracturing well or drilling into a play where hydraulic fracturing will be involved. This discussion should include the importance of describing the physical properties of the various rock layers (e.g. thicknesses, lithologies, continuity, porosities and permeabilities, fracture density), the hydrocarbon charge (entry mechanism) and maturation in the reservoir, the overall degree and complexity of deformation, the extent of separation from base potable groundwater to the objective producing section, and geothermal and stress field gradients.

In addition, the EPA should provide more or improved figures to illustrate each model/scenario described in Chapter 6. The EPA should add a description of the modeling assumptions and the strengths and weaknesses of any modeling parameters, and should make clear that the models described only provide insights that depend on the quality of input data and the assumed physics and geology.

The chapter's description of natural fractures and the nature of induced vs. natural fractures is brief and should be rewritten to include more clarity and information. The EPA should gather data that are abundantly available from industry, academia and service companies regarding how fractures grow and whether fractures are likely to reach ground surfaces, and describe such data and analysis in the draft

Assessment Report. Recent research efforts such as those conducted at Colorado School of Mines' Reservoir Characterization Project (RCP), indicate hydraulically induced fractures generally stay within a very narrow range above and below the fractured horizon (see Vinal and Davis, 2015).

The SAB notes that Figure 6-1 misleadingly depicts what appears to be a fresh water zone behind an uncemented intermediate casing string. The SAB recommends that Figure 6-1 be revised since it does not depict a realistic scenario of current industry practice.

While Figure 6-5 is a potentially helpful pictorial guide for the well injection stage of the HFWC, the EPA should describe the complexity of the subsurface geology and well construction within the chapter in the interpretation of this figure. In addition, Figure 6-5 should be revised to address the misleading distances and scale and oversimplified geology associated with the figure. The EPA should also describe a typical industry injection rate and pressure plot for a hydraulic fracturing injection as a function of time, as related to Figure 6-5, and include the entire fall-off period within this description.

The SAB notes that hydraulic fracturing simulation and design software, such as STIMPLAN, have been used in an attempt to create fractures that grow to intersect base of potable water-bearing units, and that such simulations were unsuccessful in propagating fractures to potable water without assuming geological and geophysical parameters which contradict actual conditions in the subsurface. Smith and Montgomery (2015) provides useful information on parameters that affect fracture height growth. Dr. Mike Smith performed a number of modeling experiments using STIMPLAN. He created a horizontal well at typical depth. In an unpublished effort, Dr. Smith ran a fracture simulation with zero stress contrast in all formations from depth to surface which was the only way he could get a fracture to propagate to the surface. The SAB agrees this is not a realistic scenario, and that all other models that the SAB is aware of do not allow propagation of fractures to the surface. The EPA may find it useful to contact Dr. Smith directly for specific results.

The EPA should acknowledge in the chapter that unidentified abandoned wells of questionable integrity can provide a conduit to freshwater sources, and conduct a literature or other search to identify the order of magnitude of this problem.

In addition, the draft Assessment Report should include some discussion about what is known regarding induced seismicity and impacts on drinking water resources associated with HFWC activities. A reference that the EPA should consider when developing this discussion regarding the occurrence and causal factors of such events includes the work by Dillon and Clark (2015). Detailed discussion of induced seismicity from wastewater disposal should be reserved for Chapter 8 which is focused on wastewater treatment and disposal. Since 2009 a significant increase in induced seismicity has been noted in Texas, Oklahoma, Ohio, and other states, and this induced seismicity has been typically linked to high-rate disposal injection wells and not hydraulically fractured wells. Induced seismicity from well injection for hydraulic fracturing should be distinguished from induced seismicity associated with hydraulic fracturing wastewater disposal via Class II deep well injection. The SAB notes that there have been reports of slightly higher magnitude seismicity at hydraulic fracturing sites (up to Magnitude 4+ in Alberta and British Columbia as well as Ohio) (Fischetti, M., 2012; Skoumal, R.J., et al., 2015; Holland, A., 2011; Horner, R. B., et al., 1994; and Perry, S.A., et al., 2011). The SAB recommends that the EPA include better documentation within this chapter on the occurrence and any causal factors of such events (e.g. increased rates or volumes of injection in BC and Alberta). The SAB also recommends that the EPA describe information on available micro-seismic data and how such data may impact assessments regarding induced seismicity. Although the SAB recognizes that induced seismicity at hydraulic fracturing sites is anticipated to be a rare occurrence, the EPA should have improved documentation and monitoring data from when such events do occur. The SAB therefore recommends that the EPA discuss in the draft Assessment Report the importance of continual seismic monitoring at new hydraulic fracturing sites or hydraulic fracturing sites that have the potential for elevated seismicity and impacts on drinking water resources.

3.4.5. Uncertainties, Assumptions and Limitations

c. Are the uncertainties, assumptions, and limitations concerning well injection fully and clearly described?

Overall, while Chapter 6 discusses many hydraulic fracturing well injection technologies and scenarios and possibilities, the EPA should revise the chapter and describe the uncertainties, assumptions and limitations of the data and the use of data associated with well injection. In addition, this chapter should include an assessment on the probability or likelihood of occurrence of impacts to drinking water resources from well injection. Such an assessment would improve the readers' understanding of uncertainties associated with this chapter.

The EPA should more clearly describe the uncertainties associated with the probability, risk, and relative significance of potential hydraulic fracturing-related failure mechanisms, and the frequency of occurrence and most likely magnitude of water quality impacts associated with the well injection stage of the HFWC. In particular, the EPA should provide more information on the relative probability of scenarios presented for potential impacts of the well injection stage of the HFWC. Specific examples of possible improvements are discussed in the following paragraphs.

The discussion in Chapter 6 on the frequency and severity of impacts associated with the well injection stage of the HFWC leaves the reader with high uncertainty on the frequency and severity of impacts, and whether any impacts can happen at any location at any time. The EPA should identify, prioritize and describe hydraulic fracturing-related issues that have arisen in regard to well injection in order to reduce uncertainties and help identify methods to minimize impacts of the well injection stage of the HFWC and minimize the uncertainties associated with abandoned wells.

As described above within the response to sub-questions 4b1 and 4b2, the SAB finds that cement integrity, initially and over time, is critical to ensuring hydraulic fracturing well integrity, and that the limited discussion on hydraulic fracturing cement integrity and issues surrounding such integrity within Chapter 6 increase the uncertainties associated with how cement integrity may affect impacts to drinking water resources. The EPA should describe the uncertainties surrounding hydraulic fracturing well cementing integrity. The EPA should also discuss how mechanical integrity testing in wells prior to, during, and after hydraulic fracturing operations have been completed would lessen the uncertainties associated with hydraulic fracturing well cementing integrity. The SAB also notes that the EPA can, as a longer-term future activity, reduce uncertainties associated with hydraulic fracturing cement and casing integrity by examining and assessing more or all of the 20,000 well files referenced in the draft Assessment Report. The SAB also recommends that the EPA conduct full statistical analyses on such an expanded Well File Review, and develop graphs or tables associated with the results of such analyses.

As also described above within the response to sub-questions 4b1 and 4b2, the SAB finds that the draft Assessment Report should not make definitive statements regarding whether some or all hydraulically fractured wells are or are not leaking due to uncertainties associated with the EPA's analysis on hydraulic fracturing well integrity.

3.4.6. Additional Information, Background or Context to be Added

d1. What additional information, background, or context should be added, or research gaps should be assessed, to better characterize any potential impacts to drinking water resources from this stage of the HFWC?

The EPA should conduct as longer-term future activities the various recommended activities suggested above within the responses to Charge Questions 4a and 4b to better characterize any potential impacts to drinking water resources from the well injection stage of the HFWC. Wastewater injection and detailed discussion of induced seismicity from wastewater disposal should be reserved for Chapter 8 which is focused on wastewater treatment and disposal.

The EPA should also further assess hydraulic fracturing case studies, conduct and assess hydraulic fracturing water quality measurements, describe new hydraulic fracturing technologies, assess hydraulic fracturing-related impacts from a systems view, and describe regulatory improvements associated with hydraulic fracturing, as further discussed below. The recommendations in this paragraph may be considered longer term future activities.

<u>Case Studies</u>

The EPA should include a discussion within Chapter 6 on the strengths and weaknesses of available case studies for well injection activities. The EPA should clarify known data, inferences, and the success of remedial activities that may have occurred associated with these case studies. The EPA describes two case studies in the chapter: Bainbridge, OH (which was a cement failure and not related to hydraulic fracturing injection) (Bair, E.S., et al., 2010); and Kildeer, ND (which was a blowout that happened coincidentally, but was not related to hydraulic fracturing injection) (Battelle, 2013). While these cases are interesting, they are not directly related to the hydraulic fracturing injection process but are possibly relevant as part of the greater HFWC picture. The SAB agrees that this is an important distinction to be made if references to these cases are to remain included.

However, the SAB finds that the agency should include and fully explain the status, data on potential releases, and findings if available for the EPA and state investigations conducted in Dimock, Pennsylvania; Pavillion, Wyoming; and Parker County, Texas where hydraulic fracturing activities are perceived by many members of the public to have caused impacts to drinking water resources. Examination of these high-visibility, well-known cases is important so the public can more fully understand the status of investigations in these areas, conclusions associated with the investigations, lessons learned if any for the different stages of the hydraulic fracturing water cycle, what additional work should be done to improve the understanding of these sites and the HFWC, plans for remediation if any, and the degree to which information from these case studies can be extrapolated to other locations.

While the EPA describes casing and cement issues causing gas migration behind outer well casings, the SAB recommends that the EPA provide specific examples of such issues.

Water Measurements

The EPA should discuss the importance of baseline or pre-drilling activity water quality data measurements in order to better understand whether impacts from drilling and completion activities can be identified. The SAB notes that this information is important to understand because it provides a baseline reference as to water quality surrounding hydraulic fracturing sites before HFWC activities occurred. The EPA should identify and describe best practices such as those now required by the State of Colorado. The SAB notes that pre-drilling water results will fluctuate with seasonal changes in the groundwater. The State of Colorado is now requiring sampling and measurement prior to and after all oil and gas drilling activity (State of Colorado, 2014). Many oil and gas companies are also implementing such requirements as part of their own best practices. Shell is one example; see Shell Inc. (undated). In addition, the requirements of several states for baseline or pre-drilling testing is described in a recent publication (Bosquez, et al., 2015). This publication describes the strategies that these states have taken to encourage the collection of baseline data, which in some states differ from the approach of Colorado. For instance, some states have a rebuttable presumption that contamination of a domestic well within half a mile of a gas well is caused by the development of the well. The scarcity of baseline data is mentioned as a limitation in EPA's draft Assessment, at least in the Executive Summary, but the steps that these states have taken to require or encourage baseline data collection are not.

As discussed further in the response to Charge Question 7, the EPA should also characterize the toxicity and mobility of the most important hydraulic fracturing chemicals of concern that are injected into hydraulically fractured wells. The EPA should also be careful to distinguish between hydraulic fracturing chemicals injected into a hydraulic fracturing well vs. constituents, chemicals and hydrocarbons that come back out of the hydraulic fracturing well in produced fluids.

The EPA should also discuss in Chapter 6 what is known or inferred about the fate of un-recovered fracture fluids that are injected into hydraulically fractured wells. The EPA should describe and include an assessment on where these fluids go if they do not come back to the surface. If this is not possible to do with any rigor, a description of the differences between milli-darcy, microdarcy and nanodarcy permeability rocks may help the reader understand the variability in fluid recovery under various geologic scenarios, at least in concept, if not using actual recovery analyses. In addition, the EPA should describe the challenge of monitoring and modeling the fate of injected fracture fluids over time.

The SAB notes that the general public usually does not distinguish between hydraulic fracturing flowback and hydraulic fracturing produced water, and recommends that the agency reconsiders its decision to distinguish between these waters within the draft Assessment Report. The EPA should also describe what is meant by produced water and whether this water comes from hydraulic fracturing and/or from non-HF activities. The EPA should also consider moving Chapter 6's discussion on flowback and produced water to Chapter 7. Further discussion on this topic is provided in Section 3.5.1 of this SAB report.

Technology

The EPA should include discussions of new technologies that relate to the protection of drinking water resources and are associated with the well injection stage of the HFWC, including: cement bond logs, acoustic logs used to "hear" gas movement such as spectral noise testing, cement development technologies, and monitoring technologies. For example, new cement designs and swellable elastomers are being used in the hydraulic fracturing industry but are not and should be described within Chapter 6. In addition, many states require the use of newer "greener" hydraulic fracturing technologies and the EPA should consider adding a discussion on such technologies to this chapter. A recent publication highlights some of these advancements in technology (Todd et al., 2015).

Systems View

The SAB recommends that the EPA undertake, as a longer-term future activity, a systems approach to identify and list the highest probability and highest magnitude issues associated with the well injection stage of the HFWC, and distinguish what is naturally occurring and what is induced via oil and gas development and completion. Such an approach would assess an engineered hydraulic fracturing system coupled to a heterogeneous natural system, and identify leading causes of failures in the engineered hydraulic fracturing systems. It would also assess which activities are or are not common to all oil and gas development, and which problems are uniquely caused by hydraulic fracturing-related activity. The approach would distinguish which issues arise from the natural earth and which may have been anthropogenically induced, identify systemic failures, and describe heterogeneities and site-specific variations in natural systems. The EPA could identify actionable issues within the findings of such a systems analysis. In addition, the SAB recommends the EPA examine the best practices of some major oil and gas producers as well as the regulatory requirements by various states to ascertain best practices in sampling for ground water before and after development and completion activities. Such descriptions may provide valuable insights in identifying and distinguishing pre-existing water quality issues as well as water quality issues associated with oil and gas development activity. Such best practices and analyses would certainly be beneficial on a forward looking basis, but may also help discriminate between pre-existing and development–induced problems in certain cases where data may have been captured in the past. The recommendations in this paragraph may be considered longer term future activity.

Regulatory Improvements

The EPA should examine, as a longer-term future activity, state standards and regulations that have been implemented with the aim of improving hydraulic fracturing operations associated with the well injection stage of the HFWC. The SAB recommends that the EPA investigate the evolution of oilfield and state regulatory practices that are relevant to hydraulic fracturing operations, as the evolution of such practices is not described adequately in Chapter 6. The EPA should describe best management practices associated with state standards and regulations related to the well injection stage of the HFWC. The EPA should consider hydraulic fracturing-related standards and regulations within a few key states such as Pennsylvania, Wyoming, Texas, Colorado and California who all have implemented new hydraulic fracturing-related regulations since 2012. The EPA could consider the work completed on this topic by the State Review of Oil and Natural Gas Regulations, Inc. (STRONGER) organization The EPA should also more accurately describe changes in such standards and regulations as an "evolution" vs. "improvement" in these state regulations. The recommendations in this paragraph may be considered longer term future activity.

The EPA should also consider conducting an assessment on whether new hydraulic fracturing well construction standards have lowered the frequency and severity of potential impact of hydraulic fracturing well injection on drinking water resources. The recommendations in this paragraph may be considered longer term future activity.

d2. Are there relevant literature or data sources that should be added in this section of the report?

The SAB recommends that the EPA consider the following additional literature sources within this chapter of the draft Assessment Report:

Aly, M., B. Clancey, J. Montgomery, M. A. Bugti, A. F. Ahmadzamri. 2015. Geochemical Applications for Identifying the Source of Hydrocarbons in Well Annuli. International Petroleum Technology Conference. IPTC-18309-MS.

Balashov, V.N., T. Engelder, X. Gu, M.S. Fantle, and S.L. Brantley. 2015. A model describing flowback chemistry changes with time after Marcellus Shale hydraulic fracturing. *American Association of Petroleum Geologists Bulletin* 99(1), 143-154. January 2015. doi: 110.1306/06041413119.

Blanton, T. L. 1982. An experimental study of interaction between hydraulically induced and pre-existing fractures, *SPE Unconventional Gas Recovery Symposium*, 16-18 May, Pittsburgh, Pennsylvannia, 1982. *Society of Petroleum Engineers Publication* SPE-10847-MS.

Bosquez, Teodoro IV, Daniel Carmeli, Jeremy Esterkin, Mae Kieng Hau, Kenneth Komoroski, Camarin Madigan, and Matthew Sepp. 2015. Fracking debate: the importance of pre-drill water-quality testing. *American Bar Association Section of Litigation*. February 18, 2015.

Browning, R., M. Duffy, D. Gaugler, and P. Jones. 2012. Effectiveness of Self-Healing Cement Additives Based on Test Methodology Using Simulated Cement Sheath Cracks. *Society of Petroleum Engineers Publication.* SPE 161028.

Bui, B. T. and A.N. Tutuncu. 2013. Modeling the Failure of Cement Sheath in Anisotropic Stress Field, *Society of Petroleum Engineers Publication* SPE 167178.

Cavanagh, P., C.R. Johnson, S. LeRoy-Delage,, G.DeBruin, I. Cooper, H. Bulte and B. Dargaud. 2007. Self-Healing Cement- Novel Technology to Achieve Leak-Free Wells, IADC Drilling Conference Paper, SPE/IADC 105781,

De Andrade, J., S. Sangesland, J. Todorovic and T. Vralstad. 2015. Cement Sheath Integrity During Thermal Cycling: A Novel Approach for Experimental Tests of Cement Systems. Society of Petroleum Engineers Publication, SPE-173871-MS.

Dillon, David K. and Don Clarke. Findings and Update on the National Research Council's Committee on Induced Seismicity Potential of Energy Production and Related Technologies. 2015. Oral presentation given at American Association of Petroleum Geologists Annual Convention & Exhibition, Denver, Colorado, May 31-June 3, 2015.

King, G., and R. L. Valencia. 2016. Well Integrity for Fracturing and Re-Fracturing: What is Needed and Why? *Society of Petroleum Engineers Publication*. SPE-179120-MS.

Landry, G. R.D. Welty, M. Thomas, M. L. Vaughan and D. Tatum. 2015. Bridging the Gap: An Integrated Approach to Solving Sustained Casing Pressure in the Cana Woodford Shale, *Society of Petroleum Engineers Publication.* SPE-174525-MS.

Lee, H.P., J.E. Olson, J. Holder, J.F.W. Gale, and R. D. Myers. 2015.The interaction of propagating opening mode fractures with preexisting discontinuities in shale. *Journal of Geophysical Research* 120(1), p. 169-181. January 2015. http://dx.doi.org/10.1002/2014JB011358.

Leslie, I., T. Bradley, J. Balamaga, and I. Whyte. 2015. The Effect of Time on Apparent Cement Integrity – Time Lapse Logging of Cement Bond Logs, SPWLA 56th Annual Logging Symposium.

Llewellyn, G., F.L. Dorman, J.L. Westland, D. Yoxtheimer, P. Grieve, T. Sowers, E. Humston-Flumer, and S.L. Brantley. 2015. Evaluating a groundwater supply contamination incident attributed to Marcellus Shale gas development. *Proceedings of the National Academy of Sciences* 112(20), 6325-6330. May 19, 2015. doi: 10.1073/pnas.1420279112.

McDaniel, J., L. Watters, and A. Shadravan. 2014. Cement Sheath Durability: Increasing Cement Sheath Integrity to Reduce Gas Migration in the Marcellus Shale Play. Society of Petroleum Engineers Publication. SPE 168650.

Montague, J. A., and G.F. Pinder. 2015, Potential of hydraulically induced fractures to communicate with existing wellbores. *American Geophysical Union Water Resour. Res.* 51. September 18, 2015. doi:10.1002/2014WR016771.

Olson, J.E., B. Bahorich, and J. Holder. 2012. Examining hydraulic fracture: Natural fracture interaction in hydrostone block experiments. *Society of Petroleum Engineers Publication* SPE-152618-MS, SPE Hydraulic Fracturing Technology Conference, 6-8 February, The Woodlands, Texas, USA, 2012.

Parmar, J., H. Dehghanpour, and E. Kuru. 2012. Unstable displacement, A missing factor in fracturing fluid recovery. *Society of Petroleum Engineers Publication* SPE-162649-MS, SPE Canadian Unconventional Resources Conferences, 30 October-1 November, 2012, Calgary, Alberta, Canada.

Parmar, J., H. Dehghanpour, and E. Kuru. 2014. Displacement of water by gas in propped fractures: Combined effects of gravity, surface tension, and wettability. *Journal of Unconventional Oil and Gas Resources* 5, p. 10-21. March 2014. DOI: 10.1016/j.juogr.2013.11.005.

Shadravan, A., A. Alegria, and Ro Castanedo. 2015. Rheological Hierarchy Optimization Improves Fluid Displacement and Well Integrity, 3 Worldwide Cases. *Society of Petroleum Engineers Publicaiton.* SPE 174773-MS

Shadravan, A., E. Kias, R. Lew and R. Maharidge. 2015. Utilizing the Evolving Cement Mechanical Properties under Fatigue to Predict Cement Sheath Integrity. Society of Petroleum Engineers Publication, SPE-175231-MS

Shadravan, A. J. Schubert, M. Amani and C. Teodoriu. 2015. Using Fatigue-Failure Envelope for Cement-Sheath-Integrity Evaluation. *SPE Drilling and Completions Journal, March 2015. p. 68-75.*

Shell Inc. Shell onshore tight sand or shale oil and gas operating principles. Undated. Available at http://www.shell.com/content/dam/shell-new/local/corporate/corporate/downloads/pdf/shell-operating-principles-tight-sandstone-shale.pdf

Smith, M.B., and C. Montgomery. 2015. Hydraulic Fracturing, published by CRC Press, p. 59-105.

Todd, B.N., D.C. Kuykendell, M.P. Peduzzi, and J. Hinton. Hydraulic Fracturing – Safe, Environmentally Responsible Energy Development. 2015. Society of Petroleum Engineers SPE-173515-MS. For presentation at the SPE E&P Health, Safety, Security and Environmental Conference – Americas, held in Denver CO, March 16-18, 2015.

Tutuncu A.N. and Bui B. T., 2016, A Coupled Geomechanics and Fluid Flow Model for Induced Seismicity Prediction in Oil and Gas Operations and Geothermal Applications, Journal of Natural Gas Science and Engineering, Volume 29, 110 – 124. doi:10.1016/j.jngse.2015.12.039.

Tutuncu, A.N. and B.T. Bui. 2015. Coupled Geomechanical and Fluid Flow Modeling for Injection Induced Seismicity Prediction, *85th Society of Exploration Geophysicists Annual Meeting Proceedings*, SEG 2015 SS 2.2, p. 4848-4852.

Tutuncu, A. N. 2014. Microseismic Coupled Geomechanical Modeling for Environmental Risk Evaluation in Shale Reservoir Developments. *International Society for Rock Mechanics Publication* ARMS8-2014-325, ISRM Conference Paper.

Vargas Bermea, J. A., S. Taoutaou, K. Olutimehin, M. Vinaipanit, S. Ashraf, G. Segret, J. Asawakowitkorn, and N. Kongpat. 2015. A Case Study of Flexible/Expandable and Self-Healing Cement for Ensuring Zonal Isolation in Shallow, Hydraulically Fractured Gas Well, Onshore Thailand. SPE/IADC-173065-MS.

Vinal, I, and Davis, T. Surface time-lapse multi-component seismology – a new technology for hydraulic fracture monitoring? A Montney Shale gas case study. 2015. *First Break* 33(2): 65-70.

Wang, W. and A. Dahi Taleghani. 2014. Cement sheath integrity during hydraulic fracturing; An integrated modeling approach. *Society of Petroleum Engineers Publication* SPE-168642-MS, SPE Hydraulic Fracturing Technology Conference, 4-6 February, 2014, The Woodlands, Texas, USA. http://dx.doi.org/10.2118/168642-MS.

Warpinski, N. R., J. Du, and U. Zimmer. 2012. Measurements of Hydraulic-Fracture-Induced Seismicity in Gas Shales. *Society of Petroleum Engineers Publication* SPE-151597, SPE Prod. Operations, V. 27, p. 240-252. doi: 10.2118/151597-PA.

Weijers, L., C. Wright, M. Mayerhofer and C. Cipola. 2005. Developing Calibrated Fracture Growth Models for Various Formations and Regions across the United States. *Society of Petroleum Engineers Publidation.* SPE 96080

Weingarten, M., Ge S., Godt J., Bekins B.A. and Rubinstein J.L. 2015. High-rate injection is associated with the increase in U.S. mid-continent seismicity. *Science* 348(6241), p.1336-1339, June 19, 2015.

Wilson, B. 2014. Geologic and baseline groundwater evidence for naturally occurring, shallowly sourced, thermogenic gas in northeastern Pennsylvania. *American Association of Petroleum Geologists Bulletin* 98(2), p. 373–394. February 2014. doi: 10.1306/08061312218

Zoback, M.D, Rummel, F., Jung, R. and C.B. Raleigh. 1977. Laboratory hydraulic fracturing experiments in intact and pre-fractured rock. *International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts* 14(2), p. 49-58. March 1977. doi: 10.1016/0148-9062(77)90196-6.

3.5. Flowback and Produced Water Stage in the HFWC

Question 5: The fourth stage in the HFWC focuses on flowback and produced water: the return of injected fluid and water produced from the formation to the surface and subsequent transport for reuse, treatment, or disposal. This is addressed in Chapter 7.

a. *Does the assessment clearly and accurately summarize the available information concerning the composition, volume, and management of flowback and produced waters?*
b. *Are the major findings concerning flowback and produced water fully supported by the information and data presented in the assessment? Do these major findings identify the potential impacts to drinking water resources due to this stage of the HFWC? Are there other major findings that have not been brought forward? Are the factors affecting the frequency or severity of any impacts described to the extent possible and fully supported?*
c. *Are the uncertainties, assumptions, and limitations concerning flowback and produced water fully and clearly described?*
d. *What additional information, background, or context should be added, or research gaps should be assessed, to better characterize any potential impacts to drinking water resources from this stage of the HFWC? Are there relevant literature or data sources that should be added in this section of the report?*

Chapter 7 presents a discussion on flowback and produced water, in particular the return of injected fluid and water produced from the formation to the surface and subsequent transport for reuse, treatment, or disposal. The chapter examines the volume of hydraulic fracturing flowback and produced water, including a discussion on data sources and formation characteristics. The chapter also examines the composition of hydraulic fracturing flowback and produced water, including temporal changes in flowback composition, total dissolved solids enrichment, radionuclide enrichment, leaching and biotransformation of naturally occurring organic compounds, similarity and variability of produced water from conventional and unconventional formations, general water quality parameters, salinity, organics and metals, naturally occurring radioactive material, and reactions within formations. Chapter 7 also includes a discussion on spatial trends, potential spill impacts on drinking water resources, produced water management and spill potential, spills of hydraulic fracturing flowback and produced water from unconventional oil and gas production, and case studies of potentially impacted sites. In addition, the chapter presents a discussion on roadway transport of produced water and studies of environmental transport of released produced water, includes a discussion on coalbed methane, describes transport properties, and a chapter synthesis of major findings, factors affecting the frequency or severity of impacts, and uncertainties.

3.5.1. Summary of Available Information on Hydraulic Fracturing Flowback and Produced Waters

a. Does the assessment clearly and accurately summarize the available information concerning the composition, volume, and management of flowback and produced waters?

Overall, Chapter 7 provides a clear and accurate summary of the available information concerning composition, volume, and management of flowback and produced waters. The chapter is generally encyclopedic in providing a summary of the information that is available concerning chemistry and volume of flowback and production waters. Since industry practices and available data are changing rapidly, the EPA should update the chapter with additional information and literature searches. The SAB identifies several references below for the EPA's consideration.

Some SAB recommendations regarding suggested points of emphasis or improvements in clarity of this chapter of the draft Assessment Report are noted below and relate to: 1) the organic content of waste waters, 2) the distinction between flowback and produced waters, 3) the occasional use of tracers by operators, 4) duration of time needed for well completion versus well lifetime, 5) the proportion of wells in conventional versus unconventional formations, 6) the relationship of leaks or spills to the process of hydraulic fracturing itself, 7) the source of salt in waters, 8) best management practices, and 9) issues related to coal bed methane.

<u>1) The organic content of waste waters:</u> The water composition data provided in Chapter 7 are limited, reflecting the fact that few compositional analyses of waters have been published, making analysis of the available data more complicated. For example, most of the available data on produced water content were for shale formations and coal bed methane basins, while little data were available for sandstone formations. One observation from the compilation as presented in the draft Assessment Report that is notable (and should be addressed) is that the majority of data were for inorganics: only limited data were available for organics (see, however, Section 7.5.7). The draft Assessment Report summarizes the organic chemicals reportedly used in hydraulic fracturing fluid. The SAB recommends that the EPA improve this chapter by further discussion of organic compounds in produced water, and the extent to which these organic compounds are derived from the shale itself rather than from injections. Some references are available (e.g., Leenheer et al., 1982; Hayes, 2009; Llewellyn et al., 2015; Bair and Digel, 1990).

<u>2) The distinction between flowback and produced waters:</u> The SAB questions the importance of distinguishing between hydraulic fracturing flowback and hydraulic fracturing produced water because in some cases the flowback and produced fluids are mixed in the flow stream very soon after fracturing and in many cases the flowback and produced waters are stored in the same impoundments or containers at the surface. Assuming the agency decides to carry forth the distinction between these waters into the final Assessment Report, the SAB recommends that the EPA describe the differences in composition between flowback and produced waters. Importantly, the EPA should note that produced water over the longer term more closely resembles formation waters, i.e., produced waters represent pre-existing conditions prior to hydraulic fracturing, whereas, in contrast, flowback over the shorter term includes chemicals from injection of hydraulic fracturing fluids (Vidic, R.D., et al., 2013; Haluszczak, L.O., et al., 2013; and Balashov, V.N., et al., 2015).

In terms of distinguishing between flow-back and produced water, it may also help to provide a description of the differences between milli-darcy, microdarcy and nanodarcy permeability rocks to help the reader understand the variability in fluid recovery under flowback vs produced water phases under these various geologic conditions. In the more porous and permeable rocks, formation or produced water may come to the surface quickly along with flowback water from the actual HF activity. In less porous and permeable rocks, flowback water often precedes the flow of formation water into the borehole. However, these are not clear and unambiguous distinctions. The SAB also recommends that the EPA develop, as a longer-term future activity, additional information on changes in produced water chemistry over time. While this chapter of the draft Assessment Report distinguishes the terms “flowback” and “produced water” to differentiate the terms in relation to overall well flow, the EPA should more clearly acknowledge that such differentiation can be difficult or operational at best. This is important in that releases of produced waters are more likely over time in the production phase of a well (Bair and Digel, 1990).

<u>3) The occasional use of tracers by operators:</u> In drilling, perforating, completing or remediating a well, operators may sometimes use chemical or radioactive tracers to study their technique (Scott et al., 2010). Indeed, the EPA mentions briefly the use of tracers without much discussion on Page 2-15 (*"Post-fracture monitoring of pressure or tracers can also help characterize the results of a fracturing job.")* These tracers allow an operator to either sense the location and depth of injected fluids or cements using downhole tools (for example with gamma logs for radioactive tracers) or to infer aspects of well completion. With respect to the latter, an operator may infer where fractures have opened during perforation stages by monitoring the return of these tracers to the surface. Within Chapter 7 of the draft Assessment Report, the EPA has comprehensively summarized the available public database of compounds or metals used for hydraulic fracturing but has not and should summarize what compounds or metals are used for these chemical and radioactive tracers. Since some of these compounds or metals may return to the surface during flowback or during cement squeezes, it is important that the agency summarize what tracers are used, how much and where tracers are used, what concentrations are in use, and what concentrations are measured for these tracers in the flowback or produced waters, or are in use during a cement squeeze. This is especially important for radioactive tracers, given the interest on the part of the public with respect to the topic of radioactivity in development of unconventional formations. Radioactive tracers that have been reported include antimony, iridium, and scandium (daughters include tellurium and platinum). The agency should also clarify that there are two types of tracers in use: elements naturally present in the formation or brine that can be measured in flowback or produced waters as a putative "fingerprint" of the formational waters, and elements or compounds injected into the fracturing fluids intentionally to allow analysis of well completion or cement squeeze processes. In this paragraph, the SAB is referring to the latter. Also, the SAB recommends that the EPA significantly expand and clarify the discussion provided in Chapter 7 on the use by industry of tracers for injection fluids, as well as the efforts made by the EPA to develop tracers, and describe how tracers might be an approach that could allow interpretation of the source of contamination if it occurs.

The state of Pennsylvania Department of Environmental Protection (PADEP) likely has information about how often tracers have been used (and where and when) that the EPA could access. Likewise, if spills of flowback water containing radioactive tracer isotopes occurred in Pennsylvania, then this information should be available from PADEP. The EPA should check the online PA DEP database to see if companies have been cited for NOVs (Notices of Violation). Other states such as Texas and Colorado would also likely be able to make this information available to the EPA upon request. The use of tracers in monitoring and evaluation of HF operations is well documented. A list of relevant papers which cover both the tracer types and uses in HF operations since 2014 is provided in section d2 of this response.

<u>4) Duration of time needed for well completion versus well lifetime:</u> The SAB recommends that the EPA include more information in Chapter 7 on the length of time it takes to hydraulically fracture a well and the duration of time over which the flowback is likely to return to the surface. The SAB notes that this is a pertinent aspect of the distinction between flowback water and production water because the chemistry of the fluid changes in this time interval. The draft Assessment Report accurately states that hydraulic fracturing (completion) of a well takes only a few days, while a well may produce for decades; however, throughout the chapter the EPA continues to refer to hydraulic fracturing and lifecycle, and this might imply to a casual reader that the completion process continues through the lifetime of the

well. This lack of clarity within the draft Assessment Report about the duration of time for well completion could confuse external stakeholders, and should be rewritten.

A list of relevant papers on well fracture time is provided in section d2 of this response. The time required to fracture a well will vary depending on the type of well. As indicated in the references below, the unconventional treatments will typically be less than 2-3 hours per stage with many less than 2 hours per stage. However, since some unconventional wells will have over 30 stages, the total fracturing time could be well over 24 hours. Some of the conventional wells have very long pump times (12-18 hours) from some of the lower-permeability gas fields like the Cotton Valley Lime work done in the 1980s. However, a number of wells in Lost Hills and Kernridge, California, for example, are on 1/8 acre spacing and pump time will be less than an hour for such wells.

A list of relevant papers on the monitoring of well flowback is provided in section d2 of this response. Flowback times will vary from a few days to well over a month depending on the reservoir type. For example, reservoirs with very low permeability will typically produce HF flowback fluids very rapidly. That is, what is going to flowback comes out quickly and the remaining fluid stays in the reservoir. Conventional higher permeability reservoirs will typically require longer flowback monitoring times.

<u>5) The proportion of wells in conventional versus unconventional formations:</u> Another important aspect which the draft Assessment Report does not make clear is the comparison of conventional to unconventional wells with respect to water production. Some information is summarized in one paragraph (Section 7.5.1). In relation to the number of hydraulically fractured wells drilled in the U.S., the SAB recommends that the EPA describe the percentage of hydraulically fractured wells installed in unconventional as compared to conventional formations. While unconventional wells have been the focus of the public and the media, the EPA should also describe how much hydraulic fracturing is occurring in conventional versus unconventional wells. In addition, the EPA should describe how much wastewater is produced for each type of hydraulic fracturing well when considered across the entire U.S. This information is important to describe, since some reports note that "up to 95 percent of new wells drilled today are hydraulically fractured"[2]. This recommendation regarding consideration across the entire U.S. may be considered a longer term future activity.

<u>6) The relationship of leaks or spills to the process of hydraulic fracturing itself:</u> Chapter 7 discusses surface releases during hydraulic fracturing as a potential area of interest with respect to drinking water resource impacts. The draft Assessment Report should clarify whether fluid leaks through surface outer well casings have any unique association with, or can be caused by, hydraulic fracturing. Surface releases are most likely to occur during the production phase of a well, as opposed to the hydraulic fracturing process. After production commences, hydrocarbons and water are separated, and the produced brine may be pumped to a salt water disposal well (Class II injection well). While all surface lines are subject to leaks, the EPA should discuss whether and how hydraulic fracturing potentially impacts the frequency or severity of these surface line leaks. The draft Assessment Report mentions several times in Chapter 6 that pressure cycling of wells can impact cement seals, and the EPA should discuss whether or not these effects on cement seals result in impacts to hydraulic fracturing wastewaters or change the likelihood of leaks as discussed in this chapter. The EPA should discuss the potential effects of natural and induced seismicity on wellbore integrity and the challenges of studying this phenomenon. Also, since it has been reported that the volume of water produced per unit of gas is

[2] See the U.S. Department of Energy's Office of Fossil Energy website on this topic at http://energy.gov/fe/shale-gas-101

less in an unconventional as compared to a conventional well (Vidic et al., 2013), the EPA should discuss whether impacts to drinking water resources are fewer for unconventional as compared to conventional hydraulically fractured wells. The PA DEP likely has information on this topic that the EPA could access, and Brantley et al. (2014) also summarizes some of this information. In addition, since line age and corrosion are factors in developing leaks, the EPA should describe whether leakage rates are smaller for unconventional wells because the hydraulic fracturing facilities are generally newer, and whether the materials being used today are more or less subject to corrosion and breakage than those used in the past (i.e., whether material selection is a factor positively or negatively affecting the frequency and volume of leaks and spills). All of these recommendations regarding the relationship of leaks or spills to the HF process may be considered a longer-term future activity.

7) The source of salt in waters: The draft Assessment Report emphasizes (from Blauch et al., 2009) that brine salts in produced waters derive from dissolution of halite and other evaporite salts in the target shale. The SAB suggests that the EPA rewrite this discussion, since this emphasis does not generally describe/explain the general presence of salts in produced waters (since salt is not found in all or most shales). The SAB notes that while some places may have subsurface halite that interacts with fluids, salts are largely derived from brines in the target formation itself or surrounding formations (and evaporites may be present in the basin but not necessarily in the target formation itself). In addition, on lines 25 and 26 of Page 7-16 the EPA does not comprehensively list causes of increasing solutes because the increase in salt content of production waters with time could be attributed to transport of brine from small pores in the shale into the fractures. Alternately, the increase could be related to the increasing percentage of formation waters returning through the production of the well after the hydraulic fracturing process is completed. A paper describing a mass balance calculation on the brine salt for wells in the Marcellus shale showed a proof of concept for how the salt enters the return water and why it changes with time (Balashov et al., 2015). The EPA could cite the Balashov, et al. (2015) paper in the discussion provided on page 7-7, Section 7.3, and on Page 7-26, Section 7.4.1, lines 3-16 of draft Assessment Report.

8) Best management practices: Chapter 7 provides a broad, albeit somewhat dated, overview, but should provide more details that would provide a reader enough information to understand best management practices used by industry associated with the flowback and produced water stage of the HFWC. These best management practices include regulatory requirements around secondary containment, reporting, and remediation activities associated with hydraulic fracturing spills. The SAB finds that if the draft Assessment Report provided more clarity regarding regulatory and industry response to spills, the general public would be better educated on the overall approach of the industry and its regulators towards these spills. Further investigation of regulatory and industry response to spills can be a longer term future activity. Some relevant papers on best management practices for HF flowback and produced water, and regulatory requirements for secondary containment are provided in section d2 of this response.

9) Issues related to coal bed methane. On Page 7.1.2, Produced Water, Page 7-13, Lines 12-16 of the draft Assessment Report, the EPA should note that coal bed methane (CBM) wells produce more water than hydraulically fractured wells because saturated coals are the target formations for CBM wells. The EPA should also note that since it is the head pressure of the water causing the coals to retain the gas, once the water head pressure is lifted, the coals de-gas (i.e., water is removed from the coal bed to release the gas). The EPA should also note that in contrast, shale and tight gas formations are better producers of oil and gas when these formations are found in areas with lower water saturation values,

because the water can impede the flow in those formations. The SAB recommends that the EPA include these distinctions within the draft Assessment Report since such distinctions impact the quantity and quality of hydraulic fracturing waters that are produced during hydraulic fracturing operations.

3.5.2. Major Findings

b1. Are the major findings concerning flowback and produced water fully supported by the information and data presented in the assessment?

While the major findings, found in Section 10.1.4, are generally supported by the information and data presented in the assessment, the major findings should have been more explicitly quantified and clearly identified within the chapter itself. The SAB notes that while it is difficult to find where major findings are summarized in this chapter, the SAB assumes that the major findings are listed in Section 10.1.4 and Text Box 7-1.

An example of a finding that is described but not adequately highlighted in the draft Assessment Report is the following: *spills of wastewaters from oil and gas development have happened and have affected drinking water resources*. While the SAB concurs with this statement, the EPA should place this statement in context by also describing whether such spills result in a temporary or permanent impact. As mentioned elsewhere within the draft Assessment Report, the EPA should support this statement with statistical data as much as possible.

As discussed in the SAB response to Charge Question 5a, Chapter 7 of the draft Assessment Report is generally well written and clear. It has the tone of an impartial review and is very encyclopedic, especially up to Section 7.7 and page 7-30. In this regard, the chapter does a very good job answering the question, "What is the composition of hydraulic fracturing flowback and produced water, and what factors might influence this composition?" The SAB notes, however, that only the last 16 pages of the chapter are devoted to analysis and discussion of potential impacts, modes of impacts, and analysis of related data, and the SAB finds that these data are presented in encyclopedia format without interpretation and analysis. In this regard, the SAB finds that the EPA did not adequately synthesize the implications of the data in order to emphasize what is important in summarizing the findings to answer the question, "Are the factors affecting the frequency or severity of any impacts described to the extent possible and fully supported?" The SAB also finds that the EPA presents a significant amount of information in Chapter 7 but provides very limited analysis of this information.

b2. Do these major findings identify the potential impacts to drinking water resources due to this stage of the HFWC?

Chapter 7 identifies the potential impacts to drinking water resources due to this stage of the HFWC but does not emphasize certain aspects of the system sufficiently.

While the draft Assessment Report provides an overview of fate and transport of spilled liquids and the various components necessary to evaluate migration of a spill (i.e., amount of material released, timing of the release, response efforts, timing of response measures, soils, geology, and receptors), it emphasizes the horizontal and vertical distance between spill and receptor without adequately indicating that certain subsurface geologic conditions and hydraulic gradient scenarios in the shallow subsurface can allow fluids to migrate a considerable distance from the point of release. For example, page 7-48 notes that: "…impacts to drinking water systems depend on proximity." In fact, researchers have identified some cases where compounds (both tracers intentionally spilled on the land surface for research (Brantley et al., 2014) and contaminants unintentionally spilled on the land surface or leaked from a borehole (Sloto et al., 2013; Llewellyn et al., 2015) entered fractures and moved several kilometers into aquifers. While such long-distance travel incidents have only been rarely reported (Vidic et al., 2013; Llewellyn et al., 2015), the draft Assessment Report should describe the frequency and severity of such events, or outline a plan for such an assessment as a future activity, and recognize that such events occur.

Also, the draft Assessment Report does not provide sufficient emphasis on the importance of fractures, bedding planes, and faults in the subsurface. For example, heterogeneities should be discussed on lines 30-32 on page 7-42 of the draft Assessment Report, and the chapter should note that if hydraulic fracturing fluids spill into a fractured reservoir, the constituents associated with the release could migrate long distances. Likewise, the draft Assessment Report should note that if a hydraulic fracturing spill were to enter unconsolidated sediments, migration of the chemicals associated with this spill could be observed over a considerable distance. While the draft Assessment Report appropriately emphasizes large volume spills of long duration, the importance of small volume spills in specific types of areas (e.g. ridgetops with joints that interconnect in subsurface) should also be discussed because hydraulic fracturing constituents could travel into drinking water resources (Llewellyn et al., 2015). Thus, the draft Assessment Report should clarify that long-distance travel of hydraulic fracturing constituents is possible, has been reported in the published literature though rarely, and can usually be prevented with adequate management practices. A few additional publications on long-distance travel of HF constituents are provided in section d2 of this response.

The SAB also finds that portions of the modeling summary provided in this chapter are misleading as the modelled subsurface did not include natural heterogeneities. The SAB concludes this portion of the modeling is unrealistic because preferential flow paths in the subsurface are generally important in relation to contaminant mobility. Likewise, other modelling cited in the draft Assessment Report (Myers, 2012) is also misleading as it over-emphasizes and over-simplifies highly permeable subsurface heterogeneities (e.g. the model grid limits the smallest width of fractures to be tens of feet and continuous from the target zone to the land surface, which is geologically unrealistic). The role and characteristics of heterogeneities such as hydraulic gradients, fractures, faults, and bedding planes in the movement of subsurface fluids should be explained and emphasized in the draft Assessment Report. Two modelling examples provided in this chapter of the draft Assessment Report should be counterposed and explained as endmembers in this regard. For example, the EPA could directly compare the two modelling examples and explain why one study concluded that contamination could occur within a very short time period while the other concluded such contamination was unlikely. In essence, these contradictory conclusions are related to simplifying assumptions underlying the two models: the EPA should clarify these assumptions and comment upon the state of knowledge underlying such assumptions and the veracity of the assumptions.

As mentioned in the response to Charge Question 5a, during drilling, perforating, completing or remediating a hydraulic fracturing well, operators may sometimes inject chemical or radioactive tracers to study their technique (Scott et al., 2010). Indeed, the EPA mentions briefly the use of tracers without much discussion on Page 2-15 of the draft Assessment Report, noting that *"Post-fracture monitoring of pressure or tracers can also help characterize the results of a fracturing job."* The SAB recommends that the EPA address questions related to the use of injected tracers in Chapter 7, particularly since the public has expressed repeated interest in the topic of radioactivity in the waters associated with oil/gas development. For example, the EPA should assess and discuss whether there have been any reports of spilled liquids or leaks of radioactive tracers associated with hydraulic fracturing operations.

b3. Are there other major findings that have not been brought forward?

Chapter 7 did not bring forward all the major findings associated with the flowback and produced water phase of the HFWC. The agency should also include additional major findings associated with the effects on drinking water resources of large spill events that escape containment, and sustained, undetected leaks. This over-arching observation would be useful to external stakeholders and the general public, and it is important to state this as a major finding since most of the chapter reads like an encyclopedia. In this regard, the EPA should also discuss specific areas of this phase of the HFWC that need improvement and that could help to reduce the number of actual spills, leaks, and releases associated with hydraulic fracturing. For example, the SAB recommends that the EPA consider including discussion on whether hydraulic fracturing leaks or impacts could be diminished in number or severity through closer regulation of the construction practices for hydraulic fracturing-related containment areas that are described on Page 7-35, line 29 of the draft Assessment Report, through increased monitoring of hydraulic fracturing activities, or through additional or new hydraulic fracturing technologies designed to reduce or avoid blowouts.

Another major finding that Chapter 7 does not sufficiently emphasize relates to how assessments are conducted after releases of chemicals from hydraulic fracturing operations occur to the environment. The EPA should provide additional context in this chapter of the draft Assessment Report concerning how these assessments are conducted, what information is collected, how that information is provided to external stakeholders, and what improvements could be offered in this process.

The EPA summarizes a number of steps that are needed to study a suspected impact on pages 7-35 and 7-36 of the draft Assessment Report. This discussion clearly describes how difficult it is to assess and determine causation of impacts when a hydraulic fracturing incident occurs related to contamination of groundwater, especially for subsurface leaks, mostly because the requisite data can be difficult and costly to gather for such attribution. Furthermore, impacts in the subsurface can be very difficult and costly to remediate. To help assess these issues, the SAB recommends that the EPA add a discussion on the implications for the use of tracers during drilling or hydraulic fracturing, and also on implications for the use of nonbiodegradable compounds associated with hydraulic fracturing operations.

Overall, while the draft Assessment Report emphasizes differences in hydraulic fracturing flowback and produced waters from site to site, the EPA should assess and discuss generalizations of commonalities among such waters in the draft Assessment Report. The EPA should summarize what chemistry is generally and most commonly observed in hydraulic fracturing waters, for both organic and inorganic compounds. Such a “generalized water chemistry” would assist in efforts to evaluate potential health risks associated with such waters. Some of this work could be considered longer term future activity, but the draft Assessment Report should include some discussion of general observations regarding flowback and produced water chemistry.

3.5.3. Frequency or Severity of Impacts

b4. Are the factors affecting the frequency or severity of any impacts described to the extent possible and fully supported?

While Chapter 7 of the draft Assessment Report provides support for observations made regarding impacts that are described, the chapter does not describe the factors affecting frequency or severity of impacts to the extent possible, as described further below.

Chapter 7 summarizes many types of incidents and refers to case studies that describe leaks and spills, but the draft Assessment Report could be improved by providing additional detail describing the extent and duration of the impacts, including the following, most of which will require longer-term future activities to address fully:

- The level of impact for spills and releases when they happen.
- Whether the waterway was severely impacted after a hydraulic fracturing spill or leak.
- The length of time the impact affected a surface or groundwater system.
- The spill types or volumes that are most deleterious to waterways or groundwaters.
- Outcomes: Are most or all spills cleaned up quickly with little impact?
- Whether even the larger spills had significant, long-term impact.
- Whether many or most hydraulic fracturing spills are contained within standard secondary containment barriers.

Without such information, the reader is left to assume that all spills are impacting soil/groundwater/ surface water. As one example, the chapter's discussion of the Penn Township, Lycoming County, PA incident on page 7-37 of the draft Assessment Report confirms that the impact was temporary, noting: "*By January 2011, stream chloride concentrations had dropped below the limit established by Pennsylvania's surface water quality standards.*" The EPA should describe whether any long-term impacts were observed regarding this incident. Further, within the EPA discussion on the Leroy Township, Bradford County, PA event in the draft Assessment Report, while the EPA described that localized surface water impacts were reported, the EPA should discuss whether long-term effects were reported for the potable water wells.

Within the draft Assessment Report, the EPA should generally describe the timeframes needed to remediate surface or groundwater to pre-existing conditions (e.g., National Research Council, 2013). This general description and information is important to include within the draft Assessment Report since spills into aquifers are harder to remediate than spills into surface water. As written, the draft Assessment Report leads a reader to believe spills and leaks create permanent impacts.

To understand the likely probability of releases to surface water or groundwater from hydraulic fracturing activities, the draft Assessment Report should quantify in text and in a figure the frequency of the different types of release events, including whether the spilled hydraulic fracturing material impacts groundwater or surface water. While the EPA collected a large amount of information about hydraulic fracturing wastewaters, it should evaluate the data and make tables and figures that concisely summarize the collected data. The EPA should conduct a statistical analysis on these data, perhaps using statistical tools of analysis for sparse datasets. For example, while Chapter 7 provides a good identification and description of the sources for flowback and produced water spills, leaks, and releases, it would be very helpful if the EPA clarified the text by summing up these types of release events from each section together through the use of statistics.

In addition, while the draft Assessment Report provides a number of local statistics from specific studies, these statistics should be summarized in the conclusion Section 7.8.4. For example, the EPA should specifically note the following within Chapter 7: X number of wells were drilled in the US, Y number of these wells were hydraulically fractured, and Z number of spilled liquids were reported. In addition, while Chapter 7 refers back to Chapter 5 (Text box 5-14) for spill rate data and this is described in text on page 7-33, lines 10 through 21, the chapter should include further summary evaluation of these data. The data should be shown in easily interpreted figures – perhaps histograms - to illustrate the size of leaks as well as frequency. Furthermore, in order to better understand the significance of releases from hydraulically fractured wells, the EPA should assess, as a longer-term future activity, the statistical difference between the number of releases for wells completed with hydraulic fracturing versus those that were not completed with hydraulic fracturing for a specific time period or region. Furthermore, the EPA should discuss the important finding that half of the 457 reported spills were for 1000 gallons or less of spilled fluids, and that these 457 reported spills were a lower bound of the number of spills. In addition, the EPA should describe the composition of the spills, to the extent that data are available. The finding that half of the 457 reported spills were for 1000 gallons or less of spilled fluids should also be described through an illustration in addition to text. The EPA should summarize the number of spilled liquids in absolute numbers and also in context relative to the number of wells drilled, truck trips, and pipelines miles.

The EPA should, as a longer-term future activity, also develop figures or tables that summarize the temporal and spatial scaling associated with statistics of spilled liquids/leaks/contamination events. For example, the draft Assessment Report notes that the truck accident rate is low and the likelihood of spilled liquids related to trucks is low, but does not note that truck spills could have important impacts in a small local area. The draft Assessment Report should recognize the potential for significant local effects and consider this spatial scaling issue throughout the Report when it discusses conclusions associated with hydraulic fracturing spills, leaks, and contamination events. It is important for the public to understand why personal experience may differ from broad average observations, and that while not all oil/gas development sites are problematic, some oil/gas development sites have been problematic in the past. For these reasons, the EPA should clarify through longer-term future work the spatial and temporal aspects of these hydraulic fracturing spills, leaks, and contamination events. The SAB also notes that clarification of the subtleties of this spatial and temporal scaling would help industry and the public better understand the relative frequency and significance of hydraulic fracturing-related problems in a given area.

Chapter 7 of the draft Assessment Report makes several statements that are so general that the statements have little meaning. For example, page 7-46 of the draft Assessment Report notes that: *"Conclusive determination of impacts to water resources depends on commitment of resources to the implementation of sampling analysis and evaluation strategies."* It would be more useful if the EPA synthesized the available information and described specifically what evaluation strategies and sampling analysis is needed to provide a conclusive determination of impacts. The EPA should note, for example, whether baseline data are needed to understand the impacts associated with spilled material.

3.5.4. Uncertainties, Assumptions and Limitations

c. Are the uncertainties, assumptions, and limitations concerning flowback and produced water fully and clearly described?

While the EPA acknowledges uncertainties in the information presented in Chapter 7, the EPA should examine these uncertainties in more depth, as a longer-term future activity. The uncertainties described by the EPA in this chapter provide sufficient detail to provide approximate, general indications of some risks associated with the flowback and produced water phase of the HFWC. However, the EPA should provide more information on uncertainties associated with calculating risks from contaminants in hydraulic fracturing waters (e.g., uncertainties associated with organic contaminants such as benzene commonly present in produced waters).

In addition to deeper examination of uncertainties, the EPA should summarize approaches that could be used to reduce these uncertainties and help protect drinking water resources. The EPA should provide a section outlining the additional information that is needed to more completely understand the risks and approaches that can be taken to control these risks associated with exposure to hydraulic fracturing waters.

Chapter 7 identifies data gaps, especially with respect to baseline conditions and with respect to individual incidents. However, the chapter should clarify if the gaps are present because the data are non-existent or not easily (i.e., electronically) available. The draft Assessment Report should clarify if needed data are available but not online publicly, or are not in a format that is easily scrutinized. For example, the EPA should discuss whether the research team found electronically available data that might be useful for analysis of water quality impacts, and whether the EPA was unable to provide resources to collect these data into a database format. The EPA should more explicitly describe issues surrounding the availability or lack of availability of data, including reasons for any lack of data availability. This chapter should also describe what improvements have been or are being made by regulatory agencies to improve database systems which provide more information on operational activities associated with the oil and gas industry, and recognize that states have made considerable advancements in electronic database systems that allow for increased reviews and assessments by external stakeholders.

3.5.5. Additional Information, Background or Context to be Added

d1. What additional information, background, or context should be added, or research gaps should be assessed, to better characterize any potential impacts to drinking water resources from this stage of the HFWC?

As described further below, the EPA should provide more information in Chapter 7 on radionuclides in wastes, bromide concentrations in wastes and in surface waters, best management practices (BMPs) for surface impoundments, and the natural occurrence of brines in the subsurface, to the extent that data are available. The EPA should investigate the radionuclide issue in greater depth as a longer-term future activity, including review of the new Pennsylvania Department of Environmental Protection research.

Within the draft Assessment Report, the EPA should increase the emphasis and better explain the radioactive nature of some wastes produced during hydraulic fracturing operations. Many public comments on the draft Assessment Report raised these concerns, and the EPA should expand the discussion of the importance or possible impacts related to radioactivity within this chapter. While most of the radioactivity derives from the geologic formation itself, radioactive tracers are sometimes injected. As mentioned specifically in the response to Charge Question 5a, the draft Assessment Report should specifically and carefully address the use of radioactive tracers during well completion or remediation. The EPA should also address radioactivity in shale cuttings as part of the assessment of potential impacts within the draft Assessment Report, even though such cuttings are related only to hydraulic fracturing drilling.

Chapter 7 and Appendix E of the draft Assessment Report should amplify discussion on the ratio of Cl/Br in flowback and produced water. The SAB notes that bromate is used in fluids used during HF stimulation treatment. As discussed further in the Charge Question 6 response, significant releases of bromide from hydraulic fracturing operations to surface or groundwaters subsequently become part of intake water at downstream drinking water treatment plants and upon disinfection can result in concentrations of brominated organic compounds that are potentially deleterious to human health (Wilson and VanBriesen, 2012) due to the formation of disinfection by-products (DBP). The EPA should note that the Br generally comes from the rock or pore fluids into which hydraulically fractured wells are drilled, and discuss whether bromide is ever added as an injection compound. The draft Assessment Report should also more consistently use either the terms “bromine” and “bromide.” In some places the draft Assessment Report refers to “bromine” whereas in other places the draft Assessment Report refers to “bromide.” The EPA should check that the terms are used appropriately, in each case referring to the relevant chemical form for the particular context.

The EPA should, as a longer-term future activity, also assess iodide in the same manner as bromides as recommended in the above paragraph, even though the draft Assessment Report provides very little data on the presence of iodide in flowback or produced waters. The SAB notes that iodate is not used during HF operations. Since iodide also reacts with some oxidants to produce DBPs at downstream drinking water plants, and recent evidence shows that brominated and iodinated DBPs are more cyto- and geno-toxic than the chlorinated analogs (Plewa, M.J., and Wagner, E.D., 2009; and Richardson, S.D., et al., 2014), information about iodide in wastewaters should be amplified in draft Assessment Report. The ratio of Cl/I in table E-4 is around 5000/1 which is much lower (i.e., more iodide) than the ratio in seawater which is 35,000/1. The EPA should discuss why iodide is more concentrated in flowback and produced water relative to Cl than seawater. In addition, the draft Assessment Report should discuss the degree to which flowback and produced water contains bromate, chlorate/chlorite, perchlorate or iodate. All of these chemical species have human toxicity endpoints and some have MCLs. Data sources that provide information on levels of bromine, bromate, iodide, chlorate and perchlorate in oil/gas and HF wastewaters associated with different geologic formations where HF is occurring are provided in section d2 below.

Chapter 7 should also increase the emphasis on and better explain the use of impoundments for hydraulic fracturing flowback and production waters. The chapter states that, “*The causes of these spills were human error (38%), equipment failure (17%), failures of container integrity (13%), miscellaneous causes (e.g., well communication, well blowout), and unknown causes. Most of the volume spilled (74%), however, came from spills caused by a failure of container integrity.*” While an impoundment example is given on page 7-42 and impoundments are mentioned in the draft Assessment Report, impoundments are not emphasized sufficiently. The EPA should describe best practices regarding the use of impoundments and how are they constructed. Since the EPA notes that container leakage (i.e., leakage from impoundments or man-made pits) is the single biggest source of leakage on an event basis, the nature and use of hydraulic fracturing impoundments are particularly important to fully describe in the draft Assessment Report.

The EPA should obtain and evaluate, as a longer-term future activity, available data concerning impoundment leakage and location, and describe whether leaks from impoundments or man-made pits occur more frequently if such impoundments are placed in different geographic locations such as in floodplains or along ridgelines. The SAB notes that in some parts of the country (Pennsylvania), impoundments are being used less frequently, and the EPA should summarize any such changes in best management practice and the reasons for these changes. Furthermore, page 7-44 of the draft Assessment Report points to USGS studies, but should discuss and cite these studies in Section 7.7.2.3 of the draft Assessment Report. In addition, the EPA should discuss the cause of the structural lack of integrity responsible for leaks from impoundments or man-made pits, and whether leaks from impoundments or man-made pits are induced by operational conditions, poor manufacturing of the impoundments or man-made pits, corrosion caused by the flowback or produced water chemistry, or by seismic activity. The EPA should also summarize, as a longer-term future activity, which states have laws or regulations requiring lined pits and berms to manage potential spills, leaks and runoff from hydraulic fracturing waters, and include a list of best practices currently in use in industry (such as the elimination of pits, and use of tanks stored over lined berm-surrounded catchment areas).

The draft Assessment Report should increase the emphasis on, and better explain the presence of, natural brines in the subsurface as encountered during or in the vicinity of hydraulic fracturing operations. Brine salts have been identified in an incident with respect to drinking water (Boyer et al., 2012), but available literature does not describe where these salts came from. The brines may have originated as ancient brines (millions of years old) that are contained in pores of near-surface rocks rather than from hydraulic fracturing wastewater spills or leaks; the chapter should address this type of potential source. The EPA should also explain in the chapter that there can be natural pathways of brines to the surface, that these natural pathways are not necessarily related to shale gas development, and that brine salts can contaminate aquifers and surface waters naturally. The SAB notes that this complicates the EPA's interpretation of spilled liquids and leaks of flowback and production waters because the background conditions can be marked by the same salts that influence the composition of flowback and produced waters. The SAB notes that the presence of natural brines from depth that move to the surface or to shallow groundwater is especially important since there is significant public concern regarding the transport of hydraulic fracturing fluid from the deep subsurface of unconventional gas reservoirs to groundwater or surface water. While the potential and rate of such transport may be very low in the context of shale gas development, the SAB recommends that the EPA discuss this pathway and mechanism of brine movement in this chapter in the context of natural brines. The EPA should also discuss whether the presence of shallow brines implies transport upward from depth or not, and if yes, what implications, if any, this transport may have for injected fluids during hydraulic fracturing. A publication authored by Gupta and Bair (199) shows simulated flow directions of brines in the Cambrian Mt. Simon Sandstone and other younger Paleozoic rocks around the Appalachian, Michigan, Illinois basins in the midwestern United States. The three-dimensional, variable fluid density flow model was calibrated using measured values of bottom-hole pressures in oil/gas wells and Class I injection wells in region. Both the model results and the measured bottom-hole pressures indicate that the flow rates of the brines is exceptionally slow and flow directions in the deep subsurface can be upward, downward or lateral, much like the flow systems described by Toth (1963, 1988). Thus, at least in the this region of the country, movement of brines, albeit very slow, is not always upward as assumed in many modeling studies examining the flow of injection fluids beyond the target zone for hydraulic fracturing.

The EPA should include additional discussion within Chapter 7 on the importance of gathering pre-existing baseline chemistry of surface and groundwater in order to better understand the impacts of spilled liquids and leaks. In this discussion it would be helpful for the EPA to describe how to ascertain background condition of a waterway or aquifer, define what "background" is, and describe situations where background conditions of waters may be an important factor in considering potential impacts. The chapter's discussion on pre-existing conditions in groundwater and surface waters is only provided in one paragraph on page 7-35. The EPA's discussion on background conditions should include the importance of gathering pre-existing methane concentrations or other constituents in numerous potable wells from non-target geologic zones, in order to help in assessing whether any constituent detected in groundwater near oil and gas operations is originating from those operations.

In addition, the EPA should include MCLs if available for chemicals listed in Table 7-4. A major public concern is the appearance of contaminated or degraded drinking water wells in areas where hydraulic fracturing occurs. Since naturally occurring contaminants and degraded wells can occur from issues not related to hydraulic fracturing, the EPA should also include additional discussion on how background and pre-existing baseline chemistry of surface and groundwater data is used in order to better understand the impacts of hydraulic fracturing-related spills and leaks. The scientific complexity of baseline sampling and data interpretation should be described.

As described in the EPA's research Study Plan (U.S. EPA, 2011), the EPA had planned to evaluate the potential use of tracer compounds that could be used in hydraulic fracturing injectate to fingerprint fluid provenance. While the draft Assessment Report includes little on this topic, the EPA should provide some discussion of it and clarify that there are two types of tracers in use: elements naturally present in the formation or brine that can be measured in flowback or produced waters as a putative "fingerprint" of the formational waters, and elements or compounds injected into the fracturing fluids intentionally to allow analysis of well completion or cement squeeze processes. The EPA discusses elements naturally present in the formation or brine in the chapter, but the EPA does not sufficiently discuss elements or compounds injected into the fracturing fluids intentionally in the chapter. The EPA should explicitly describe in the chapter whether it recommends the use of fingerprint compounds in injected fluids, and what additional information is needed to evaluate whether to use these compounds for this purpose. Some authors have argued that organic compounds have moved kilometers from drilled wells (Llewellyn et al., 2015), and the EPA should assess whether the use of fingerprint compounds could elucidate such mobility, if the fingerprint compounds had been injected originally into the well.

Within the EPA's Study Plan (U.S. EPA, 2011), the EPA described several activities where it planned to inject tracer or fingerprint analyses:

> i) page 39: *"Prospective case studies. The prospective case studies will give the EPA a better understanding of the processes and tools used to determine the location of local geologic and/or man-made features prior to hydraulic fracturing. The EPA will also evaluate the impacts of local geologic and/or man-made features on the fate and transport of chemical contaminants to drinking water resources by measuring water quality before, during, and after injection. The EPA is exploring the possibility of using chemical tracers to track the fate and transport of injected fracturing fluids. The tracers may be used to determine if fracturing fluid migrates from the targeted formation to an aquifer via existing natural or man-made pathways."*

> ii) page 113: *"As part of these efforts, the EPA and DOE are working together on a prospective case study located in the Marcellus Shale region that leverages DOE's capabilities in field-based monitoring of environmental signals. DOE is conducting soil gas surveys, hydraulic fracturing tracer studies, and electromagnetic induction surveys to identify possible migration of natural gas, completion fluids, or production fluids."*

Although the prospective case studies were not initiated, the EPA should nonetheless explicitly assess and describe the potential for development of tracer metals or compounds that could be injected along with hydraulic fracturing fluids, drilling fluids, or cement squeezes that could help in forensic analysis of incidents related to those injections. The DOE's National Energy Technology Laboratory evaluated fracture growth and fluid migration from HFWC activities and the results of that investigation should be considered by the EPA (US DOE, 2014).

The SAB recommends that the EPA should outline a plan for analyzing organic compounds in HF flowback and produced waters, in collaboration with state agencies. The EPA should also assess whether the costs/benefits for conducting such an intense effort, and whether such an effort would advance the assessment of potential impacts on drinking water. Chapter 7 should clarify the importance of data gaps associated with analyzing organics in public drinking water supplies, describe the difficulties in conducting such analysis, and note that such analysis may not be the most effective way to identify hydraulic fracturing-related spills. Furthermore, the discussion in Section 7.4.5 on analysis of constituents in water should cite new techniques of analysis that measure broad categories of compounds rather than individual compounds (Llewellyn et al. 2015). Llewellyn et al. argue that a better approach for determining contaminants may be to look for suites of organic compounds that provide fingerprints as patterns, rather than to search for individual compounds which may be too difficult. Llewellyn et al. could also be cited on p. 7-45. The SAB also agrees that many compounds in produced waters are often categorized as BTEX compounds, and that these compounds are frequently found in hydraulic fracturing wastewaters because the compounds come out of the shales themselves. The chapter should note that while petroleum (oil/condensate) contains many hundreds of individual compounds that could be included in the dissolved phase as trace components, these compounds are generally classified as BTEX and total petroleum hydrocarbons.

Chapter 7 of the draft Assessment Report does not adequately discuss or assess microbial processes associated with hydraulic fracturing operations and the related potential impacts to drinking water resources. The fate and transport of hydraulic fracturing constituents are often very dependent on microbial reactions, especially for organic compounds. The SAB recommends that the EPA further describe microbial processes within the discussion on adsorption, absorption, and precipitation on line 26 of page 7-42 of the draft Assessment Report. A reference on this topic is Akob (2015). Because most HF fluids contain a biocide, the influence of these on microbial processes should be considered. Some discussion should be added to the draft Assessment Report; a full investigation of microbial processes would be a longer-term future activity.

The EPA used the EPI Suite of models to estimate various properties of hydraulic fracturing chemicals. EPI Suite is a group of models that employ some parameters that are uncertain and require detailed sensitivity analysis to assess whether the model provides meaningful results. The EPA should also include information on chemical mechanisms or factors that EPI Suite does not consider when estimating various properties of hydraulic fracturing chemicals. While the draft Assessment Report notes on page 7-43 that high salinity is not adequately incorporated into those EPI Suite estimations, the EPA should revise the chapter and describe whether and how other potentially important factors such as microbiological reactions are assessed. The EPA's approach to determine mobility of certain hydraulic fracturing chemicals is based on very limited data, and the EPA should revise the chapter and describe how subsurface biogeochemical reactions may change the properties of hydraulic fracturing chemicals and make them more or less mobile than their original state. Given the large uncertainties associated with unknown hydraulic fracturing constituents and unknown subsurface reactions that may change the mobility of hydraulic fracturing chemicals, the EPA should further describe the usefulness of using EPI Suite analysis when assessing potential impacts of hydraulic fracturing chemicals on drinking water resources. In addition to using EPI Suite, the EPA should discuss the presence or absence of alternative models and the availability of physical/chemical data compilations. Additional databases that the EPA should consider using are described in the response to Charge Question 7 within this SAB report.

Also, the EPA should include additional analysis and discussion on how recycled hydraulic fracturing produced water that is reused onsite at hydraulic fracturing facilities without treatment might affect the severity or frequency of potential contamination of surrounding drinking water resources. This discussion could address whether or not certain constituents in the water might build up over time, increasing the potential for adverse impacts in the event of a leak or spill, and whether additional storage and handling of the water on site is likely to increase the frequency of leaks and spills.

The EPA should review the results of a three-year study by scientists at the University of Cincinnati who examined potential impacts of shale gas development in the vicinity of residential wells. They found no effects from nearby gas drilling or hydraulic fracturing in a network of 23 residential wells that were sampled 3 to 4 times a year over a 3-year period for methane concentration and its source (biogenic or thermogenic). The investigation was designed specifically to sample methane prior to, during, and after natural gas drilling, hydraulic fracturing, and gas extraction. Methane measured in the wells was found to be derived from shallow underground coal beds and not from natural gas in the Utica Shale, which occurs at a much greater depth (Botner et al., 2014). The study covered five counties at the epicenter of the Utica Shale gas boom in eastern Ohio and was sponsored by the National Science Foundation, two non-profit philanthropic organizations, and private citizens, with no funding provided by the oil and gas industry (Botner et al., 2015).

d2. Are there relevant literature or data sources that should be added in this section of the report?

<u>1) Data sources that provide information on chemicals used for HF tracers and HF industry use of tracers are provided below.</u>

Drylie, S., Pechiney, J., Villaseñor, R., & Woodroof, R. (2015, March 1). Determining the Number of Contributing Fractures in Shale Gas Wells with Production Analysis and Proppant Tracer Diagnostics. Society of Petroleum Engineers. doi:10.2118/173620-MS

Elahi, S. H., & Jafarpour, B. (2015, August 4). Characterization of Fracture Length and Conductivity From Tracer Test and Production Data With Ensemble Kalman Filter. Society of Petroleum Engineers. doi:10.2118/178707-MS

Goswick, R. A., & LaRue, J. L. (2014a, January 1). Utilizing Oil Soluble Tracers to Understand Stimulation Efficiency Along the Lateral. Society of Petroleum Engineers.

Goswick, R. A., & LaRue, J. L. (2014b, October 27). Utilizing Oil Soluble Tracers to Understand Stimulation Efficiency Along the Lateral. Society of Petroleum Engineers. doi:10.2118/170929-MS

Han, X., Duenckel, R., Smith, H., & Smith, H. D. (2014, May 5). An Environmentally Friendly Method to Evaluate Gravel and Frac Packed Intervals Using a New Non-Radioactive Tracer Technology. Offshore Technology Conference. doi:10.4043/25166-MS

Leong, Y., de Iongh, J. E., Bähring, S., Tuxen, A. K., & Nielsen, T. B. (2015, September 28). Estimation of Fracture Volume Between Well Pairs Using Deuterium Tracer. Society of Petroleum Engineers. doi:10.2118/174832-MS

Roney, D., Quirk, D. J., Ziarani, A., & Burke, L. H. (2014, September 30). Integration of Microseismic Data, Tracer Information, and Fracture Modeling into the Development of Fractured Horizontal Wells in the Slave Point Formation. Society of Petroleum Engineers. doi:10.2118/171605-MS

Salman, A., Kurtoglu, B., & Kazemi, H. (2014, September 30). Analysis of Chemical Tracer Flowback in Unconventional Reservoirs. Society of Petroleum Engineers. doi:10.2118/171656-MS

Srinivasan, K., Krishnamurthy, J., Williams, R., Dharwadkar, P., Izykowski, T., & Moore, W. R. (2016, February 1). Eight-Plus Years of Hydraulic Fracturing in the Williston Basin: What Have We Learned? Society of Petroleum Engineers. doi:10.2118/179156-MS

<u>2) Data sources that provide information on well fracture time are provided below.</u>

Fyten, G. C., Taylor, R. S., & Price, D. (2015, October 20). Viking Stimulation: Case History. Society of Petroleum Engineers. doi:10.2118/175955-MS

Govorushkina, A., Henderson, C., Castro, L., Allen, R., & Nasir, E. (2015, November 9). Interventionless Unconventional Multistage Hybrid Completion: Fracturing Longer Laterals in Cemented Applications. Society of Petroleum Engineers. doi:10.2118/176838-MS

Krenger, J. T., Fraser, J., Gibson, A. J., Whitsett, A., Melcher, J., & Persac, S. (2015, October 13). Refracturing Design for Underperforming Unconventional Horizontal Reservoirs. Society of Petroleum Engineers. doi:10.2118/177306-MS

Nejad, A. M., Sheludko, S., Shelley, R. F., Hodgson, T., & Mcfall, P. R. (2015, February 3). A Case History: Evaluating Well Completions in Eagle Ford Shale Using a Data-Driven Approach. Society of Petroleum Engineers. doi:10.2118/173336-MS

Qiu, F., Porcu, M. M., Xu, J., Malpani, R., Pankaj, P., & Pope, T. L. (2015, October 20). Simulation Study of Zipper Fracturing Using an Unconventional Fracture Model. Society of Petroleum Engineers. doi:10.2118/175980-MS

Reddy, L., Jenkins, A., & Fathi, E. (2015, October 13). Dynamic Assessment of Induced Stresses and In-situ Stress Reorientation during Multi-Stage Hydraulic Fracturing in Unconventional Reservoirs. Society of Petroleum Engineers. doi:10.2118/177301-MS

Temizel, C., Purwar, S., Abdullayev, A., Urrutia, K., & Tiwari, A. (2015, November 9). Efficient Use of Data Analytics in Optimization of Hydraulic Fracturing in Unconventional Reservoirs. Society of Petroleum Engineers. doi:10.2118/177549-M

Yousefzadeh, A., Li, Q., & Aguilera, R. (2015, November 18). Microseismic 101: Monitoring and Evaluating Hydraulic Fracturing to Improve the Efficiency of Oil and Gas Recovery from Unconventional Reservoirs. Society of Petroleum Engineers. doi:10.2118/177277-M

<u>3) Data sources that provide information on monitoring of well flowback are provided below.</u>

Rane, J. P., & Xu, L. (2015, August 1). New Dynamic-Surface-Tension Analysis Yields Improved Residual Surfactant Measurements in Flowback and Produced Waters. Society of Petroleum Engineers. doi:10.2118/172190-PA

Salman, A., Kurtoglu, B., & Kazemi, H. (2014, September 30). Analysis of Chemical Tracer Flowback in Unconventional Reservoirs. Society of Petroleum Engineers. doi:10.2118/171656-MS

Vazquez, O., Mehta, R., Mackay, E., Linares-Samaniego, S., Jordan, M., & Fidoe, J. (2014, May 14). Post-frac Flowback Water Chemistry Matching in a Shale Development. Society of Petroleum Engineers. doi:10.2118/169799-MS

Williams-Kovacs, J. D., Clarkson, C. R., & Zanganeh, B. (2015, October 20). Case Studies in Quantitative Flowback Analysis. Society of Petroleum Engineers. doi:10.2118/175983-MS

Zhou, Q., Dilmore, R., Kleit, A., & Wang, J. Y. (2016, February 1). Evaluating Fracture-Fluid Flowback in Marcellus Using Data-Mining Technologies. Society of Petroleum Engineers. doi:10.2118/173364-PA

Zolfaghari, A., Dehghanpour, H., Ghanbari, E., & Bearinger, D. (2015, June 1). Fracture Characterization Using Flowback Salt-Concentration Transient. Society of Petroleum Engineers. doi:10.2118/168598-PA

Zolfaghari, A., Tang, Y., Holyk, J., Binazadeh, M., Dehghanpour, H., & Bearinger, D. (2015, October 20). Chemical Analysis of Flowback Water and Downhole Gas Shale Samples. Society of Petroleum Engineers. doi:10.2118/175925-MS

<u>4) Data sources that provide information on levels of bromine, bromate, iodide, chlorate and perchlorate in oil/gas and HF wastewaters associated with different geologic formations where HF is occurring are provided below.</u>

Akob, Denise M.; Isabelle M. Cozzarelli; Darren S. Dunlap; Elisabeth L. Rowan; Michelle M. Lorah. Organic and inorganic composition and microbiology of produced waters from Pennsylvania shale gas wells. 2015. *Applied Geochemistry* 60 (116–125). September 2015. doi:10.1016/j.apgeochem.2015.04.011

Blauch, M. E. (2010, January 1). Developing Effective and Environmentally Suitable Fracturing Fluids Using Hydraulic Fracturing Flowback Waters. Society of Petroleum Engineers. doi:10.2118/131784-MS.

Chen, Ruiqian; Shikha Sharma; Tracy Bank; Daniel Soeder; and Harvey Eastman. Comparison of isotopic and geochemical characteristics of sediments from a gas- and liquids-prone wells in Marcellus Shale from Appalachian Basin, West Virginia. Applied Geochemistry 60 (59–71). September 2015. doi:10.1016/j.apgeochem.2015.01.001

Down, Adrian; Kathrin Schreglmann; Desiree L. Plata; Martin Elsner; Nathaniel R. Warner; Avner Vengosh; Katie Moore; Drew Coleman; Robert B. Jackson. Pre-drilling background groundwater quality in the Deep River Triassic Basin of central North Carolina, USA. 2015. Applied Geochemistry 60 (3–13). September 2015. doi:10.1016/j.apgeochem.2015.01.018

Houston, N. A., Blauch, M. E., Weaver, D. R., Miller, D., & O'Hara, D. (2009, January 1). Fracture-Stimulation in the Marcellus Shale-Lessons Learned in Fluid Selection and Execution. Society of Petroleum Engineers. doi:10.2118/125987-MS

Johnson, Jason D.; and Joseph R. Graney. Fingerprinting Marcellus Shale waste products from Pb isotope and trace metal perspectives. 2015. *Applied Geochemistry* 60 (104–115). September 2015. doi:10.1016/j.apgeochem.2015.04.021

Johnson, Jason D.; Joseph R. Graney; Rosemary C. Capo; Brian W. Stewart. Identification and quantification of regional brine and road salt sources in watersheds along the New York/Pennsylvania border, USA. *Applied Geochemistry* 60 (37–50). September 2015. doi:10.1016/j.apgeochem.2014.08.002

King, G. E. (2012, January 1). Hydraulic Fracturing 101: What Every Representative, Environmentalist, Regulator, Reporter, Investor, University Researcher, Neighbor and Engineer Should Know About Estimating Frac Risk and Improving Frac Performance in Unconventional Gas and Oil Wells. Society of Petroleum Engineers. doi:10.2118/152596-MS

Lu, Zunli; Sunshyne T. Hummel; Laura K. Lautz; Gregory D. Hoke; Xiaoli Zhou; James Leone; Donald I. Siegel. Iodine as a sensitive tracer for detecting influence of organic-rich shale in shallow groundwater. Applied Geochemistry 60 (29–36). September 2015 doi:10.1016/j.apgeochem.2014.10.019

Macpherson, G.L. Lithium in fluids from Paleozoic-aged reservoirs, Appalachian Plateau region, USA. *Applied Geochemistry* 60 (72–77). September 2015. doi:10.1016/j.apgeochem.2015.04.013

Phan, Thai T.; Rosemary C. Capo; Brian W. Stewart; Joseph R. Graney, Jason D. Johnson, Shikha Sharma, Jaime Toro. Trace metal distribution and mobility in drill cuttings and produced waters from Marcellus Shale gas extraction: Uranium, arsenic, barium. *Applied Geochemistry* 60 (89–103). September 2015. doi:10.1016/j.apgeochem.2015.01.013

Rane, J. P., & Xu, L. (2014, April 21). Monitoring Residual Surfactant in the Flowback and Produced Water: A Way Forward to Improve Well Productivity. Society of Petroleum Engineers. doi:10.2118/172190-MS

Rhodes, Amy L.; Nicholas J. Horton. Establishing baseline water quality for household wells within the Marcellus Shale gas region, Susquehanna County, Pennsylvania, U.S.A. 2015. Applied Geochemistry 60 (14–28). September 2015. doi:10.1016/j.apgeochem.2015.03.004

Rimassa, S. M., Howard, P. R., MacKay, B., Blow, K. A., & Coffman, N. (2011, January 1). Case Study: Evaluation of an Oxidative Biocide During and After a Hydraulic Fracturing Job in the Marcellus Shale. Society of Petroleum Engineers. doi:10.2118/141211-MS

Schachter, H. E. (2014, August 28). Detailed Description of Petro-Cycle Solutions Innovative Process for the Remediation, Recycle and Reuse of “Frac Water and Flow Back Water” for the Oil and Gas Industry Across the USA and Canada. Society of Petroleum Engineers. doi:10.15530/urtec-2014-1921626

Sharma, Shikha; Lindsey Bowman; Karl Schroeder; and Richard Hammack. Assessing changes in gas migration pathways at a hydraulic fracturing site: Example from Greene County, Pennsylvania, USA. *Applied Geochemistry* 60 (51–58). September 2015. doi:10.1016/j.apgeochem.2014.07.018

Stewart, Brian W.; Rosemary C. Capo; Carl S. Kirby. 2015. Geochemistry of unconventional shale gas from formation to extraction: Petrogenesis, hydraulic fracturing, and environmental impacts. *Applied Geochemistry* 60 (1-126). September 2015. doi:10.1016/j.apgeochem.2015.06.012

Stewart, Brian W.; Elizabeth C. Chapman; Rosemary C. Capo; Jason D. Johnson; Joseph R. Graney; Carl S. Kirby; Karl T. Schroeder. Origin of brines, salts and carbonate from shales of the Marcellus Formation: Evidence from geochemical and Sr isotope study of sequentially extracted fluids. *Applied Geochemistry* 60 (78–88). September 2015. doi:10.1016/j.apgeochem.2015.01.004

Tischler, A., Woodworth, T. R., Burton, S. D., & Richards, R. D. (2009, January 1). Controlling Bacteria in Recycled Production Water for Completion and Workover Operations. Society of Petroleum Engineers. doi:10.2118/123450-MS

<u>5) Data sources that provide information on best management practices for HF flowback and produced water, and regulatory requirements for secondary containment are provided below:</u>

Maloney, K.O. and Yoxtheimer, D.A. (2012) Production and disposal of waste materials from gas and oil extraction from the Marcellus shale play in Pennsylvania. Environmental Practice 14, 278-287, doi:210.10170S146604661200035X.

Rahm, B.G., Bates, J.T., Bertoia, L.R., Galford, A.E., Yoxtheimer, D.A. and Riha, S.J. (2013) Wastewater management and Marcelus Shale gas development: Trends, drivers, and planning implications. Journal of Environmental Management 120, 105-113, doi: 101.1016/j.jenvman.2013.1002.1029.

<u>6) Data sources that provide information on long-distance travel of HF constituents are provided below:</u>

Brantley, S.L., Yoxtheimer, D., Arjmand, S., Grieve, P., Vidic, R., Pollak, J., Llewellyn, G.T., Abad, J. and Simon, C. (2014) Water resource impacts during unconventional shale gas development: The

Pennsylvania experience. International Journal of Coal Geology 126, 140-156, dx.doi.org/110.1016/j.coal.2013.1012.1017.

Llewellyn, G., Dorman, F.L., Westland, J.L., Yoxtheimer, D., Grieve, P., Sowers, T., Humston-Flumer, E. and Brantley, S.L. (2015) A drinking water contamination incident attributed to Marcellus Shale gas development. Proceedings of the National Academy of Sciences 112, 6325-6330.

7) The SAB recommends that the EPA consider the following additional literature sources within this chapter of the draft Assessment Report:

Akob, Denise M.; Isabelle M. Cozzarelli; Darren S. Dunlap; Elisabeth L. Rowan; and Michelle M. Lorah. Organic and inorganic composition and microbiology of produced waters from Pennsylvania shale gas wells. 2015. Applied Geochemistry 60 (116–125). September 2015. doi:10.1016/j.apgeochem.2015.04.011.

Amy, G., M. Siddiqui, W. Zhai, J. DeBroux, and W. Odem. 1994. American Water Works Association Research Foundation (AwwaRF) Final Report - Survey on bromide in drinking water and impacts on DBP formation. American Water Works Association Research Foundation.

Bair, E.S., and R.K. Digel. 1990. Subsurface transport of inorganic and organic solutes from experimental spreading of oil-field brine. *Ground Water Monitoring and Remediation*, vol. 10, no. 3, p. 94 - 105.

Balashov, V.N., T. Engelder, X. Gu, M.S. Fantle, and S.L. Brantley. 2015. A model describing flowback chemistry changes with time after Marcellus Shale hydraulic fracturing. *American Association of Petroleum Geologists Bulletin* 99(1), 143-154. January 2015. doi: 110.1306/06041413119.

Botner, Elizabeth C., D. Nash, and C. Paul. Monitoring methane levels and sources in groundwater before and after the onset of fracking in the Utica Shale of Ohio, USA. 2014. 2014 GSA Annual Meeting in Vancouver, British Columbia (19–22 October 2014)

Boyer, E.W., B.R. Swistock, J. Clark, M. Madden, and D.E. Rizzo. 2012. The impact of Marcellus Gas Drilling on Rural Drinking Water Supplies. *The Center for Rural Pennsylvania, Pennsylvania General Assembly*, http://www.rural.palegislature.us/documents/reports/Marcellus_and_drinking_water_2012.pdf, accessed October 2014, Harrisburg, PA.

Brantley, S.L., D. Yoxtheimer, S. Arjmand, P. Grieve, R. Vidic, J. Pollak, G.T. Llewellyn, J. Abad, and C. Simon. 2014. Water resource impacts during unconventional shale gas development: The Pennsylvania experience. *International Journal of Coal Geology* 126, p. 140-156. June 1, 2014. dx.doi.org/110.1016/j.coal.2013.1012.1017

Drollette, B.D., K. Hoelzer, N.R. Warner, T.H. Darrah, O. Karatum, M.P. O'Connor, R.K. Nelson, L.A. Fernandez, C.M. Reddy, A. Vengosh, R.B. Jackson, M. Elsner, and D.L. Plata. 2015. Elevated levels of diesel range organic compounds in groundwater near Marcellus gas operations are derived from surface activities. *Proceedings of the National Academy of Sciences* 112(43), p. 13184-13189. October 27, 2015. doi/10.1073/pnas.1511474112.

Ferrar, K.J., D.R. Michanowicz, C.L. Christen, N. Mulcahy, S.L. Malone, and R.K. Sharma. 2013. Assessment of effluent contaminants from three facilities discharging Marcellus shale wastewater to surface waters in Pennsylvania. *Environ. Sci. & Tech.* 47(7), p.3472-81. April 2, 2013. dx.doi.org/10.1021/es301411q.

Gupta, N., and E.S. Bair, 1997. Variable-density flow in the midcontinent basins and arches region: *Water Resources Research.* vol. 33, no. 8, p. 1785-1802.

Jackson, R.B., E.R. Lowry, A. Pickle, M. Knag, D. DiGiulio, and K. Zhao. 2015. The depths of hydraulic fracturing and accompanying water use across the United States. *Environ. Sci. Technol.* 49(15), p. 8969-8976. doi: 10.1021/acs.est.5b01228.

Llewellyn, G., F.L. Dorman, J.L. Westland, D. Yoxtheimer, P. Grieve, T. Sowers, E. Humston-Flumer, and S.L. Brantley. 2015. Evaluating a groundwater supply contamination incident attributed to Marcellus Shale gas development. *Proceedings of the National Academy of Sciences* 112(20), 6325-6330. May 19, 2015. doi: 10.1073/pnas.1420279112.

Leenheer, J.A., T.I. Noyes, and H.A. Stuber, 1982. Determination of polar organic solutes in oil-shale retort water. *Environ. Sci. & Tech.* 16(10), p. 714-723. October 1982. doi: 10.1021/es00104a015.

Leri, A.C., and S.C.B. Myneni. 2012. Natural organobromine in terrestrial ecosystems. *Geochimica Cosmochimica Acta* 77, p. 1-10. January 15, 2012. doi:10.1016/j.gca.2011.1011.1012.National Research Council (2013) Alternatives for Managing the Nation's Complex Contaminated Groundwater Sites. *National Academies Press,* Washington D.C.

Sloto, R.A. 2013. Baseline groundwater quality from 20 domestic wells in Sullivan County, Pennsylvania, 2012. *U.S. Geological Survey Scientific Investigations Report* 2013-5085. http://pubs.usgs.gov/sir/2013/5085/.

States, S., G. Cyprych, M. Stoner, F. Wydra, J. Kuchta, J. Monnell, and L. Casson. 2013. Marcellus Shale drilling and brominated THMs in Pittsburgh, Pa., drinking water. *J. American Water Works Association* 105(8), p. E432-E448. August 2013. doi: http://dx.doi.org/10.5942/jawwa.2013.105.0093.

Toth, J., 1963. A theoretical analysis of groundwater flow in small drainage basins. *Journal of Geophysical Research*, vol. 68, no. 16, p. 4795-4812.

Toth, J., 1988. Ground water and hydrocarbon migration. In Hydrogeology, Geology of North America, vol. O-2, ed. Back, W., Rosenshein, J.S., and Seaber, P.R., Geological Society of America, Boulder, CO, p. 485-502.

US DOE. 2014. An Evaluation of Fracture Growth and Gas/Fluid Migration as Horizontal Marcellus Shale Gas Wells are Hydraulically Fractured in Greene County, Pennsylvania. NETL-TRS-3-2014. September 15, 2014. https://www.netl.doe.gov/File%20Library/Research/onsite%20research/publications/NETL-TRS-3-2014_Greene-County-Site_20140915_1_1.pdf

Vidic, R.D., S.L. Brantley, J.M. Vandenbossche, D. Yoxtheimer, and J.D. Abad. 2013. Impact of Shale Gas Development on Regional Water Quality. *Science* 340(6134), p. 826-835. May 17, 2013. DOI:10.1126/science.1235009.

Wilson, J.M., and J.M. VanBriesen. 2012. Oil and gas produced water management and surface drinking water sources in Pennsylvania. *Environmental Practice* 14(4), p. 288-300. December 2012. doi:10.1017/S1466046612000427.

WY Oil and Gas Commission, N.D., Appendix K Sampling and Analysis Procedures for the Wyoming Oil and Gas Conservation Commission Groundwater Baseline Sampling, Analysis, and Monitoring Program, Wyoming Oil and Gas Conservation Commission.

3.6. <u>Wastewater Treatment and Waste Disposal Stage in the HFWC</u>

Question 6: The fifth stage in the HFWC focuses on wastewater treatment and waste disposal: the reuse, treatment and release, or disposal of wastewater generated at the well pad. This is addressed in Chapter 8.

a. Does the assessment clearly and accurately summarize the available information concerning hydraulic fracturing wastewater management, treatment, and disposal?
b. Are the major findings concerning wastewater treatment and disposal fully supported by the information and data presented in the assessment? Do these major findings identify the potential impacts to drinking water resources due to this stage of the HFWC? Are there other major findings that have not been brought forward? Are the factors affecting the frequency or severity of any impacts described to the extent possible and fully supported?
c. Are the uncertainties, assumptions, and limitations concerning wastewater treatment and waste disposal fully and clearly described?
d. What additional information, background, or context should be added, or research gaps should be assessed, to better characterize any potential impacts to drinking water resources from this stage of the HFWC? Are there relevant literature or data sources that should be added in this section of the report?

Chapter 8 presents a discussion on wastewater treatment and waste disposal, in particular the reuse, treatment and release, or disposal of wastewater generated at the well pad in the HFWC. The chapter describes volumes of hydraulic fracturing wastewater (including estimates at national, regional, state and formation-level, and estimation methods and their associated challenges), and wastewater characteristics including a discussion on what is wastewater. The chapter presents a discussion on chemical constituents in wastewater treatment residuals, wastewater management practices, underground injection for disposal, CWTFs, hydraulic fracturing water reuse, evaporation, publicly owned treatment works, and other management practices and issues. The chapter also examines treatment processes for hydraulic fracturing wastewater, treatment of hydraulic fracturing waste constituents, and potential impacts on drinking water resources, and discusses hydraulic fracturing treatment issues associated with bromide and chloride, radionuclides, metals, volatile organic compounds, semi-volatile organic compounds, and oil and grease. The chapter concludes with a synthesis of major findings, discussion on factors affecting the frequency or severity of impacts, and description of uncertainties.

3.6.1. Summary of Available Information on Hydraulic Fracturing Wastewater Management, Treatment and Disposal

a. Does the assessment clearly and accurately summarize the available information concerning hydraulic fracturing wastewater management, treatment, and disposal?

Chapter 8 in the draft Assessment Report clearly and accurately summarizes a large amount of available information concerning the management, treatment, and disposal of hydraulic fracturing wastewater. However, the chapter should also clearly and accurately summarize available information concerning the regulatory framework for wastewater management; the fundamental principles of some of the treatment technologies described; the occurrence and removal of disinfection by-product (DBP) precursors other than bromide; additional aspects of "waste disposal," including cuttings, drilling muds, and treatment residuals; the locations of wastewater treatment and disposal facilities relative to downstream / downgradient public water supply (PWS) intakes and wells; the impacts (increased risks) of water recycling on pollutant concentrations and their potential impacts on drinking water quality should spills of recycled water occur; trends in wastewater disposal methods, including the scientific and economic drivers of these changes and their potential impacts on drinking water resources; and the potential impacts of seismic activity on wastewater disposal (deep well injection), on oil and gas (O&G) production infrastructure (e.g., damage to wells, storage vessels, and pipelines transporting wastewater), and on PWS infrastructure (e.g., damage of public water supply wells).

The regulatory framework for oversight of CWTFs, and of publicly owned treatment works (POTWs) receiving discharges of wastewater associated with hydraulic fracturing, is inadequately described. Some regulatory information is provided in fragmentary and anecdotal fashion (e.g., in Text Box 8-1), but the pertinent regulations are not clearly summarized, so it is not clear to the reader who is responsible for each of the various aspects of wastewater treatment and waste disposal discussed in Chapter 8. The draft Assessment Report should specify: which, if any, local, state or federal agencies regulate CWTFs and their residuals, including under which statutes [e.g., the Clean Water Act (CWA)/National Pollutant Discharge Elimination System (NPDES), Resource Conservation and Recovery Act (RCRA), and state regulations]; whether any exemptions for CWTFs exist; and whether POTWs accepting wastewater discharges associated with oil and gas production are required to adopt a sewer use ordinance limiting such discharges (or specific components thereof) before receiving an NPDES permit, and whether the treatment residuals from these POTWs are exempt under RCRA.

While the summary of treatment technologies in Chapter 8 is generally adequate, the chapter requires more accurate and fundamentally sound descriptions of some technologies and their performance. Chapter 8 does not adequately consider temporal trends or costs of hydraulic fracturing water purification technologies over the past decade, trends in wastewater disposal methods including the scientific, regulatory and economic drivers of these changes and their potential impacts on drinking water resources, nor potential future trajectories (e.g., if deep well injection of wastewater is reduced because of regulatory changes driven by public concerns about seismic activity and its associated costs), and should include an assessment of these trends and costs. The EPA should consider use of the EPA's costing information developed for wastewater treatment (U.S. EPA, 1979a, b and c). The draft Assessment Report should use the EPA cost-curves or other comparative assessment tools to address relative capital plus operation and maintenance costs for the major wastewater treatment technologies.

Chapter 8 should clearly and accurately summarize trends in oil and gas wastewater disposal. Disposal techniques have changed significantly over the past 15 years, and are likely to continue changing. There is inadequate scientific or economic description of the drivers for these changes. The economic costs associated with different wastewater disposal options for hydraulic fracturing wastewater are not and should be adequately summarized. The draft Assessment Report should also discuss likely future trends in wastewater disposal, and describe and assess future uncertainties. For example, the draft Assessment Report should discuss where hydraulic fracturing wastewaters would likely end up if seismic activity leads to curtailment of deep well injection of hydraulic fracturing wastes, and what will be done with hydraulic fracturing produced waters that are recycled if well drilling slows and there is less demand for recycled water for hydraulic fracturing.

The draft Assessment Report should clarify what is meant by "waste disposal." The title of Chapter 8 (Wastewater Treatment and Waste Disposal) is a bit ambiguous and the text does not make it immediately clear to the reader whether "waste" includes only those wastes generated during wastewater treatment or is more broadly construed to include other wastes associated with hydraulic fracturing.

While the draft Assessment Report does address treatment residuals, the SAB finds that it should further describe the management of other hydraulic fracturing materials such as drill cuttings and drilling muds and the potential of these materials to impact drinking water resources. The EPA should explicitly describe and provide supporting documentation regarding the disposal route for these wastes, and whether drilling wastes are normally disposed in regulated landfills having low potential to leach chemicals of concern into nearby drinking water sources. The draft Assessment Report should also discuss how hydraulic fracturing spill-contaminated soils, pond sediments, and other solid media that are potentially impacted by hydraulic fracturing chemicals are managed and disposed, and whether the EPA considers these potentially impacted media as "site reclamation" activities that the EPA excluded from this report (as noted on p. ES-4). If so, the EPA should reiterate this point in Chapter 8 for clarity. Within this discussion, the EPA should clarify the extent to which these wastes are regulated, and options for disposing of these wastes in a legal manner. If the regulations include reporting requirements (e.g., as required for other hazardous wastes under RCRA), then the EPA should consider reviewing the repositories for such reports as a source of data for this discussion.

Chapter 8 describes typical wastewater characteristics for flowback and produced water with major categories including organics, inorganics, total dissolved solids (TDS), and radionuclides. While the description provided for TDS and inorganic characteristics for flowback and produced water is adequate (Abualfaraj, N., et al., 2014; Fan, W., et al., 2014; Kondash, A.J., et al., 2014; Lester, Y., et al., 2015; and Wang, L., et al., 2014), the organic composition of flowback/produced water is not adequately described within the draft Assessment Report. This may be because there is a major gap in knowledge of hydraulic fracturing chemicals that are designated as confidential business information (CBI), and that a significant portion of hydraulic fracturing injection fluid chemicals being used by operators are considered proprietary information. The sphere of unknown chemicals is further enlarged by the fact that subsurface reactions can change the structure and toxicity of both known and unknown compounds. The EPA tried to express some of that uncertainty in Chapter 8, but certain statements within the chapter on this topic are confusing, such as the following statement on page 8-11: *"Certain organic compounds are of concern in drinking water because they can cause damage to the nervous system, kidneys, and/or liver and can increase the risk of cancer if ingested over a period of time (U.S. EPA, 2006). Some organics in chemical additives are known carcinogens, including 2-butoxyethanol (2BE), naphthalene, benzene, and polyacrylamide (Hammer and VanBriesen, 2012). Many organics are regulated for drinking water under the National Primary Drinking Water Regulations."* Such statements suggest that if organic compounds do not fall into these categories, then there may not be a concern regarding such compounds. To address these concerns that the draft Assessment Report contains limited information on chemical identity and concentrations in hydraulic flowback and produced water, the agency should acknowledge that there is a lack of information on what is being injected, and should describe these concerns regarding its reliance on an early version of FracFocus data within the draft Assessment Report. Within the draft Assessment Report, the agency should also characterize in some way data on proprietary compounds that the EPA may have, and information provided in newer versions of FracFocus on chemical class and concentration (% mass of hydraulic fracturing fluid). As the FracFocus data that the agency assessed was current up to February 2013, the SAB also recommends that the EPA should discuss the current status of FracFocus and changes that have been made to the FracFocus platform and system, and articulate needs for information that is collected and available from individual states and that could help with assessment yet is not readily accessible.

Regarding the residuals generated from wastewater treatment, given the processes used to remove many of the contaminants discussed in Chapter 8, various contaminants can become highly concentrated in the residuals. While treatment residuals may contain sufficiently high concentrations of metals, TDS, radionuclides, and organics that these residuals could be classified as hazardous waste under RCRA rules based on their concentrations, residuals associated with oil and gas operations have an existing exclusion from being considered hazardous waste under RCRA (EPA 40 CFR 261.4(b)). The draft Assessment Report should clarify which specific hydraulic fracturing wastes (including treatment residuals) are exempt under RCRA, whether management of these wastes is governed by other federal or state regulations, and how these wastes are actually managed. Since hydraulic fracturing treatment residuals and other wastes can be a significant source of leaching of hazardous chemicals into the environment if not properly managed, the draft Assessment Report should clearly and accurately summarize available information on this topic. If there are no known data sources and these wastes are simply being disposed of in unknown locations with no records being kept, the EPA should identify this as a data gap that would impact the ability of the EPA and others to evaluate the impacts of waste disposal on drinking water resources.

In Table F-2 on page F-15 of the draft Assessment Report, “Organics” should be divided into particulate, liquid, dissolved, and perhaps emulsified states. Mechanisms (and processes) for removing these different types (states) of organic matter differ greatly, and lumping them together oversimplifies such mechanisms and processes and will almost certainly cause confusion in the minds of at least some readers.

In Section 8.6.1.2 of the draft Assessment Report, the EPA used modeling to examine strategies for reducing the impact of bromide on downstream users. The EPA should have included a description of the model and its assumptions. The agency should reconsider or reassess its use of modeling to determine definitive strategies for reducing impacts on PWS, since experimental data that were reported earlier in this section of the draft Assessment Report discusses how significant dilution of waters containing bromide may not reduce levels to background concentrations.

Although N-Nitrosodimethylamine (NDMA) is mentioned in Appendix F (p. F-28), the discussion there focuses on the possible role of bromide in forming NDMA and on possible future regulation of NDMA and other nitrosamines. The potential for hydraulic fracturing wastewaters to form nitrosamines is otherwise ignored. There is no mention of NDMA in Chapter 8. Considering that (1) hydraulic fracturing wastewaters may contain high levels of known NDMA precursors (including bromide, ammonia, and amines), (2) industrial discharges have been found to pose significant problems with respect to NDMA formation (e.g., for the Orange County (CA) Water District’s Groundwater Replenishment System), and (3) disinfection of water and wastewater can potentially result in formation of problematic levels of NDMA, increased NDMA formation is a potentially significant impact of hydraulic fracturing wastewater discharges on drinking water resources. The EPA should add within the draft Assessment Report additional analyses on the potential for hydraulic fracturing wastewaters to form nitrosamines. Also, the EPA should further describe how the reported high levels of Total Kjeldahl Nitrogen (TKN) for some samples (e.g., on p. E-8) are also of concern, since TKN includes nitrogenous organic compounds that may also be NDMA precursors.

On page F-28, lines 19-20 of the draft Assessment Report, in the discussion on drinking water treatment at downstream drinking water treatment plants, the text states that: *“Studies generally report that the ratios of halogen incorporation into DBPs reflect the ratio of halogen concentrations in the source water.”* Though technically true, the statement is misleading in that bromide is preferentially incorporated into halogenated DBPs and needs to be revised. The SAB notes that bromate, chlorides and hypochlorate are used in fluids used during HF stimulation. The SAB notes that up to half of the bromide in a given raw water supply may be incorporated into halogenated DBPs during drinking water treatment at downstream drinking water treatment plants, while less than one percent of the chloride may be consumed in this manner. The Br-to-Cl ratio in the DBPs can be orders of magnitude higher than the ratio in the raw water. (Hua, G.H., et al., 2006; Obolensky, A., and P.C. Singer, 2005; and Westerhoff, P., et al., 2004).

Some hydraulic fracturing wastewaters may contain significant concentrations of antiscalants, if antiscalants are used in preparation of hydraulic fracturing fluids, and some may contain various complexing agents used for other purposes besides scale control. Such chemicals may, if discharged into drinking water sources in sufficient amounts, influence the transport and fate of metal ions, and adversely impact metal ion removal by various treatment processes. Chapter 8 should address this potential concern. Data sources that would provide information on concentrations of antiscalants in HF waters are provided in section d2 below.

In addition, the draft Assessment Report should discuss the degree to which flowback and produced water is comprised of bromate, chlorate/chlorite, perchlorate or iodate. The SAB notes that bromate is used in fluids used during HF stimulation treatment. All of these chemicals have human toxicity endpoints and some have MCLs, and the EPA should describe whether these compounds are ever found in hydraulic fracturing waters. The SAB finds that the EPA’s discussion on halogens in Chapter 8 is inadequate.

The draft Assessment Report includes a number of inaccurate statements regarding treatment technologies and the removal mechanisms involved, and the SAB recommends that the EPA correct these statements to address concerns noted below:

- On page 8-38, electrocoagulation is characterized as an *“emerging technology.”* Perhaps it has only recently begun to be used (or tested for use) to treat hydraulic fracturing wastewater, but the technology is a niche technology that been available for decades. Fundamentally, it is simply another way to add metal salt coagulants to water, which has been a common water treatment process for well over a century. Coagulation has long been used to treat wastewaters containing emulsified oils or small droplets of oil (page 8-68), such as refinery wastewaters. It seems inappropriate to lump this technology together with technologies that are clearly both new and emerging, such as forward osmosis. Also, the draft Assessment Report notes (page 8-47) that recent tests of electrocoagulation *“illustrated challenges, with removal efficiencies affected by factors such as pH and salt content.”* These challenges have also been well known for many decades. See, for example, the EPA-600/8-77/005 (Manual of Treatment Technologies for Meeting the Interim Primary Drinking Water Regulations) for information on the effects of pH and chemical dosage on removal of selected metals by coagulation.

- In some places the draft Assessment Report refers to “bromine” whereas in other places the draft Assessment Report refers to “bromide.” The EPA should check that the terms are used appropriately, in each case referring to the relevant chemical form for the particular context.

- On page 8-46, the draft Assessment Report states that *“TSS can be removed by several processes, such as coagulation, flocculation, sedimentation, and filtration (including microfiltration and media and bag and/or cartridge filtration), and with hydrocyclones, dissolved air flotation, freeze-thaw* *evaporation, electrocoagulation, and biological aerated filters."* The SAB notes that coagulation, flocculation, and electrocoagulation do not *"remove"* TSS. Coagulation and electrocoagulation destabilize colloidal particles (often by neutralizing their charge), allowing them to aggregate into larger particles so they can be aggregated (flocculated) into larger particles that are more readily removed by processes designed to remove particles, such as sedimentation, filtration, and dissolved air flotation.

- On pages 8-46 and 8-47, the draft Assessment Report states that monovalent ions are not removed by basic treatment processes and require more advanced treatment such as nanofiltration. The SAB notes that nanofiltration removes divalent ions well, but typically achieves little or no removal of monovalent ions.

- On page 8-47, the draft Assessment Report states that *"Media filtration can remove metals if coagulation / oxidation is implemented prior to filtration."* This is a gross oversimplification of the processes involved. Metals can be present in both particulate and dissolved forms. Those present in particulate form can often be effectively removed by filtration; but, depending on the characteristics of the particles and the filter, coagulation and flocculation may be required prior to filtration. Dissolved metals can only be removed by filtration if they are first incorporated into particles, which could occur if they are precipitated (e.g., precipitation of barium as $BaSO_4$) or adsorbed onto solids such as iron or aluminum oxides produced by coagulation, various other precipitates, or powdered activated carbon. However, only certain combinations are effective. Furthermore, although oxidation promotes the removal of some metals (such as Fe^{2+} and Mn^{2+}), it hinders the removal of chromium by converting it to a more soluble (and more toxic) form (Cr^{6+}).

- On page 8-47, the draft Assessment Report states that *"Advanced treatment processes such as … nanofiltration can remove dissolved metals and metalloids."* Nanofiltration is expected to be highly effective only for those dissolved metals present in the form of multivalent ions or large coordination complexes.

- On page 8-64, the draft Assessment Report states that *"Radium … will also co-precipitate calcium, barium, and strontium in sulfate minerals."* Radium is present in only trace amounts, but can be co-precipitated (removed from solution) when a sufficient amount of sulfate is added to precipitate calcium, magnesium, or barium. Carbonate addition, forming calcium carbonate, would also be expected to work reasonably well. It may be unlikely that enough radium would ever be present for it to form a precipitate and for the other metals to then be co-precipitated with radium sulfate. Co-precipitation, by definition, is the incorporation of a substance into a precipitate when it would have remained in solution had the precipitate not formed. SAB suggests that the EPA reword this sentence to read: *"Radium … can also be removed by co-precipitation if sulfate or carbonate is added to hydraulic fracturing wastewater to precipitate calcium, barium, or strontium."*

- On page 8-65, the draft Assessment Report states that *"Common treatment processes, such as coagulation, are effective at removing many metals."* As noted above, "coagulation" *per se* does not remove metals. Coagulation can facilitate removal of metal-containing particles by neutralizing their charge, and precipitates formed by metal-salt coagulants can adsorb (co-precipitate) certain metal ions, depending on the ability of the metal to adsorb to the precipitate and other factors such as pH, ionic strength, and the presence of competing ions.

- On page 8-66, line 23, aeration is listed as a process able to remove volatile organic compounds (VOCs). Although the term "aeration" is often used to describe this process, it is more accurately referred to as "air stripping."

- On page F-7, electrocoagulation is said to be *"… less effective for removing TDS and sulfate."* This technology is simply not effective at all for removing TDS and sulfate, nor is any other coagulation process, except perhaps under extreme conditions one would not expect to encounter in practice. Any incidental removal associated with changes in pH or ionic composition could be just as readily and less expensively obtained by simply adding an appropriate acid, base, or salt. Electrocoagulation is correctly characterized in Table F-2, page F-15, as "not effective" for TDS and anion removal; and it "removes" TSS and organics only to the extent that coagulated solids (including organic solids), and dissolved organics coprecipitated with the coagulated solids, are removed by subsequent treatment processes that removal particles.

- On page F-9, the draft Assessment Report notes that electrodialysis relies on *"positively and negatively charged particles and coated membranes to separate contaminants from the water."* This statement is incorrect. The process relies on positive and negative charges (provided by electrodes, not particles) that repel or attract anions and cations, causing them to pass through anion and cation exchange membranes, respectively. Stacks of these membranes (alternating cation and anion exchange membranes) separate the water into channels alternately enriched with dissolved solids or depleted. The channels are segregated and manifolded together to produce a concentrate (brine) stream and a fresh demineralized (product water) stream.

- On page F-10, the draft Assessment Report states: *"Forward osmosis, an emerging technology for treating hydraulic fracturing wastewater, uses an osmotic pressure gradient across a membrane to draw the contaminants from a low osmotic solution (the feed water) to a high osmotic solution."* This is incorrect. Only water passes through the membrane, not salts. The water is drawn into the "high osmotic solution," which is made using a volatile salt such as ammonium carbonate that can be driven off with heat, leaving behind pure water. The volatile salt is then condensed and reused.

- In Table F-2, page F-16, the draft Assessment Report indicates that electrodialysis (ED) is very effective for removing organics. However, this technology is very ineffective for nearly all organics. Particulate organics, oil and grease, and high molecular weight organic anions foul ED membranes (which are ion-exchange membranes), either ruining them or significantly shortening their life. Only small, charged organic ions could potentially be removed, but removal would probably be rather poor in most cases.

- Throughout the draft Assessment Report, the EPA refers to centralized waste treatment (CWT) and centralized water treatment facilities (CWTFs). In these discussions the EPA is describing centralized *wastewater* treatment facilities. For clarity, the EPA should redefine both abbreviations noting that "wastewater" is being addressed in these scenarios, and use these terms consistently throughout the draft Assessment Report.

3.6.2. Major Findings

b1. Are the major findings concerning wastewater treatment and disposal fully supported by the information and data presented in the assessment?

Certain major findings concerning wastewater treatment and disposal are not fully supported by the information and data presented in Chapter 8. The available information and data do not support the conclusion in the chapter (page 8-75) that *"there is no evidence that these contaminants have affected drinking water facilities."* In addition, page 8-68 of the draft Assessment Report describes the "Summary of Findings," and begins with the statement that: *"Hundreds of billions of gallons of wastewater are generated annually in the United States by the oil and gas industry."* This statement is qualified, and the limitations of the methodologies are explained, in part, in Section 8.2.3 (page 8-9). However, Chapter 8 of the draft Assessment Report should clearly and accurately describe the basis for this estimate. The basis for this wastewater generation estimate is not very clear, and efforts to find it in the draft Assessment Report are complicated by the many disparate estimates (for different years or time periods, different groups of states, and different segments of the industry) in various places in the draft Assessment Report and by the different units of volume and flowrate used in the draft Assessment Report (appropriately used, but nevertheless confusing to some readers). To provide more clarity regarding this statement, the SAB recommends that the EPA include a table in Chapter 8 that more clearly illustrates the basis for this particular estimate, since it is arguably a "major finding." Such a table could perhaps include reasonable estimates derived from several sources, including correction factors applied to adjust for increased production over time and for other factors, and the range of estimates from which the "hundreds of billions of gallons" estimate emerged. In addition, the EPA should provide a validated approach to predict future wastewater generation trends and describe uncertainty in these predictions.

On page 8-70, line 29, of the draft Assessment Report, in the discussion on drinking water treatment at downstream drinking water treatment plants, the text notes that bromide is of *"concern due to the formation of disinfection by-products (DBPs)."* The SAB notes that bromide does not simply form DBPs - it also increases both the rate and extent of THM and HAA formation. The draft Assessment Report states on page 8-60 that *"… brominated and iodinated [DBPs] are considered more toxic than other types of DBPs (Richardson et al., 2007)"* and on page 8-70 that *"Brominated DBPs (and iodinated DBPs) are more toxic than other species of DBPs."* The draft Assessment Report should clarify whether these statements are based on toxic effects observed in cell cultures or on human toxicity data. If the former, the type of cells tested and the relevant references should be noted; if the latter, supporting references should be cited. Since humans differ greatly from cell cultures, and chemicals that cause toxicity in cell cultures (cytotoxicity) may not be toxic to humans, the EPA should revise the text to note that brominated and iodinated DBPs may be more toxic to humans than DBPs containing chlorine as the only halogen species, based on their toxicity to cells. Unless the EPA is able to find data to the contrary, the chapter should also note that there are no data currently available to prove that this is the case for humans. If human toxicity data are available, then the EPA should cite the appropriate references.

On page 8-72, lines 3-4, the draft Assessment Report states: *"There may be consequences for downstream drinking water systems if the sediments are disturbed or entrained due to dredging or flood events."* The EPA should more clearly summarize these consequences, and provide an example or two to clarify this statement. Since water treatment plants are typically well equipped to remove suspended solids, and since the sediments would already have been sitting in water for an extended period of time (such that hazardous chemicals soluble in water would already have had an opportunity to leach out of them), the EPA should assess and describe how such entrained or disturbed sediments may have potentially adverse impacts on drinking water quality.

b2. Do these major findings identify the potential impacts to drinking water resources due to this stage of the HFWC?

Potential impacts to drinking water resources are not adequately addressed in Chapter 8. The EPA should describe potential impacts from other DBPs besides THMs and HAAs that are produced in drinking water treatment when intake water contains some amount of hydraulic fracturing wastewater. .

Deep well injection systems for oil and gas wastewater disposal are not uniformly distributed among the different states or within states. The draft Assessment Report did not consider at least two issues associated with this wastewater disposal issue. First, transport of wastewater from a specific wellsite to a disposal injection well poses risks for spills. Longer distances increase likelihood of crossing surface waters where spills could impact surface water intakes, or spills could impact water supply wells. Second, the draft Assessment Report should summarize the extent to which varied permitting of injection wells in different states consider their proximity and potential impacts to water supplies (production wells, private wells, surface water intakes).

An additional concern about injection wells for oil and gas wastewater disposal is their potential impact on seismic activity and the resulting impacts on the surrounding drilling infrastructure. The draft Assessment Report does not mention anything about reporting of seismic activity discussed in the literature (Ellsworth, 2013; Yeck et al., 2015; Weingartern et al., 2015; McNamara et al., 2015) related to deep well injection. The SAB recommends that the EPA include discussion on this issue in Chapter 8, and assess how this issue may affect operator selection of appropriate flow rates and pressures to minimize or eliminate significant seismic events when this management approach is selected. The SAB encourages the agency to collaborate with other federal/state regulatory agencies, universities, industry and other stakeholders to update the research associated with this issue as a longer-term future activity.

The draft Assessment Report should note that reuse of wastewater to prepare hydraulic fracturing fluids may significantly increase the concentrations of various contaminants (e.g., TDS and radionuclides) in both the flowback and produced water. This would especially occur if the reused water is only partially diluted/treated or if new hydraulic fracturing fluid technologies that can tolerate significantly higher TDS concentrations are utilized (which could possibly alleviate the need to even partially treat wastewater before it is reused). The draft Assessment Report should note that the storage of any reused water with these elevated contaminant concentrations can be a potential leak/spill source of potential impacts to local drinking water resources.

Chapter 8 of the draft Assessment Report cites limited studies that investigated radionuclides in effluents from POTWs, CWTFs, and zero-liquid-discharge facilities. Based on the reporting of the data, the EPA noted that POTWs receiving wastewater from hydraulic fracturing-related CWTFs did not show higher effluent radionuclide concentrations than POTWs not receiving such waste streams. However, the draft Assessment Report should note that the reported concentrations were all significantly elevated above the MCLs and several orders of magnitude above background river levels. In addition, the draft Assessment Report should further describe that technology-enhanced naturally occurring radioactive materials (TENORMs) may pose a significant risk since treatment processes used to remove other constituents (such as metals, biological oxygen demand (BOD), or TDS) from these hydraulic fracturing wastewaters may not remove radionuclides to levels that are protective of public health (depending on the influent concentration). While the draft Assessment Report does mention these topics, it should emphasize these as topics of significant concern. The draft Assessment Report should also acknowledge that other strategies for disposal of treated wastewater from CWTFs include deep well injection and reuse, and that these strategies also have similar concerns with respect to spills and leaks.

The draft Assessment Report does not provide sufficient discussion on where residuals from zero-liquid discharge facilities or reuse facilities end up, and should add to the discussion on this topic. Since these residuals concentrate many water soluble pollutants that could potentially find their way into drinking water resources if not properly managed, the draft Assessment Report should clearly and accurately summarize available information regarding the regulatory framework applicable to these wastes. Data sources that would provide information on fate of residuals from zero liquid discharge facilities or reuse facilities are provided in section d2 below.

Chapter 8 provides a limited review of the different unit processes that can be used to reduce various types of pollutants known to be commonly present in hydraulic fracturing flowback water and produced water (Table 8-6). The chapter should recognize that there are no data on the removal of unknown hydraulic fracturing constituents, and that the presence of these unknown chemical constituents results in a significant amount of uncertainty in the selection of a management strategy that involves discharges into a drinking water resource, land application, or road spreading.

To help assess the potential impacts of hydraulic fracturing wastewaters on drinking water resources, the EPA should consider mapping of all regulated injection well sites in the U.S. relative to locations of intakes for drinking water treatment plants, and the locations of domestic wells. Inclusion of such maps with a corresponding analysis within the draft Assessment Report would strengthen the examination of the potential impacts of hydraulic fracturing wastewaters on drinking water resources.

b3. Are there other major findings that have not been brought forward?

Chapter 8 of the draft Assessment Report did not bring forward all the major findings associated with the wastewater treatment and waste disposal phase of the HFWC. The draft Assessment Report does not mention that elevated radionuclide concentrations are likely to be present in the effluents from some CWTFs and most POTWs treating hydraulic fracturing-related wastewaters. The study that the draft Assessment Report cited as evidence of significant removal of radionuclides used data from another study, and not direct evidence, to estimate removal. The draft Assessment Report notes that effluent radium concentrations from CWTFs and zero-discharge facilities were on the order of thousands of pCi/L. The SAB is concerned that the zero discharge facilities that will produce water for reuse will have extremely high radium concentrations that will consequently pose an elevated risk if leaks or spills of these reuse waters occurs. Within the draft Assessment Report, the EPA describes a study that assumed a 3-log reduction in radium concentration using co-precipitation with barium sulfate. However, this cited study did not actually measure the influent concentration. The SAB recommends that the EPA include an assessment of the potential accumulation of radium in pipe scales, sediments, and residuals; the potential for leaching of this radium into drinking water resources; and the potential impacts of such leaching.

The use of CWTFs is a management strategy to reduce the pollutant load from flowback and produced wastewater. While Chapter 8 discusses the unit processes typically used at these facilities, the draft Assessment Report should further describe that these processes may not be able to reduce the concentrations to levels that allow for discharge to a drinking water resource. Examples of constituents and discharge limits specified in NPDES discharge permits for CWTFs would be informative to include.

Due to the non-disclosure of chemicals used in hydraulic fracturing injection fluids and to unknown subsurface reactions that affect the quality of flowback and produced water, the draft Assessment Report should address directly the extent to which the EPA can assess whether the effluent water from CWTFs is treated to a level that provides sufficient environmental and public health protection. An additional point regarding the discussion of CWTFs is that many of the descriptions of unit processes used are very general and sometimes incorrect. As discussed in the response to Charge Question 4a, these descriptions should be corrected.

The draft Assessment Report should also assess iodide in the same manner as bromide would be assessed as recommended in the response to sub-question b1 above, even though the draft Assessment Report provides very little data on the presence of iodide in flowback or produced waters. During drinking water treatment at downstream drinking water treatment plants, since iodide also reacts with some oxidants to produce DBPs, and recent evidence shows that brominated and iodinated DBPs are more cyto- and geno-toxic than the chlorinated analogs (Plewa, M.J., et al., 2009), information about iodide in waste waters should be amplified in draft Assessment Report. The ratio of Cl/I in Table E-4 is around 5000/1 which is much lower (i.e., more iodide) than the ratio in seawater which is 35,000/1. The EPA should discuss why iodide is more concentrated in flowback and produced water, relative to Cl, than in seawater.

3.6.3. Frequency or Severity of Impacts

b4. Are the factors affecting the frequency or severity of any impacts described to the extent possible and fully supported?

Chapter 8 does not adequately address the potential frequency and severity of impacts of hydraulic fracturing wastewater treatment and waste disposal on drinking water quality, nor potential scenarios in the near future that could influence such impacts (e.g., reduced access to deep well injection due to restrictions associated with seismic activity). The EPA should more clearly describe the potential frequency and severity of impacts associated with the wastewater treatment and waste disposal stage in the HFWC, before drawing conclusions on water quality impacts associated with this stage of the HFWC. Factors affecting the frequency or severity of potential impacts are not adequately described for either private wells or municipal water systems.

There is inadequate information and analysis in the draft Assessment Report, including Appendix E, related to bromide and iodide. Bromide is important for drinking water because upon addition of oxidants or disinfectants (chlorine, ozone) brominated disinfection by-products form in drinking water (e.g., brominated THM or HAA, bromate). The ratio of Cl/Br in Table E-4 is roughly 200/1, which is lower than the ratio in seawater (~300/1) and lower than the ~300/1 ratio observed in an American Water Works Association (AWWA) national survey of bromide in drinking waters (Amy, G., 1994). The EPA should describe the reasons for elevated bromide in these flowback and produced waters, relative to chloride, and further describe the severity of impacts associated with bromide in these waters.

Additional data are needed on DBP formation in drinking water treatment plants downstream from CWTFs or from POTWs receiving hydraulic-fracturing related wastewater. The draft Assessment Report should discuss what are the fluctuations in total organic halide (TOX) at water treatment plants downstream from CWTFs and from POTWs receiving discharges of hydraulic fracturing-related wastewater, since upstream POTWs and CWTFs likely receive “pulses” or “extended releases” of high salinity water. The draft Assessment Report should also describe the NPDES permits for CWTFs and POTWs receiving hydraulic-fracturing related wastewater, and note whether these permits regulate based upon grab samples. The EPA should also describe whether impacted POTWs are required to install and/or would benefit from installation of real-time conductivity meters. The SAB notes that pulses of Br^-, I^- or other salts to downstream WTPs can lead to pulses of DBPs in distribution systems. This is relevant because the EPA recognizes the potential for acute health risks to sensitive populations (e.g., pregnant women) from exposure to high levels of DBPs.

Naturally occurring organic matter (NOM), typically measured as TOC or DOC, is a well-known major precursor for formation of a broad spectrum of disinfection by-products in drinking water treatment, including THMs and HAAs. Hydraulic fracturing wastewater can contain very high levels of TOC (e.g., as indicated by the data shown on pages E-9, E-25, and E-27). The draft Assessment Report inadequately describes the potential for the organic matter in hydraulic fracturing wastewater to form THMs, HAAs, and other by-products during drinking water treatment at downstream drinking water treatment plants, and when present in PWS intake water and subjected to oxidation treatment for disinfection, which could be readily evaluated using simple DBP formation potential tests. The EPA previously noted that research on the DBP formation potential of hydraulic fracturing-related wastewaters was important to conduct, as described in the EPA's research Study Plan (U.S. EPA, 2011), and the SAB recommends that the EPA describe these issues in the draft Assessment Report. The SAB recognizes that there is relatively little published data on concentrations of TOC/NOM found in HF-related wastewaters, its UV absorbance (an indicator of precursor strength), and the extent to which such wastewaters actually forms DBPs (i.e., is it strong, weak, average, or highly variable compared to other sources of precursors). The EPA should include any available data on TOC/NOM and ammonium concentrations in HF-related wastewater in the draft Assessment Report and note that these concentrations are a factor that may influence the potential impacts of HF on drinking water resources. The SAB also notes that the apparent lack of such data is a serious data gap and the EPA should prioritize this as a research need as a longer-term future activity. Data sources that would provide information on DBPs are provided in section d2 below.

HF wastewaters can contain high concentrations of ammonium (e.g., as shown on page E-7), which can interfere with drinking water treatment by increasing chlorine demand and by converting free chlorine to chloramines. The latter poses a significant risk to human health if the water treatment plant operators are not aware that ammonium is present and therefore assume that the chlorine they add will be present as free chlorine rather than combined chlorine; the draft Assessment Report should describe this scenario. Also, the draft Assessment Report should mention the chlorine demand associated with hydraulic fracturing wastewaters, which if significant could also adversely impact drinking water treatment plants. Data sources that would provide information on HF wastes with high ammonium levels, resulting in the formation of chloramines, are limited. However, citations for high ammonia and chloramine chemistry are provided in section d2 below.

Strontium is mentioned a number of times in Chapter 8. The draft Assessment Report lacked discussion of the EPA's plans to regulate (establish an MCL for) Sr in drinking water, as the agency announced in 2014. The current Health Reference Level is only 4 mg/L. Since hydraulic fracturing wastewater can contain hundreds to over a thousand mg/L of Sr (page 8-65), discharge of even of small amount of inadequately treated hydraulic fracturing wastewater to a drinking water source could compromise a water utility's ability to comply with the anticipated MCL for strontium. The frequency and severity of impacts associated with strontium in hydraulic fracturing wastewaters should be acknowledged in the draft Assessment Report.

3.6.4. Uncertainties, Assumptions and Limitations

c. Are the uncertainties, assumptions, and limitations concerning wastewater treatment and waste disposal fully and clearly described?

Chapter 8 of the draft Assessment Report does not fully and clearly describe uncertainties, assumptions, and limitations concerning wastewater treatment and waste disposal.

CWT unit processes and disposal techniques have changed significantly over the past 15 years, and are likely to continue changing. The draft Assessment Report does not adequately describe past trends or anticipated future developments in treatment of produced water, nor does it adequately address future uncertainties. For example, the draft Assessment Report should describe where hydraulic fracturing-related wastewaters would likely end up if significant seismic activity leads to curtailment of deep well injection of wastes, and what will be done with produced waters that are recycled if well drilling slows and there is less demand for recycled water for hydraulic fracturing.

A key limitation of Chapter 8 is that, although this chapter addresses potential impacts of wastewater treatment and disposal from a watershed perspective, especially in Section 8.6, the chapter should put into a watershed perspective CWTFs discharging to surface waters or POTWs (Table 8-4, page 8-24), or other treatment and disposal facilities, such as disposal wells. Chapter 3 provided information regarding the number of PWSs within 1 mile of a hydraulically fractured well. Such information can be useful in assessing the potential impacts of spilled liquids and migration through faults, especially if viewed in a three-dimensional setting. Additional analyses of this type for the range of facilities noted would provide more insight into risks to drinking water resources.

Chapter 8 inadequately describes potential impacts on public drinking water supplies that rely upon intakes from surface waters located in watersheds downstream of hydraulic fracturing activities or discharges of hydraulic fracturing wastewaters. Many drinking water systems rely upon surface water supplies which could be located many miles downstream of hydraulic fracturing sites, but subject to potential impacts from hydraulic fracturing wastewater discharges (e.g., States et al., 2013, which is cited in the draft Assessment Report). In order to assess this topic, a variety of information is needed including the size and location of injection wells, CWTFs, POTWs receiving wastewater discharges (directly or indirectly), drinking water treatment facilities as well as the locations of streams and lakes and their flowrates and volumes, respectively. There are relatively few CWTFs known to be discharging to surface waters or POTWs (Table 8-4), and the EPA should provide information on the contributions that CWTFs may make to TDS, regulated contaminants, and other contaminants of concern in downstream PWSs. The EPA should also provide similar information for any POTWs known to be still accepting wastewater associated with hydraulic fracturing.

On page 8-70 of the draft Assessment Report, the summary of findings states that modeling suggests that small percentages of hydraulic fracturing wastewater in a river may cause a notable increase in DBP formation in a drinking water treatment plant. Experimental data from a literature study described that effect. Modeling was used to propose and evaluate strategies for diluting bromide to lessen impacts on downstream drinking water resources. The EPA's use of modeling is not adequately supported, as inadequate information is provided regarding the modeling approach, parameters involved, assumptions made, and whether any sensitivity or uncertainty analysis was performed to estimate the probable range of possible answers. The EPA should explicitly describe this information within the draft Assessment Report. If this information is included in the draft Assessment Report, the limitations associated with the modeling should be explicitly identified and the results should be appropriately qualified.

In the uncertainty section (8.7.3) of Chapter 8, it is stated on page 8-73 that limited monitoring data may be available from CWTFs with NPDES permits. Although the draft Assessment Report notes that monitored constituents may be limited, the discharge permit holders may not test for even a small fraction of the constituents found in hydraulic fracturing-related wastewater. The EPA has not and should present monitoring requirements and analyses associated with NPDES permits for CWTFs and evaluate the extent to which existing permits protect drinking water resources from hydraulic fracturing-related wastewater discharges from CWTFs or POTWs.

The draft Assessment Report should describe the treatment capacity (in millions of gallons per day, MGD) of the CWTFs identified in Table 8-4, relative to the annual produced water volume within a fixed distance (e.g., 100 miles). There EPA should also provide adequate justification for limiting analysis to 1 mile. The EPA should also develop maps of watersheds that have drinking water treatment plants located down-gradient from active or planned hydraulic fracturing activities for oil or gas development. Limiting proximity analysis to 1 mile results in considerable uncertainty associated with potential impacts to drinking water resources. A Geographic Information System (GIS)-based research method is available that can be used to estimate the number of drinking water treatment plants with upstream municipal wastewater discharges (Rice, J. et al., 2015a; and Rice, J. and P. Westerhoff, 2015b). The EPA should conduct similar work to understand potential risks to municipal surface water drinking water intakes greater than 1 mile away from hydraulic fracturing-related treatment and disposal facilities.

3.6.5. Additional Information, Background or Context to be Added

d1. What additional information, background, or context should be added, or research gaps should be assessed, to better characterize any potential impacts to drinking water resources from this stage of the HFWC?

The EPA should include various additional and important information into the draft Assessment Report, including the following research described in the final Study Plan (U.S. EPA, 2011) and the EPA's December 2012 Progress Report (U.S. EPA, 2012). Specifically, this includes the results of laboratory experiments to simulate wastewater treatment processes to assess their ability to remove a range of pollutants, such as radionuclides, VOCs, anions, metals, and inorganics, as well as DBP formation potential tests on hydraulic fracturing fluids, produced waters, and treated and untreated hydraulic fracturing-related wastewaters. While a limited number of such tests were performed in studies cited in the draft Assessment Report, the SAB recommends that the EPA conduct these additional research efforts.

The draft Assessment Report also includes little or no information on, or discussion of, several important DBPs (including bromate and nitrosamines such as NDMA) and stakeholder activities (e.g., Technical Workshop 2011, Technical Roundtable 2012, Technical Workshop 2013), and this information should be described within the draft Assessment Report.

The draft Assessment Report concludes, in its summary of findings on page 8-68 that *"Hundreds of billions of gallons of wastewater are generated annually in the United States by the oil and gas industry."* While this statement is qualified in the text and its limitations are explained in part in Section 8.2.3 on page 8-9 of the draft Assessment Report, the EPA should provide a more clear explanation of the basis for this estimate. The EPA also should more clearly and consistently describe the estimates that are provided on this topic in various different locations within the draft Assessment Report, and consistently describe units of volume and flowrate. This statement, unlike other statements in the draft Assessment Report, applies to the entire oil and gas industry rather than unconventional hydraulically fractured wells, and the draft Assessment Report explains that it was difficult to come up with an estimate pertaining specifically to unconventional wells, but the draft Assessment Report appears to include sufficient information to allow such an estimate to be made.

Also, based on the title of this chapter, Chapter 8 addresses both wastewater treatment and waste disposal. While the draft Assessment Report does briefly address wastewater treatment residuals, the draft Assessment Report provides little information regarding other wastes associated with hydraulic fracturing such as drill cuttings and drilling muds, and their potential to impact drinking water resources, and the SAB agrees that it should provide more information and analyses on these topics.

d2. Are there relevant literature or data sources that should be added in this section of the report?

The SAB recommends that the EPA consider the following additional literature sources within this chapter of the draft Assessment Report:

<u>References on Seismic Activity</u>

Ellsworth, W.L. 2013. Injection-induced earthquakes. *Science* 341(6142). July 12, 2013. doi: 10.1126/science.1225942.

McNamara, D.E., H.M. Benz, R.B. Hermann, E.A. Bergman, P. Earle, A. Holland, R. Baldwin, and A. Gassner. 2015. Earthquake hypocenters and focal mechanisms in central Oklahoma reveal a complex system of reactivated subsurface strike-slip faulting. *Geophysical Research Letters* 42(8), p. 2742-2749. doi: 10.1002/2014GL062730.

Weingartern, M., S. Ge, J.W., Godt, B.A. Bekins, and J.L. Rubinstein. 2015. High-rate injection is associated with the increase in U.S. mid-continent seismicity. *Science* 348(6241), p. 1336-1340. June 19, 2015. doi: 10.1126/science.aab1345

Yeck, W.L., L.V. Block, C.K. Wood, and V.M. King. 2015. Maximum magnitude estimations of induced earthquakes at Paradox Valley, Colorado, from cumulative injection volume and geometry of seismicity clusters. *Geophys. J. Int.* 200(1), p. 322–336. January 2015. doi: 10.1093/gji/ggu394.

<u>References on Energy in Treatment Plants</u>

McGucken, R., J. Oppenheimer, M. Badruzzaman, and J. Jacangelo. 2013. Toolbox for Water utility Energy and Greenhouse Gas Emission Management. Sponsored by the Water Research Foundation, Global Water Research Coalition, and NYSERDA. *Water Resource Foundation*. Denver, Colorado.

U.S. EPA (U.S. Environmental Protection Agency). 2013. Energy Efficiency in Water and Wastewater Facilities: A Guide to Developing and Implementing Greenhouse Gas Reduction Programs, EPA-430-R-09-038. http://www3.epa.gov/statelocalclimate/documents/pdf/wastewater-guide.pdf

References on Bromides

Amy, G., M. Siddiqui, W. Zhai, J. DeBroux, and W. Odem. 1994. American Water Works Association Research Foundation (AwwaRF) Final Report - Survey on bromide in drinking water and impacts on DBP formation. American Water Works Association Research Foundation.

References on concentrations of antiscalants in HF waters

There are many websites with information from vendors on what they sell and why (e.g., http://www.aimgroup.com.au/pdf/1207%20BWA_oil_seam_gas_chemicals.pdf). FracFocus would presumably be one good source of data, since antiscalants are considered a common ingredient in hydraulic fracturing fluids. Here are three of many journal publications:

Lester, Y., et al., Characterization of hydraulic fracturing flowback water in Colorado: Implications for water treatment. Science of the Total Environment, 2015. 512: p. 637-644.

Ferrer, I. and E.M. Thurman, Analysis of hydraulic fracturing additives by LC/Q-TOF-MS. Analytical and Bioanalytical Chemistry, 2015. 407(21): p. 6417-6428.

Thurman, E.M., et al., Analysis of Hydraulic Fracturing Flowback and Produced Waters Using Accurate Mass: Identification of Ethoxylated Surfactants. Analytical Chemistry, 2014. 86(19): p. 9653-9661.

References on fate of residuals from zero liquid discharge facilities or reuse facilities

If disposal of these wastes is regulated, e.g., under RCRA, then the reporting requirements may identify the relevant data source. While the SAB Panel could not locate specific documentation on zero liquid discharge technologies for HF activities, the following publications on zero liquid discharge technologies for other applications should be useful to the EPA as it summarizes these technologies:

Badruzzaman, M., et al., Innovative beneficial reuse of reverse osmosis concentrate using bipolar membrane electrodialysis and electrochlorination processes. Journal of Membrane Science, 2009. 326(2): p. 392-399.

Ji, X., et al., Membrane distillation-crystallization of seawater reverse osmosis brines. Separation and Purification Technology, 2010. 71(1): p. 76-82.

Kim, D.H., A review of desalting process techniques and economic analysis of the recovery of salts from retentates. Desalination, 2011. 270(1-3): p. 1-8.

Martinetti, C.R., A.E. Childress, and T.Y. Cath, High recovery of concentrated RO brines using forward osmosis and membrane distillation. Journal of Membrane Science, 2009. 331(1-2): p. 31-39.

Perez-Gonzalez, A., et al., State of the art and review on the treatment technologies of water reverse osmosis concentrates. Water Research, 2012. 46(2): p. 267-283.

Zhao, S., L. Zou, and D. Mulcahy, Brackish water desalination by a hybrid forward osmosis-nanofiltration system using divalent draw solute. Desalination, 2012. 284: p. 175-181.

References on DBPs

There are hundreds of publications on DBPs, here are a few representative publications:

Archer, A.D. and P.C. Singer, An evaluation of the relationship between SUVA and NOM coagulation using the ICR database. Journal American Water Works Association, 2006. 98(7): p. 110-123.

Hsu, S. and P.C. Singer, Removal of bromide and natural organic matter by anion exchange. Water Research, 2010. 44(7): p. 2133-2140.

Singer, P.C., Control of disinfection by-products in drinking water. Journal of Environmental Engineering-Asce, 1994. 120(4): p. 727-744.

References on high ammonia and chloramine chemistry

Hayes-Larson, E.L. and W.A. Mitch, Influence of the Method of Reagent Addition on Dichloroacetonitrile Formation during Chloramination. Environmental Science & Technology, 2010. 44(2): p. 700-706.

Mitch, W.A. and D.L. Sedlak, Formation of N-nitrosodimethylamine (NDMA) from dimethylamine during chlorination. Environmental Science & Technology, 2002. 36(4): p. 588-595.

Schreiber, I.M. and W.A. Mitch, Influence of the order of reagent addition on NDMA formation during chloramination. Environmental Science & Technology, 2005. 39(10): p. 3811-3818.

Schreiber, I.M. and W.A. Mitch, Influence of chloramine speciation on NDMA formation: Implications for NDMA formation pathways. Abstracts of Papers of the American Chemical Society, 2005. 230: p. U1503-U1504.

Additional resources:

Jackson, R.B., E.R. Lowry, A. Pickle, M. Knag, D. DiGiulio, and K. Zhao. 2015. The depths of hydraulic fracturing and accompanying water use across the United States. *Environ. Sci. Technol.* 49(15), p. 8969-8976. doi: 10.1021/acs.est.5b01228.

Rice, J., S. Via, and P. Westerhoff. 2015. Extent and Impacts of Unplanned Wastewater Reuse in U.S. Rivers. *Journal American Water Works Association*, 107, p.11:93 In Press. doi: 10.5942/jawwa.2015.107.0178.

Rice, J. and P. Westerhoff. 2015. Spatial and Temporal Variation in De Facto Wastewater Reuse in Drinking Water Systems across the USA. *Environ. Sci. & Tech.* 49(2), p. 982-989. January 20, 2015. doi: 10.1021/es5048057.

Thorp, L.W., and J. Noël. 2015. Aquifer Exemptions: Program Overview and Emerging Concerns. *Journal of the American Water Works Association* 107(9), p. 53-59. September 2015. doi: http://dx.doi.org/10.5942/jawwa.2015.107.0138

U.S. EPA-a. 1979. Estimating Water Treatment Costs. Volume 1 – Summary. EPA-600/2-79-162e. 1979. http://nepis.epa.gov/Exe/ZyNET.exe/30000909.TXT?ZyActionD=ZyDocument&Client=EPA&Index=1976+Thru+1980&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=&File=D%3A%5Czyfiles%5CIndex%20Data%5C76thru80%5CTxt%5C00000001%5C30000909.txt&User=ANONYMOUS&Password=anonymous&SortMethod=h%7C-&MaximumDocuments=1&FuzzyDegree=0&ImageQuality=r75g8/r75g8/x150y150g16/i425&Display=p%7Cf&DefSeekPage=x&SearchBack=ZyActionL&Back=ZyActionS&BackDesc=Results%20page&MaximumPages=1&ZyEntry=1&SeekPage=x&ZyPURL

U.S. EPA-b. 1979. Estimating Water Treatment Costs: Volume 2 - Cost Curves Applicable to 1 to 200 mgd Treatment Plants. EPA-600/2-79-162b. 1979. http://yosemite.epa.gov/water/owrccatalog.nsf/9da204a4b4406ef885256ae0007a79c7/b772717b690a5b1a85256b0600723835!OpenDocument

U.S. EPA-c. 1979. Estimating Water Treatment Costs. Volume 3 – Cost Curves Applicable to 2, 500 GPD to 1 mgd Treatment Plants. Summary. 1979. EPA-600/2-79-162c. 1979. http://nepis.epa.gov/Exe/ZyNET.exe/300009IH.TXT?ZyActionD=ZyDocument&Client=EPA&Index=1976+Thru+1980&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=&File=D%3A%5Czyfiles%5CIndex%20Data%5C76thru80%5CTxt%5C00000001%5C300009IH.txt&User=ANONYMOUS&Password=anonymous&SortMethod=h%7C-&MaximumDocuments=1&FuzzyDegree=0&ImageQuality=r75g8/r75g8/x150y150g16/i425&Display=p%7Cf&DefSeekPage=x&SearchBack=ZyActionL&Back=ZyActionS&BackDesc=Results%20page&MaximumPages=1&ZyEntry=1&SeekPage=x&ZyPURL

3.7. Chemicals Used or Present in Hydraulic Fracturing Fluids

Question 7: The assessment used available information and data to identify chemicals used in hydraulic fracturing fluids and/or present in flowback and produced waters. Known physicochemical and toxicological properties of those chemicals were compiled and summarized. This is addressed in Chapter 9.

a. *Does the assessment present a clear and accurate characterization of the available chemical and toxicological information concerning chemicals used in hydraulic fracturing?*
b. *Does the assessment clearly identify and describe the constituents of concern that potentially impact drinking water resources?*
c. *Are the major findings fully supported by the information and data presented in the assessment? Are there other major findings that have not been brought forward? Are the factors affecting the frequency or severity of any impacts described to the extent possible and fully supported?*
d. *Are the uncertainties, assumptions, and limitations concerning chemical and toxicological properties fully and clearly described?*
e. *What additional information, background, or context should be added, or research gaps should be assessed, to better characterize chemical and toxicological information in this assessment? Are there relevant literature or data sources that should be added in this section of the report?*

Chapter 9 presents a discussion on the identification and hazard evaluation of chemicals used and encountered across the HFWC. The chapter describes chemicals used in hydraulic fracturing fluids, chemicals detected in flowback and produced water, toxicological and physicochemical properties of hydraulic fracturing chemicals, the selection of toxicity values including reference values and oral slope factors, and physicochemical properties of such chemicals, and provides a summary of additional sources of toxicity information. The chapter presents a discussion on hazard identification of reported hydraulic fracturing chemicals, including how chemicals were selected for hazard identification, a multi-criteria decision analysis framework for hazard evaluation, and a summary of chemicals detected in multiple stages of the HFWC. The chapter concludes with a synthesis of major findings, discussion of factors affecting the frequency or severity of impacts, and description of uncertainties.

3.7.1. Summary of Available Information on Hydraulic Fracturing Chemicals

a. Does the assessment present a clear and accurate characterization of the available chemical and toxicological information concerning chemicals used in hydraulic fracturing?

In the draft Assessment Report the EPA clearly articulates their approach for characterizing the available chemical and toxicological information, including listing several sources for toxicological data in Appendix G that did not meet their criteria. The assessment in Chapter 9 does a good job as a first attempt to assess a very large and complex situation on a nationwide basis and introduce an approach that integrates toxicology data with physicochemical properties.

The EPA developed a multi-criteria decision analysis (MCDA) approach to analyze hydraulic fracturing chemicals for those which may be of most concern. The SAB agrees that inclusion of both exposure and toxicity data are of paramount importance in such an approach. Physicochemical properties of chemicals (mobility in water, volatility, and persistence) were included as surrogates of exposure in the approach developed by the EPA. A significant limitation of the EPA's approach was that criteria for physicochemical data and toxicological data were applied inconsistently, which resulted in underutilization of much relevant available information and did not recommend inclusion of exposure or concentration data when available.

The toxicological information was not characterized in Chapter 9 of the draft Assessment Report in an "inclusive" manner, because the criteria applied for data acceptability were too restrictive (discussed in greater detail under Charge Question 7c). While the SAB agrees with the EPA's inclusion of several important sources for reference values listed in Section 9.3.1 and Appendix G (e.g., IRIS,[3] HHBP,[4] PPRTVs,[5] Agency for Toxic Substances and Disease Registry (ATSDR) Minimal Risk Levels (MRLs),[6] California EPA Toxicity Criteria Database, IPCS CICAD,[7] IARC,[8] NTP RoC[9]), the SAB does not agree that the EPA should limit toxicological information to reference values (RfV) or oral slope factors (OSFs) that were peer reviewed only by a governmental or intergovernmental source. By doing so, the EPA ignored available toxicology data that may be acceptable for risk assessment, including sources listed in Appendix G.1.2 that the EPA excluded. Thus, the EPA's estimate that toxicity data were <u>unavailable</u> for 87% of the 1,173 chemicals is an overstatement of the scope of the problem. At a minimum, the EPA should explicitly indicate what fraction of the identified chemicals have hazard/toxicity information if reliable sources from states, other federal agencies, and international bodies would be employed, even if those sources do not meet the very stringent criteria used for MCDA analysis. It would be very useful for stakeholders to have this information and references available. As part of this effort, the EPA should reference and discuss the Organisation for Economic Co-operation and Development (OECD) (2014) hydraulic fracturing scoping project which identified 1121 "unique" hydraulic fracturing chemicals based on input from OECD member countries including the U.S. The SAB reviewed the OECD summary document but did not have access to the databases and spreadsheets that were referenced. The SAB agrees with the broader inclusion of toxicological data outlined in the OECD summary. This OECD project concluded that *"a large majority of substances were likely to have data available that would allow basic hazard assessment"* based on an initial survey of the EU REACH registration database, the EU classification and labelling inventory, and titles of citations in the literature" (OECD, 2014).

The EPA also briefly described the ACToR[10] database as another potential source of toxicological information in Section 9.3.4.2 of the draft Assessment Report, but did not include this data set in the MCDA approach or Appendix A-2 listing of toxicological information. The EPA reported that taking all assays related to oral toxicity together, ACToR had data available on 1145 of the 1173 hydraulic fracturing chemicals, but that only 55% of chemicals had "relevant" oral toxicity data. The EPA should clarify the definition of "relevant" and should broaden this definition to include short-term or chronic oral toxicity studies considered acceptable for risk assessment purposes. The EPA should explicitly state the total number of chemicals for which *in vivo* toxicology data are available in ACToR, OECD, EU, and other databases excluded by the EPA, and should incorporate this information into the MCDA

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[3] Integrated Risk Information System, U.S. Environmental Protection Agency
[4] Human health benchmarks for pesticides, U.S. Environmental Protection Agency
[5] Provisional peer-reviewed toxicity values, U.S. Environmental Protection Agency
[6] ATSDR Minimum risk levels
[7] International Programme on Chemical Safety Concise International Chemical Assessment Documents
[8] International Agency for Research on Cancer
[9] National Toxicology Program Report on Carcinogens, U.S. Department of Health and Human Services
[10] Aggregated Computational Toxicology Resource, U.S. Environmental Protection Agency

approach and add this information to Appendix A-2. As discussed in the SAB's response to Charge Question 7e, in cases where no *in vivo* data are available, the EPA is encouraged to consider emerging high-throughput computational approaches, which are included in the ToxCast database and also searchable in the ACToR database.

The draft Assessment Report also fails to note or make clear that some of the identified chemicals without reported toxicity information are (a) food additives, dietary supplements or, by FDA criteria are generally recognized as safe (GRAS) at specified levels with known human safety profiles (http://www.fda.gov/Food/IngredientsPackagingLabeling/GRAS/); or (b) are chemically related forms of the same substance, for which it would be reasonable to attribute similar safety profiles within the quartiles of toxicity used in the evaluation. In fact, the problem of availability of toxicological information for many chemicals is not unique to hydraulic fracturing, and the EPA should consider developing a tiered approach for toxicological information, including read-across methods of grouping chemicals of similar structure (http://echa.europa.eu/support/grouping-of-substances-and-read-across) [European Centre for Ecotoxicology and Toxicology of Chemicals (Ecetox) Technical Report 116].

A more important limitation of the EPA's hazard characterization is that very little attention is paid to the initial problem formulation stage of risk assessment, as recommended by NAS (2008). This initial problem formulation step should be used to identify the most likely potential hazards of greatest concern, and then this should be used to guide what toxicological information is most relevant. Instead, the EPA focuses exclusively on identifying formal noncancer oral reference values (RfVs) and cancer oral slope factors (OSFs) for chemicals, without providing sufficient rationale for frequency, duration, or intensity of exposure. Potential hazards that were highlighted in previous chapters and are of public concern were not addressed adequately in this chapter (e.g., flammability of methane gas in Chapter 6, and possible disinfection by-products [DBPs] in Chapter 8). Furthermore, if the most likely exposures of concern are findings in shorter term exposures, then findings in shorter term toxicology studies that are available from or used by governmental or non-governmental international organizations for risk assessment (e.g., OECD screening information data set) could be just as relevant as chronic studies. The ATSDR publishes acute, intermediate, and chronic ATSDR MRLs for many chemicals. American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit values (TLVs) and National Research Council's acute exposure guideline levels (http://dels.nas.edu/global/best/AEGL-Reports) pertain to inhalation exposures, which may be pertinent to some drinking water exposure scenarios. The EPA should characterize toxicological information on chemicals employed in hydraulic fracturing in an inclusive manner, and not restrict the criteria for selection of hydraulic fracturing chemicals of concern to those that have formal noncancer oral reference values (RfVs) and cancer oral slope factors (OSFs) for those chemicals.

In contrast to the toxicological information, the EPA uses chemical databases that are not peer reviewed for physicochemical parameters. The EPA uses the frequency of reporting in FracFocus, and K_{ow} values calculated from EPI Suite KowWIN software, to develop lists of chemicals of interest (Section 9.4.1) and characterize "exposure" (Section 9.5.2). The SAB agrees with the EPA's general approach to use available data to estimate exposure for MCDA assessments. However, more rigorous discussion of the limitations of these data is needed to estimate exposure in drinking water and thus, potential adverse effects. Since the MCDA gives equal weight to information on physicochemical scores, occurrence and toxicity, this may place undue emphasis on physiochemical score. While it may be useful in judging a chemical's likelihood of occurrence in drinking water, this value may be a relatively poor surrogate for actual exposure. Compounds may not be addressed that tend to remain at their original deposition site and serve as a reservoir for prolonged release. In light of these limitations, the agency should use MCDA results for preliminary evaluation purposes only. The agency should use MCDA on a regional or site-specific basis where more complete constituent identity, concentrations and toxicity information is available.

The SAB has concerns about the selection of specific factors in the examples. The EPA describes the limitations of the voluntary FracFocus database, but does not adequately justify their selection of frequency of occurrence, instead of the median maximum concentration in hydraulic fluid, to estimate the likelihood of exposure. A chemical could be used frequently but at very low concentrations in hydraulic fracturing fluids, and therefore be of little concern toxicologically. The EPA should also acknowledge that very potent chemicals can be present but maybe only at specific sites. Considerations of these situations should also be included in the explicit problem formulations. The EPA should also recognize the concerns regarding its reliance on the FracFocus version 1.0 data, and, if possible, provide an initial characterization of differences in uses of HF chemicals reported in FracFocus 3 compared to FracFocus 1.0.

The SAB recommends that the EPA should use experimental K_{ow} values when available, and discuss the reliability of the EPI Suite KowWIN software to estimate K_{ow} for the structures and range of values estimated. ACToR and REACH are potential sources of experimental K_{ow} and other physicochemical values that the EPA should use. In addition, the EPA should discuss the chemical information within the context of the HFWC, to describe differences in chemical characteristics, such as mobility when the chemical spills as a solvent (100% concentration), and after it is diluted to much lower concentrations in hydraulic fracturing fluid, flowback, or produced water. The SAB encourages EPA to more broadly include available physicochemical data on chemicals, which may be limited in that they only provide suggestions on bioavailability, lipid solubility, and potential for exposure. Such data together with toxicology data can be used to identify possible exposure boundaries that will allow the agency to prioritize chemical exposures of greater concern.

3.7.2. HF Constituents of Concern

b. Does the assessment clearly identify and describe the constituents of concern that potentially impact drinking water resources?

EPA clearly identifies and describes 1,076 chemicals historically used in hydraulic fracturing fluids (Appendix A-2), and 134 chemicals reported in flowback and produced water (Appendix A-4). The EPA should be commended for being very clear and transparent in Appendix A about the sources of information on which they relied for each chemical listed. These lists provides a valuable starting point for further refinement and updates. The SAB encourages the EPA to reconcile its lists of chemicals with the international OECD (2014) list of chemicals as a further check of potential chemicals of interest, although the SAB recognizes that there are differences in regulations and practices between the EU and U.S.

In addition, Chapter 9 of the draft Assessment Report notes that 70% of disclosures contain at least one CBI chemical. The SAB recommends that the EPA bring forward information and approaches from Chapter 5 to clarify that 11% of all hydraulic fracturing chemicals were CBI and characterize the toxicological properties of CBI chemicals that were provided to USEPA by nine service companies (discussed further under the SAB response to Charge Question 7e).

EPA indicates that there is a paucity of information on chemical identity and concentrations in flowback and produced water, with only three references cited in Table A-4. Previous chapters suggest numerous pathways for potential impacts to drinking water but do not indicate which of them are most likely to lead to drinking water contamination. Absent such directional information, it is not feasible to conclude which constituents—each differing in occurrence, concentration, and volume during the various phases of hydraulic fracturing gas and oil extraction—are of greatest concern. While additional field studies should be given a high priority in order to better understand the intensity and duration of exposures to constituents of flowback and produced water (discussed further under the SAB response to Charge Question 7e), such field studies may be considered a longer-term future activity.

In the absence of exposure information, the multi-criteria decision analysis (MCDA) approach presented by the EPA is a commendable and reasonable conceptual approach to prioritize chemicals of concern, but not as the EPA prescribed it for a national level. The EPA clearly states that the approach is described for illustrative purposes, in order to demonstrate how combining toxicological and physicochemical information may be informative. The EPA SAB supports an approach that considers both hazard and exposure potential. However, due to the limitations described above and in the SAB's response to Charge Question 7a, the EPA's MCDA results should be considered for preliminary hazard evaluation purposes only, as the EPA originally intended. The MCDA approach presented is useful on a regional or site-specific basis when more adequate toxicological data (i.e., not based solely on RfD) and constituent information (e.g., concentration and volume of spill) are available. In light of these limitations, and given that the EPA applied this approach to only 37 chemicals used in hydraulic fracturing fluids and 23 chemicals detected in flowback or produced water, the EPA should explicitly state that these MCDA results should not be used for prioritization of chemicals of most concern nationally nor to direct future toxicity testing research needs.

EPA's MCDA results give equal weight to physicochemical score (water solubility, volatility, and persistence in water) as to occurrence (concentration) and toxicity. The SAB is concerned that this may place undue emphasis on the physicochemical scores, which may be a relatively poor surrogate for exposure. While the SAB agrees that the three physicochemical sub-factors (water solubility, volatility, persistence) are useful to judge the chemical's likelihood of higher concentrations in drinking water, this approach may not adequately address compounds that tend to remain at their original site of deposition and serve as potential reservoirs for sustained/prolonged low level release into drinking water. The EPA discussed this uncertainty in Section 9.6.3 (last paragraph on page 9-8). However, the EPA should clearly emphasize that local exposure data on concentration and volume of spilled liquids should take priority over these physicochemical score surrogate measures and/or consider different weights for the physicochemical scores compared to concentration and toxicity data. In addition, structure activity databases and approaches may provide additional information relevant for estimating physicochemical properties (references listed in the SAB's response to Charge Question 7e).

3.7.3. Major Findings

c1. Are the major findings fully supported by the information and data presented in the assessment?

The SAB has concerns regarding three of the major findings included in Chapter 9, as follows.

1. The EPA concludes, *"Agencies may use these [MCDA] results to prioritize chemicals for hazard assessment or for determining future research priorities"* (page 9-39 of the draft Assessment Report). The SAB disagrees with this finding, based on the current method and limited scope of the MCDA exercise. The incomplete characterization of the available toxicological information in Chapter 9 could misdirect policy makers to close inaccurately perceived hazard information gaps. The lack of clarity or exclusion of such information inflates the "unknown" hazard information, rather than making clear that there is a substantial body of unused hazard information. The EPA should broaden the definition of relevant hazard information to include, for example, toxicity data available from or used by U.S. or state governments or international non-governmental organizations used for risk assessment purposes, or publicly available peer-reviewed data. The draft Assessment Report should explicitly indicate what fraction of the compounds identified in hydraulic fracturing fluid and/or produced waters have some hazard information (e.g., toxicity data available from or used by U.S. or state governments or international non-governmental organizations for risk assessment purposes, or publicly available peer-reviewed data), and what fraction have no available information. The EPA should also provide information on toxicological properties of CBI chemicals based on the voluntary disclosures to the EPA and updated information provided in the recent versions of FracFocus.

2. The EPA describes a list of potential hazards associated with chemicals in multiple places in Chapter 9: *"Potential hazards associated with these chemicals include carcinogenesis, immune system effects, changes in body weight, changes in blood chemistry, cardiotoxicity, neurotoxicity, liver and kidney toxicity, and reproductive and developmental toxicity."* In its present form, this statement does not take into account factors that affect the frequency, duration, or severity of exposure. This major finding should be qualified with "depending on the level and duration of exposure" at the end of each of these sentences throughout Chapter 9 and other parts of the document. In addition, the EPA should include in Chapter 9 the paragraph found in the Executive Summary and Synthesis Chapters 10-8 line 13-20, which clarifies that hazards, and thus impact on water quality, depend on magnitude of exposure, and that this is best evaluated in site-specific assessments at the regional, local, or water-tap level.

3. The EPA's major conclusion is that there is a significant data gap with regard to hazard identification, making it challenging to understand the toxicity and potential health impacts of the large majority of chemicals. As discussed in the SAB's response to Charge Question 7a, this conclusion is not fully supported because the EPA did not use all reasonably qualified toxicological information and approaches (e.g., did not use all U.S. and EU government- or international non-governmental organization-based toxicity data and safety assessments, nor accepted read-across approaches for highly similar compounds).

c2. Are there other major findings that have not been brought forward?

In Chapter 9 of the draft Assessment Report the EPA should summarize from previous chapters the discussions of potential hazards from methane (physical hazard), bromide and/or chloride-related disinfection by-products formed in drinking water, and organics in hydraulic fracturing wastewater. Information about exposure levels when available and regulatory action levels should be included to provide context for these constituents as well as the naturally occurring radioactive materials.

The EPA should use the full body of toxicological information, consistent with the agency's usual approach in hazard assessment. A criterion for acceptable toxicology data should be scientific and regulatory guideline quality, rather than funding source and formal assessments of chronic reference doses (RfDs). The EPA should take full advantage of the available peer-reviewed hazard assessments that were excluded in Section G.1.2 of the draft Assessment Report, as well as other sources of toxicological information. The SAB lists these additional sources below in the response to Charge Question 7e. At a minimum, the EPA should include all state and federal government hazard assessments in its analysis. This is particularly appropriate, because the EPA concludes that hazards are best assessed on a local level. The European Chemicals Agency Website for Registration, Evaluation Authorization Restriction of Chemicals (REACH/ECHA) is a database for toxicology and physicochemical data that may be useful for a large spectrum of chemicals. The EPA excluded MCLs because they are treatment based (page 9-6), but the EPA could consider MCLs or Maximum Contaminant Level Goals (MCLGs, which are not treatment based) when evaluating concern levels using the proposed MCDA approach. As the EPA broadens inclusion of toxicological information to populate missing toxicity data, they can develop a more expanded version of the tiered hierarchy of toxicity values described in Section 9.3.1. This allows the EPA to give higher priority to RfVs without excluding other toxicological information that is useful for hazard and risk assessment purposes.

The problem of availability of toxicology data for chemicals is not unique to hydraulic fracturing, so the EPA might consider approaches used for toxicological data evaluation by the EPA and other regulatory agencies, such as read-across and GRAS (generally recognized as safe) for some of the substances (http://www.fda.gov/Food/IngredientsPackagingLabeling/GRAS/).

The EPA should also directly consider and include exposure, use of threshold-of-toxicological-concern (TTC) concepts, and use of best practices for mitigation of hazards identified in the course of the analysis (e.g., recent information from FracFocus 3 and other sources on trends in substitution of less hazardous chemicals, as well as containment practices). These should be used to the extent feasible in the draft Assessment Report or be explicitly noted as gaps in the Assessment Report. The SAB suggests the TTC be used to deprioritize contaminants potentially present in these HF fluids based on calculated masses of constituents used in HF considering the volume of dilution in various fluids (HF fluids, flowback, and produced water) or based on measured concentrations. Constituents with calculated or measured concentrations yielding daily intakes below the TTC could be eliminated as having potential impacts on drinking water. This could focus any analyses to those compounds that have the potential to be present at levels of concern.

3.7.4. Frequency or Severity of Impacts

c3. Are the factors affecting the frequency or severity of any impacts described to the extent possible and fully supported?

There appears to be minimal emphasis on and discussion of factors that influence the frequency or severity of potential impacts. For example, while there is some information on hydraulic fracturing fluids used in various volumes and storage containers, as well as some mention of variations in secondary containment, there is no discussion of how these factors could influence spill conditions, aside from noting container (i.e., impoundment or man-made pit) failure as a substantial contribution to spills. Likewise, while there is discussion of well failures as a potential impact on drinking water resources, there is limited discussion of the likelihood of failure at different production stages (e.g., well communication failures, overpressuring failures, and structural failures during operation) and the type of chemical constituents that would be released. Each of these elements (and numerous others) is discussed in the draft Assessment Report, but there is limited synthesis of how this may affect the severity of impacts on drinking water resources.

3.7.5. Uncertainties, Assumptions and Limitations

d. Are the uncertainties, assumptions, and limitations concerning chemical and toxicological properties fully and clearly described?

The EPA clearly states in Chapter 9 the relevant uncertainties, assumptions, and limitations. However, the SAB notes areas of disagreement with some of the assumptions, limitations, and uncertainties presented within the draft Assessment Report.

A major assumption was that chronic toxicity data should be the basis for identifying chemicals of potential concern. It is not likely, based on the nature of the exposures (for example, local surface spills), that all exposures or impacts will be chronic. Data provided in some of the cases where measurements were made point to transient, rather than chronic, exposure durations. This assumption, while perhaps a useful simplification, should be explicitly indicated as resulting in some data gaps and overestimates of some impacts (e.g., those noted to yield transient exposures).

A major uncertainty is whether the list of chemicals used for hydraulic fracturing (Table A-2), based on references listed in Table A-1, is representative of current hydraulic fracturing practices. This could be better characterized by comparing chemicals listed in FracFocus version1.0 with those in FracFocus 3 to help assess whether the hydraulic fracturing industry is changing chemicals used within the HFWC, and whether there is movement in the U.S. toward “greener” chemistry. While this use of the FracFocus database may provide useful information, the SAB expresses concern that the FracFocus database may not be complete or sufficient because does not include certain CBI information which is proprietary in nature, and lacks information on the identity, properties, frequency of use, and magnitude of exposure for approximately 11% of hydraulic fracturing chemicals used in HF operations (which are considered CBI; see EPA draft Assessment Report, p. 5-73). The agency should acknowledge that there is limited information on what is being injected, and should describe these concerns regarding its reliance on FracFocus version 1.0 data within the draft Assessment Report. Within the draft Assessment Report, the agency should also characterize data on proprietary compounds that the EPA may have, and information provided in FracFocus on chemical class and concentration (% mass of hydraulic fracturing fluid).

3.7.6. Additional Information, Background or Context to be Added

e1. What additional information, background, or context should be added, or research gaps should be assessed, to better characterize chemical and toxicological information in this assessment?

As discussed in the SAB’s response to Question 7a, very little attention is paid to the initial problem formulation stage of risk assessment, as recommended by NAS (2008). The EPA should carry forward to this chapter discussion of the most likely pathways for potential impacts to drinking water resources based on consideration of case studies, retrospective studies, and/or scenarios for private well and downstream surface water municipal water treatment plants that were discussed in previous chapters. In doing so, the EPA should clearly distinguish between HFWC event versus health impact in Chapter 9.

For example, a temporary HFWC event could result in shorter term or longer term impact, and an event limited in geographical scale could have long-term health impact depending on local conditions and severity of impact.

When discussing the most likely scenarios for spills or leaks through the HFWC, it would be useful to provide background and context on best practices and existing federal and state regulations that govern spills and leaks that could be employed to further mitigate potential for exposure. The SAB agrees that resumption of local case studies or initiation of the originally planned studies described in the research Study Plan (U.S. EPA, 2011) could provide better understanding of exposure to constituents based on actual scenarios, provided that adequate baseline data exist. Such data could also be used to "validate" the MCDA approach by comparing the MCDA results using actual exposure data with results based on use of the physicochemical properties in the MCDA equations (i.e., occurrence and K_{ow}).

Additional field studies should be given a high priority, in order to develop a much more comprehensive chemical exposure database. It is acknowledged in several places in the document that chemical hazard evaluation should be most useful to conduct on a regional or site-specific basis. It is essential to have more extensive and reliable information on the intensity and duration of human exposures to determine whether hydraulic fracturing activities in different locales pose health risks. Therefore it is important to bring forward and synthesize the key information from case studies, retrospective studies, and/or scenarios for private well and downstream surface water municipal water treatment plants that were discussed in previous chapters. The recommendations in this paragraph may be considered longer term future activity.

As discussed in the SAB's response to Charge Questions 7a and 7c, the EPA should use the full body of toxicological information, consistent with the agency's usual approach for hazard evaluation. A criterion for acceptable toxicology data should be scientific and regulatory guideline quality, rather than funding source and formal assessments of chronic RfDs. The EPA should include all state and federal government hazard assessments, as well as peer-reviewed hazard assessments (especially those following the EPA's approach for peer review), and MCLs or MCLGs in its analysis. Shorter term and chronic toxicology studies that meet OECD and GLP guidelines (e.g., OECD screening information data set) are relevant hazard data that should be included even if a formal chronic RfD has not been established. The EPA should reference and utilize the OECD (2014) initial survey and spreadsheets that identify chemicals used in hydraulic fracturing with potential hazard data based on EU REACH, EU Classification and Labeling inventory, and publications. Similarly, the EPA should utilize ACToR to search for relevant oral short-term and chronic studies. Potential hazards that were highlighted in previous chapters and are of public concern should also be added to Chapter 9 (e.g., flammability of methane gas in Chapter 6, and potential disinfection by-products [DBPs] in drinking water treatment plants in Chapter 8).

There is a gap in knowledge of chemicals that are designated as confidential business information (CBI). The chemical and toxicological information for CBI chemicals used in hydraulic fracturing activities should be better characterized using data that the EPA may have and/or information provided in FracFocus regarding chemical class and concentration (% mass of the hydraulic fracturing fluid). The EPA should indicate in Chapter 9 that 11% of all ingredients reported in FracFocus were CBI (page 5-73 line 28). The EPA can provide aggregate information on potential hazards posed by CBI chemicals without publically disclosing specific information. The EPA can characterize the toxicological and MCDA results in a manner similar to the approach used for known chemicals. This would enable an assessment of the potential for significant impact (or not) from CBI chemicals relative to known chemicals. The EPA should also recognize the concerns regarding its reliance on an early version of FracFocus data.

The EPA should distinguish between chemicals injected into a hydraulic fracturing well vs. constituents, chemicals and hydrocarbons that come back out of the well in produced fluids. The SAB suggests that if no chemicals are added to a hydraulic fracturing well, there is still a potential for impacts to drinking water resources from constituents and compounds present naturally in the subsurface which could also be present in produced water. In Chapter 9 and throughout the draft Assessment Report, chemical constituents and potential impacts unique to hydraulic fracturing oil and gas extraction should be clearly distinguished from those that also exist as a component of conventional oil and gas development. This is not to say that the ones that overlap both production methods should not be included, but rather that the ones that may cause unique potential impacts from the specific methods of hydraulic fracturing production should be highlighted. For example, it is not clear from this chapter of the draft Assessment Report to what extent hydraulic fracturing produced water—through its chemical constituents—poses significant, unique potential impacts to drinking water resources (other than over the first few days when flowback water contains hydraulic fracturing fluid constituents). As such, the agency should clarify whether compounds identified as being of most concern in produced water are products of the hydraulic fracturing activity, flowback, or late-stage produced water, or are chemicals of concern derived from oil and gas production activities that are not unique to hydraulic fracturing activity. These efforts may require the development of analytical methods. This will help inform the public about the different characteristics of HF injection flowback and produced waters and in-situ subsurface brines relative to formation water produced in conventional oil and gas development.

To help prioritize future research and risk assessment efforts, the agency should identify the most likely exposure scenarios and hazards and obtain toxicity information relevant to the exposure scenarios. The EPA provides a wide range of possible scenarios along the HFWC, but more emphasis is need on identifying the most likely durations and routes of exposures of concern so that EPA can determine what toxicity information is most relevant and focus research and monitoring efforts on the most important and/or likely scenarios. The SAB agrees that this should be based on consideration of findings in prospective and retrospective site investigations, as well as case studies of public and private wells and surface water supplies impacted by spills or discharges of flowback, produced water or treated or partially treated wastewater.

e2. Are there relevant literature or data sources that should be added in this section of the report?

As stated in the SAB's response to Charge Question 7a, the SAB supports use of the sources of toxicological information that the EPA included. However, several additional sources were excluded or not mentioned by the EPA and should be included; these are listed below. Many of these sources of relevant *in vivo* toxicology data were mentioned in the SAB's response to previous the EPA Charge Questions 7a–d and are listed below. In addition, while the draft Assessment Report briefly described the ACToR database in Chapter 9, the agency should fully utilize the *in vivo* toxicology and physicochemical data available through ACToR, including acute, short-term, and chronic toxicity data, data on corrosivity, and experimental physicochemical data. The physicochemical data (e.g., K_{ow}) are not only useful for predicting toxicant fate and transport in drinking water resources, but also can contribute toward evaluating the ability of a compound to cross cell membranes, which is relevant for predicting toxicity.

When no *in vivo* data are available, the EPA is encouraged to consider emerging high-throughput screening approaches that also incorporate estimates of external doses (Wambaugh et al. 2013; Wetmore et al. 2015). This approach is an advancement in the use of high-throughput screening data to prioritize the use of oil spill dispersants (Judson et al. 2010). Despite limitations of the Judson et al. (2010) approach, this paper illustrates a use of emerging approaches to address risk management needs when in-vivo toxicology data are not available. The EPA should, as a longer-term future activity, review the *in vivo* data sets and computational results available through ACToR and specifically state which compounds have relevant *in vivo* data that can be used for risk assessment purposes despite not achieving the EPA's strict inclusion criteria used in the draft Assessment Report. The SAB recommends that the EPA also specify where emerging high-throughput test data are available within the ToxRef database as a result of the EPA's computational toxicology research efforts.

Further, application of the threshold of Toxicological Concern may be appropriate when evaluating the potential impact of highly diluted chemicals (e.g. in flowback or produced water).

<u>List of sources of *in vivo* toxicological information:</u>

State RfV values: the EPA collected all publicly available RfVs and/or OSFs from different states, including Texas, but they only included the California EPA values because they were peer-reviewed according to the EPA's definition (Appendix G). The EPA should use all state values, especially because the EPA encourages risk assessments at the local level. The EPA can choose to give lower priority to state values that are not peer reviewed in their tiered hierarchical priority scheme, but should not exclude these values as toxicological information.

ACToR: the EPA discussed ACToR but did not include available *in vivo* toxicology data if they did not meet the EPA's narrow definition of acceptable toxicological information. Thus, toxicology studies reviewed by the EPA that are used to compare with high-throughput in silico data were not included. The EPA should use the experimental physicochemical and *in vivo* toxicology database available through ACToR. In addition, ACToR provides links to other databases, including tools for using structure activity to predict toxicity.

National Library of Medicine (NLM).The National Library of Medicine (NLM) has a comprehensive website, the Toxicology and Environmental Health Information Program: (TEHIP;

https://www.nlm.nih.gov/pubs/factsheets/tehipfs.html). This website provides "one-stop shopping" for toxicant information that is available free to the public. It provides resources from the NLM and from other agencies/organizations. Included in this is the NLM's TOXNET database, which has integrated all of the free toxicology and environmental health databases available (see Appendix 1 for list). The SAB strongly encourages the EPA to discuss what toxicity information is useful from this database. European Chemicals Agency Registration, Evaluation Authorization Restriction of Chemicals (REACH) Information on Chemicals. http://echa.europa.eu/information-on-chemicals. Includes physicochemical and toxicological data for chemicals registered under REACH. As of September 2015 it provided data for 13441 unique substances and contains information from 51920 Dossiers.

U.S. FDA Generally Recognized as Safe (GRAS) http://www.fda.gov/Food/IngredientsPackagingLabeling/GRAS. List of chemicals found in food that are considered by FDA as generally recognized as safe (GRAS) either through scientific procedures or, for a substance used in food before 1958, through experience based on common use in food.

American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values (TLV's). http://www.acgih.org/tlv-bei-guidelines/policies-procedures-presentations/overview. The EPA excluded these assessments because they are specific to workers and not generalizable to the general public and because it is not a governmental or intergovernmental body. Rather than ignore these values completely, the EPA should consider these assessments as valuable sources of peer reviewed toxicological values that can be adapted for drinking water risk assessment needs when other RfVs are unavailable.

Organisation for Economic Co-operation and Development (OECD). 2014. Provision of knowledge and information - chemicals used in hydraulic fracturing. *52nd Joint Meeting of the Chemicals Committee and the Working Part on Chemicals, Pesticides and Biotechnology*. ENV/JM(2014)25. For presentation at November 4-6, 2014 Meeting, Paris, France. September 19, 2014. The report provides data to support their conclusion that a large majority of substances used in hydraulic fracturing are likely to have data available that would allow basic hazard assessment. This report includes "factsheets" for each responding country including the U.S., one spreadsheet that identifies chemicals and elucidates hazard data availability and a second that contains (limited) information on commercial products in which chemicals were found, concentrations of chemicals in commercial products, typical concentrations of chemicals and product in hydraulic fracturing fluids.

Toxicology Excellence for Risk Assessment International Toxicity Estimates for Risk Assessment http://www.tera.org/iter/. *ITER* (International Toxicity Estimates of Risk) is a free Internet database of human health risk values for over 680 chemicals of environmental concern from several government organizations worldwide (e.g. ATSDR, Health Canada, U.S. The EPA, RIVM.)

Toxicology Excellence for Risk Assessment Voluntary Children's Chemical Evaluation Program Peer Consultations. http://www.tera.org/Peer/VCCEP/index.html. The VCCEP pilot program uses a tiered testing approach to assessing need of data for risk assessment purposes. For toxicity data, specific types of studies have been assigned to one of three tiers. For exposure data, the depth of exposure information increases with each tier. These data and the proposes risk assessments are reviewed based on procedures in accordance with the U.S. Office of Management and Budget, the National Academy of Sciences, and the U.S. The EPA.

European Chemicals Agency Grouping of substances and read-across http://echa.europa.eu/support/grouping-of-substances-and-read-across. Provides general guidance and examples of how to group substances based on the read-across approach.

European Centre for Ecotoxicology and Toxicology of Chemicals (2012). Category approaches, Read-across, (Q)SAR. Technical Report 116). Provides state-of-the art practical read-across strategies in applying non-testing approaches for regulatory purposes.

Additional relevant literature:

The SAB recommends that the EPA consider the following additional literature sources within this chapter of the draft Assessment Report:

Elliot, Elise G., A.S. Ettinger, B.P. Leaderer, M.B. Bracken, and N.C. Deziel. A systematic evaluation of chemicals in hydraulic-fracturing fluids and wastewater for reproductive and developmental toxicity. 2016. *Jrnl. of Exp. Sci. and Env. Epi.* Advance online publication, 6 January 2016; doi:10.1038/jes.2015.81." Note: this reference has been added for the EPA's consideration since it shows the use of chemical/physical factors in reviewing HF chemicals.

Judson RS, Martin MT, Reif DM, Houck KA, Knudsen TB, Rotroff DM, Xia M, Sakamuru S, Huang R, Shinn P, Austin CP, Kavlock RJ and Dix DJ. 2010. Analysis of eight oil spill dispersants using rapid, in vitro tests for endocrine and other biological activity. *Environ Sci Technol.* 44, p. 5979-5985.

National Academies Press. 2008. Science and Decisions: Advancing Risk Assessment. ISBN:0-309-12047-0; http://www.nap.edu/catalog/12209.html.

Organisation for Economic Co-operation and Development (OECD). 2014. Provision of knowledge and information - chemicals used in hydraulic fracturing. *52nd Joint Meeting of the Chemicals Committee and the Working Part on Chemicals, Pesticides and Biotechnology*. ENV/JM(2014)25. For presentation at November 4-6, 2014 Meeting, Paris, France. September 19, 2014.

Wambaugh, J.F., R.W. Setzer, D.M. Reif, S. Gangwal, J. Mitchell-Blackwood, J.A. Arnot, O. Joliet, A. Frame, J. Rabinowitz, T.B. Knudsen, R.S. Judson, P. Egeghy, D. Vallero, and E.A. Cohen Hubal. 2013. High-throughput models for exposure-based chemical prioritization in the ExpoCast Project. *Environ Sci Technol* 47(15), p. 8479-8488. August 6, 2013. doi: 10.1021/es400482g.

Wetmore, B.A., J.F. Wambaugh, B. Allen, S.S. Ferguson, M.A. Sochaski, R.W. Setzer, K.A. Houck, C.L. Strope, K. Cantwell, R.S. Judson, E. LeCluyse, H. Clewell, R.S. Thomas, and M.E. Andersen. 2015. Incorporating high-throughput exposure predictions with dosimetry adjusted in vitro bioactivity to inform chemical toxicity testing. *Toxicol Sci.* 148(1), p. 121-36. November 2015. doi: 10.1093/toxsci/kfv171.

APPENDIX 1 The National Library of Medicine (NLM) Toxicology and Environmental Health Information Program (TEHIP) Fact Sheet. https://www.nlm.nih.gov/pubs/factsheets/tehipfs.html

TEHIP maintains a comprehensive web site that provides access to resources produced by it and by other government agencies and organizations. This web site includes links to databases, bibliographies, tutorials, and other scientific and consumer-oriented resources. TEHIP also is responsible for the Toxicology Data Network (TOXNET®), an integrated system of toxicology and environmental health databases that are available free of charge on the web. TOXNET includes:

- HSDB® (Hazardous Substances Data Bank) provides data for over 5,000 hazardous chemicals. HSDB has information on human exposure, industrial hygiene, emergency handling procedures, environmental fate, regulatory requirements, nanomaterials, and related areas. The information in HSDB has been assessed by a Scientific Review Panel.
- TOXLINE® has references to the biomedical literature on biochemical, pharmacological, physiological, and toxicological effects of drugs and other chemicals. It contains over 4 million citations, almost all with abstracts and/or index terms and CAS Registry Numbers.

- ChemIDplus® provides access to the structure and nomenclature authority files used for the identification of chemical substances cited in NLM databases. The database contains more than 400,000 chemical records, of which over 300,000 include chemical structures.

- IRIS (Integrated Risk Information System) contains data in support of human health risk assessment, including hazard identification and dose-response assessments. It is compiled by the Environmental Protection Agency (EPA) and contains descriptive and quantitative information related to human cancer and non-cancer health effects that may result from exposure to substances in the environment. IRIS data is reviewed by the EPA scientists and represents the EPA consensus.

- ITER contains data in support of human health risk assessments. It is compiled by Toxicology Excellence for Risk Assessment (TERA) and contains data from CDC/ATSDR, Health Canada, RIVM, U.S. The EPA, IARC, NSF International and independent parties offering peer-reviewed risk values. ITER provides comparison charts of international risk assessment information and explains differences in risk values derived by different organizations.

- TRI (Toxics Release Inventory) is a set of publicly available databases containing information on releases of specific toxic chemicals and their management as waste, as reported annually by U.S. industrial and federal facilities to the EPA. There is information on over 650 chemicals and chemical categories. Pollution prevention data is also reported by each facility for each chemical.

- CCRIS (Chemical Carcinogenesis Research Information System) is a factual data bank developed by the National Cancer Institute. It contains evaluated data and information, derived from both short and long-term bioassays on over 9,000 chemicals. Studies relate to carcinogens, mutagens, tumor promoters, carcinogens, metabolites and inhibitors of carcinogens.

- GENE-TOX provides genetic toxicology (mutagenicity) test data from expert peer review of open scientific literature for more than 3,000 chemicals from the EPA.

- DART® (Developmental and Reproductive Toxicology) provides biomedical journals references covering teratology and other aspects of developmental and reproductive toxicology.

- LactMed (Drugs and Lactation Database) is a database of drugs and other chemicals to which breastfeeding mothers may be exposed. It includes information on the levels of such substances in breast milk and infant blood, and the possible adverse effects in the nursing infant.

- CPDB (Carcinogenic Potency Database) reports analyses of animal cancer tests used in support of cancer risk assessments for human. It was developed by the Carcinogenic Potency Project at the University of California, Berkeley and the Lawrence Berkeley National Laboratory. It includes 6,540 chronic, long-term animal cancer tests.

- CTD (Comparative Toxicogenomics Database) contains manually curated data describing cross-species chemical-gene/protein interactions and chemical- and gene-disease relationships. CTD was developed at North Carolina State University (NCSU).

In addition to TOXNET, other toxicology and environmental health-related web resources available from TEHIP include:

- ALTBIB® provides access to PubMed®/MEDLINE® citations relevant to alternatives to the use of live vertebrates in biomedical research and testing. Many citations provide access to free full text.

- Dietary Supplement Label Database (DSLD) is a joint project of the National Institutes of Health (NIH) Office of Dietary Supplements (ODS) and the National Library of Medicine (NLM). The DSLD contains the full label contents from a sample of dietary supplement products marketed in the U.S.

- Drug Information Portal is a gateway to selected drug information from the U.S. National Library of Medicine and other key U.S. government agencies. It includes information on more than 48,000 drugs from the time they are entered into clinical trials (Clinicaltrials.gov) through their entry in the U.S. market place.

- Haz-Map® is an occupational health database designed for health and safety professionals and for consumers seeking information about the adverse effects of workplace exposures to chemical and biological agents. The main links in Haz-Map are between chemicals and occupational diseases. These links have been established using current scientific evidence.

- Household Products Database links over 13,000 consumer brands to health effects from Material Safety Data Sheets (MSDS) provided by manufacturers and allows scientists and consumers to research products based on chemical ingredients.

- LiverTox provides up-to-date, comprehensive and unbiased information about drug induced liver injury caused by prescription and nonprescription drugs, herbals and dietary supplements. It is a joint effort of the Liver Disease Research Branch of the National Institute of Diabetes and Digestive and Kidney Diseases (NIDDK) and the Division of Specialized Information Services of the National Library of Medicine (NLM).

- TOXMAP® is a web site from the National Library of Medicine (NLM) that uses maps of the United States to show the amount and location of toxic chemicals released into the environment. Data is derived from the EPA's Toxics Release Inventory (TRI), which provides information on the releases of toxic chemicals into the environment as reported annually by industrial facilities around the United States.

- ToxMystery is an interactive learning site helping children age 7 to 10 find clues about toxic substances that can lurk in the home. ToxMystery provides a fun, game-like experience, while teaching important lessons about potential environmental health hazards. ToxMystery is available in English and Spanish.

- Tox Town is an interactive guide to the connections between commonly encountered toxic substances, the environment, and the public's health. Tox Town is available in English and Spanish.

TEHIP is part of the Division of Specialized Information Services (SIS) which produces information resources covering toxicology, environmental health, outreach to underserved and special populations, HIV/AIDS, drugs and household products, and disaster/emergency preparedness and response.

3.8. Synthesis of Science on Potential Impacts of Hydraulic Fracturing on Drinking Water Resources, and Executive Summary

Question 8: The Executive Summary and Chapter 10 provide a synthesis of the information in this assessment. In particular, the Executive Summary was written for a broad audience.

a. *Are the Executive Summary and Chapter 10 clearly written and logically organized?*
b. *Does the Executive Summary clearly, concisely, and accurately describe the major findings of the assessment for a broad audience, consistent with the body of the report?*
c. *In Chapter 10, have interrelationships and major findings for the major stages of the HFWC been adequately explored and identified? Are there other major findings that have not been brought forward?*
d. *Are there sections in Chapter 10 that should be expanded? Or additional information added?*

Chapter 10 provides a synthesis of the information in the draft hydraulic fracturing Assessment Report. The chapter describes the major findings for each of the five HFWC stages: (1) water acquisition for hydraulic fracturing fluids; (2) chemical mixing to form fracturing fluids; (3) well injection of fracturing fluids; (4) flowback and produced water; and (5) wastewater treatment and disposal. It presents a discussion on key data limitations and uncertainties, including limitations in monitoring data and chemical information. It also presents conclusions and uses for the draft Assessment Report. The Executive Summary provides a similar synthesis of the information as provided in Chapter 10, and also includes a discussion of the scope and approach of the draft Assessment Report and a description of the proximity of current hydraulic fracturing activity and drinking water resources.

3.8.1. Organization of Executive Summary and Chapter 10

a. Are the Executive Summary and Chapter 10 [Synthesis] clearly written and logically organized?

The organization of the Executive Summary is logical, mirroring the draft Assessment Report's overall structure that is framed around the stages of the HFWC. As currently written, the Executive Summary is understandable to technical experts in geoscience and engineering, but will be less clear to a general audience. This broader audience comprises a substantial portion of the Executive Summary's readership and will include policy makers, regulators, the media, and general public. The SAB therefore recommends that the EPA should significantly modify the form and content of the Executive Summary and Chapter 10 Synthesis of the draft Assessment Report to make these discussions more understandable to the general public and more suitable for a broad audience.

The SAB recommends that the EPA employ several strategies to facilitate the readership's understanding of the Executive Summary and Chapter 10 Synthesis of the draft Assessment Report. The EPA should provide clearer statements on the goals and scope of the assessment and on specific descriptions of hydraulic fracturing activities, and additional diagrams and illustrations should be provided to enhance the public's understanding of hydraulic fracturing activities and operations. Technical terms should be clearly defined. Examples of these terms include, but are not limited to, "chronic oral reference value," "slope factor," and "well pad," "conductivity," and "integrity failure." Measurements should, whenever possible, be placed in context to allow the reader to gain perspective. For example, the text notes that approximately 4 million gallons is an average volume of water used in during hydraulic fracturing of a horizontal well. The text should note how this volume compares to water consumed for other uses. As a second example, the draft Assessment Report describes wastewater with radium activities exceeding tens of thousands of picocuries per liter. The draft Assessment Report should describe whether this is a dangerous level of radioactivity, and how these levels compare with levels from activities of other common radioactive sources.

Another way to facilitate understanding of the Executive Summary and Chapter 10 for a general audience is to employ more figures, graphs, and text boxes. The EPA should include additional figures to clarify key concepts. Since many readers will struggle to visualize a constructed gas well, the heterogeneous nature of rocks and sediments that comprise drinking water aquifers and confining units, and pathways by which surface spills may contaminate groundwater, soil water, and surface water, diagrams and photographs would help in this regard. A map of the major U.S. shale plays should also be considered for inclusion so that readers can visualize the geographic distribution of unconventional oil-and-gas plays addressed in the Executive Summary.

The Executive Summary should cover the history of the EPA ORD effort surrounding the assessment of hydraulic-fracturing impacts on drinking water. In particular, the Executive Summary should describe the Research Scoping Plan, the development of the EPA's research Study Plan (U.S. EPA, 2011), and the EPA's 2012 Progress Report (U.S. EPA, 2012). The peer review by the Science Advisory Board, as well as efforts that the EPA undertook to engage stakeholders should also be summarized.

Prospective case studies, whereby drinking water resources at specific field sites were to be assessed before and after hydraulic-fracturing activities, were part of the EPA's research Study Plan. These prospective studies were not conducted, although the draft Assessment Report acknowledges the lack of before-and-after studies as a serious limitation in the assessment of hydraulic fracturing effects on drinking water. Since the EPA's exclusion of these studies could potentially be construed as a lack of due diligence on the part of the EPA without further explanation, the EPA should include in the Executive Summary its rationale for excluding the prospective case studies. Further the agency should highlight those studies that have occurred by other organizations that have conducted work associated with a "prospective" view.

The Executive Summary focuses on national- and regional-level generalizations of the potential effects of hydraulic fracturing-related activities on drinking water resources. Although these generalizations are often desirable and useful, the EPA should make these conclusions cautiously, and clearly qualify these conclusions through acknowledgement of the substantial heterogeneity existing in both natural and engineered systems. Furthermore, the EPA should provide more emphasis in the Executive Summary on the importance of local hydraulic fracturing impacts. These local-level hydraulic fracturing impacts may occur infrequently, but they can be severe and the Executive Summary should more clearly describe such impacts. Data sources that suggest the possibility that hydraulic fracturing-related activities may have contaminated surface or groundwater at the local to sub-regional scale are provided in section d below.

The SAB finds that Chapter 10 – the Report Synthesis – is nearly identical to the Executive Summary. The SAB concludes that this chapter should be rewritten. The EPA should revise the Synthesis to integrate information and findings from the various chapters of the draft Assessment Report. Conclusions that are presented in the Synthesis should be more than results (e.g., measurements, observations, model calculations); they should describe what is learned from the analyses, results and findings across the chapters and describe what these imply when considered together. In the present version of the Synthesis, the Conclusions (Section 10.3) are presented on a single page, which is far too cursory given the expansiveness of the draft Assessment Report's coverage. Moreover, the conclusions are not illuminating: they reflect little new or original information and reveal only an incremental advance in the knowledge of hydraulic fracturing impacts. The draft Assessment Report contains a great deal of valuable information, yet the Synthesis does not carry forth that information, fully describe and assess what the EPA learned from the assessment, nor describe the implications of results that have been identified.

The SAB suggests that the EPA reorganize the Synthesis by prioritizing the major findings that have been identified within Chapters 4-9 of the draft Assessment Report (as opposed to mimicking the overall organization of these chapters). The EPA could prioritize these findings according to expectations regarding the magnitude of the potential impacts of hydraulic fracturing-related activities on drinking water resources. This structure could, in turn, facilitate consideration and explication of particular practices that have mitigated, or could mitigate, the frequency and severity of water-resource impairments that may be linked to the hydraulic fracturing-related activities.

3.8.2. Major Findings and Interrelationships of Major Hydraulic Fracturing Stages

b. Does the Executive Summary clearly, concisely, and accurately describe the major findings of the assessment for a broad audience, consistent with the body of the report?

The Executive Summary does not clearly, concisely, and accurately describe the major findings of the assessment for a broad audience. Some of the major findings are presented ambiguously within the Executive Summary and appear inconsistent with the observations and data presented in the body of the draft Assessment Report. The statements of findings in the Executive Summary should be made more precise. These statements should also be linked clearly to evidence provided in the body of the draft Assessment Report and scrutinized to avoid any drift in tone or in the way impacts are described or implied.

The SAB has concerns regarding the clarity and adequacy of support for several major findings presented within the draft Assessment Report that seek to draw national-level conclusions regarding the impacts of hydraulic fracturing on drinking water resources. The SAB is concerned that these major findings do not clearly, concisely, and accurately describe the findings developed in the chapters of the draft Assessment Report, and that the EPA has not adequately supported these major findings with data or analysis from within the body of the draft Assessment Report. The SAB is concerned that these major findings are presented ambiguously within the Executive Summary and appear inconsistent with the observations, data, and levels of uncertainty presented and discussed in the body of the draft Assessment Report. Most SAB Panel members expressed particular concern regarding the draft Assessment Report's high-level conclusion statement on page ES-6 that "We did not find evidence that these mechanisms have led to widespread, systemic impacts on drinking water resources in the United States." Most members of the SAB find that this statement does not clearly describe the system(s) of interest (e.g., groundwater, surface water) nor the definitions of "systemic" and "widespread"." Most Panel members agree that the statement has been interpreted by members of the public in many different ways, and conclude that the statement requires clarification and additional explanation. A Panel member finds that this statement is acceptable as written and that the EPA should have provided a more robust discussion on how the EPA reached this conclusion (e.g., through a comparison of the number of wells drilled vs. reported spills, or analysis on reported potable wells shown to be impacted by HFWC). Most members of the SAB agree that specific concerns regarding these data limitations include the generally voluntary nature of reported incidents of spilled liquids and releases associated with hydraulic fracturing, the lack of systematic study of hydraulic fracturing-related impacts that have occurred, the limited ability to review significant amounts of hydraulic fracturing data due to litigation and confidential business information issues, and the lack of knowledge about or monitoring methods for many chemicals and compounds in hydraulic fracturing fluids. Most Panel members agree that the statement requires clarification and additional explanation.

The above statement is presented also in Chapter 10 in somewhat different form on pages 10-19 and 10-20, where it is noted that a major finding of the assessment is a *"lack of evidence that hydraulic fracturing processes have led to widespread, systemic impacts on drinking water resources in the U.S. The number of identified cases appears to be small compared to the number of hydraulically fractured wells."* While the draft Assessment Report points out that there are insufficient data, a paucity of long-term systemic studies, and other mitigating factors, most Panel members agree that the EPA has not gone far enough to emphasize how preliminary these key conclusions are and how limited the factual bases are for these judgments. A Panel member finds that the statement on page ES-6 is acceptable as written and that the EPA should have provided a more robust discussion on how the EPA reached this conclusion (e.g., through a comparison of the number of wells drilled vs. reported spills, or analysis on reported potable wells shown to be impacted by HFWC).

The SAB notes that the EPA's estimates on the frequency of on-site spills were based upon information from two states. While the SAB recognizes that the states of Pennsylvania and Colorado likely have the most complete datasets on this topic that the EPA could access, the SAB notes that geologies vary between states and encourages the agency to contact the state agencies and review state databases and update the draft Assessment Report to reflect a broader analysis. While the SAB recognizes that state database systems vary, the databases should be incorporated into the EPA's reporting of metrics within the draft Assessment Report. As written, the SAB finds that the draft Assessment Report's analysis of spill data cannot confidently be extrapolated across the entire U.S. The SAB recommends that the agency revisit a broader grouping of states and "refresh" the draft Assessment Report with updated information on the reporting of spills associated with HFWC activities.

In addition, the SAB finds that available data on the presence/identity of chemicals in flowback and produced water appears to be very limited. For example, only three references are cited for all of the chemicals listed in Table A-4 of the draft Assessment Report. Since information could not be located on measured concentrations for many hydraulic fracturing chemicals, it is not possible to estimate human exposures or begin to assess the potential risks to health associated with exposures to these chemicals. The EPA should have some information, at least in terms of orders of magnitude, on how exposures to certain hydraulic fracturing chemicals compare to adverse effect doses for these chemicals (e.g., for a few of the most potent chemicals) in order to make this major finding. The statement is ambiguous and requires clarification and additional explanation.

Other examples of insufficient precision or elaboration on major findings within the Executive Summary include:

- Page ES-6, lines 20-21: "*The number of identified cases, however, was small compared to the number of hydraulically fractured wells*." The descriptor "small" is vague and subjective. The agency should quantify this statement based on the available data, and acknowledge the uncertainty in the estimates.

- Page ES-9, lines 19-20: "*High fracturing water use or consumption alone does not necessarily result in impacts to drinking water resources.*" This statement infers that to have an impact, hydraulic fracturing activity must be the sole water use or source of consumption. The agency should revise this statement and discussion surrounding this statement to reflect situations where hydraulic fracturing may have contributed to impacts that have occurred, and to refer to cases described in Chapter 4 of the draft Assessment Report that describe situations where hydraulic fracturing may have influenced streams that ran dry or experienced very low flows and drinking water wells that ran out of water or experienced significant declines in water level.

- Page ES-13, lines 22-23: "None of the spills of hydraulic fracturing fluid were reported to have reached groundwater." This statement is not supported by the information and data presented in the assessment, due to the EPA's incomplete assessment of spilled liquids and consequences. The SAB is concerned that this major finding is supported only by an absence of evidence rather than by evidence of absence of impact.

- Page ES-15, lines 34-35: "*According to the data examined, the overall frequency of occurrence [of hydraulically fractured geologic units that also serve as a drinking water sources] appears to be low.*" The agency should clarify this ambiguous statement, including the use of the word "low," and provide evidence within the assessment for this statement.

- Page ES-19, lines 18-19: "*Chronic releases can and do occur from produced water stored in unlined pits or impoundments, and can have long-term impacts*." The agency should discuss the frequency of this occurrence, provide details on in what states reported releases occur most frequently (which presumably depends on reporting requirements), describe whether the frequency has decreased over time, and discuss the impacts that may occur.

The SAB is concerned that these major findings do not clearly, concisely, and accurately describe the major findings of the assessment for a broad audience, and that the EPA has not supported these six major findings with data or analysis from within the body of the draft Assessment Report. The SAB is also concerned that these major findings are presented ambiguously within the Executive Summary and appear inconsistent with the observations and data presented in the body of the draft Assessment Report. The SAB recommends that the EPA revise these statements of findings in the Executive Summary and elsewhere in the draft Assessment Report to be more precise, and to clearly link these statements to evidence provided in the body of the draft Assessment Report. The SAB also recommends that the EPA discuss the significant data limitations and uncertainties associated with these major findings, as documented in the body of the draft Assessment Report, when presenting the major findings.

c1. In Chapter 10 [Synthesis], have the interrelationships and major findings for the major stages of the HFWC been adequately explored and identified.

Chapter 10 devotes little attention to the interrelationships among the major stages of the HFWC. Its presentation of major findings is incomplete, owing to insufficient analyses and omission of information that should have been taken into account within the draft Assessment Report.

The draft Assessment Report compartmentalizes the major stages of the HFWC into separate chapters. This compartmentalization is preserved in the Synthesis. As a result, implications that stem from integration of the major findings and potential issues that cut across chapters of the draft Assessment Report go largely unexplored.

The Synthesis does not culminate with any sort of integrated assessment of the relative contributions of hydraulic fracturing-related activities to the drinking water resource impairment or depletion. Such an integrated assessment would be useful and thus the EPA should consider rewriting Chapter 10 to describe the integrated assessment of these activities. The agency should strengthen the Executive Summary and Chapter 10 Synthesis by linking the stated findings more directly to evidence presented in the body of the draft Assessment Report. The SAB recognizes there may be difficulties in conducting such an integrated assessment given the limitations in the availability of monitoring and other types of environmental data as described repeatedly throughout the draft Assessment Report.

SAB's response above to sub-question b for Charge Question 8 regarding the Executive Summary describes SAB's concerns and recommendations regarding the presentation of major findings within Chapter 10 (since the presentation of major findings within Chapter 10 replicates the presentation of major findings within the Executive Summary). As described in that response, some of the major findings are presented ambiguously within the Executive Summary and appear inconsistent with the observations and data presented in the body of the draft Assessment Report. The statements of findings in the Executive Summary should be made more precise. These statements also should be linked clearly to evidence provided in the body of the draft Assessment Report and scrutinized to avoid any drift in tone or in the way impacts are described or implied. Additional specific concerns and recommendations on this topic are provided in SAB's response above to sub-question b for this charge question.

c.2 Are there other major findings that have not been brought forward?

The Synthesis (and the draft Assessment Report, more generally) fails to bring forward important findings on the relationships between the HFWC and reported impacts to public and private wells and surface water supplies, including private wells in Dimock, Pennsylvania; Pavillion, Wyoming; and Parker County, Texas. Although the role of hydraulic fracturing-related activities in water-well contamination within these localities continues to be debated, these sites have a high profile and many members of the public including other stakeholders view them as being of high potential relevance to hydraulic fracturing-related impacts to drinking water resources.

While the EPA appropriately aimed to develop national-level analyses and perspective, most stresses to surface or groundwater resources associated with stages of the HFWC are localized. For example, the impacts of water acquisition will predominantly be felt locally at small space and time scales. These local-level hydraulic fracturing impacts, when they occur, can be severe, and the draft Assessment Report needs to recognize better the importance of local impacts. In this context, the SAB recommends that the EPA should include and fully explain the status, data on potential releases, and findings if available for the EPA and state investigations conducted in Dimock, Pennsylvania; Pavillion, Wyoming; and Parker County, Texas where hydraulic fracturing activities are perceived by many members of the public to have caused impacts to drinking water resources. Examination of these high-visibility, well-known cases is important so the public can more fully understand the status of investigations in these areas, conclusions associated with the investigations, lessons learned if any for the different stages of the hydraulic fracturing water cycle, what additional work should be done to improve the understanding of these sites and the HFWC, plans for remediation if any, and the degree to which information from these case studies can be extrapolated to other locations.

3.8.3. Additional Information, Background or Context to be Added

8d. Are there sections in Chapter 10 [Synthesis] that should be expanded? Or additional information added?

The Synthesis should be revised and expanded. As currently written, the Synthesis is a replication of findings presented in the previous chapters. The Synthesis should be revised to be more integrative according to SAB's response above to sub-questions a and c for Charge Question 8. Moreover, the Synthesis should be expanded to present recommendations drawn from a holistic consideration of the findings presented in Chapters 4-9 of the draft Assessment Report. These recommendations could include discussion of current practices identified in the study that have been demonstrated to lower the frequency of accidents (e.g., spills) and other problems (e.g., well-integrity failure) or improvements to existing hydraulic fracturing practices.

While the Synthesis identifies several limitations and uncertainties that hinder evaluation of the potential effects of hydraulic fracturing-related activities on drinking water resources, the Synthesis should describe recommended next steps (e.g., where we go from here). Chapter 10 should leverage the draft Assessment Report's review of relevant literature and synthesis of knowledge gaps to identify data and research needs and steps that could reduce the uncertainties associated with the potential effects of hydraulic fracturing-related activities on drinking water resources. This research agenda should be appropriately selective, perhaps consisting of one or two priority research areas associated with each stage of the HFWC, as well as critical research foci that cut across these stages.

The draft Assessment Report should also identify future research and assessment needs and future field studies. The SAB has identified a number of data and research needs in this report. Research needs identified by other organizations who have studied potential impacts of unconventional oil and gas development, e.g., the Health Effects Institute (HEI, 2015), should be examined in assembling the EPA list of research needs. The SAB agrees that this discussion should include the EPA's plans for conducting prospective studies and other research that the EPA had planned to conduct but did not conduct. One Panel member concluded that this prospective study work is not needed and should not be conducted. The recommendations for prospective and additional field studies may be considered longer term future activity. This SAB Report also identifies several recommendations for future research and assessment needs that should be considered for inclusion.

Data sources that suggest the possibility that hydraulic fracturing-related activities may have contaminated surface or groundwater at the local to sub-regional scale:

A. Surface activities implicated in groundwater contamination:

(1) Drollette et al. 2015. Elevated levels of diesel range organic compounds in groundwater near Marcellus gas operations are derived from surface activities. *PNAS*, 112: 13184-13189, doi: 10.1073/pnas.1511474112.

B. Impacts to surface-water by inadequate treatment and disposal of HF-related wastewaters:

(2) Warner et al. 2013. Impacts of shale gas wastewater disposal on water quality in western Pennsylvania. *Environmental Science and Technology*. 47: 11849-11857.

(3) Olmstead et al. 2013. Shale gas development impacts on surface water quality in Pennsylvania. PNAS, 110: 4962-4967, doi: 10.1073/pnas.1213871110.

C. Effects of gas-well drilling or improper zonal isolation on groundwater contamination.

(4) Llewellyn et al. 2015. Evaluating a groundwater supply contamination incident attributed to Marcellus Shale gas development. *PNAS*. 112: 6325–6330.

(5) Jackson et al. 2013. Increased stray gas abundance in a subset of drinking water wells near Marcellus shale gas extraction. Proceedings of the National Academy of Sciences. 110: 11250-11255.

(6) Fontenot et al. 2013. An evaluation of water quality in private drinking water wells near natural gas extraction sites in the Barnett Shale Formation. *Environmental Science and Technology*. 47: 10032-10040.

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APPENDIX A–EPA'S CHARGE QUESTIONS

Charge Questions for the SAB Review of the USEPA Report:
Assessment of the Potential Impacts of Hydraulic Fracturing for Oil and Gas on Drinking Water Resources
Revised (October 8, 2015)

Background

The purpose of this assessment (U.S. EPA, 2015), entitled *Assessment of the Potential Impacts of Hydraulic Fracturing for Oil and Gas on Drinking Water Resources*, was to synthesize available scientific literature and data on the potential for hydraulic fracturing for oil and gas to change the quality or quantity of drinking water resources, and to identify factors affecting the frequency or severity of any potential changes. In fiscal year 2010, the U.S. Congress urged the U.S. Environmental Protection Agency (EPA) to examine the relationship between hydraulic fracturing and drinking water. In response, the EPA developed a research study plan (U.S. EPA, 2011) which was reviewed by the Agency's Science Advisory Board (SAB) and issued in 2011. A progress report (U.S. EPA, 2012) on the study detailing the EPA's research approaches and next steps was released in late 2012, and was followed by a consultation with individual experts convened under the auspices of the SAB in May 2013. The EPA's study included original research, and the results from these research projects were considered in the development of this draft assessment report.

This assessment follows the HFWC described in the Study Plan and Progress Report. The water cycle includes five stages: (1) water acquisition for hydraulic fracturing fluids; (2) chemical mixing to form fracturing fluids; (3) well injection of fracturing fluids; (4) flowback and produced water; and (5) wastewater treatment and disposal. Potential impacts on drinking water resources are considered at each stage in this cycle. Drinking water resources are defined broadly within this report to include any body of groundwater or surface water that now serves, or in the future could serve, as a source of drinking water for public and private use.

EPA authors examined over 3,500 individual sources of information, and cited over 950 of these sources for this assessment. Sources evaluated included articles published in science and engineering journals, federal and state reports, non-governmental organization reports, oil and gas industry publications, other publicly-available data and information, and data, including confidential and non-confidential business information, submitted by industry to the EPA. The assessment also included citation of relevant literature developed as part of the Study Plan.

This assessment is a synthesis of the science. It is not a human exposure or risk assessment, and does not attempt to evaluate policies or make policy recommendations. Rather, it focuses on the potential impacts of hydraulic fracturing activities, and factors affecting the frequency or severity of any potential changes. As such, this report can be used by federal, tribal, state, and local officials; industry; and the public to better understand and address vulnerabilities of drinking water resources to hydraulic fracturing activities.

EPA asks the SAB to review the hydraulic fracturing drinking water assessment and provides the following charge questions for that review. The charge questions follow the structure of the assessment. Charge question 1 asks about the introduction of the assessment (Chapter 1), and descriptions of hydraulic fracturing activities and drinking water resources (Chapters 2-3). Charge questions 2 through 6 ask about the individual stages in the HFWC (Chapters 4-8). Charge question 7 asks about the identification and hazard evaluation of chemicals (Chapter 9); and charge question 8 asks about the synthesis of the material presented in the Executive Summary and Chapter 10.

Charge Questions

1. The goal of the assessment was to review, analyze, and synthesize available data and information concerning the potential impacts of hydraulic fracturing on drinking water resources in the United States, including identifying factors affecting the frequency or severity of any potential impacts. In Chapter 1 of the assessment, are the goals, background, scope, approach, and intended use of this assessment clearly articulated? In Chapters 2 and 3, are the descriptions of hydraulic fracturing and drinking water resources clear and informative as background material? Are there topics that should be added to Chapters 2 and 3 to provide needed background for the assessment?

2. The scope of the assessment was defined by the HFWC, which includes a series of activities involving water that support hydraulic fracturing. The first stage in the HFWC is water acquisition: the withdrawal of ground or surface water needed for hydraulic fracturing fluids. This is addressed in Chapter 4.
    a. Does the assessment accurately and clearly summarize the available information concerning the sources and quantities of water used in hydraulic fracturing?
    b. Are the quantities of water used and consumed in hydraulic fracturing accurately characterized with respect to total water use and consumption at appropriate temporal and spatial scales?
    c. Are the major findings concerning water acquisition fully supported by the information and data presented in the assessment? Do these major findings identify the potential impacts to drinking water resources due to this stage of the HFWC? Are there other major findings that have not been brought forward? Are the factors affecting the frequency or severity of any impacts described to the extent possible and fully supported?
    d. Are the uncertainties, assumptions, and limitations concerning water acquisition fully and clearly described?
    e. What additional information, background, or context should be added, or research gaps should be assessed to better characterize any potential impacts to drinking water resources from this stage of the HFWC? Are there relevant literature or data sources that should be added in this section of the report?

3. The second stage in the HFWC is chemical mixing: the mixing of water, chemicals, and proppant on the well pad to create the hydraulic fracturing fluid. This is addressed in Chapter 5.
    a. Does the assessment accurately and clearly summarize the available information concerning the composition, volume, and management of the chemicals used to create hydraulic fracturing fluids?

   b. Are the major findings concerning chemical mixing fully supported by the information and data presented in the assessment? Do these major findings identify the potential impacts to drinking water resources due to this stage of the HFWC? Are there other major findings that have not been brought forward? Are the factors affecting the frequency or severity of any impacts described to the extent possible and fully supported?
   c. Are the uncertainties, assumptions, and limitations concerning chemical mixing fully and clearly described?
   d. What additional information, background, or context should be added, or research gaps should be assessed, to better characterize any potential impacts to drinking water resources from this stage of the HFWC? Are there relevant literature or data sources that should be added in this section of the report?

4. The third stage in the HFWC is well injection: the injection of hydraulic fracturing fluids into the well to enhance oil and gas production from the geologic formation by creating new fractures and dilating existing fractures. This is addressed in Chapter 6.
   a. Does the assessment clearly and accurately summarize the available information concerning well injection, including well construction and well integrity issues and the movement of hydraulic fracturing fluids, and other materials in the subsurface?
   b. Are the major findings concerning well injection fully supported by the information and data presented in the assessment? Do these major findings identify the potential impacts to drinking water resources due to this stage of the HFWC? Are there other major findings that have not been brought forward? Are the factors affecting the frequency or severity of any impacts described to the extent possible and fully supported?
   c. Are the uncertainties, assumptions, and limitations concerning well injection fully and clearly described?
   d. What additional information, background, or context should be added, or research gaps should be assessed, to better characterize any potential impacts to drinking water resources from this stage of the HFWC? Are there relevant literature or data sources that should be added in this section of the report?

5. The fourth stage in the HFWC focuses on flowback and produced water: the return of injected fluid and water produced from the formation to the surface and subsequent transport for reuse, treatment, or disposal. This is addressed in Chapter 7.
   a. Does the assessment clearly and accurately summarize the available information concerning the composition, volume, and management of flowback and produced waters?
   b. Are the major findings concerning flowback and produced water fully supported by the information and data presented in the assessment? Do these major findings identify the potential impacts to drinking water resources due to this stage of the HFWC? Are there other major findings that have not been brought forward? Are the factors affecting the frequency or severity of any impacts described to the extent possible and fully supported?
   c. Are the uncertainties, assumptions, and limitations concerning flowback and produced water fully and clearly described?
   d. What additional information, background, or context should be added, or research gaps should be assessed, to better characterize any potential impacts to drinking water

resources from this stage of the HFWC? Are there relevant literature or data sources that should be added in this section of the report?

6. The fifth stage in the HFWC focuses on wastewater treatment and waste disposal: the reuse, treatment and release, or disposal of wastewater generated at the well pad. This is addressed in Chapter 8.
   a. Does the assessment clearly and accurately summarize the available information concerning hydraulic fracturing wastewater management, treatment, and disposal?
   b. Are the major findings concerning wastewater treatment and disposal fully supported by the information and data presented in the assessment? Do these major findings identify the potential impacts to drinking water resources due to this stage of the HFWC? Are there other major findings that have not been brought forward? Are the factors affecting the frequency or severity of any impacts described to the extent possible and fully supported?
   c. Are the uncertainties, assumptions, and limitations concerning wastewater treatment and waste disposal fully and clearly described?
   d. What additional information, background, or context should be added, or research gaps should be assessed, to better characterize any potential impacts to drinking water resources from this stage of the HFWC? Are there relevant literature or data sources that should be added in this section of the report?

7. The assessment used available information and data to identify chemicals used in hydraulic fracturing fluids and/or present in flowback and produced waters. Known physicochemical and toxicological properties of those chemicals were compiled and summarized. This is addressed in Chapter 9.
   a. Does the assessment present a clear and accurate characterization of the available chemical and toxicological information concerning chemicals used in hydraulic fracturing?
   b. Does the assessment clearly identify and describe the constituents of concern that potentially impact drinking water resources?
   c. Are the major findings fully supported by the information and data presented in the assessment? Are there other major findings that have not been brought forward? Are the factors affecting the frequency or severity of any impacts described to the extent possible and fully supported?
   d. Are the uncertainties, assumptions, and limitations concerning chemical and toxicological properties fully and clearly described?
   e. What additional information, background, or context should be added, or research gaps should be assessed, to better characterize chemical and toxicological information in this assessment? Are there relevant literature or data sources that should be added in this section of the report?

8. The Executive Summary and Chapter 10 provide a synthesis of the information in this assessment. In particular, the Executive Summary was written for a broad audience.
   a. Are the Executive Summary and Chapter 10 clearly written and logically organized?

b. Does the Executive Summary clearly, concisely, and accurately describe the major findings of the assessment for a broad audience, consistent with the body of the report?
c. In Chapter 10, have interrelationships and major findings for the major stages of the HFWC been adequately explored and identified? Are there other major findings that have not been brought forward?
d. Are there sections in Chapter 10 that should be expanded? Or additional information added?

APPENDIX B–DISSENTNG OPINION FROM [PANEL MEMBER]