January 2017

Response to the U.S. Environmental Protection Agency's Science Advisory Board Review of the Draft Report

Assessment of the Potential Impacts of Hydraulic Fracturing for Oil and Gas on Drinking Water Resources

Office of Research and Development
U.S. Environmental Protection Agency
Washington, DC

PREFACE

This report was prepared by the U.S. Environmental Protection Agency's Office of Research and Development. It provides EPA's responses to the independent peer review of the June 2015 draft report *Assessment of the Potential Impacts of Hydraulic Fracturing for Oil and Gas on Drinking Water Resources* conducted by the EPA's Science Advisory Board (SAB). The SAB's final report was provided to EPA in August 2016 and is available online at www.epa.gov/sab (EPA-SAB-16-005).

To complete this response to comments report, EPA started with the SAB's August 2016 final report. Below each of the SAB's key comments and recommendations, EPA scientists provided responses indicating how each comment was addressed in the final assessment report. EPA responses are provided in blue font and begin with the bolded text, "**EPA Response**".

EPA's final assessment report, *Hydraulic Fracturing for Oil and Gas: Impacts from the Hydraulic Fracturing Water Cycle on Drinking Water Resources in the United States*, was released in December 2016 and is available online at www.epa.gov/hfstudy.

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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON D.C. 20460

OFFICE OF THE ADMINISTRATOR
SCIENCE ADVISORY BOARD

August 11, 2016

EPA-SAB-16-005

The Honorable Gina McCarthy
Administrator
U.S. Environmental Protection Agency
1200 Pennsylvania Avenue, NW
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 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 impacts 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 could result in impacts to drinking water.

The SAB was asked to comment on the EPA's statements on the goals, background and history of its Assessment; on the EPA's analyses regarding the water acquisition, chemical mixing, well injection, flowback and produced water, and wastewater treatment and waste disposal steps of the hydraulic fracturing water cycle (HFWC); on the EPA's analysis of chemicals used or present in hydraulic fracturing fluids; and on the EPA's synthesis of science on potential impacts of hydraulic fracturing on drinking water resources as presented in the Assessment's Chapter 10 and Executive Summary. The specific charge questions to the SAB Hydraulic Fracturing Research Advisory Panel (SAB Panel) from the EPA are provided as Appendix A to the SAB Report.

The EPA developed the draft Assessment Report in response to a request in 2009 from the U.S. Congress, which urged the EPA to examine the relationship between hydraulic fracturing and drinking water resources. The EPA consulted with stakeholders, and developed a Research Scoping document followed by a detailed research Study Plan, both of which were reviewed by the SAB, in 2010 and in 2011, respectively. An EPA Progress Report on the study detailing the research approaches, activities, and remaining work was released in late 2012. A consultation on the Progress Report was conducted in May 2013 with members of the SAB Panel. The EPA's draft Assessment Report was released in June

2015 for public comment and review by the SAB Panel operating under the auspices of the chartered SAB.

In general, the SAB finds the EPA's overall approach to assess the potential impacts of HFWC processes for oil and gas production on drinking water resources, focusing on the individual stages in the HFWC, to be comprehensive but lacking in several critical areas. 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, including concerns regarding several major findings presented within the draft that seek to draw national-level conclusions regarding the impacts of hydraulic fracturing on drinking water resources. The SAB has recommendations for changes to text in the draft Assessment Report and for follow-on activities to address gaps. Also included, as Appendix B, is a dissenting view from four of the 30 members of the SAB Panel regarding the broader SAB Panel's viewpoint on one of the EPA's major findings.

The SAB's key findings and recommendations are summarized below.

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 the EPA did not support quantitatively its conclusion about lack of evidence for widespread, systemic impacts of hydraulic fracturing on drinking water resources, and did not clearly describe the system(s) of interest (e.g., groundwater, surface water), the scale of impacts (i.e., local or regional), nor the definitions of "systemic" and "widespread." The SAB observes that the statement has been interpreted by readers and members of the public in many different ways. The SAB concludes that if the EPA retains this conclusion, the EPA should provide quantitative analysis that supports its conclusion that hydraulic fracturing has not led to widespread, systemic impacts on drinking water resources. Twenty-six of the 30 members of the SAB Panel concluded that the statement also requires clarification and additional explanation (e.g., discuss what is meant by "any observed change" in the definition of "impact" in Appendix J, and consider including modifying adjectives before the words "widespread, systemic impact" in the statement on page ES-6). Four members of the SAB Panel concluded that this statement is clear, concise and accurate.

The SAB recommends that the EPA revise the major statements of findings in the Executive Summary and elsewhere in the final Assessment Report to clearly link these statements to evidence provided in the body of the final Assessment Report. The EPA should consider prioritizing the major findings that have been identified within Chapters 4-9 of the final Assessment Report according to expectations regarding the magnitude of the potential impacts of hydraulic fracturing-related activities on drinking water resources. 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. Regarding the EPA's findings of gaps and uncertainties in publicly available data that the agency relied upon to develop conclusions within the draft Assessment Report, the EPA should clarify and describe the different databases that contain such data and the challenges of accessing them, and make recommendations on how these databases could be improved to facilitate more efficient investigation of the data they contain.

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

> **EPA Response:** Statements of major findings included in the Executive Summary and elsewhere in the final Assessment Report have been revised for clarity. We have also revised the Executive Summary and the technical chapters (Chapters 4-9) to more clearly link statements of major findings to observations and data that support those findings.
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> In particular, the SAB expressed concerns about the sentence "We did not find evidence that these mechanisms have led to widespread, systemic impacts on drinking water resources in the United States" and recommended that EPA clarify and provide quantitative support for this conclusion. We note that the majority of SAB reviewers, but not all, held this view. EPA scientists carefully considered the SAB's recommendation and concluded that the sentence could not be quantitatively supported given the existing data gaps and uncertainties. Additionally, as noted by the SAB, the sentence was interpreted by readers and members of the public in many different ways, which showed that it did not clearly communicate the findings of the draft report. As a result, this sentence was not included in the final Assessment Report.
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> Chapter 10 of the final Assessment Report identifies combinations of hydraulic fracturing water cycle activities and factors that are more likely than others to result in more frequent or more severe impacts on drinking water resources. This information can help decision makers reduce current vulnerabilities of drinking water resources to activities in the hydraulic fracturing water cycle. Chapter 10 also provides perspective on data gaps and uncertainties that, if filled or reduced, could further understanding of impacts on drinking water resources from activities in the hydraulic fracturing water cycle. We do not make specific recommendations on how to conduct future research or collect data. Finally, Chapter 10 explicitly states that the Assessment Report is a snapshot in time. Evaluating the potential for activities in the hydraulic fracturing water cycle to impact drinking water resources will need to keep pace with emerging technologies and new scientific studies.

Recognition of Local Impacts: The SAB finds that the EPA's initial goal of assessing the HFWC using national-level analyses and perspective was appropriate. However, the final Assessment Report should also recognize that many stresses to surface or groundwater resources associated with stages of the HFWC are often localized in space and temporary in time but nevertheless can be important and significant. For example, the impacts of water acquisition will predominantly be observed locally at small space and time scales. These local-level impacts, when they occur, have the potential to be severe, and the final Assessment Report needs to better recognize 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 many members of the public have stated that hydraulic fracturing activities have caused local impacts to drinking water resources. Examination of these high-visibility cases is important so that the reader 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.

> **EPA Response:** The final Assessment Report highlights the role of local- or regional-scale factors in impacts on drinking water resources from activities in the hydraulic fracturing water cycle. We also state, in the final Assessment Report that identified impacts generally occurred near hydraulically fractured oil and gas production wells and ranged in severity, from temporary changes in water quality to contamination that made private drinking water wells unusable.
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> Chapter 6 of the final Assessment Report includes text boxes on each of the locations identified by the SAB—Dimock, Pennsylvania; Pavillion, Wyoming; and Parker County, Texas. For each location, we reviewed information in existing, publicly-available reports. Each text box describes possible pathways or sources for reported impacts on drinking water resources.

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

> **EPA Response:** Appendix A of the final Assessment Report provides background on EPA's *Study of the Potential Impacts of Hydraulic Fracturing for Oil and Gas on Drinking Water Resources*, hereafter the Hydraulic Fracturing Drinking Water Study[1,2], including a list of reports and publications produced as part of the study. As noted in Appendix A, we were unable to find suitable locations for the prospective case studies that met both the scientific criteria of a rigorous study and the business needs of potential partners.
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> [1] U.S. EPA (U.S. Environmental Protection Agency). (2011). Plan to study the potential impacts of hydraulic fracturing on drinking water resources [EPA Report]. (EPA/600/R-11/122). Washington, D.C.: U.S. Environmental Protection Agency, Office of Research and Development. https://www.epa.gov/hfstudy/hydraulic-fracturing-study-plan-2011
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> [2] U.S. EPA (U.S. Environmental Protection Agency). (2012). Study of the potential impacts of hydraulic fracturing on drinking water resources: Progress report. (EPA/601/R-12/011). Washington, D.C.: U.S. Environmental Protection Agency, Office of Research and Development. https://nepis.epa.gov/exe/ZyPURL.cgi?Dockey=P100FH8M.txt

Probability and Risk of Failure Scenarios: To help the reader understand the most significant failure mechanisms associated with the various stages in the HFWC, the EPA should 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 such failure mechanisms. For example, 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 cementation techniques, hydraulic fracturing operator error, migration of hydraulic fracturing chemicals from the deep subsurface, and abandoned/orphaned oil and gas wells. The agency should also provide more information regarding the extent or potential extent of the effects of chemical mixing processes from hydraulic fracturing operations on drinking water supplies. The EPA should provide additional detail on the extent and duration of the impacts of spilled liquids and releases of flowback and produced waters when they occur. Furthermore, the agency should also include additional major findings associated with the effects on drinking water resources of large spill events that escape site containment, and sustained, undetected leaks.

> **EPA Response:** The goals of EPA's study and Assessment Report were to assess the potential for activities in the hydraulic fracturing water cycle to impact the quality or quantity of drinking water resources and to identify factors that affect the frequency or severity of those impacts. The final Assessment Report identifies combinations of hydraulic fracturing water cycle activities and factors that are more likely than others to result in more frequent or more severe impacts on drinking water resources, including:
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> - Water withdrawals for hydraulic fracturing in times or areas of low water availability, particularly in areas with limited or declining groundwater resources;
> - Spills during the management of hydraulic fracturing fluids and chemicals or produced water that result in large volumes or high concentrations of chemicals reaching groundwater resources;
> - Injection of hydraulic fracturing fluids into wells with inadequate mechanical integrity, allowing gases or liquids to move to groundwater resources;
> - Injection of hydraulic fracturing fluids directly into groundwater resources;
> - Discharge of inadequately treated hydraulic fracturing wastewater to surface water resources; and
> - Disposal or storage of hydraulic fracturing wastewater in unlined pits, resulting in contamination of groundwater resources.
>
> This information can help decision makers reduce current vulnerabilities of drinking water resources to activities in the hydraulic fracturing water cycle.
>
> Because of the significant data gaps and uncertainties in the available data, it was generally not possible to calculate or estimate failure or impact probabilities or frequencies. We were able to estimate impact frequencies in some, limited cases (i.e., spills of hydraulic fracturing fluids or produced water and mechanical integrity failures), as described in Chapter 10. The data used to develop these estimates were often limited in geographic scope or otherwise incomplete.

Chemical Toxicity and Hazard: The agency should compile toxicological information on constituents (e.g., chemicals, dissolved compounds and ions, and particulates) employed in hydraulic fracturing in a more inclusive manner, and not limit the selection of hydraulic fracturing constituents of concern to those that have noncancer oral reference values (RfVs) and cancer oral slope factors (OSFs) that were peer reviewed only by a governmental or intergovernmental source. 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 constituents. 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 constituents 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 constituents across the HFWC is the agency's lack of analysis of the 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 these exposure scenarios. The EPA provides a wide range of possible scenarios along the HFWC, but more emphasis is needed on identifying the most likely durations and routes of exposures of concern so that the EPA can determine what toxicity information is most relevant and focus its research and monitoring efforts on the most important and/or likely scenarios. The SAB concludes that the selection of likely scenarios 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 from HFWC operations. Furthermore, the EPA developed a multi-criteria decision analysis (MCDA) approach to analyze hydraulic fracturing constituents 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 constituents, the EPA should explicitly state that these MCDA results (based only on constituents with RfVs) should not be used to prioritize the constituents of most concern nationally, nor to identify future toxicity testing research needs.

EPA Response: We compiled noncancer, chronic oral reference values (RfVs) and cancer oral slope factors (OSFs) as a first step for informing site-specific risk assessments. Chronic RfVs were compiled because they are generally preferred as the default by risk assessors when conducting site-specific risk assessments and when developing regional screening levels. Chapter 9 in the final Assessment Report has been revised to clearly state that our effort was not intended to be an exhaustive compilation of toxicological information on these chemicals. Rather, we focused on collecting high-quality toxicological information that met EPA's criteria for inclusion in this study.

Although the primary focus of the chapter is on chronic oral RfVs and OSFs from selected data sources, Section 9.4 has been expanded to include information on:

- Estimating toxicity using quantitative structure-activity relationship (QSAR) models,
- Chemical data available from EPA's Aggregated Computational Toxicology Resource (ACToR) database, and
- Additional tools for hazard evaluation.

Chapter 9 has been revised to better integrate information from Chapters 4-8. In particular, we have added a section at the beginning of the chapter that summarizes the ways in which chemicals associated with hydraulic fracturing can enter drinking water resources (Section 9.2). Similar text has been added throughout Section 9.5, which focuses on hazard identification for specific subsets of hydraulic fracturing-related chemicals (e.g., chemicals used in hydraulic fracturing fluids). We also provide an overview of cases in which there is direct and indirect evidence of contamination of drinking water resources. We note which chemicals detected in these studies are known to be associated with hydraulic fracturing activities and instances in which chemical concentrations in these field studies exceeded MCLs. As noted in Chapter 1, the Assessment Report does not identify populations that are exposed to chemicals or other stressors in the environment, estimate the extent of exposure, or estimate the incidence of human health impacts.

In the final Assessment Report, the multi-criteria decision analysis (MCDA) presented in Chapter 9 is characterized as one possible approach that can be used to facilitate data integration.

Section 9.6 includes a discussion of both the limitations and uncertainties associated with the MCDA framework and the applicability of the MCDA framework for preliminary hazard evaluation.

Characteristics of HF Fluids: For the sake of clarity, the final Assessment Report should distinguish between hydraulic fracturing constituents injected into a hydraulic fracturing well vs. constituents that come out of the hydraulic fracturing well in produced fluids, and between those 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 constituents that are naturally occurring in the formation waters of the production zone. The agency should also clarify whether constituents identified as being of most concern in produced water are products of the hydraulic fracturing activity, initial flowback, or later-stage produced water, or are constituents 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 readers about the different characteristics of HF injection flowback and produced waters and in-situ subsurface constituents relative to formation water produced in conventional oil and gas development.

The SAB finds that the data presented by the EPA within Chapter 5 of the Assessment Report indicate 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 constituents and their safety. The SAB also finds that the EPA's conclusion based on these limited data (i.e., 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. The EPA should revise its interpretation of these limited data. In addition, Chapter 8's summary of water quality characteristics of hydraulic fracturing wastewaters from various sites clearly indicates that spills or discharges of inadequately treated hydraulic fracturing wastewater could result in significant adverse impacts on drinking water quality.

The EPA uses FracFocus 1.0 as the primary source of information on the identity and frequency of use of constituents in hydraulic fracturing processes, and the SAB expresses concern that the FracFocus database may not be sufficient. Although the agency acknowledged limitations of the FracFocus data, the EPA can do more to address these limitations by characterizing available toxicology data on proprietary constituents, and by using information provided in updated versions of FracFocus on chemical class, type, mass and concentration.

EPA Response: The final Assessment Report distinguishes between chemicals identified in hydraulic fracturing fluids and chemicals identified in produced water. In particular, we qualitatively describe the composition of produced water and how it changes over time (Text Box ES-9). Additionally, Chapter 9 of the final Assessment Report includes an improved discussion on the hazard of chemicals used in hydraulic fracturing fluids and chemicals found in produced water. We note that many organic and inorganic compounds found in produced water are naturally occurring and are not unique to hydraulic fracturing.

Statements of major findings included in the Executive Summary and elsewhere in the final Assessment Report (including Chapters 5 and 8) have been revised for clarity. Specifically, we highlight spills of hydraulic fracturing fluids and chemicals or produced water that result in large volumes or high concentrations of chemicals reaching groundwater resources as a condition that likely results in more frequent or more severe impacts on drinking water resources.

Despite the limitations associated with FracFocus, it provides substantial insight into water and chemical use for hydraulic fracturing. To address concerns regarding our use of data submitted to FracFocus 1.0, we compared results from our analysis of FracFocus 1.0 to the results presented in Konschnik and Dayalu (2016)[1]. Konschnik and Dayalu (2016) presents results of an analysis of data submitted to FracFocus 1.0 and 2.0. This comparison identified 263 new chemicals. Of these chemicals, only one was Reported in more than 1% of disclosures, which suggests that these chemicals were used at only a few sites. The comparison also showed an increase of the percentage of disclosures that claimed at least one chemical as confidential. In the final Assessment Report, we note that the available information on chemicals used in hydraulic fracturing fluids is incomplete.

[1]Konschnik, K; Dayalu, A. (2016). Hydraulic fracturing chemicals reporting: Analysis of available data and recommendations for policymakers. Energy Policy 88: 504-514. http://dx.doi.org/10.1016/j.enpol.2015.11.002

Baseline Water Quality Data: The EPA should discuss the importance of background and preexisting chemistry of surface and groundwater in developing a better understanding of whether impacts from drilling and completion activities can be identified. A major public concern is the appearance of contaminated or degraded drinking water in wells in areas where hydraulic fracturing occurs. Since naturally occurring contaminants and degraded drinking water in 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 are used to better understand the impacts of hydraulic fracturing-related spills and leaks. The scientific complexity of baseline sampling and data interpretation should be clearly and concisely described.

EPA Response: Chapter 10 of the final Assessment Report discusses uncertainties and data gaps identified throughout the Assessment Report. In particular, we highlight the importance of baseline water quality data in identifying and quantifying changes in water quality after hydraulic fracturing occurs within an area. We also note that it is often difficult to separate the potential effects of hydraulic fracturing activities from effects of broader oil and gas industry activities and other industries or causes. It was outside of the scope of this Report to include a review of the scientific complexity of baseline sampling and data interpretation.

Approach for Assessing Water Quality and Quantity Impacts: The SAB provides several suggestions to improve the agency's approach for assessing the potential that the hydraulic fracturing water cycle processes for oil and gas production may change the quality or quantity of drinking water resources. While the draft Assessment Report comprehensively summarizes available information concerning the sources and quantities of water used during HFWC operations from surface water, groundwater, and treated HFWC 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 notes, but did not independently confirm, the EPA conclusion that there are important gaps in the data available to assess water use that limit understanding of hydraulic fracturing potential impacts on water acquisition.

EPA Response: Chapter 4 has been revised to clearly state that the potential for impacts depends on the combination of water withdrawals and water availability at a given withdrawal location. Where water withdrawals are relatively low compared to water availability, impacts are unlikely to occur. Where water withdrawals are relatively high compared to water availability, impacts are more likely. As stated in Chapter 4, we agree that seasonal or long-term drought can make impacts more frequent and severe for surface water and groundwater resources. Chapter 4 also includes a discussion of the uncertainties inherent in our assessment of the potential impacts of water acquisition for hydraulic fracturing on drinking water resources.

Definition of Proximity: The final Assessment Report should discuss the agency's rationale for selecting 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 distances greater than one mile from a hydraulic fracturing operation. The EPA should present more information regarding the vertical distance between surface-water bodies and the target zones being fractured, the depths of most existing and potential future water-supply aquifers compared to the depths of most hydraulically fractured wells, and the increased potential, if any, for impacts on drinking water quality in aquifers. In regard to potential impacts on aquifers, of particular interest are situations where the vertical distance between the hydraulically fractured production zone and a current or future drinking water source is relatively small depending on local hydrogeological conditions.

EPA Response: Chapter 2 of the final Assessment Report describes both lateral and vertical distances between hydraulically fractured oil and gas production wells (and hydraulically fractured rock formations) and surface water and groundwater resources. Chapter 2 also clarifies that the one-mile radius used to discuss lateral distances simply provides a consistent approach. We acknowledge that local topographic conditions could support the use of a different radius at any specific site.

Vertical separation distances between underground drinking water resources and hydraulically fractured rock formations are also discussed in Chapters 6 and 10 and are highlighted in the Executive Summary.

Treatment of Hydraulic Fracturing Wastewater: The agency should provide clearer information on the fundamentals of certain hydraulic fracturing wastewater treatment processes, and the occurrence and removal of disinfection by-product precursors in addition to 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 hydraulic fracturing-related 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 hydraulic fracturing-related wastewater disposal methods and their potential impacts on drinking water resources.

EPA Response: We have revised Chapter 8 to address the comments provided by the SAB. In particular, we have incorporated comments provided by the SAB on the descriptions of treatment technologies by either accepting suggested rewording or clarifying our original text in response to the comments. The discussion of disinfection byproducts in Chapter 8 has also been revised to provide information on a wider range of disinfection byproducts. We have also added a map in Section 8.4 showing the relationship between Pennsylvania potable water supplies and the centralized waste treatment facilities in their upstream watersheds that accept or have accepted Marcellus wastewater. The map provides a general illustration of how centralized waste treatment facilities are situated within catchments in Pennsylvania.

Chapter 8 has also been revised to better describe the potential for concentration of contaminants in wastewater during successive reuse cycles and notes that the storage and transport of minimally treated wastewaters provides a potential route for impacts on water resources in the event of spills or leaks. We also note that wastewater management strategies have changed over time and may continue to change, particularly in areas where induced seismicity related to underground injection control wells is of concern.

Best Management Practices and the Applicable Regulatory Framework: To better inform the readers on available processes, methods and technologies that can minimize hydraulic fracturing's potential impacts to drinking water resources, the SAB recommends that the agency describe best management practices used by industry at each stage of the HFWC. The EPA should also discuss: (1) federal, state and tribal standards and regulations implemented with the aim of minimizing the potential impacts to drinking water resources associated with hydraulic fracturing operations, and (2) the evolution of oilfield and federal, state and tribal regulatory practices relevant to HFWC activities. The EPA may develop these summaries as a longer-term future activity.

EPA Response: A comprehensive summary of best management practices and the regulatory framework was outside of the scope of the Assessment Report. Ways to reduce the frequency or severity of impacts from activities in the hydraulic fracturing water cycle are described in the Report when they were reported in the scientific literature. Additionally, Text Box 1-1 briefly describes the regulatory framework for protecting drinking water resources in the United States.

Accessibility of the Assessment to a Broad Audience: The SAB recommends that the draft Assessment Report be revised to make it 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, and clarify ambiguities.

EPA Response: The Executive Summary has been revised to be more understandable to the general public. We have clarified the language in the Executive Summary and have provided numerous text boxes and figures to illustrate key concepts. Chapters 4-9 of the final Assessment Report are written to be accessible to an audience with a moderate amount of technical training and expertise in the respective topic areas.

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 to conduct after finalization of the Assessment Report.

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,

Dr. Peter S. Thorne
Chair

Dr. David A. Dzombak
Chair

Enclosure

NOTICE

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

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Acronyms and Abbreviations

ACToR	Aggregated Computational Toxicology Resource Database
ATSDR	Agency for Toxic Substances and Disease Registry
BMP	Best Management Practices
BOD	Biochemical Oxygen Demand
Br	Bromine
BTEX	Benzene, Toluene, Ethylbenzene, and Xylenes
CBI	Confidential Business Information
CBM	Coal Bed Methane
Cl	Chlorine
Cl^- / Br^-	Chlorine/Bromine Ion Ratio
Cl^- / I^-	Chlorine/Iodine Ion Ratio
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
GLP	General Laboratory Practices
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
MCLGs	Maximum Contaminant Level Goals
mg/L	Milligrams per Liter
MRLs	Minimal Risk Levels
NAS	National Academy of Sciences
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
OSFs	Cancer Oral Slope Factors
POTW	Publicly Owned Treatment Works
pCi/L	Picocuries per Liter
PWS	Public Water Supply
PWSS	Public Water Supply Systems
RCRA	Resource Conservation and Recovery Act
RfDs	Chronic Reference Doses
RfV	Reference Value
SABEPA	Science Advisory Board
Sr	Strontium
TDS	Total Dissolved Solids

TENORMS	Technologically-Enhanced Naturally Occurring Radioactive Materials
THM	Trihalomethane
TLVs	Threshold Limit Values
TOC	Total Organic Carbon
TOX	Total Organic Halide
TTC	Threshold of Toxicological Concern
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 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 the hydraulic fracturing water cycle processes involved in oil and gas production to impact the quality or quantity of drinking water resources, and identifies factors affecting the frequency or severity of any potential impacts.

The EPA developed the draft Assessment Report in response to a request in 2009 from the United States Congress, which urged the EPA to examine the relationship between hydraulic fracturing and drinking water resources. The EPA consulted with stakeholders, and developed a Research Scoping document followed by a detailed research Study Plan, both of which were reviewed by the SAB, in 2010 and in 2011, respectively. An EPA Progress Report on the study detailing the research approaches, activities, and remaining work was released in late 2012. A consultation on the Progress Report was conducted in May 2013 with members of SAB's Hydraulic Fracturing Research Advisory Panel (the Panel). The EPA's draft Assessment Report was released in June 2015 for public comment and review by the Panel. 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 Panel reviewed the draft Assessment Report and considered many oral and written public comments to develop advice on the scientific adequacy of the EPA's draft Assessment Report. The SAB encourages the EPA to review and consider the public comments received as it finalizes the draft Assessment Report. At a public meeting on June 14, 2016, the chartered SAB deliberated on the SAB Panel's draft Report and agreed that chair and the lead reviewers on the chartered SAB would work with the chair of the SAB Panel to revise the draft SAB Report in accordance with discussions at the June 14, 2016 public meeting. 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 constituents (e.g., chemicals, dissolved compounds and ions, and particulates), 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 finalization of the Assessment Report. Also included, as Appendix B, is a dissenting view from four of the 30 members of the Panel associated with a position taken by the SAB Panel with respect to one of the EPA's major findings. 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 water cycle processes involved in oil and gas production on drinking water resources, focusing on the individual stages in the HFWC, to be comprehensive but lacking in several critical areas. 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 recommendations for changes to its text and follow-on activities to address gaps that the SAB has identified.

The SAB recognizes that there are a large number of recommendations included in the body of the SAB Report. The SAB has identified recommendations that the agency may consider longer-term future activities that the agency can conduct after finalization of the Assessment Report. The SAB recommends that the agency describe the additional research needed to adequately assess knowledge and information gaps for the HFWC stages and include this in Chapter 10 or in a chapter that the EPA would add to the final Assessment Report on ongoing research, and data and research needs.

Thematic Areas for Improving the Draft Assessment Report

The SAB Report is organized around the chapters of the draft Assessment Report, which correspond to the identified stages of the HFWC. However, the SAB identified the following cross-cutting thematic areas for improvement of the draft Assessment Report, presented by topic area below.

<u>Revisions to the Assessment's 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 finds 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.

The SAB expresses 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." The SAB finds that the EPA did not support quantitatively its conclusion about lack of evidence for widespread, systemic impacts of hydraulic fracturing on drinking water resources, and did not clearly describe the system(s) of interest (e.g., groundwater, surface water), the scale of impacts (i.e., local or regional), nor the definitions of "systemic" and "widespread". The SAB observes that the statement has been interpreted by readers and members of the public in many different ways. The SAB concludes that if the EPA retains this conclusion, the EPA should provide quantitative analysis that supports its conclusion that hydraulic fracturing has not led to widespread, systemic impacts on drinking water resources. Most Panel members also conclude that the statement requires clarification and additional explanation (e.g., consider including possible modifying adjectives before the words “widespread, systemic impact” in the statement on page ES-6). The SAB also concludes that the EPA should carefully consider whether to revise the definition of impact as provided in Appendix J of the draft Assessment Report (e.g., discuss what is meant by “any observed change” in the definition of “impact” in Appendix J). Four of the 30 Panel members find that this statement on page ES-6 is acceptable as written, but note that the EPA should have provided a more robust discussion on how it reached this conclusion. Further details regarding these four Panel members’ opinion are noted in Appendix B 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, including specific cases of drinking water impacts that relate to these major findings. The EPA should consider prioritizing the major findings that have been identified within Chapters 4-9 of the final Assessment Report according to expectations regarding the magnitude of the potential impacts of hydraulic fracturing-related activities on drinking water resources.

The agency should revise the synthesis discussion in Chapter 10 to present integrated conclusions, rather than a summary of findings from Chapters 4-9. 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. Integrated conclusions are needed. The agency should also revise Chapter 10 to discuss methods to reduce uncertainties related to the HFWC, including ongoing research, and data and research needs.

EPA Response: Statements of major findings included in the Executive Summary and elsewhere in the final Assessment Report have been revised for clarity. We have also revised the Executive Summary and the technical chapters (Chapters 4-9) to more clearly link statements of major findings to observations and data that support those findings.

In particular, the SAB expressed concerns about the sentence "We did not find evidence that these mechanisms have led to widespread, systemic impacts on drinking water resources in the United States" and recommended that EPA clarify and provide quantitative support for this conclusion. We note that the majority of SAB reviewers, but not all, held this view. EPA scientists carefully considered the SAB's recommendation and concluded that the sentence could not be quantitatively supported given the existing data gaps and uncertainties. Additionally, as noted by the SAB, the sentence was interpreted by readers and members of the public in many different ways, which showed that it did not clearly communicate the findings of the draft report. As a result, this sentence was not included in the final Assessment Report

Chapter 10 of the final Assessment Report has been rewritten. Chapter 10 of the final Assessment Report identifies combinations of hydraulic fracturing water cycle activities and factors that are more likely than others to result in more frequent or more severe impacts on drinking water resources. This information can help decision makers reduce current vulnerabilities of drinking water resources to activities in the hydraulic fracturing water cycle. Chapter 10 also provides perspective of data gaps and uncertainties that, if filled or reduced, could further understanding of impacts on drinking water resources from activities in the hydraulic fracturing water cycle. We do not make specific recommendations on how to conduct future research or collected data.

More Attention to Local Impacts

The SAB finds that the EPA's initial goal of assessing the HFWC using national-level analyses and perspective was appropriate. However, the final Assessment Report should recognize that many stresses to surface or groundwater resources associated with stages of the HFWC are often localized in space and temporary in time but can nevertheless be important and significant. For example, the impacts of water acquisition will predominantly be felt locally at small space and time scales. These local-level potential impacts have the potential to be severe, and the final 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.

With regard to local impacts, the SAB 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 many members of the public have stated that hydraulic fracturing activities have caused local impacts to drinking water resources. Examination of these high-visibility cases is important so that the reader 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 SAB is concerned that the EPA had planned to but did not conduct various assessments, field studies, and other research, and the SAB recommends that the EPA delineate these planned activities within the final Assessment Report and discuss why they were not conducted or completed. For example, the EPA had planned to conduct prospective case studies that contemplated drilling observation wells, collection of groundwater samples and other monitoring before and during drilling, hydraulic fracturing, and production operations. The goal was to follow the complete development of production wells, and to collect data prior to, during, and after hydraulic fracturing at the sites. Such studies would allow EPA to evaluate changes in water quality over time: throughout drilling, injection of fracturing fluids, flowback, and production. These planned prospective studies were not conducted or completed by the EPA, and the reasons for not conducting them were not described in the draft Assessment Report. The datasets collected during planned prospective case studies would have benefited the EPA's assessment in evaluating changes in water quality over time, if any, and assessing the fate and transport of HFWC constituents if a release was observed. The SAB finds that the EPA should evaluate lessons learned from its initial attempts and implementation challenges in developing the prospective case studies, including how these lessons could inform design of future prospective case studies.

The SAB concludes that the lack of prospective case studies as originally planned by the EPA and described in the research 2011 Study Plan is a limitation of the draft Assessment Report, since the studies would have allowed 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 regulations. Such detailed data would enable EPA to reduce current uncertainties and research gaps regarding the relationship between hydraulic fracturing and drinking water. Two Panel members do not find the lack of prospective case studies to be a limitation to the draft Assessment Report, based on the perspective that investigations conducted by universities, consulting firms, and other external stakeholders could be used in lieu of the agency conducting such studies.

The SAB recommends that the EPA investigate prospective studies that may have been conducted by other organizations on site-specific hydraulic fracturing operations to identify research gaps regarding the relationship between hydraulic fracturing and drinking water resources, and to describe such studies in the final Assessment Report. The final Assessment Report should identify ongoing and future needs for research, assessments, and field studies. The EPA, as a longer-term future activity, should continue research on expanded case studies and long-term prospective case studies in collaboration with appropriate state and regional regulatory agencies. The SAB finds that the final Assessment Report should describe the agency's plans for conducting prospective studies and other research that the EPA had planned but did not conduct as described in the research Study Plan.

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 finds that the draft Assessment Report's analysis of spill data cannot be extrapolated across the entire United States. The SAB recommends that the agency revisit a broader grouping of states and "refresh" the final 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 exposures to constituents to determine whether hydraulic fracturing activities in different locales pose health risks in relation to water quality impacts.

EPA Response: The final Assessment Report highlights the role of local- or regional-scale factors in impacts on drinking water resources from activities in the hydraulic fracturing water cycle. We also state, in the final Assessment Report, that identified impacts generally occurred near hydraulically fractured oil and gas production wells and ranged in severity, from temporary changes in water quality to contamination that made private drinking water wells unusable.

Chapter 6 of the final Assessment Report includes text boxes on each of the locations identified by the SAB—Dimock, Pennsylvania; Pavillion, Wyoming; and Parker County, Texas. For each location, we reviewed information in existing, publicly-available reports. Each text box describes possible pathways or sources for reported impacts on drinking water resources.

Appendix A of the final Assessment Report provides background on EPA's *Study of the Potential Impacts of Hydraulic Fracturing for Oil and Gas on Drinking Water Resources*, including a list of reports and publications produced as part of the study. As noted in Appendix A, we were unable to find suitable locations for the prospective case studies that met both the scientific criteria of a rigorous study and the business needs of potential partners. Since we were unable to identify suitable locations within the timeframe of the study, we did not conduct the prospective case studies.

The final Assessment Report summarizes available information on hydraulic fracturing-related spills in Chapters 5 and 7. We have clarified that the final Assessment Report incorporates results from a separate EPA report—*Review of State and Industry Spill Data: Characterization* *of Hydraulic Fracturing-Related Spills.* As described in Text Box 5-10, this report characterized 457 spills identified from state and industry data sources, including data sources maintained by nine state agencies. In response to comments from the SAB, we also incorporated results from an additional analysis of spill data from the North Dakota Department of Health (Chapter 7 and Appendix E.5). It was outside of the scope of the Assessment Report to assess and discuss the current status of data reporting on spills, including the frequency and types of data reported by the hydraulic fracturing industry.

Although we identified and evaluated potential human health hazards of hydraulic fracturing-related chemicals in Chapter 9, the final Assessment Report is not a human health risk assessment or an exposure assessment.

Data Limitations and What Needs to Be Done to Address Such Limitations

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.

For example, based on information in the draft Assessment Report analyses on sources and quantities of water used in hydraulic fracturing, the SAB notes, but did not independently confirm, the EPA conclusion that there are gaps and uncertainties in publicly available data upon which the EPA relied. 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 final Assessment Report the agency should describe the scale of the EPA's task for investigating, gathering and organizing data collected by states and data available from state agencies. The agency should also describe the challenges associated with conducting this investigation and the critical lessons learned from the effort. The EPA should also clarify and describe the different databases that contain relevant data, the challenges of assessing them, and make recommendations on how these databases could be improved to facilitate more efficient investigation of these databases. Such descriptions would also provide for greater transparency to external stakeholders.

EPA Response: Throughout the final Assessment Report, we have identified data gaps and uncertainties. In particular, Chapter 10 provides perspective of data gaps and uncertainties that, if filled or reduced, could further understanding of impacts on drinking water resources from activities in the hydraulic fracturing water cycle. It was outside of the scope of this report to comprehensively investigate, gather, and organize data collected by states. It was also outside of the scope of this report to make recommendations on how existing databases could be improved for studying impacts on drinking water resources from activities in the hydraulic fracturing water cycle.

Data Needs Regarding Constituents of Concern

The SAB finds that the EPA could improve its use of the FracFocus Chemical Disclosure Registry database. 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 final Assessment Report. The agency should also revise the final Assessment Report to characterize data on proprietary compounds that the EPA may have, and information provided in FracFocus on chemical class, type, mass and concentration (i.e., concentration of the constituent, in terms of % by mass, in the hydraulic fracturing fluid).

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

There is uncertainty regarding which hydraulic fracturing constituents 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 constituents and analytical assessment of the many uncommon constituents used in hydraulic fracturing. The SAB recommends that the EPA assess impacts and the underlying uncertainty associated with these undetected, unmonitored hydraulic fracturing constituents and incorporate such an assessment into this chapter of the final Assessment Report. This assessment should also consider how many hydraulic fracturing constituents that are in use do not have analytical methods, and are not undergoing monitoring.

The SAB recommends that the EPA, in collaboration with state agencies, outline a plan for analyzing organic compounds in HF flowback and produced waters. Flowback and produced water composition data are limited and the majority of available data are for inorganics. Furthermore, 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. Also, significant releases of bromide from hydraulic fracturing operations to surface or ground waters 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 due to the formation of disinfection by-products (DBP). The EPA should discuss whether a bromide salt is ever added as an injection constituent.

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

The SAB finds that the data presented by the EPA within Chapter 5 indicate 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 constituents and their safety. The SAB also finds that the EPA's conclusion based on these limited data (i.e., 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. The EPA should revise its interpretation of these limited data. In addition, Chapter 8's summary of water quality characteristics of hydraulic fracturing wastewaters from various sites clearly indicates that spills or discharges of inadequately treated hydraulic fracturing wastewater could result in significant adverse impacts on drinking water quality.

EPA Response: Despite the limitations associated with FracFocus, it provides substantial insight into water and chemical use for hydraulic fracturing. To address concerns regarding our use of data submitted to FracFocus 1.0, we compared results from our analysis of FracFocus 1.0 to the results presented in Konschnik and Dayalu (2016)[1]. Konschnik and Dayalu (2016) presents results of an analysis of data submitted to FracFocus 1.0 and 2.0. This comparison identified 263 new chemicals. Of these chemicals, only one was reported in more than 1% of disclosures, which suggests that these chemicals were used at only a few sites. The comparison also showed an increase on the percentage of disclosures that claimed at least one chemical as confidential. In the final Assessment Report, we note that the available information on chemicals used in hydraulic fracturing fluids is incomplete.

In the final Assessment Report, the multi-criteria decision analysis (MCDA) presented in Chapter 9 is characterized as one possible approach that can be used to facilitate data integration. Section 9.6 includes a discussion of both the limitations and uncertainties associated with the MCDA framework and the applicability of the MCDA framework for preliminary hazard evaluation. Although the primary focus of the chapter is on chronic oral RfVs and OSFs from selected data sources, Section 9.4 has been expanded to include information on:

- Estimating toxicity using quantitative structure-activity relationship (QSAR) models,
- Chemical data available from EPA's Aggregated Computational Toxicology Resource (ACToR) database, and
- Additional tools for hazard evaluation.

Chapter 7 and Appendix H have been revised to include additional information on organic chemicals detected in produced water. As noted in the chapter, many of these additional organic chemicals are naturally-occurring constituents of petroleum. Chapter 7 also highlights the importance of analytical methods for characterizing the chemical composition of produced water.

The final Assessment Report distinguishes between chemicals identified in hydraulic fracturing fluids and chemicals identified in produced water. In particular, we qualitatively describe the composition of produced water and how it changes over time (Text Box ES-9). Additionally, Chapter 9 of the final Assessment Report includes an improved discussion on the hazard of chemicals used in hydraulic fracturing fluids and chemicals found in produced water. We note that many organic and inorganic compounds found in produced water are naturally occurring and are not unique to hydraulic fracturing.

Statements of major findings included in the Executive Summary and elsewhere in the final Assessment Report (including Chapters 5 and 8) have been revised for clarity. Specifically, we highlight spills of hydraulic fracturing fluids and chemicals or produced water that result in large volumes or high concentrations of chemicals reaching groundwater resources as a condition that likely results in more frequent or more severe impacts on drinking water resources.

[1] Konschnik, K; Dayalu, A. (2016). Hydraulic fracturing chemicals reporting: Analysis of available data and recommendations for policymakers. Energy Policy 88: 504-514. http://dx.doi.org/10.1016/j.enpol.2015.11.002

Best Management Practices and Changes in Hydraulic Fracturing Operations

The SAB recognizes that the EPA did not intend for the final Assessment Report to serve as a guide to best management practices for hydraulic fracturing operations. Nevertheless, it is clear that management practices can significantly influence the potential for adverse impacts to drinking water resources to occur, both in terms of frequency and occurrence. Therefore, the SAB recommends that the agency describe best management practices used by industry at each stage of the HFWC, to better inform the readers on available processes, methods and technologies that can prevent or minimize hydraulic fracturing's potential impacts to drinking water resources. Also, the EPA should summarize significant technological changes that have occurred since 2012 in hydraulic fracturing operations related to the HFWC (e.g., changes in well construction practices, well integrity testing, and well injection) and assess the influence of these changes on the frequency and severity of potential impacts to drinking water resources). This summary of best management practices and technological changes need not be an exhaustive analysis of such practices and changes. The EPA may develop this summary as an item for longer-term future activity.

EPA Response: A comprehensive summary of best management practices was outside of the scope of the Assessment Report. Ways to reduce the frequency or severity of impacts from activities in the hydraulic fracturing water cycle are described in the Report when they were reported in the scientific literature. In Chapter 10 and the Executive Summary, we note that evaluating the potential for activities in the hydraulic fracturing water cycle to impact drinking water resources will need to keep pace with emerging technologies and new scientific studies.

Evolving Regulatory Framework

In Chapter 1, the agency should provide a concise overview discussion of the relevant federal, state and tribal laws and requirements pertaining to HFWC 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 typically responsible for monitoring and regulating HFWC activities, and describe: (1) federal, state and tribal standards and regulations that have been implemented with the aim of preventing or minimizing the potential impacts of hydraulic fracturing on drinking water resources; and (2) changes in oilfield operations and regulations that are relevant to HFWC activities. The final 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. The EPA should consider reviewing hydraulic fracturing-related standards and regulations within a few key states such as Pennsylvania, Wyoming, Texas, Colorado and

California, which all have implemented new hydraulic fracturing-related regulations since 2012. The EPA could consider the work completed on this topic by the Interstate Oil and Gas Compact Commission, the State Review of Oil, Natural Gas, Environmental Regulations, Inc. organization, and the Groundwater Protection Council. This overview discussion of the relevant laws and requirements need not be an exhaustive analysis of such practices and changes. The EPA may develop this overview as a longer-term future activity.

> **EPA Response:** Although a comprehensive summary of the regulatory framework was outside of the scope of the Assessment Report, we have added a text box in Chapter 1 that briefly describes the regulatory framework for protecting drinking water resources in the United States.

Transparency and Clarity of the Assessment

The SAB recommends that the draft Assessment Report be revised to make it 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 (including photographs of field site equipment and facilities) 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.

> **EPA Response:** The Executive Summary has been revised to be more understandable to the general public. We have clarified the language in the Executive Summary and have provided numerous text boxes and figures to illustrate key concepts. Chapters 4-9 of the final Assessment Report are written to be accessible to an audience with a moderate amount of technical training and expertise in the respective topic areas.

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 that HFWC activities may change the quality or quantity of drinking water resources. Among these is a recommendation that the final Assessment Report should identify critical data and research needs for reducing uncertainties. A more detailed description of the technical recommendations is included in the body of the SAB report, and the responses to specific charge questions are highlighted below.

> **EPA Response:** Our responses to SAB comments on specific charge questions are available in Section 3 of this report.

Goals, Background and History of the Assessment (Charge 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?

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 water well and oil/gas well construction. The description of drinking water resources in Chapter 3 is also clear and informative, but 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 overlying water-supply aquifers.

As the intended users of the final 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 the technical material. Within Chapters 2 and/or 3, the final Assessment Report should also include discussions of new hydraulic fracturing technologies. Within Chapter 1 or an appendix, the final Assessment Report should include an overview discussion of federal, state and tribal 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 regulating 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, and aquifer thicknesses). The final 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 existing and potential future water-supply aquifers compared to the depths of most hydraulically fractured wells. In addition, in regard to potential impacts on aquifers, the final Assessment Report should present more information regarding situations where the vertical distance between the hydraulically fractured production zone and a current or future drinking water source is relatively small depending on local hydrogeological conditions. Differences in the fracturing morphology as a function of depth should also be discussed. The final Assessment Report should include text to describe why the EPA assessed certain HF-related topics and issues, while others (e.g., contamination from drilling fluids and cuttings) were considered to be beyond the scope of the assessment.

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 final Assessment Report.

Also, the section on site identification and well development in Chapter 2 should include some discussion noting that the geological formations now being targeted for oil and gas production using hydraulic fracturing and horizontal drilling require closer well spacing that, compared to conventional drilling methods, may have greater potential impacts on drinking water resources. More discussion of the potential impacts on drinking water resources, both positive and negative, of well densities and multiple wells on one pad in unconventional oil and gas development should be included. 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.

<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?*

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 available information concerning the sources and quantities of water used during HFWC operations from surface water, groundwater, and treated wastewaters, the SAB finds that the EPA's statistical extrapolation to describe average conditions at the national scale masks important regional and local differences in water acquisition impacts. Many stresses to surface or groundwater resources associated with water acquisition and hydraulic fracturing are often localized in space and temporary in time but nevertheless can be important and significant.

The SAB concurs with the EPA's findings that water withdrawals for hydraulic fracturing are capable of temporarily 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, within the final Assessment Report the agency should succinctly summarize the regulatory, legal, management, and market frameworks in which the HFWC activities are managed that aim to minimize the potential for these negative impacts. For example, the regulatory framework in Pennsylvania that is discussed in the draft Assessment Report and its effects on managing water withdrawal could be cited among the EPA's major findings.

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 as a longer-term future activity. In the final 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, 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 EPA should enhance the understanding of localized impacts by providing more focus and analysis on the Well File Review and on examining other information not in literature and common databases to provide information about actual hydraulic fracturing water acquisition and its relationship to drinking water.

The SAB is concerned that the EPA had planned to conduct, but did not conduct, prospective case studies that contemplated drilling observation wells, collection of groundwater samples and other monitoring before and during drilling, hydraulic fracturing and production operations. The goal for the prospective studies was to follow the complete development of production wells, and to collect data prior to, during, and after hydraulic fracturing at the sites. Such studies would allow EPA to carefully evaluate changes in water quality over time: throughout drilling, injection of fracturing fluids, flowback, and production.

The SAB finds that the datasets collected during planned prospective case studies would have benefited the EPA's assessment in evaluating changes in water quality over time, if any, and assessing the fate and transport of potential constituent contaminants if a release was observed. The SAB finds that such detailed data would enable the EPA to reduce current uncertainties and research gaps about the relation between hydraulic fracturing water acquisition and drinking water. The SAB finds that the EPA should evaluate lessons learned from its initial attempts and implementation challenges in developing the prospective case studies, including how these lessons could inform design of future prospective case studies.

There are several additional major findings that the EPA should identify within this chapter. First, it should more clearly emphasize that many stresses on water resources are expected to be localized in space and temporary in time but can be important and significant, and should not understate the potential for localized problems associated with such stresses. Second, the final 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 and quality of drinking water. Third, the EPA final Assessment Report should expand on the discussion of the evolution and utilization of technologies that are being used to facilitate use and reuse of produced water and use of other historically underutilized sources of water (e.g., seawater, brackish groundwater containing 3,000–10,000 mg/L TDS, mine drainage, and treated wastewaters) that if used for hydraulic fracturing (or other purposes) could reduce the impacts of water acquisition on drinking water sources.

<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 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. The potential failure of these processes, including on-site and 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 indicate 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 constituents and their safety. While the EPA conducted a large effort in developing this chapter, all but one Panel member 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?

The SAB is also concerned that the EPA's major finding that: "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. The EPA should assess the likelihood of detecting an impact given the current state of groundwater and surface water monitoring in the United States. If routine monitoring systems are adequate to capture this impact if it occurred, then a lack of evidence of impact may support a conclusion that there was no impact. If the routine monitoring systems would not be expected to capture an impact that occurred, then a lack of evidence of impact may not support a conclusion of no impact. The limitations of the data sources (e.g., FracFocus) appear to have led to an incomplete record associated with the potential impacts associated with such spills. 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. One 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 two areas of uncertainty in this chapter of the draft Assessment Report that should be described more clearly in the final Assessment Report:

(1) There is uncertainty regarding which hydraulic fracturing constituents have been used globally and at any specific site; and

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

To reduce these uncertainties, the EPA should make Chapter 5 more current by including more recent available data, and conduct a more comprehensive and thorough analysis of the available data, on these topics. Chapter 5, as it stands, provides little information on the magnitude of hydraulic fracturing spills and it does not adequately describe either the uncertainty associated with the data 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 finds that the draft Assessment Report's analysis of spill data cannot be extrapolated across the entire United States. The SAB also notes that subsurface conditions commonly vary within and between states and this limits potential extrapolation of this dataset towards topics other than frequency of spills (e.g., while the geology may not have a large effect on the frequency or volume of a spill, the dataset could be used to assess issues regarding the fate and potential impacts of spilled hydraulic fracturing constituents in different geologies). The SAB encourages the agency to contact state agencies, review state databases and update the final 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 final Assessment Report.

The SAB recommends that the agency revisit a broader grouping of states and "refresh" the final Assessment Report with updated information on the reporting of spills associated with HFWC activities. The SAB finds that the reported 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 final 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; whether related to specific HF activity, and if so which aspect (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 conclusion based on these limited data (i.e., 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. The EPA should revise its 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 aforementioned concerns, the agency should:

- Revise Chapter 5 of the final 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 on drinking water supplies.
- Define "severity" in a way that is amenable to quantitative analysis and clearly delineate those factors contributing to spill severity.
- Describe the type of data needed to provide a meaningful assessment of the extent, severity and potential impacts of spills. The assessment needs to be critical and based on the relevant factors contributing to spill severity, including the mass of constituents spilled, the total volumes of the spills, duration of the spills, and site geology.
- Describe clearly the efforts that the EPA made to use available data, and barriers, if any, that the EPA encountered.

- Include within the final 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.
- 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 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 may not be accessible to the nontechnical reader. The SAB recommends that the EPA include additional, clearer diagrams and illustrations in this chapter to help the reader 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 federal, state and tribal standards and regulations intended to improve 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. Before drawing conclusions on water quality impacts associated with this HFWC stage, 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 federal, state and tribal regulatory standards that have changed, or may have changed, the probability of risk of water quality impacts associated with this stage in the HFWC.

- Include an analysis and discussion on hydraulic fracturing case studies and example situations where impacts may have occurred.

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 constituents 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.

In the descriptions of the interpretive models used to assess fracture propagation and fluid migration introduced and discussed in this chapter, the EPA should clarify that the model results are not based on construction of a rigorous, predictive model that has been verified by reproducing field measured values of fluid pressure and as such the model results cannot be called "evidence." In the final Assessment Report the EPA should clearly describe the limitations of interpretive models. The EPA should clarify that the models provide possible outcomes that are limited by the assumptions made in design and implementation of the model. Any reference to a model needs to state the assumptions/limitations of the model. Predictive models need to be validated with actual field measurements/data before making forward predictions of fracture propagation and fluid migration.

The final 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 hydraulic fracturing-related wastewater disposal and related federal, state and tribal regulatory response should be reserved for Chapter 8 which is focused on hydraulic fracturing-related wastewater treatment and disposal. The trends associated with such induced seismicity should also be discussed, including whether deep well injection of hydraulic fracturing-related wastewater is being reduced because of regulatory changes driven by public concerns about seismic activity and its associated costs, as recently occurred in Oklahoma.

A key aspect associated with assessing impacts from HFWC operations on drinking water supplies is well construction and operations that are protective of drinking water resources, location and characterization of abandoned/orphaned oil and gas wells, and isolation of potable water from hydraulic fracturing operations. The agency should recognize in the final Assessment Report that the following activities are essential activities for the protection of drinking water resources during the well injection stage of hydraulic fracturing operations: 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 characterization by examining and assessing substantially more than the 327 well files evaluated out of the approximately 24,000 well files referenced in the draft Assessment Report. The SAB recommends that the EPA conduct full statistical analyses on such an expanded Well File Review, communicate more fully the statistical analyses that were conducted, and develop graphs or tables associated with such analyses. The recommendations in this paragraph can 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 Well File Review or are inferred from graphs. The EPA should also discuss whether the relatively low percentage of horizontal well completions covered by the Well File 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 cementation techniques, hydraulic fracturing operator error, migration of hydraulic fracturing constituents from the deep subsurface, and abandoned/orphaned oil and gas 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?*

Overall, the discussion on hydraulic fracturing flowback and produced water within Chapter 7 provides a clear and accurate summary of the available information concerning composition, volume, and management of flowback and produced waters. The chapter 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).

The EPA should provide additional detail on 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 on the extent and duration of the impacts associated with these incidents, including details on the impact of spilled liquids and releases when they occur. In Chapter 7, the agency 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, to understand the likely probability of these events.

- 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 Chapter 7.
- 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 final Assessment Report should discuss what is known about the fate of 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. The final Assessment Report should describe the frequency and severity of such events and recognize that such events could occur.
- While data gaps have been identified in Chapter 7, especially with respect to baseline conditions and individual incidents, the final Assessment Report should clarify whether there are data gaps because the data are non-existent or just not easily (i.e., electronically) available.
- The final 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 expand and clarify the discussion provided in Chapter 7 on the current use by industry of tracers for injection fluids, as well as any efforts made by the EPA or other researchers to develop tracers, and describe how the use of tracers might be an approach that could allow assessment of releases of contamination and interpretation of the source of contamination if it occurs. For example, the agency should summarize what constituents, metal cations, and isotopes 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 flowback or produced waters.
- Regarding constituents of concern in flowback and produced waters:
    - The agency should clarify whether constituents identified as being of most concern in produced water are products of the hydraulic fracturing activity, flowback, or later-stage produced water, or are constituents 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, which can be considered a recommendation for longer-term future research activity.
    - The SAB recommends that the EPA, in collaboration with state agencies, outline a plan for analyzing organic constituents in HF flowback and produced waters since data on flowback water composition are limited and the majority of the available data are for inorganics. In addition, the EPA should evaluate as a longer-term future activity the potential for using non-targeted chemical analysis to identify currently unmonitored HF constituents.
    - The agency should present additional information in Chapter 7 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, and the natural occurrence of brines in the subsurface.
- The agency should develop a summary of best management practices for hydraulic fracturing surface impoundments as a longer-term future activity.

The final Assessment Report should also include a discussion on the importance of background and preexisting chemistry of surface and groundwater in developing a better understanding of whether impacts from drilling and completion activities can be identified. A major public concern is the appearance of contaminated (e.g., chemical constituents introduced into the water through HFWC activities) or degraded (e.g., adverse changes in water quality associated with naturally occurring chemicals influenced by HFWC activities) drinking water in wells in areas where hydraulic fracturing occurs. Since naturally occurring contaminants and degraded drinking water in 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 are used to better understand the impacts of hydraulic fracturing-related spills and leaks. The scientific complexity of baseline sampling and data interpretation should be clearly and concisely described. Although baseline sampling is simple in concept, it can be very difficult to obtain meaningful results in practice. Concentrations of naturally occurring contaminants, including methane, aromatic hydrocarbons, radionuclides, and disinfection by-product precursors, can vary significantly, both temporally and spatially, especially in surface water and in groundwater drawn from shallow and/or alluvial wells. Water quality can be significantly influenced by hydrological events (rainfall, flooding, drought), by water acquisition for purposes other than hydraulic fracturing, and by spills or discharges or constituents not associated with hydraulic fracturing. Obtaining representative samples, characterizing natural variations in water quality, properly collecting (and preserving and storing) samples for the analytes of interest, accurately determining the concentrations of the analytes of interest, and correctly interpreting the data can be challenging tasks. In addition, the analysis of water chemistry data from private wells requires the water chemistry data to be integrated with water-level data and details about the construction and maintenance history of each well.

<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?*

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 hydraulic fracturing-related wastewaters from various sites states in several locations that spills or discharges of inadequately treated wastewater from HFWC operations could 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 in the way of 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 hydraulic fracturing-related 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 also are not supported by peer reviewed literature that has demonstrated contaminants from oil and gas wastewater disposal facilities have reached drinking water facilities and have had effects (e.g., see States et al. 2013, which is cited in the draft Assessment Report; and Landis et al. 2016). The agency should clearly and accurately describe the basis for this statement in Chapter 8.

Chapter 8 of the draft Assessment Report also 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 SAB also 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.

To address the above-noted concerns, the EPA should conduct further analyses including the following listed activities. The SAB recommends that these activities be addressed in the final Assessment Report. However, to avoid undue delay in publishing the final Assessment Report, the SAB recommends that the activities that cannot be promptly addressed without further study should be identified in the final Assessment Report as research that needs to be addressed as a longer-term future activity:

- The final 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 stage.
- The chapter describes unit processes and treatment technologies used in both CWTFs and other treatment facilities (e.g., on-site and at POTWs), but many of these descriptions are very general and sometimes incorrectly describe such unit processes; the chapter needs to be revised to address this issue.
- The agency should further assess impacts on public drinking water supplies that rely upon surface water intakes downstream of hydraulic fracturing activities or discharges of hydraulic fracturing fluids. To assess this topic, a variety of information is needed including: the size and location of injection wells, CWTFs and POTWs receiving wastewater discharges (directly or indirectly); the locations and treatment capabilities of drinking water treatment facilities; and 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, and the EPA should provide information on the contributions that CWTFs may make to TDS, regulated contaminants, and other contaminants of concern in downstream public water supplies. The EPA should also provide similar information for any POTWs known to be accepting wastewater associated with hydraulic fracturing.

- The chapter should clearly summarize the regulatory framework around CWTFs and 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, the agency should also discuss in Chapter 8 other DBPs that could form at downstream water treatment plants (and water resource reclamation facilities) impacted by wastewater discharges associated with hydraulic fracturing.
- The agency should clearly and accurately summarize in Chapter 8 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.
- The agency should revise Chapter 8 in the draft Assessment Report 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.
- The agency should further consider, in Chapter 8: temporal trends for costs of hydraulic fracturing water purification technologies over the past decade; trends in hydraulic fracturing-related 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 hydraulic fracturing-related wastewater is being reduced because of regulatory changes driven by public concerns about seismic activity and its associated costs).
- The SAB finds that the chapter does not adequately assess other waste disposal issues such as: (1) 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 (2) disposal of soils, pond sediments, and other solid media contaminated by hydraulic fracturing constituents. The chapter should be revised to include some level of assessment on these topics, and to outline data gaps that should be addressed in longer-term future activity.
- The agency should also describe, in Chapter 8, the potential impacts of induced seismicity (associated with and likely caused by 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 and storage vessels, and also to pipelines transporting hydraulic fracturing-related water and wastewater).
- The final Assessment Report should further describe that technologically-enhanced naturally occurring radioactive materials (TENORM) may pose a significant risk since treatment processes used to remove other constituents (such as metals, biochemical oxygen demand, or TDS) from hydraulic fracturing wastewaters may not remove radionuclides to levels that are protective of public health. The frequency and severity of impacts associated with strontium in hydraulic fracturing wastewaters should also be acknowledged in the final Assessment Report.
- The final Assessment Report should include analyses on the potential for hydraulic fracturing wastewaters to form nitrosamines (e.g., N-Nitrosodimethylamine, NDMA,) and describe the potentially significant impacts of nitrosamine formation within hydraulic fracturing wastewater discharges on drinking water resources.

Chemicals Used or Present in Hydraulic Fracturing Fluids (Charge 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?

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 constituents employed in hydraulic fracturing in an inclusive manner, and not restrict the criteria for selection of hydraulic fracturing constituents of concern to solely constituents that have noncancer oral reference values (RfVs) and cancer oral slope factors (OSFs) that were peer reviewed only by a governmental or intergovernmental source. 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 constituents 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 constituents with RfVs without excluding other quality toxicological information that is useful for hazard and risk assessment purposes.

The final Assessment Report should explicitly indicate what fraction of the constituents identified in hydraulic fracturing fluid and/or produced waters have some hazard information (e.g., toxicity data available from or used by the U.S. federal government, state governments, 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 other constituents (e.g., metals, radionuclides) in hydraulic fracturing wastewater that were discussed in earlier chapters. An important limitation of the EPA's hazard evaluation of constituents across the HFWC is the agency's lack of 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 within the final Assessment Report the most important/likely exposure scenarios (durations and routes) and hazards (constituents) and obtain toxicity information relevant to those exposure scenarios.

The EPA uses FracFocus 1.0 as the primary source of information on the identity and frequency of use of constituents in hydraulic fracturing processes. The SAB expresses concern that the FracFocus database may not be sufficient because it does not include certain confidential business information (CBI) which is proprietary, and lacks information on the identity, properties, and frequency of use for approximately 11% of hydraulic fracturing constituents used in HF operations (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 constituents that the EPA may have, and by using information provided in updated versions of FracFocus on chemical class, type, mass and concentration (i.e., concentration of the constituent, in terms of % by mass, in the hydraulic fracturing fluid). Based on this information, the agency should assess and clearly describe how gaps in knowledge about proprietary constituents affect the uncertainty regarding conclusions that can be drawn on potential impacts of hydraulic fracturing on drinking water resources. Since the FracFocus data that the agency assessed were current up to February 2013, the SAB also recommends that the final 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. As feasible, the EPA should consider conducting some preliminary analyses of trends as part of the final Assessment Report. For example, analyses on trends in green chemical usage in HF could be conducted. Further, the EPA should 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 constituents used during HF operations (for example, chemical type and categories).

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 to better understand the intensity and duration of exposures to constituents of flowback and produced water, the SAB recommends this as a longer-term future activity.

In Chapter 9, the EPA presents a MCDA approach that the EPA conceived, designed and formulated as a logical approach for assessing the scope and potential impacts of hydraulic fracturing on national drinking water resources given that the information used is limited and fragmented (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 of, 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 physicochemical score. While useful in judging a constituent's likelihood of occurrence in drinking water, this value may be a relatively poor surrogate for actual exposure. As an example, constituents 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 constituents used in hydraulic fracturing fluids and 23 constituents 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 clarity, the final Assessment Report should distinguish between constituents injected into a hydraulic fracturing well vs. constituents and hydrocarbons that come out of the well in produced fluids.

The SAB suggests that if no constituents are added to a hydraulically fractured well, there is still a potential for impacts to drinking water resources from constituents present naturally in the subsurface which could also be brought to the surface in produced water. In Chapter 9 and throughout the draft Assessment Report, 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 constituents identified as being of most concern in produced water are products of the hydraulic fracturing activity, flowback, or later-stage produced water, or are constituents 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, which can be considered a recommendation for longer-term future research activity. Such activities will help inform the readers about the different characteristics of HF flowback and produced waters and in-situ groundwater constituents 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 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 were discussed at length by the SAB Panel. The SAB finds that several major findings 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.*" (on page ES-6).
- "*High fracturing water use or consumption alone does not necessarily result in impacts to drinking water resources.*" (on page ES-9, lines 19-20).
- *"None of the spills of hydraulic fracturing fluid were reported to have reached groundwater."* (on pages ES-13 and 10-8)
- "*The number of identified cases, however, was small compared to the number of hydraulically fractured wells.*" (on page ES 6).

- "*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.*" (on page ES-15, lines 34-35).
- "*Chronic releases can and do occur from produced water stored in unlined pits or impoundments, and can have long-term impacts*." (on page ES-19, lines 18-19).

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. Four Panel members concluded that the major finding described above under the first bullet is clear as written.

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 final Assessment Report in both the Executive Summary and Chapter 10 Synthesis, including specific cases of drinking water impacts, that relate to these major findings.

The agency should revise the synthesis discussion in Chapter 10 to present integrated conclusions, rather than a summary of findings from Chapters 4-9. The agency should also revise Chapter 10 to discuss methods to reduce uncertainties related to the HFWC, including ongoing research, and 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 impacts may occur infrequently, but they have the potential to be severe and the Executive Summary should more clearly describe such impacts. Further, the locally important impacts are unlikely to be captured in a national level summary of impacts.

The final Assessment Report should also identify ongoing research and needs for future research, assessment and field studies. The SAB recommends 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 or complete.

2. INTRODUCTION

2.1. <u>Background</u>

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 and oil from sources such as coalbed methane and shale formations. The 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 2015a), 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 and respond to specific charge questions.

The draft Assessment Report synthesizes available scientific literature and data on the potential that hydraulic fracturing for oil and gas production may 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. <u>SAB Review Process</u>

In response to the U.S. Congress, the EPA developed a study scope for the HF study (U.S. EPA 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, 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 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. The SAB Hydraulic Fracturing Research Advisory Panel held a consultation with agency staff in an open meeting on May 7-8, 2013. At the May 2013 consultation meeting, ORD briefed the SAB Panel on the current status of its research, and the 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 individual written responses which were posted on the SAB May 2013 meeting webpage.

On June 4, 2015, ORD released its draft Assessment Report and requested the SAB to conduct a peer review on the draft Assessment Report. On September 30, 2015, the SAB 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 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 at the beginning of each section below and in Appendix A.

The SAB Panel held a public teleconference call on December 3, 2015 to complete agenda items from the October 28-30, 2015 SAB Panel meeting and further develop preliminary key points in response to charge questions on the agency's draft assessment. The SAB Panel then held public teleconferences on February 1, February 2, March 7 and March 10, 2016, to discuss substantive comments from Panel members on this draft SAB report. At a public meeting on June 14, 2016, the chartered SAB deliberated on the SAB Panel's draft report and agreed that chair and the lead reviewers on the chartered SAB would work with the chair of the SAB Panel to revise the draft SAB report in accordance with discussions at the June 14, 2016 public meeting.

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 United States, 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 to 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 be explicit about how its own research was used 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 final Assessment Report should provide additional explanation of the rationale for the agency's choice to use the HFWC to assess impacts of hydraulic fracturing on drinking water resources. The EPA should discuss in the final 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 final Assessment Report, while others (e.g., contamination from drilling fluids and cuttings) were considered to be beyond the scope of this assessment. Also, the EPA should consistently revise text throughout the final Assessment Report when referring to hydraulic fracturing to note that the EPA is referring to the entire HFWC, consisting of the five stages defined in the 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, the statement in Chapter 1 about aspects of the draft Assessment Report that are outside 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 revise statements in Chapter 1 to include situations and analyses that are discussed later in the draft Assessment Report, or if appropriate to the draft Assessment Report's goals, exclude them from later discussion.

The intended users of the final Assessment Report range from policy makers and regulators to the industry and the public; however, parts of Chapters 1 to 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 the technical material. Where appropriate, the EPA should move some technical details to an appendix of the final Assessment Report, replaced by graphical material. The SAB recognizes that many readers of the final 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 is generated by experiences at individual sites. In Chapter 1, the agency should acknowledge the importance of these experiences, and the needs associated with public outreach and education related to drinking water quality.

In Chapter 1, the agency 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 regulating HFWC activities.

The final 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.

EPA Response: In response to SAB's comment about distinguishing the goals of the assessment, we now have a "Goals" heading in Chapter 1 and a clear, direct statement of the assessment goals.

We now clarify, in several places, that research conducted by EPA under the Agency's Hydraulic Fracturing Drinking Water Study and published separately from the Assessment Report was cited in the Assessment Report. We also emphasize that the original research was integrated and interpreted in the assessment in the context of other sources of publicly available data and information.

Concerning SAB's request for more explanation on why the hydraulic fracturing water cycle was used, we clarify that the hydraulic fracturing water cycle was developed with input from stakeholders and the SAB. The hydraulic fracturing water cycle, and consequently the Assessment Report, reflect interest from stakeholders in not only understanding impacts from the act of hydraulic fracturing itself, but also the activities involving water that enable it, without broadly examining impacts from oil and gas production development.

Regarding presenting overly technical material, Chapter 2 in the draft Assessment Report, upon which the SAB commented, is now Chapter 3 in the final Assessment Report. Chapter 3 of the final Assessment Report has been significantly revised to make it more accessible to a non-technical audience. Throughout the chapter, the technical level of discussion has been reduced and figures, photographs, and illustrations have been integrated into the chapter discussions to facilitate understanding of the information presented. The text has generally been made more "plain language," and technical footnotes have been edited or replaced with simpler, in-text definitions. Simpler discussions are included along with in-text references that point the reader toward more detailed discussions in the technical chapters that follow.

We acknowledge concerns raised by residents living in close proximity to hydraulically fractured wells about the quality of their water. We clarify that a comprehensive review of federal, state, tribal, and local laws, regulations, policies, and guidance are outside the scope of this assessment, but we do present a general overview of how federal and state governments work together to protect drinking water resources from potential impacts of activities in the hydraulic fracturing water cycle. We emphasize (and support with published literature) that states have the primary responsibility in this area.

In Chapter 10, the synthesis chapter, we have added text to acknowledge the industry is rapidly evolving and this Assessment Report represents a snapshot 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 finds that the section on site identification and well development should include some discussion noting that the geological formations now being targeted for oil and gas production using hydraulic fracturing and horizontal drilling require closer well spacing that, compared to conventional drilling methods, may have greater potential impacts on drinking water resources (Zoback and Arent 2014). More discussion of the potential impacts on drinking water resources, both positive and negative, of well densities and multiple wells on one pad in unconventional oil and gas development should be included. 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. In Chapter 3, the agency 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 over pumping or ground subsidence associated with the deeper aquifers in the West if such aquifers are considered potential future hydraulic fracturing water sources). The EPA should also consider including a discussion in Chapter 3 on how the EPA and states protect underground sources of drinking water from oil, gas, and injection wells via well completion standards.

EPA Response: The draft Assessment Report described drinking water resources in its Chapter 3 and an overview of hydraulic fracturing activities in its Chapter 2. These chapters have now been reversed in their order.

Regarding time scale of hydraulic fracturing, the original figure in the chapter illustrating the timeline and summary of operational activities at a hydraulic fracturing well site has been revised and now includes the approximate time span/duration of each activity, including that of the hydraulic fracturing event. The revised figure (now Chapter 3, Figure 3-5) also identifies each of the Assessment's hydraulic fracturing water cycle components within the broader well-site activities. The relatively short duration of the hydraulic fracturing phase of work ("up to several weeks") is now identified in this figure, is explicitly noted in the accompanying text, and has been referenced in another section of Chapter 3.

Regarding closer well spacing, text was added in Chapter 3 to note that multiple wells can be located on a single well pad and that multiple laterals can extend from a single well that result in a higher well density in the subsurface. Additional discussion of the subsurface implications on potential impacts to drinking water resources due to multiple wells and well density is included in Chapter 6.

Regarding hydraulic fracturing being conducted in close proximity to large populations, the proximity between hydraulic fracturing locations and drinking water resources, including public water supplies, is discussed in several places in the final Assessment Report, including the Executive Summary.

In response to SAB's comment asking for more description of the geological framework and local geology, we generally did not add this information to Chapter 2. We did not do this because Chapter 2 is a general introductory chapter, giving an overview of drinking water resources in the United States. We did add more information on the relative vertical separation between drinking water resources and hydraulic fracturing in the subsurface (Figure 2-3). This figure, along with figures in Chapter 6 illustrating production well construction, rock mechanics, the actions of hydraulic fracturing, and in some cases, the local geology, improve the reader's ability to understand the 3-dimensional aspects of hydraulic fracturing and measures of proximity between drinking water resources and hydraulic fracturing.

Concerning more description of potential water supply issues in the future, Chapter 2 also describes studies describing losses of groundwater over time, including, that between 1900 and 2008, the U.S. Geological Survey estimates a loss of approximately 240 cubic miles of groundwater of which about 20% occurred in the last eight years and that the depletion is more pronounced in arid and semi-arid western states than in more humid eastern states.

Regarding well completion standards, regulatory and best management practices are outside the scope of this assessment. We have added to Chapter 1 a general overview of how federal and state governments work together to protect drinking water resources from potential impacts of activities in the hydraulic fracturing water cycle.

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 of 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, references to "co-location" of hydraulic fracturing with surface and groundwater should be clarified.

Within Chapters 2 and 3, the EPA also should discuss new hydraulic fracturing technologies, best management practices and federal, state and tribal standards and regulations intended to improve hydraulic fracturing operations associated with each stage of the HFWC. The EPA may develop these summaries as a longer-term future activity.

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, and aquifer thicknesses). All of this information is available from the U.S. Geological Survey (USGS 1996; 2000).

The final Assessment Report should discuss the criteria that the agency used to select 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 distances greater than one mile 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 final 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 existing and potential future water-supply aquifers compared to the depths of most hydraulically fractured wells. In addition, in regard to potential impacts on aquifers, the final Assessment Report should present more information regarding situations where the vertical distance between the hydraulically fractured production zone and a current or future drinking water source is relatively small depending on local hydrogeological conditions. Differences in the fracturing morphology as a function of depth should also be discussed. The EPA should include a graphical representation of this topic to improve the clarity of the discussion, and consider including graphs from a 2012 publication on microseismic fractures in shale plays (Fisher and Warpinski 2012).

Many of the public comments on the EPA's draft Assessment Report expressed concern that operations associated with the HFWC had impacted nearby water wells or springs; often describing problems with attribution even after water testing by homeowners, regulators, or industry. This highlights important challenges with understanding whether the observed conditions (regarding methane, dissolved mineral constituents, or other contaminants) existed prior to the drilling; were caused by the drilling and extraction process; or were caused by other factors. The SAB suggests that the EPA address these issues in Chapter 4 of the final Assessment Report, with brief descriptions of: (1) Regulatory frameworks of the oil and gas industry aimed at the protection of source water supplies and the presumption of liability (over specific setback distances and timeframes); (2) Regulatory frameworks (or lack thereof) of the oil and gas industry affecting standards for construction of water wells; and (3) Educational needs toward public understanding of water well construction, maintenance, water testing, and data interpretation. Some publications on water well construction, maintenance, water testing, and data interpretation that may assist the EPA in addressing these topics in the final Assessment Report include DeSimone et al. (2014); Matheson and Bowden (2012); Minnesota Department of Health (2014); and US. Geological Survey (1994).

Within the final Assessment Report, the agency should also consider including a discussion highlighting communities experiencing water constraints that are or might be related to hydraulic fracturing activities in those regions. To the extent that data are available, the EPA could include quantifiable information on specific local and regional aquifers that are particularly impacted by hydraulic fracturing activities. The EPA should consider including maps of aquifers similar to the county-specific maps that the EPA provided within Chapter 3.

EPA Response: As noted previously, Chapters 2 and 3 have been reversed in their order. Concerning SAB's suggestion of discussing the temporal characteristics of the hydraulic fracturing water cycle, see our response above.

Regarding clarifying the lateral and vertical distance between hydraulic fracturing operations and drinking water resources, illustrations in Chapter 2 convey the hydrologic cycle (Text Box 2-1), depict the relative lateral proximity between public drinking water sources and hydraulically fractured wells (Figure 2-2), and describe the relative vertical separation between drinking water resources and hydraulic fracturing in the subsurface (Figure 2-3). These figures, along with figures in Chapter 6 illustrating production well construction, rock mechanics, and the actions of hydraulic fracturing, improve the reader's ability to understand the 3-dimensional aspects of hydraulic fracturing and measures of proximity between drinking water resources and hydraulic fracturing.

Regarding new technologies and continued improvement, text has been added to Chapter 3 that acknowledges and describes that hydraulic fracturing technologies and processes have changed and continue to evolve with several specific examples included.

Chapter 2 now provides greater descriptive emphasis on groundwater. It addresses groundwater and aquifer characterization, including discussion of the ubiquity, origin, depth, quality and quantity of groundwater.

Concerning the one-mile radius, we have added explanation in Chapter 2 that the selected one-mile distance simply provides a consistent approach and that local topographic conditions could support the use of a different analysis at any specific site.

Regarding regulatory and best management practices, several references are made to general regulatory topics in Chapter 3 (e.g., "Pit construction is generally governed by local regulations."). However, regulatory and best management practices are outside the scope of this assessment. We have added to Chapter 1 a general overview of how federal and state governments work together to protect drinking water resources from potential impacts of activities in the hydraulic fracturing water cycle.

Chapter 2 now also includes examples of loss of drinking water resources and challenges faced in some areas of the United States to meet local drinking water demand. More information, including on specific locations and water use values, is presented in Chapter 4.

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 available information concerning the sources and quantities of water used from surface water, groundwater, and treated wastewaters from CWTFs or POTWs. 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 from CWTFs or POTWs is nicely characterized. References are included regarding the use or reuse of wastewater, as well as brackish groundwaters containing 3,000–10,000 mg/L TDS that are 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 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. 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 in the final Assessment Report, the agency should succinctly summarize the regulatory, legal, management, and market frameworks in which the HFWC activities are managed that aim to minimize the potential for these negative impacts. For example, the regulatory framework in Pennsylvania that is discussed in the draft Assessment Report and its effects on managing water withdrawal could be cited among the EPA's major findings.

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.

The SAB notes, but did not independently confirm, the EPA conclusion, that there are important gaps in the data available to assess water use that limit understanding of hydraulic fracturing's potential impacts on water acquisition, which were identified and discussed in the draft Assessment Report in the context of areas 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 U.S. database from the USGS, where major limitations are associated with limitations of the spatial and temporal scale of the data (e.g., information is not available at sub-county scales, and information on water used in hydraulic fracturing is reported as part of larger categories of mining water use).

> **EPA Response:** Concerning SAB's comment on focusing on local scales, we have further emphasized the potential for localized impacts throughout the chapter. We now clearly state that the potential for impacts depends primarily on the balance between water use and availability at local scale, and a variety of regional- and site-specific factors (e.g., reuse rates, water management) can modify this balance. We frame the chapter with this concept in the introduction and revisit it again in the conclusions. In between, we emphasize the local scale wherever possible, including providing illustrative case studies. We believe this chapter now conveys the critical importance of focusing on local scales when evaluating the potential impacts of hydraulic fracturing water acquisition. Finally, we reviewed the chapter for accuracy and consistency of terminology.
>
> A summary or evaluation of regulations and best management practices regarding water acquisition is outside the scope of this assessment. Where documented in the scientific literature, we considered water management practices that help mitigate the potential for water acquisition impacts at the local level (e.g., reuse of wastewater, brackish water use, low-flow criteria). For instance, we included a discussion of management practices in the Susquehanna River Basin (SRB), where prescribed low-flow thresholds can reduce the potential for impacts. The SRB example is provided because it is extensively described in the scientific literature, including a case study showing low-flow thresholds can reduce the potential for impacts at the local scale.

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 the 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 final Assessment Report should discuss regulatory mechanisms that are in place to address the potential for local impacts.

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 the 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 15 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 volumes of water required in the hydraulic fracturing process are used infrequently, during initial well completions and re-stimulation operations. The final Assessment Report should explicitly state that many stresses to surface or groundwater resources associated with water acquisition and hydraulic fracturing are often localized in space and temporary in time, but nevertheless can be important and significant.

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 effects of hydraulic fracturing water withdrawals on short-term water availability, since case studies may provide information on the most relevant and appropriate spatial and temporal scales discussed in the draft Assessment Report for assessing the impacts of water acquisition. The SAB anticipates that this further work is anticipated to involve EPA assessment of a large number of case studies that would explore varying factors such as climate, geology, water management, and water sources. While the draft Assessment Report discusses 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 agency should consider the recent publication by Botner et al. (2014) on this topic. 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. Two Panel members do not find the lack of prospective case studies to be a limitation to the draft Assessment Report, based on the perspective that investigations conducted by universities, consulting firms, and other external stakeholders could be used in lieu of the agency conducting such studies. The SAB recommends that as a future activity the EPA should collect data available from state agencies such as the Pennsylvania Department of Environmental Protection on this topic. The EPA should clarify if any information from 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 to put numeric values in the proper time perspective. The SAB is concerned 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 of 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, to make sure the information is accurately conveyed.

EPA Response: As noted previously, we agree with the SAB on the importance of focusing on the local scale—see our more detailed response above.

Regarding a comparison with other water use categories or annual streamflow, we compared hydraulic fracturing water use with total water use, which is a composite of multiple water use categories. We believe a comparison with annual streamflow at larger scales would not be informative, since it would suffer from the same limitations of examining water acquisition at larger spatial or temporal scales. A more local-scale examination of this question would require longer-term research as noted by the SAB. It was generally beyond the availability of data and our means for a national assessment, but we did cite local case studies that did examine water acquisition in relationship to streamflow at finer spatial and temporal scales.

Concerning SAB's comment to cite local case studies, we note that the chapter includes discussion of several local case studies (e.g., in the SRB, the Upper Colorado River Basin, and the Eagle Ford Shale in southern Texas).

Appendix A includes an explanation of why the Agency was unable to conduct the prospective case studies identified in the Hydraulic Fracturing Drinking Water Study Plan. We revised the chapter to include a footnote in our introduction, explaining that the Well File Review was planned to inform the water acquisition stage of the water cycle, but did not yield any useable information on this topic. Although information in some well files was of good quality, the well files generally contained insufficient or inconsistent information on nearby surface and groundwater quality, injected water volumes, and wastewater volumes and disposition; therefore, these data were not summarized.

Finally, we have reviewed the units and values in the chapter for clarity and accuracy. We have added timeframes associated with water usage or impacts where appropriate.

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 from CWTFs or POTWs) 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 an appropriate criterion to use to determine occurrence 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. While the agency concluded they documented no case of stream impacts associated with the process of hydraulic fracturing, there may be impacts associated with the HFWC or other activities that may have occurred. 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 (negative or positive).

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 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 many stresses to surface or groundwater resources associated with water acquisition for hydraulic fracturing are often localized in space and temporary in time, but nevertheless can be important and significant. 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 final 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, groundwater use caused substantial changes in water storage and drawdown of the water table in a relatively small portion of the shale play area; though overall supply was found to be sufficient in most of the shale play area; as described in Text Box 4-3 of the draft Assessment Report (Scanlon et al. 2014).

EPA Response: In response to SAB's comment on a stream or well running dry as being an inappropriate criterion, we have removed this finding from the chapter.

We agree that impacts will occur locally (i.e., at particular withdrawal points) and during specific time periods (e.g., during seasonal low flows or drought)—see our more detailed response on this above. We do emphasize that the potential for impacts is greatest in areas with high hydraulic fracturing water acquisition, low water availability, and frequent or severe drought.

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.

> **EPA Response:** In response to this comment, we have revised our discussion of the case studies in Colorado and Pennsylvania to better reflect the specific language used in the studies. As a result, we have removed the phrase "did not show impacts."

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, the chapter should more clearly emphasize that many stresses on water resources from water acquisition for hydraulic fracturing are expected to be localized in space and temporary in time, 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 in 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 final Assessment Report should discuss regulatory mechanisms that are in place to address the potential for local impacts.

Second, the SAB encourages the EPA to explore and describe how water acquisition and associated potential impacts on lowered streamflow and water tables experiencing local or 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 final Assessment Report should describe what might be the effects on chloride or total dissolved solids concentrations in streamflow, and how this might affect water supply and treatment costs. The SAB also recommends that the EPA conduct a more thorough study of this issue, including a detailed economic analysis, as a long-term future activity.

Third, reuse of hydraulic fracturing-related 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 being used to facilitate use and reuse of produced water and use of other historically underutilized sources of water (e.g., seawater, brackish groundwater containing 3,000–10,000 mg/L TDS, mine drainage, and treated wastewater) that if used for hydraulic fracturing (or other purposes) could reduce the impacts of water acquisition on drinking water sources. 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 final 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 a dry climate, the wastewater quantity and 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). The SAB also notes that the use of municipal wastewater for hydraulic fracturing could remove this source for future consideration as a permanent or emergency water supply.

> **EPA Response:** As noted previously, we agree with the SAB on the importance of focusing on the local scale—see our more detailed response above.

Concerning how water acquisition for hydraulic fracturing could affect drinking water quality, we note that we did discuss this topic in the locations where we had information (e.g., see Sections 4.5.1 and 4.5.3). As SAB notes, a more thorough study of this issue, including a detailed economic analysis, would require longer-term research.

Regarding reuse, we discussed water management practices that help mitigate the potential for water acquisition impacts at the local level (e.g., reuse of wastewater, brackish water use, low-flow criteria). A detailed discussion of reuse technologies is outside the scope of Chapter 4. However, we have responded to this comment by acknowledging reuse technologies and referring our readers to Chapter 8 (Wastewater Disposal and Reuse) for further discussion (see Section 4.2.2). Also, in response to this comment, we have updated our reuse numbers from the latest scientific literature.

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 water 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 an appropriate criterion to use to determine occurrence 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. While the agency concluded they documented no case of stream impacts associated with the process of hydraulic fracturing, there may be impacts associated with the HFWC or other activities that may have occurred. 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 (negative or positive.)

EPA Response: As noted previously, in response to SAB's comment on a stream or well running dry as being an inappropriate criterion, we have removed this finding from the chapter. We state that the potential for impacts depends on the balance between water use and availability at local scales, and a variety of regional- and site-specific factors (e.g., reuse) can modify this balance.

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. The SAB notes, but did not independently confirm, the EPA conclusion, that there are reportedly important gaps in the data and information available to assess water use. 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 (http://fracfocus.org) is a database platform 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. Another database EPA utilized is the 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 reportedly 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 the various regulatory approaches for their efficacy in safeguarding against freshwater depletion at local scales. The EPA should compile the various regulatory approaches in local areas that should be succinctly summarized within the final Assessment Report, and conduct evaluation of these approaches for their efficacy in safeguarding against freshwater depletion at local scales. The EPA may consider addressing both of these recommendations as a longer-term activity.

At local scales, where the greatest impacts are most likely to occur, the draft Assessment Report describes these data as generally lacking. 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 examining other information not in the archival scientific literature and common databases 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 uses, and less focus on hypothetical scenarios and modeling.

EPA Response: We agree with the SAB that updating FracFocus and USGS water use volumes would require longer-term future activity. We did not do this for the final Assessment Report because of resource and time constraints. Moreover, this information is unlikely to change the conclusions of our county level assessment and does not directly address impacts. We explored the implications and uncertainties of using FracFocus water use data in the chapter (see Text Box 4-1). We included updated water use per well numbers based on Gallegos et al. (2015),[1] which show an increase in water use per well over time due to an increased proportion of horizontal wells. We did not update our total water use numbers from the USGS because their *Water Use in the United States*[2] data are published every five years and are, therefore, unavailable at this time.

It was outside of the scope of this assessment to provide a review of regulations and their efficacy.

Concerning the use of the Well File Review and other databases, data from the Well File Review were of insufficient quality for water use, and thus the sources and volumes of water used for hydraulic fracturing among study wells were not incorporated into the second Well File Review report. We included a footnote in our introduction, explaining that the Well File Review was planned to inform the water acquisition stage of the water cycle, but did not yield useable information on this topic (see Section 4.1). More broadly, we were generally limited to published scientific data, and we were not able to analyze data collected, but not published or otherwise accessible.

[1] Gallegos, TJ; Varela, BA; Haines, SS; Engle, MA. (2015). Hydraulic fracturing water use variability in the United States and potential environmental implications. Water Resour Res 51: 5839-5845. http://dx.doi.org/10.1002/2015WR017278
[2] Maupin, MA; Kenny, JF; Hutson, SS; Lovelace, JK; Barber, NL; Linsey, KS. (2014). Estimated use of water in the United States in 2010. (USGS Circular 1405). Reston, VA: U.S. Geological Survey. http://dx.doi.org/10.3133/cir1405

3.2.6. 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 data on water consumption and use, especially at local scales, and in the representativeness of the case studies used, many interactive factors that influence the potential for effects of hydraulic fracturing on water availability and quality (e.g., climate, geology, water management, and multiple water sources) could not be fully characterized.

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 datasets 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 excel at 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. 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's *Thematic Areas for Improving the Draft Assessment Report* and also within Section 3.2.5 of this SAB report.

The EPA could 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 that the EPA developed to support the draft Assessment Report. 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. Within the final Assessment Report, the EPA should add at least a brief summary of the information about water acquisition that was provided by the Well File Review and explain why that information was not included within the 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 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 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. For example, in the Susquehanna River Basin, the Susquehanna River Basin Commission (SRBC) has the regulatory authority and has well-established programs in permitting, collecting, monitoring and managing water resources. The EPA may develop this summary as an item for longer-term future activity.

For the Susquehanna River Basin, the EPA could present more detail, using monitoring data from industry and from the SRBC, to develop a better understanding of 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 examining 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 final Assessment Report, the EPA is encouraged to describe its efforts to investigate data available from state agencies, and describe what critical lessons were learned from the effort.

> **EPA Response:** Concerning the SAB's comments about describing what datasets were used and future needs, Chapter 1 describes our sources of information for the Assessment, which include data from the states. A detailed description of future data and research needs is also outside our scope, but limitations and data gaps are discussed in our uncertainties section (see Section 4.6.3). The suggestion to estimate the level of effort that would be required to gather and organize data collected from the states is outside the scope of this Assessment Report.
>
> Regarding our use of data from FracFocus 1.0 and the Well File Review, see our responses above.
>
> In answer to SAB's urging of additional local scale studies or synthesizing information collected by the states in the future, there are no additional research plans at this time.
>
> In regards to summarizing best management practices, we discussed water management practices when they were addressed in the scientific literature. For instance, we included a discussion of management practices in the SRB, where prescribed low-flow thresholds can reduce the potential for impacts. The SRB example was provided because it is extensively described in the scientific literature, including a case study showing low-flow thresholds can reduce the potential for impacts at the local scale. A full summary of best management practices was outside of the scope of this Assessment Report.
>
> In response to SAB's request to present more detail on the SRB, we note that this was one of the EPA studies highlighted in the chapter and subject of a text box (Text Box 4-4).

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 Review 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 final 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.

- DeSimone, L.A., P.B. McMahon, and M.R. Rosen. 2014. The quality of our nation's waters—water quality in principal aquifers of the United States, 1991–2010. U.S. Geological Survey Circular 1360, 151 p. http://dx.doi.org/10.3133/cir1360 Available at http://pubs.usgs.gov/circ/1360/pdf/circ1360Report.pdf

- 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

- Fisher, M., and N. Warpinski. 2012. Hydraulic fracture height growth: Real data. *SPE Prod. Oper.* 27: 8-19. http://dx.doi.org/10.2118/145949-PA

- 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.

- Matheson, M., and J. Bowden. 2012. How well do you know your water well? Available at: http://epa.ohio.gov/Portals/0/general%20pdfs/HowWellDoYouKnowYourWaterWell.pdf

- Minnesota Department of Health. 2014. Well owner's handbook - a consumer's guide to water wells in Minnesota. Well Management Section, Environmental Health Division, Minnesota Department of Health. Available at: http://www.health.state.mn.us/divs/eh/wells/construction/handbook.pdf.

- Rahm, B.G., and 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. 2014.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.

- USGS (U.S. Geological Survey). 1994. Ground water and the rural homeowner. Available at: http://pubs.usgs.gov/gip/gw_ruralhomeowner/.

- 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.

EPA Response: We considered all literature recommended by the SAB and included new citations in the final Assessment Report where appropriate.

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 the chemical mixing of water, constituents, 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 constituent use. The chapter describes the frequency with which hydraulic fracturing constituents are used at the national scale, oil vs. gas usage of constituents nationally, and a state-by-state discussion on the frequency of hydraulic fracturing constituent use. Chapter 5 also examines constituent management and spill potential associated with hydraulic fracturing operations, constituent 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 constituents, trends in constituents used in hydraulic fracturing, and a chapter synthesis of major findings, factors affecting the frequency or severity of impacts, and uncertainties.

3.3.1. Composition, Volume and Management of Hydraulic Fracturing Constituents

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 on-site and 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 constituents used to create hydraulic fracturing fluid. Chapter 5, as it stands, provides little information on the magnitude of hydraulic fracturing spills and it does not adequately describe either the uncertainty associated with the data or the lack of understanding of such spills. Consequently, the EPA should revise its assessments associated with this stage of the HFWC to address these concerns. An accurate assessment would detail data gaps and quantitative uncertainties and provide 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 educate and alleviate the basic concerns regarding 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 on drinking water supplies.

EPA Response: We believe this chapter does accurately and clearly summarize information on the chemical mixing stage of the hydraulic fracturing water cycle. Where appropriate, we have added additional text to improve accuracy and clarity.

Regarding spill information, EPA performed an analysis of spill reports (which was published separately from the Assessment Report)[1], and we have added spill details in Section 5.6.1. We have added a figure on the magnitude of spills and their distribution (for the entire hydraulic fracturing water cycle and the chemical mixing stage in particular). We have included additional analysis of the North Dakota data set and other spills studies in Section 5.2.1.

Concerning information on chemical additives, the process of managing chemicals is discussed in Section 5.5 “Chemical Management and Spill Potential.” In Text Box 5-1, we have added text discussing the challenges of the reporting structure used in the FracFocus database (neither chemical volumes nor masses are provided as they are submitted as maximum fractions). In Text Box 5-2 we discuss confidential business information (CBI). We provided two general fluid compositions in Table 5-4. The challenge of presenting a fluid composition is that we do not know how representative it is of fluids in general. We have included a new figure, Figure 5-4, of two example fluids. We estimated individual chemical volumes based on a series of simplifying assumptions in Figure 5-5. We added additional text stating these were the only data we had. There is not much research on the fate and transport of spilled chemicals. We provide a discussion on the general processes governing fate and transport and exposure concentrations in the environment. We have incorporated more discussion on the data gaps and uncertainties.

[1]U.S. EPA (U.S. Environmental Protection Agency). (2015). Review of state and industry spill data: Characterization of hydraulic fracturing-related spills [EPA Report]. (EPA/601/R-14/001). Washington, D.C.: U.S. Environmental Protection Agency, Office of Research and Development. http://www2.epa.gov/hfstudy/review-state-and-industry-spill-data-characterization-hydraulic-fracturing-related-spills-1

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, within the Executive Summary's *Thematic Areas for Improving the Draft Assessment Report* and also within Section 3.2.5 of this SAB report.

The draft Assessment Report broadly describes the extent of the constituent 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 constituents will behave. Since the majority of hydraulic fracturing fluids are aqueous-based, concentrations in this report are calculated based on water as the solvent. 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 final Assessment Report provide a more rigorous explanation of volume, concentration, mass and chemical activity as it relates to the solvent. The final 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 types of data available from state agencies. If the appropriate data are not currently available (e.g., the masses of constituents spilled have not been reported), then the final Assessment Report needs to detail the data that must be acquired by states so that critical assessments can be made.

In addition, novel hydraulic fracturing fluids (e.g., energized fluids, foams, and gases) are currently in development, and the Assessment Report should provide further discussion regarding the impacts of these fluids on water quality, and the degree to which use of these fluids reduce water quantity requirements for flowback and produced water.

EPA Response: We base our discussion of hydraulic fracturing fluid composition on a wide range of literature, including textbooks on hydraulic fracturing, industry publications, and FracFocus. Despite the limitations associated with FracFocus, it provides substantial insight into water and chemical use for hydraulic fracturing. To address concerns regarding our use of data submitted to FracFocus 1.0, we compared results from our analysis of FracFocus 1.0 to the results presented in Konschnik and Dayalu (2016)[2]. Konschnik and Dayalu (2016) presents results of an analysis of data submitted to FracFocus 1.0 and 2.0. This comparison identified 263 new chemicals. Of these chemicals, only one was reported in more than 1% of disclosures, which suggests that these chemicals were used at only a few sites. The comparison also showed an increase on the percentage of disclosures that claimed at least one chemical as confidential. In the final Assessment Report, we note that the available information on chemicals used in hydraulic fracturing fluids is incomplete.

Throughout this chapter, we have added information on data required to reduce uncertainties. Section 5.10.3 "Uncertainties and Data Gaps" deals with these issues, and we explicitly state the types of data that would be required.

Section 5.9 discusses trends in the use of hydraulic fracturing chemicals. In this section, we discuss the ramifications on other stages of the hydraulic fracturing water cycle by the choice of different fluid composition. We discuss how the example of an energized fluid requires much less water, and thus less water in the water acquisition stage, with consequently less flowback and produced water and wastewater.

[2]Konschnik, K; Dayalu, A. (2016). Hydraulic fracturing chemicals reporting: Analysis of available data and recommendations for policymakers. Energy Policy 88: 504-514. http://dx.doi.org/10.1016/j.enpol.2015.11.002

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 for spilled liquids during routine operations; and (2) actions that can improve spill prevention. For example, Figure 5.13 indicates that approximately one-third 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 "site containment" or "outside containment" structures. 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 final Assessment Report, with an emphasis on what was spilled "outside containment."

Another source of uncertainty is the behavior of mixed constituents. To a certain extent the sub-text of the discussion is that the various additives behave 'conservatively' (i.e., are non-reactive) upon mixing. The EPA should describe what occurs when an acid comes into contact with some of the organic additives, and whether constituent behavior depends on the solvent (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.

EPA Response: Section 5.6 addresses spill prevention, containment, and mitigation. The goals of this Assessment were to discuss the potential impacts from activities in the hydraulic fracturing water cycle and the factors affecting the frequency or severity of impacts. It was not a risk assessment, and did not set out to quantify the efficiency of routine operations. Despite this, we did find and include information on spill rates. When a spill is reported, the volume of the spill is reported, and it does not necessarily state whether this is caused by multiple small leaks or a single leak. In some cases, the report may state that there were multiple spills of different volumes. In our revision, we have added a new figure that shows the distribution of spill volumes reported for the hydraulic fracturing-related spills characterized in US EPA (2015)[1] as well as the distribution of spill volumes for the subset of those spills that relate to the chemical mixing stage of the hydraulic fracturing water cycle. More than half of chemical mixing spills are less than or equal to 500 gallons). The information in our assessment for the 60% of spilled liquids in Colorado came from COGCC (2014)[2]. The information the SAB is requesting is not available in this reference.

Regarding the chemistry and behavior of mixtures, we did not intend to imply that these processes are well understood. Section 5.8 has been reorganized and rewritten to address the concerns of the SAB and the uncertainty introduced due to the complex nature of mixtures and fate and transport. We did not think that we had enough information to describe the reactions that could occur subsurface or once chemicals in the fluid interacted. We therefore did not include these topics.

Section 5.6 is devoted to spill prevention, containment, and mitigation. In this section, we specifically discuss primary containment and secondary containment, including discussing berms, booms, dikes, etc. We are not aware of literature we can cite to discuss how effective these approaches are or how much they are actually used.

[1]U.S. EPA (U.S. Environmental Protection Agency). (2015). Review of state and industry spill data: Characterization of hydraulic fracturing-related spills [EPA Report]. (EPA/601/R-14/001). Washington, D.C.: U.S. Environmental Protection Agency, Office of Research and Development. http://www2.epa.gov/hfstudy/review-state-and-industry-spill-data-characterization-hydraulic-fracturing-related-spills-1
[2]COGCC (Colorado Oil and Gas Conservation Commission). (2014). Risk-based inspections: Strategies to address environmental risk associated with oil and gas operations. (COGCC-2014-PROJECT #7948). Denver, CO.

Chemical and spill management and potential impacts on the environment: Within the Chapter 5 discussion on constituent and spill management and potential impacts on water resources, the datasets 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 finds that the draft Assessment Report's analysis of spill data cannot be extrapolated across the entire United States. The SAB also notes that geologies commonly vary within and between states and this limits potential extrapolation of this dataset towards topics other than frequency of spills (e.g., while the geology may not have a large effect on the frequency or volume of a spill, the dataset could be used to assess issues regarding the fate and potential impacts of spilled hydraulic fracturing constituents in different geologies). The SAB encourages the agency to contact state agencies, 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 final Assessment Report. The SAB recommends that the agency revisit a broader grouping of states and "refresh" the final 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 final 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.

EPA Response: As part of the Hydraulic Fracturing Drinking Water Study, the EPA undertook the spills study to investigate data from nine states, nine service companies, and nine oil and gas well operators. This is the most comprehensive analysis of spills related to hydraulic fracturing activities to date. EPA determined that Colorado spill reports were the most detailed of the nine states, and we performed an analysis for spill frequency. We state explicitly in our report that these numbers may not be representative of national spill rates or rates in other regions. However, given the limited data we have, we believe it is useful to include these data to provide context for what spill rates could be. We have included an additional analysis of the North Dakota data set as recommended by the SAB to add additional information on the spills rate. For this analysis, we have chemical mixing related spills solely, to provide context with the other studies. The North Dakota data provided additional information on spill volumes.

The SAB suggests that we stated that the risk to drinking water supplies is not substantial. This was not a risk assessment, and we did not address whether spills represent a substantial risk or not. We have reviewed our chapter and clarified any text that may suggest this is a conclusion of this chapter.

Trends in constituent use in hydraulic fracturing operations: Section 5.9 of the draft Assessment Report describes ongoing changes in the hydraulic fracturing industry in the form of developing fracturing fluid 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 fluid constituents and their safety. The SAB recommends that the EPA clarify in this section of the final Assessment Report that many issues may play an important role in the hydraulic fracturing industry's substitution of fracturing fluid 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 constituents used in the completion process.

EPA Response: We have expanded this section slightly. We have stated that there are a few reasons why the types of chemicals used may change: improving the hydraulic fracturing process, using greener/safer chemicals, and reducing overall cost. We have incorporated some text to discuss how the selection of fluid and chemicals used affects other stages of the hydraulic fracturing water cycle. There is not much information on trends. We have included a discussion of a more recent study of FracFocus data (Dayalu and Konschnik, 2016; Konschnik and Dayalu, 2016)[1,2], and a comparison to our findings.

[1] Dayalu, A; Konschnik, K. (2016). FracFocus Chemical Disclosure Registry 1.0 and 2.0: Data conversion and cleaning methods paper. Cambridge, MA: Harvard Law School.
[2] Konschnik, K; Dayalu, A. (2016). Hydraulic fracturing chemicals reporting: Analysis of available data and recommendations for policymakers. Energy Policy 88: 504-514. http://dx.doi.org/10.1016/j.enpol.2015.11.002

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. All but one Panel member are concerned that this major finding is supported only by an absence of evidence rather than by evidence of absence of impact. The EPA should assess the likelihood of detecting an impact given the current state of groundwater and surface water monitoring in the United States. If routine monitoring systems are adequate to capture this impact if it occurred, then a lack of evidence of impact may support a conclusion that there was no impact. If the routine monitoring systems would not be expected to capture an impact that occurred, then a lack of evidence of impact may not support a conclusion of no impact. The 'available information' has been broadly summarized in the draft Assessment Report but the limitations of the data sources (e.g., FracFocus) appear to have led to an incomplete record associated with the potential impacts associated with such spills. The SAB identifies issues regarding the EPA's reliance on the FracFocus version 1.0 database, and provides suggestions for acknowledging and addressing these concerns, within the Executive Summary's *Thematic Areas for Improving the Draft Assessment Report* and also within Section 3.2.5 of this SAB report. 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.

EPA Response: We used the word "documented" for the purpose of stating that there were no reported cases of impacts to groundwater. We did not mean to imply there could be no impacts. To address this unintended impression, we have rephrased the presentation of our results to clarify that we are not saying there are no impacts, but rather that we have no evidence of impacts. We now make it clear we have not seen any reported impacts to groundwater from spills in the chemical mixing stage. We discuss that the pathway exists and spills in other stages of the hydraulic fracturing water cycle have resulted in groundwater impacts. We additionally discuss the challenges in sampling and lack of sampling, and we do not imply that this means there are no impacts to groundwater.

Concerning our use of FracFocus, see our prior responses, including in the Thematic Areas Section of the Executive Summary above.

We did not intend to imply that spill volume is the sole metric for severity. However, if a single chemical is spilled, the severity of the spill of that chemical is related to the spill volume. Also, the larger volume spilled, the greater potential for it to reach a drinking water resource. There are many factors governing severity. This was clearly ambiguous in our presentation, and we have restructured our wording to minimize ambiguity. We have added a section to discuss fluid and additive composition based on FracFocus 1.0 data and the EPA FracFocus study[1]. We now include the maximum concentration (% by mass) to provide additional information on the fluid and additive composition.

[1] U.S. EPA (U.S. Environmental Protection Agency). (2015). Analysis of hydraulic fracturing fluid data from the FracFocus chemical disclosure registry 1.0: Project database [EPA Report]. (EPA/601/R-14/003). Washington, D.C.: U.S. Environmental Protection Agency, Office of Research and Development. http://www2.epa.gov/hfstudy/epa-project-database-developed-fracfocus-1-disclosures

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 finds 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 EPA's 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 2010 to 2011. Gross et al. (2013) write that:

> 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 final Assessment Report on the lack of data on spills, and also clarify whether the reported apparent lack of data is reflective of non-existent data or data reported somewhere but are not readily available. The SAB also recommends that the agency expand this chapter of the final 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 final 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 constituent that has the potential to reach an environmental receptor, and the toxicity of spilled constituents). Additionally, a number of states have spill reporting requirements, and processes, that may not yield data that are 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., see North Dakota Department of Health 2015). The final Assessment Report should include a discussion of this investigation and analysis

> **EPA Response**: Regarding our discussion of the EPA's analysis of the 457 spills, see our previous comment (note: this particular analysis examined 457 spills, not 497).
>
> On Gross et al. (2013)[2], the paper reports on all spills that happened on a hydraulic fracturing site, regardless of whether the spill was hydraulic fracturing related. We reviewed this paper, and no spills that were related to hydraulic fracturing fluids or chemicals reached groundwater. We have added to the text that this paper did not provide evidence of spills during the chemical mixing process. We have added some discussion of the Gross et al. (2013) as evidence that groundwater can be contaminated by hydraulic fracturing-related spills, but these were not

chemical mixing stage related. We have additionally added the work done by Drollette et al. (2015)[3], which had a similar result.

The Assessment used all publicly available data, citable data, and data that industry provided the EPA. We note when there may be data we do not have access to, such as CBI chemicals reported to FracFocus. An analysis of how spills are reported is out of the scope of this chapter. We have provided information on hydraulic fracturing fluids when available. We have included in this revision a section on the composition of fluids as reported in the EPA FracFocus study[4].

The revised Assessment defines severity as "the magnitude of change in the quality or quantity of a drinking water resource as measured by duration, spatial extent, contaminant concentration, or some other metric as defined in the text." In the revision, we have separated the discussion of “frequency” from “severity.”

We investigated the North Dakota database and identified spills related to injection fluids and chemicals. We report the number and the fraction of total spills, as well as the range of spill volumes and the median volume associated with spills. We also use the North Dakota data to estimate an additional spill rate.

[2] Gross, SA; Avens, HJ; Banducci, AM; Sahmel, J; Panko, JM; Tvermoes, BE. (2013). Analysis of BTEX groundwater concentrations from surface spills associated with hydraulic fracturing operations. J Air Waste Manag Assoc 63: 424-432. http://dx.doi.org/10.1080/10962247.2012.759166
[3] Drollette, BD; Hoelzer, K; Warner, NR; Darrah, TH; Karatum, O; O'Connor, MP; Nelson, RK; Fernandez, LA; Reddy, CM; Vengosh, A; Jackson, RB; Elsner, M; Plata, DL. (2015). Elevated levels of diesel range organic compounds in groundwater near Marcellus gas operations are derived from surface activities. Proc Natl Acad Sci USA 112: 13184-13189. http://dx.doi.org/10.1073/pnas.1511474112
[4] U.S. EPA (U.S. Environmental Protection Agency). (2015). Analysis of hydraulic fracturing fluid data from the FracFocus chemical disclosure registry 1.0: Project database [EPA Report]. (EPA/601/R-14/003). Washington, D.C.: U.S. Environmental Protection Agency, Office of Research and Development. http://www2.epa.gov/hfstudy/epa-project-database-developed-fracfocus-1-disclosures

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 dataset is that it does not represent the full suite of hydraulic fracturing operations taking place within the United States 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, within the Executive Summary’s *Thematic Areas for Improving the Draft Assessment Report* and also within Section 3.2.5 of this SAB report.

EPA Response: Concerning our use of FracFocus, see our prior responses, including in the Thematic Areas Section of the Executive Summary above. Considerable uncertainty persists because of the lack of data, and we have increased our discussion of the implications in the revised chapter.

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 constituents to environmental receptors. 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.

> **EPA Response**: In this Assessment, we explicitly define impact as "any change in the quality or quantity of drinking water resources, regardless of severity, that results from an activity in the hydraulic fracturing water cycle." We distinguish between "impact" and "severity," which we define as "the magnitude of change in the quality or quantity of a drinking water resource as measured by duration, spatial extent, contaminant concentration, or some other metric as defined in the text." The Assessment has two goals: one is to present potential impacts, and the other is to address factors affecting frequency and severity. We were unable to quantify severity, although we do discuss it qualitatively. We agree that the magnitude of impact is a function of the parameters stated by the SAB. However, given our limited data and/or access to data, we are unable to take the next step to assess the potential severity of impacts with an acceptable level of certainty. We do address chemical composition and types of spills. We cannot state what the composition of a spill is, because spill reports typically use terms like "fluid" or "biocide" without naming specific chemicals.

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

There are three areas of uncertainty in this chapter of the draft Assessment Report that should be described more clearly in the final Assessment Report:

1. <u>Uncertainty regarding undetected and unmonitored hydraulic fracturing constituents.</u> There is uncertainty regarding which hydraulic fracturing constituents 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 constituents and analytical assessment of the many uncommon constituents used in hydraulic fracturing. The SAB recommends that the EPA assess impacts and the underlying uncertainty associated with these undetected, unmonitored hydraulic fracturing constituents and incorporate such an assessment into this chapter of the final Assessment Report. This assessment should also consider how many hydraulic fracturing constituents that are in use do not have analytical methods, and are not undergoing monitoring.

2. <u>Uncertainty regarding the identity of hydraulic fracturing constituents used in particular hydraulic fracturing operations, as compounded by limited knowledge about on-site storage of constituents.</u> There is uncertainty regarding the identity of constituents used in particular hydraulic fracturing operations, and this uncertainty is compounded by limited knowledge about on-site hydraulic fracturing constituent 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 constituent contamination. The EPA should bring such information, either by direct EPA study or analogue studies, into the final Assessment Report.

3. Uncertainty regarding spills and their associated impacts. There is uncertainty regarding the frequency, severity, and type of HFWC-related spills, and the agency should address this uncertainty in this chapter of the final 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. A 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).

To reduce these uncertainties, the EPA should make Chapter 5 more current by including more recent available data, and conduct a more comprehensive and thorough analysis on the available data, on these topics.

EPA Response: Regarding point #1 above, we have added a new discussion, Section 5.8.9, "Challenges with Unmonitored and Undetected Chemicals" to address this topic specifically. In this section we discuss the issue of the large number of chemicals, the lack of analytical techniques, and challenges, such as being complex mixtures, which complicates analysis.

Regarding point #2, we are not aware of any study that delves into on-site storage of chemicals and gives the information SAB is interested in.

On point #3, the EPA performed an analysis of spills in its Spills Report[1] as part of the Hydraulic Fracturing Drinking Water Study, with data from nine states, nine service companies, and nine operators. This is the most comprehensive analysis of spills related to hydraulic fracturing activities we are aware of. Further analysis as suggested here is beyond the scope of the assessment. We did add information on spill rates and volumes from North Dakota to this chapter. The North Dakota database was used to investigate spill rates and volumes of spills related to the chemical mixing stage.

[1] U.S. EPA (U.S. Environmental Protection Agency). (2015). Review of state and industry spill data: Characterization of hydraulic fracturing-related spills [EPA Report]. (EPA/601/R-14/001). Washington, D.C.: U.S. Environmental Protection Agency, Office of Research and Development. http://www2.epa.gov/hfstudy/review-state-and-industry-spill-data-characterization-hydraulic-fracturing-related-spills-1

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? One 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 constituent use in hydraulic fracturing operations. 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 constituents. The SAB finds that this section portrays that more is known about fate and transport of hydraulic fracturing constituents 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 constituents 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). The SAB also recommends that the EPA minimize the value of the speculative transport scenarios that the agency assessed and reported on in this chapter. The SAB concludes that there are too many factors affecting the fate of hydraulic fracturing constituents 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 constituents in mixtures, constituents in non-aqueous phases, and the nature of the environmental media into which these hydraulic fracturing constituents may be released.

> **EPA Response:** In this chapter, we discuss the potential for activities in the chemical mixing stage to impact drinking water resources, and identify factors affecting the frequency or severity of impacts. Regarding severity, we could not provide a quantification of severity in most cases given the absence of site-specific data associated with spills.
>
> Concerning our discussion of fate and transport, we agree that this is a complex topic and have restructured this section to more fully describe the complexity and uncertainty. We use Chapter 5 to present the hydraulic fracturing chemicals and their properties to set the stage for their subsequent use in Chapter 9. We agree that there are many factors affecting the fate and transport of chemicals in the environment. The complexities the SAB states are important, and we have rewritten the fate and transport section with these concepts in mind. While we think the octanol-water partition coefficient is useful, we have de-emphasized its importance in the text. In the "Fate and Transport" section, our goal was to provide an overview of the processes and issues governing transport. It was not meant to be exhaustive. The other issues governing transport are discussed to give a perspective on the complexities of fate and transport in general and the additional complexities for chemical mixing activities. We had comments on the usefulness of the cases in helping a reader to see real examples of the movement of chemicals in the environment. For that reason, we have left the cases in the Assessment.

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 reported uncertainties, assumptions, and limitations concerning chemical mixing are not fully and clearly described. Data limitations compromise the EPA's 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 constituents used in hydraulic fracturing operations do not exist, and the lack of detection of such constituents does not mean they are not present in the environment. To address these concerns, although the final 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.

> **EPA Response**: In response to these comments, we have added a new section entitled "Challenges with Unmonitored and Undetected Chemicals". There is a general lack of data on failure rates of handling equipment and the efficiency of containment measures. This issue is incorporated in the new section mentioned above. We have also incorporated a section on uncertainty at the end of the chapter to discuss the uncertainties, assumptions, and limitations. It was out of scope of this assessment to make recommendations on monitoring protocols. Data gaps were discussed at the end of each chapter and not within each section. Identifying associated research needs was also out of the scope of this assessment.

3.3.5. 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 develops the final Assessment Report:

- What qualifies as a 'spill' is not defined clearly in the draft document. The final 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 impacts 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 final Assessment Report include a summary of current federal, state and tribal monitoring requirements before, during and after hydraulic fracturing operations, including types of monitoring wells (i.e., construction specifications), analytical protocols for constituents, and sampling intervals that would provide the data needed to assess the impact of hydraulic fracturing on water quality (e.g., see Bunn et al. 2012). The final 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 final 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). The SAB finds that the agency should outline its plans 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 the body of the SAB report).
- A quantitative assessment of containment failure.
- An emphasis on the *mass* of constituents potentially released, not volumes (as indicated in Fig. 5-5).
- An analysis of the *mass* of constituents 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 effects 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 consequences.
- 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 cases of leaking underground storage tanks as a source of example spills that the EPA could consider for such an assessment.

EPA Response: Regarding defining a spill, our revised Assessment now includes a specific definition of spill. We have included an additional figure on the distribution of spill volumes—see response above. We purposefully only present data that can be readily cited.

A review of polices regarding spills and spill reporting, and identifying research needs were out of scope of this assessment. Also, there is a lack of data on the frequency and type of equipment and containment failure. We discuss the uncertainties and the challenges associated with the lack of these data.

There is not much information on spill composition in a spill report. If there is information, it is usually general, like "hydraulic fluid" or "biocide." We cannot present spill details in terms of mass or concentration. We have added text to discuss this. In our estimates, we calculated mass as well as volumes of chemicals, which are presented in the appendix. We revised our text to reduce ambiguity on spill volume, frequency, and severity. We have added a figure of the distribution of spill volumes—again, see response above. We discuss the frequency of spills via our analysis and literature. We added a section on "Fluid and Additive Chemical Composition" to discuss the potential for what could be spilled. We have also included a new table that discusses the mass percent of a given chemical in the final fluid composition as well as the mass percent in the additive itself. There is very limited information on how these chemicals behave in combination. We have included a discussion on mixtures and how that may impact the fate and transport of chemicals. We have included text on the limitations of property estimation methods and the effect of uncertainties. We incorporated the recent publication by Konschnik and Dayalu (2016)[2], which provides a new analysis of FracFocus, more information on CBI withholding, and the chemicals most commonly used.

Regarding containing and preventing hydraulic fracturing spills, we discuss the different methods used, but we cannot assess how much these efforts are actually implemented or what their success rates are. We provide example spills in text boxes, and state if there were spill containment methods in place. We have a section on "Spill Prevention, Containment, and Mitigation," where we explicitly discuss efforts to contain spills.

We agree that the fate and transport of spilled fluids are complex. Hydraulic fracturing spills are not monolithic, and we did not intend to give the impression that these processes are well understood. This section has been reworked to emphasize the complexities and uncertainties. Using cases from Superfund or Leaking Underground Storage Tank (LUST) Trust Fund would be specific to those conditions and not necessarily appropriate to the type of spills that would occur on a hydraulic fracturing site. We include the three example spills to discuss what was observed during a spill event, and how it may or may not have impacted drinking resources.

[1] U.S. EPA (U.S. Environmental Protection Agency). (2015). Review of state and industry spill data: Characterization of hydraulic fracturing-related spills [EPA Report]. (EPA/601/R-14/001). Washington, D.C.: U.S. Environmental Protection Agency, Office of Research and Development. http://www2.epa.gov/hfstudy/review-state-and-industry-spill-data-characterization-hydraulic-fracturing-related-spills-1
[2] Konschnik, K; Dayalu, A. (2016). Hydraulic fracturing chemicals reporting: Analysis of available data and recommendations for policymakers. Energy Policy 88: 504-514. http://dx.doi.org/10.1016/j.enpol.2015.11.002

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 final 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:

- 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.

- 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.

- 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.

- 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.

- 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.

- 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 final 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:

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

- 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 final 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:

- U.S. EPA (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.

> **EPA Response:** We considered all literature recommended by the SAB and included new citations in the final Assessment Report where appropriate.

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 reader better understand the complex issues and technologies discussed.

A key aspect of assessing impacts to drinking water resources from the well injection stage of hydraulic fracturing operations is well construction and operations that are protective of drinking water resources, location and characterization of abandoned/orphaned oil and gas wells, and isolation of potable water from hydraulic fracturing operations. The agency should recognize in the final Assessment Report that the following are essential activities for the protection of drinking water resources during the well injection stage of hydraulic fracturing operations: inspection, testing and monitoring of the tubing, tubing-casing annulus and other casing annuli; and monitoring and testing of the potable groundwater aquifers 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, to improve the explanation to the reader on what has happened and why, and to help address concerns that have been raised by the public. Furthermore, the chapter should include more information on borehole construction, geologic layering and heterogeneities in physical properties, and well integrity issues presented in language that will be understood by the nontechnical reader.

To better inform the readers on available processes, methods and technologies that can minimize hydraulic fracturing's potential impacts to drinking water resources, the SAB also recommends that this and other chapters of the final Assessment Report should summarize the many improvements, changes or accomplishments that have occurred since 2012 in hydraulic fracturing operations related to the HFWC, including significant technological and regulatory oversight improvements that have occurred related to well construction, well integrity and well injection.

Important lessons from carbon capture and storage studies, such as those conducted by and with support of the DOE, have shown that well construction and integrity issues are a primary concern with potential releases of constituents 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.

> **EPA Response:** In response to the comment about adding illustrations, we added figures to illustrate the separation between hydraulic fracturing wells and groundwater resources, and demonstrate how some hydraulic fracturing operations are shallow while others are deep. These

new figures also help show some of the complex issues and technologies presented in the chapter.

Concerning adding more information on various topics, including such topics as borehole construction and testing and monitoring groundwater, we note the need to balance the education of the reader and concerns that the draft chapter was too long and dense. We wrote Chapter 6 for an audience with a moderate amount of technical training and expertise in injection technology and subsurface fluid movement. To achieve this balance, we added limited background information to the chapter itself, and included new information in Appendix D (Designing, Constructing, and Testing Wells for Integrity) and referenced Chapter 3 where appropriate to improve understanding of relevant injection-related topics.

Regarding summarizing major improvements in hydraulic fracturing technology, we describe (in Chapter 6 and Appendix D) practices to construct and test hydraulic fracturing wells that could, if implemented, reduce the frequency/severity of impact to drinking water quality associated with the injection stage. These practices were limited to those described in the scientific literature. They are employed by some hydraulic fracturing well operators and required by some states. We note that review of regulatory oversight was out of scope for this assessment. Instead, Chapter 1 provided a general overview of this topic.

We agree that related injection activities, such as carbon dioxide (CO_2) geologic sequestration, have relevance to injection for hydraulic fracturing. Chapter 6 presented the results of relevant research on oil and gas production wells in general or on injection wells, including those used for CO_2 geologic sequestration.

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?

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 final Assessment Report so that the reader can better understand the intricacies of hydraulic fracturing well design and of well integrity issues.

The chapter’s well construction discussion should discuss federal, state and tribal 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.

In Chapter 6, the agency 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 information on well construction, injection and well integrity design. The EPA should strengthen the chapter's presentation of technical concepts by including clearer geologic illustrations and improved figures to help the reader understand heterogeneity (e.g., natural 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.

> **EPA Response:** Chapter 6, like the other technical chapters in this assessment, was written for an audience with a moderate amount of technical training and expertise in injection technology and subsurface fluid movement. We added a limited amount of background information to the chapter itself and expanded the Executive Summary to better illustrate the complex concepts in the chapter for a more general audience.
>
> Concerning changes to oversight or practices, as we note in the response above, we added information about practices that could, if implemented, reduce the frequency/severity of impacts. However, there is insufficient information in the peer-reviewed literature to evaluate the frequency/degree to which all existing best management practices (BMPs) are implemented and whether/to what degree they have reduced impacts to drinking water. Also, as we note above, a review of regulations is outside the scope of this assessment.
>
> Regarding the suggestions to add illustrations, diagrams, and charts to Chapter 6, as we note in the response above, Chapter 6 includes additional or updated graphics to enhance the reader's understanding of well construction, the relationship of hydraulic fracturing wells to oil and gas operations and drinking water resources, and subsurface geologic features and processes.
>
> Regarding strengthening the chapter's presentation of technical concepts, we included additional information about new hydraulic fracturing injection technologies in Chapter 6 and Appendix D. We present a list of acronyms and their definitions in the front material of the assessment and worked to expand the explanation or definition of any new concepts (including acronyms) introduced in the chapter to enhance understandability.

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?

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 many conceivable potential impacts to drinking water associated with this stage in the HFWC. However, the EPA should 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 stage, 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 standards for hydraulic fracturing well design, required mechanical integrity testing in wells, new technologies and fracture fluid mixes, and federal, state and tribal regulatory standards that have changed, or may have changed, the probability of risk of water quality impacts associated with this stage in the HFWC; and
- Include an analysis and discussion on hydraulic fracturing case studies and example situations where impacts may have occurred.

To improve the presentation and identification of major findings in Chapter 6, the EPA should provide a hierarchy 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 cementation techniques, hydraulic fracturing operator error, migration of hydraulic fracturing constituents from the deep subsurface, and abandoned/orphaned oil and gas wells (including likelihood of impacts, number of abandoned/orphaned oil and gas 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 occurrence, and what the EPA considers high vs. low probability impacts. The EPA should include a conceptual, 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.

EPA Response: Regarding the suggestions to present and/or prioritize (i.e., as first and second order factors) the probability, frequency, risk, or hierarchical order of failure mechanisms associated with the injection stage, we note that data limitations preclude these types of analyses. These limits preclude developing definitive numbers in which: the various pathways described in the chapter (i.e., related to cementation, abandoned wells, and subsurface fluid movement) have formed or impacts to groundwater resources occurred.

Concerning calculating the frequency at which failures/impacts occur, because of the complex and unobserved nature of subsurface fluid movement, it is not possible to definitively state whether we have identified all instances of drinking water contamination associated with the injection phase of the hydraulic fracturing water cycle. Therefore, we cannot identify the frequency of such impacts relative to the number of wells known to have been hydraulically fractured. However, we did perform a qualitative prioritization of which factors associated with injection for hydraulic fracturing could lead to impacts or increase/decrease the frequency or severity of impacts. We describe this in Section 6.4 and Chapter 10.

Concerning recent state standards related to hydraulic fracturing wells, please see the response to a similar comment above.

To the suggestion to include hydraulic fracturing case studies, we added three text box descriptions of the origin and investigations of groundwater complaints in Pavillion, Wyoming; Dimock, Pennsylvania; and Parker County, Texas. These text boxes incorporate the salient aspects of these three site investigations. We also include discussions of other example situations where impacts may have occurred, including events in Bainbridge Township, Ohio and Killdeer, North Dakota.

Regarding the comments about specific sentences on pages 6-56 and 6-57 of the draft, we have removed these from Section 6.4 as part of our revision of the synthesis to address other SAB comments.

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 identify many conceivable potential impacts 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, which are further described below. The EPA's further assessment on these issues may result in additional major findings within this chapter of the final 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 reader better understand cement integrity.

The highest priority for improving the EPA's hydraulic fracturing cement and casing discussion in the final 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 final 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 final Assessment Report mention that: (a) these tests are vitally important to conduct to ensure hydraulic fracturing well integrity; (b) 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 (c) 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 final 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 final 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/orphaned oil and gas wells. Regarding abandoned/orphaned oil and gas wells, the EPA should provide a profile diagram of an abandoned well with typical placement of cement, and include discussion on the frequency of, and requirements for, cementing of abandoned wells. The EPA should also describe how abandoned wells of questionable integrity can provide a pathway 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 better describe 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 well cement and casing integrity.

The SAB finds that databases and data exist for cement and casing integrity in hydraulic fracturing, and 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. In order to reduce uncertainties associated with cement and casing characterization in hydraulic fracturing, the SAB also provides recommendations regarding the well file review under the 'Statistical Analysis' heading of Section 3.4.4 of this SAB report.

Within Chapter 6 of the final 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 final Assessment Report, the EPA should avoid use of words such as "conduits" to describe minute cracks and fissures in rocks, since mechanical discontinuities occur on a range of scales and very few cracks/fissures are as large-scale as implied by words such as "conduits."

EPA Response: We agree that cement integrity is a critical aspect of reducing impacts to drinking water resources. We have identified the factors associated with injection for hydraulic fracturing that could lead to impacts on drinking water resources or increase/decrease the frequency or severity of impacts. The condition of the well (e.g., the design, construction) and the proximity of other wells to the hydraulic fracturing well (and their condition) are among the primary factors we identified as impacting the frequency or severity of impacts to drinking water resources. However, in response to the suggestion to include design principles or other recommended practices, recommending their use is beyond the scope of the Assessment Report.

Regarding adding a discussion of the various types of cements and casings used in hydraulic fracturing wells and cement evaluation technologies, we added minimal new background text to Chapter 6 in order to balance the need to educate the reader and concerns that the draft chapter is too long/dense. However, we did include new information in Appendix D (including additional text about cement evaluation) and referenced Chapter 3 where appropriate to improve understanding. Regarding the suggestion to include a cement bond log, we did not add such a diagram because of readability concerns. These logs are difficult to reproduce and interpret, and so such a graphic would reduce readability, without adding information that supports the goals of the chapter.

Concerning the suggestion to describe and provide depictions of improperly abandoned/orphaned oil and gas wells, we discuss the potential for these wells to become pathways for fluid movement to drinking water resources in Section 6.3.2.3 of the final assessment (and provide an accompanying graphic). To enhance the linkage to other aspects of well design that are common to hydraulically fractured wells and abandoned wells, we added linkage and references between the well casing/cement discussions in Sections 6.2 and 6.3.2.3.

With respect to aging and recompleted hydraulically fractured wells, we added new information from the EPA's Well File Review[1] on re-fracturing rates, and discussed in Section 6.4 how hydraulic fracturing in such wells could affect the frequency or severity of impacts to drinking water resources. Appendix D describes techniques for evaluating well integrity, including logging and pressure testing.

Regarding the existence of cement and casing integrity data, we note in Section 6.4 that most of this information is proprietary, or otherwise not readily available to the public in a compiled or summary manner. Recommending industry disclosure of this information is outside the scope of the Assessment Report.

Regarding new research and technologies on cements and the prevalence of their use, Chapter 10 identifies some practices that could, if implemented, decrease the frequency or severity of impacts of hydraulic fracturing operations on drinking water resources; these include considerations for the location and quality of casing and cement in the hydraulic fracturing well and nearby active and abandoned wells. Data limitations preclude an evaluation of the degree to which these practices are implemented or their effectiveness, however. As we note above, some of these techniques are described in Appendix D.

Concerning cementing across karst limestone formations and porous zones, we include some background information related to the challenges of cementing in various geologic conditions in Section 6.2.1. However, as we note in other responses, we limited the amount of background text added.

To the comment about the effects of seismicity on cementing integrity, in the final report, all discussion of induced seismicity is in Chapter 8. Finally, to address the comment about using the term "conduit," we have revised the text to eliminate the use of this term.

[1] U.S. EPA (U.S. Environmental Protection Agency). (2015). Review of well operator files for hydraulically fractured oil and gas production wells: Well design and construction [EPA Report]. (EPA/601/R-14/002). Washington, D.C.: U.S. Environmental Protection Agency, Office of Research and Development. http://www2.epa.gov/hfstudy/review-well-operator-files-hydraulically-fractured-oil-and-gas-production-wells-well-design

Spatial and Temporal Issues

Within Chapter 6 of the final Assessment Report, the EPA should include additional 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 conclusions regarding temporal trends 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 duration of different events in the "life-cycle" of a well. For example, see the graph suggested by SAB Panel member Dr. Scott Bair in his preliminary individual Panel member comments for Charge Question 4.[1] 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.

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 reader better understand the physical situation in which

[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.

hydraulic fracturing well injection is conducted. In addition, the SAB notes that statistical information on hydraulic fracturing well data summaries is generally not available. The recommendations in the above two sentences can be considered longer term future activity. In addition, the EPA should provide more information on the three-dimensional nature and aspects of well injection in the HFWC.

> **EPA Response:** Regarding the suggestions to address temporal variations in hydraulic fracturing-related events, we included the dates of the incidents and events described in Chapter 6 to provide this temporal context. As to the duration of events in the "life-cycle" of a well, we included additional references to a discussion in Chapter 3 that explains the duration of injection for hydraulic fracturing in the life of the well.
>
> Concerning comments about the spatial proximity of wells to various potential pathways for fluid movement, we added discussion of how the proximity of the hydraulic fracturing well to other active and abandoned wells can affect the frequency or severity of impacts on drinking water resources. We also included additional graphics that illustrate the spatial context within the subsurface, including possible variances in the vertical separation between formations where hydraulic fracturing operations occur and drinking water resources exist.

Stray Gas

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.

> **EPA Response:** To address the various points raised in this comment, we expanded Text Box 6-2 (Stray Gas Migration) and associated text in Section 6.2 to address or clarify the topics SAB mentions. These include the use of noble gas tracers and the challenges associated with determining the sources and migration routes for stray gas (i.e., along induced vs naturally-occurring fractures), particularly when there are no baseline measurements or detailed monitoring data. We also added the results of some peer-reviewed studies on stray gas that have been published since the draft assessment. We also added cross references between the discussions of cement and well integrity and the Stray Gas text box. See also our responses to SAB's comments under "Distinguishing Sources of Stray Gas" below.

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 final 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 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 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 impacts or severity.

As recommended in the following paragraphs, the EPA should further assess data 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.

> **EPA Response**: Chapter 6, Chapter 10, and Appendix D discuss practices—if they are described in peer-reviewed literature—that could reduce the frequency/severity of impacts. However, as we note above, because of the complex and unobserved nature of subsurface fluid movement, it is not possible to definitively state whether we have identified all instances of drinking water contamination associated with the injection phase of the hydraulic fracturing water cycle. Therefore, we cannot identify the frequency of such impacts relative to the number of wells known to have been hydraulically fractured.

<u>Statistical Analysis</u>

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 approximately 24,000 wells. The SAB notes that the EPA can reduce uncertainties associated with hydraulic fracturing cement and casing characterization by examining and assessing substantially more than the 327 well files evaluated out of the approximately 24,000 well files total that are 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 recommendations in this paragraph can 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.

> **EPA Response:** Regarding the request to examine additional well files, we note that this would not have been possible without requesting more information from operators. To perform the Well File Review[1], EPA obtained 323 well files for hydraulically fractured production wells. The

Agency obtained the well files via information requests from nine oil and gas companies, using a list of approximately 23,200 production wells reported by nine service companies to have been hydraulically fractured between September 2009 and September 2010. The Well File Review results are based on information for these 323 wells, and are extrapolated to the list of approximately 23,200 wells. We clarify that we cannot review more well files without an additional information request. We have clarified this in Text Box 6-1.

In response to the suggestion to include relevant confidence intervals from the Well File Review, we included the 95% confidence intervals for the findings of the Well File Review cited in Chapter 6.

Regarding the comment about the relatively low percentage of horizontal wells represented in the Well File Review, we acknowledge that the use of these wells is increasing; however limited data exist from other sources about the performance of these wells that are exclusive to known hydraulic fracturing operations.

[1] U.S. EPA (U.S. Environmental Protection Agency). (2015). Review of well operator files for hydraulically fractured oil and gas production wells: Well design and construction [EPA Report]. (EPA/601/R-14/002). Washington, D.C.: U.S. Environmental Protection Agency, Office of Research and Development. http://www2.epa.gov/hfstudy/review-well-operator-files-hydraulically-fractured-oil-and-gas-production-wells-well-design

Distinguishing Sources of Stray Gas

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/orphaned oil and gas wells). The SAB recommends that the EPA rely on scientifically sound peer-reviewed papers (e.g., 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, such as noble gas tracers, used to identify the source of stray gas, and as noted earlier, more clearly describe the pathways for such migration. The final 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.

The EPA should expand and clarify the discussion on the current use by industry of tracers for injection fluids, as well as any efforts made by the EPA or other entities to develop tracers, and describe how the use of tracers might be an approach that could allow assessment of releases of contamination and interpretation of the source of contamination if it occurs. For example, the agency should summarize what constituents, metal cations, and isotopes 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 injection fluids. The EPA should consider the publication of Warner et al. (2014) in its expansion of discussion on the use of tracers for assessing potential releases of hydraulic fracturing fluids.

Distinguishing sources and pathways for gas resulting from casing failure, from natural migration in faults or shallow formations, or from unknown abandoned/orphaned oil and gas 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 finds that clear evidence of the existence of these pathways is needed 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 isotopic 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.

EPA Response: To the comment about the types of studies cited, we agree that there are challenges in determining the cause of stray gas. While it is beyond the scope of the Assessment to evaluate the conclusions drawn in the stray gas studies cited, the chapter does describe conflicting findings about the data where appropriate.

To the request to describe the frequency of impacts relative to the number of hydraulically fractured wells, as we note in responses above, the complex and unobserved nature of subsurface processes preclude a calculation of such a frequency.

To the request to expand the discussion about the use of tracers, we added text to Section 6.2 describing the use of emerging isotopic techniques and examples of studies that used hydrocarbon and noble gas isotope data to investigate the source of stray gas. Regarding the suggestion to expand on the development of other tracer techniques, we note that, while the findings of studies on the use of tracers are relevant to understanding stray gas and its impacts to drinking water resources, the science of developing tracer techniques is not. Chapter 6 also describes events where stray gas was detected in wells near hydraulic fracturing operations and investigations that were performed to identify the cause and source of the stray gas.

To the final comment above, we clarified in Text Box 6-2 (Stray Gas Migration) that determining the sources and migration routes for stray gas is complicated and challenging, particularly when there are no baseline measurements or detailed monitoring data. However, recommendations for baseline sampling are beyond the scope of the Assessment.

Modeling Fluid Flow

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 modeling associated with this stage of the HFWC that the EPA conducted as part of its Assessment Report 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 results from an *interpretive* model are not presentable as “evidence”, and that *predictive* models must match natural physical and/or chemical properties measured in the field or in the laboratory. The EPA should note that the modeling results presented in section 6.2.2 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). The EPA should clarify that the models provide possible outcomes that are limited by the assumptions made in design and implementation of the model. Any reference to a model needs to state the assumptions/limitations of the model. Predictive models must be validated with measurements/data in order to justify making predictive simulations. 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 installing a hydraulic fracturing well or drilling into a play where hydraulic fracturing will be involved. The brief overview of regional geologic factors should acknowledge the importance of 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 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 final 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). In addition, fracture propagation distances are reported by Davies et al (2012). The SAB notes that Figure 6-1 misleadingly depicts what appears to be a fresh water zone behind an un-cemented 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, has been used in an attempt to create fractures that grow to intersect the base of potable water-bearing units, and that such simulations were unsuccessful in propagating fractures upward from the target zone 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.

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

EPA Response: Regarding the comment to incorporate the results of forthcoming modeling studies under additional conditions, we added discussions of some modeling studies published after the draft Assessment; however, we limited these to published peer-reviewed papers. We recognize that some relevant modeling studies are anticipated to be published in the coming months, but cannot include these modeling efforts in Chapter 6 if they are not peer-reviewed and their results are not published.

To the comment about describing/presenting modeling results, we added text to explain the limitations of models (i.e., the specific conditions on which the inputs were based) and revised the chapter as needed to avoid any presumption that models provide evidence of fluid movement or impacts to drinking water. We also clarified throughout the chapter whether the studies we cited were based on modeling, field studies, or laboratory research.

We agree with SAB on the importance of understanding regional geologic features. The final Assessment identifies limited availability of information on how flow regimes or other subsurface processes change at sites where hydraulic fracturing is conducted as a data limitation associated with the injection stage.

In response to the request to include additional figures to illustrate each model/scenario described, we did not add such figures, because this would have significantly increased the length of the chapter.

To the request to expand the discussions of natural fractures, we incorporated into Section 6.3.2.4 ("Migration via Fractures Intersecting Geologic Features") some additional studies of natural fractures and their relationship to subsurface fluid movement that may impact drinking water resources. Regarding the requests to revise Figures 6-1 and 6-5, we revised these and other figures and added figures to illustrate the technical concepts in the chapter (see earlier responses).

Regarding the use of the specific modeling products SAB mentions, we did not include these, as no peer-reviewed studies of these evaluations were identified. We did include the Smith and Montgomery (2015)[1] paper.

To the comment about unidentified abandoned/orphaned oil and gas wells, Section 6.4 and Chapter 10 discuss factors associated with hydraulic fracturing operations that can increase or decrease the frequency or severity of impacts to drinking water, including inadequately constructed or degraded abandoned/orphaned oil and gas wells near hydraulic fracturing operations. Also, as described in an earlier response, we added linkage and references between the well casing/cement discussion and the discussion of "Migration via Fractures Intersecting with Offset Wells and Other Artificial Structures" in Section 6.3.2.3.

[1] Montgomery, CT; Smith, MB. (2010). Hydraulic fracturing - History of an enduring technology. J Pet Tech 62: 26-32.

Induced Seismicity

In addition, the final Assessment Report should include some discussion about what is known regarding induced seismicity and impacts on drinking water resources associated with HFWC activities. The EPA should consider the publication by Dillon and Clark (2015) when developing this discussion regarding the occurrence and causal factors of such events. Detailed discussion of induced seismicity from hydraulic fracturing-related wastewater disposal and related federal, state and tribal regulatory response should be reserved for Chapter 8 which is focused on hydraulic fracturing-related 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 in Ohio) (Fischetti 2012; Skoumal et al. 2015; Holland 2011; Horner et al. 1994; and Perry 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. For example, the EPA should include discussion on whether the increased rates or volumes of injection in British Columbia and Alberta were causal factors for seismicity in those areas, or whether slippage along natural fractures was the main cause for such seismicity. If fracturing was induced by Class II deep well injection, the EPA should describe the vertical extent of such induced fracturing and how such induced fractures compare to fractures caused by hydraulic fracturing activity. The SAB also recommends that the EPA discuss in the final 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, and provide information on available micro-seismic data and how such data may impact assessments regarding induced seismicity.

The EPA should provide an overview of the state of seismic monitoring technology and advances of monitoring technology regarding the detection of seismicity, and provide documentation and monitoring data available for induced seismicity for hydraulic fracturing and deepwell injection. The trends associated with such induced seismicity should also be discussed, including whether deep well injection of hydraulic fracturing-related wastewater is being reduced because of regulatory changes driven by public concerns about seismic activity and its associated costs, as recently occurred in Oklahoma (Wines 2016). The EPA can consider the recommended activities in this paragraph for longer-term future activity.

EPA Response: In the final Assessment, all discussion of induced seismicity is in Chapter 8.

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 better 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 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/orphaned oil and gas 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 reduce uncertainties associated with hydraulic fracturing cement and casing characterization by examining and assessing substantially more than the 327 well files evaluated out of the approximately 24,000 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. The recommendations in this paragraph can be considered longer-term future activities.

> **EPA Response:** Regarding the suggestions to identify ways to reduce uncertainty associated with specific pathways, we note recommending the types of practices SAB mentions is beyond the scope of the Assessment. However, in Chapter 6, Chapter 10, and Appendix D, we describe practices—including those related to cement integrity and evaluating pre- and post-hydraulic fracturing mechanical integrity testing (MIT) data—that could, if implemented, reduce the frequency/severity of impacts. We discussed these practices if they were described in the peer-reviewed literature. We agree that collecting the types of data the SAB mentions including pre-and-post hydraulic fracturing MIT data would reduce uncertainty, and describe this in Section 6.4. However, recommending their use is out of scope of the assessment. Further, as we note in Section 6.4, there is insufficient information in the literature to evaluate the frequency/degree to which these practices are implemented.
>
> To the comments that we provide more information on the frequency, severity, or relative probability of—or prioritize—impacts, data limitations preclude identifying the frequency of impacts relative to the number of wells known to have been hydraulically fractured. However, we did perform a qualitative prioritization of which factors associated with injection for hydraulic fracturing could lead to impacts or increase/decrease the frequency or severity of impacts (see earlier responses and Section 6.4 and Chapter 10 of the final Assessment).
>
> Regarding characterizing additional well files, we cannot review more well files without an additional information request (see earlier responses).

3.4.6. 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 hydraulic fracturing-related wastewater disposal and related federal, state and tribal regulatory response should be reserved for Chapter 8 which is focused on hydraulic fracturing-related 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 can be considered longer-term future activities.

EPA Response: Regarding comments about induced seismicity and wastewater disposal, in the final Assessment, all discussion of induced seismicity is in Chapter 8.

Chapter 6 of the final Assessment Report includes three text box descriptions of the origin and investigations of groundwater complaints in Pavillion, Wyoming; Dimock, Pennsylvania; and Parker County, Texas. Chapter 6 incorporates salient aspects of these three site investigations

Case Studies

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, Ohio (which was a cement failure and not related to hydraulic fracturing injection) (Bair et al. 2010); and Killdeer, North Dakota (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 relevant as part of the greater HFWC picture. The SAB finds that this is an important distinction to be made.

While the EPA describes casing and cement issues causing gas migration behind outer well casings, the SAB recommends that the EPA discuss publications describing cases of such migration.

EPA Response: Regarding the events at Bainbridge Township, Ohio, and Killdeer, North Dakota, we retained this discussion in Chapter 6. Based on the peer-reviewed literature, the only potential sources consistent with the conditions observed in drinking water resources at these sites were the hydraulic fracturing operations. These two events are distinguished from other events reported in the literature and described in the chapter, where the hydraulic fracturing operation appears to be a potential contributing cause to an impact on the drinking water resource, but causation is less definitive.

Regarding the recommendation to discuss other cases of migration behind the well casing, we note that studies of this phenomenon are described in Section 6.2.

Water Measurements

The EPA should discuss the importance of baseline (prior to drilling activity) water quality data measurements in developing a better understanding of 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 and water levels surrounding hydraulic fracturing sites before HFWC activities occurs. 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 quality and water level data will fluctuate with seasonal and other changes in the groundwater flow system. 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 construction of the gas 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 constituents of concern that are injected into hydraulically fractured wells. An overview of HF fluid constituents with toxicity risks is presented by Stringfellow et al. (2014). The EPA should also be careful to distinguish between hydraulic fracturing constituents injected into a hydraulic fracturing well vs. constituents and hydrocarbons that come 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 millidarcy, 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. Two publications with information on constituents in flowback fluids are Abualfaraj et al. (2014) and U.S. DOE (2011). In addition, the EPA should describe the challenge of monitoring and modeling the fate of injected fracture fluids over time.

The SAB acknowledges that there are times when distinction between flowback and produced water is helpful, especially in considering the temporal evolution of post-fracturing water returned to the surface, but more specific definitions of the two terms are needed in Appendix J of the final Assessment Report to clarify the distinction. 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 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 the body of the SAB report.

> **EPA Response:** Regarding the importance of baseline water quality measurements, we identify studies that conclude that the lack of baseline monitoring makes identifying specific geologic or well pathways challenging. Also, in Section 6.4, we identify pre- and post-hydraulic fracturing water quality sampling results among the types of data that are not routinely collected that could improve our understanding of the impacts of hydraulic fracturing on water quality. However, recommending collection of this is beyond the scope of the Assessment. Also, as we note above, review of regulatory oversight was out of scope for this assessment.
>
> In response to the suggestion that we characterize the toxicity and mobility of hydraulic fracturing fluid constituents, we note that this information is presented in Chapter 9.
>
> Regarding information on the fate of un-recovered fracture fluids that are injected into hydraulically fractured wells, we did not include a discussion of the characteristics and composition of produced water in Chapter 6. Produced water is not within the scope of activities in the injection stage of the hydraulic fracturing water cycle.

<u>Technology</u>

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).

> **EPA Response:** We added new background text to Chapter 6 and in Appendix D and referenced Chapter 3, where appropriate, to describe technologies available to reduce the frequency or severity of impacts to drinking water (including proper cementing and the use of logging and other well monitoring techniques to evaluate mechanical integrity). However, data limitations preclude an evaluation of the degree to which they are used or their effectiveness in reducing impacts to drinking water.

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 can be considered as recommendations for longer-term future activity.

> **EPA Response:** As we describe in other responses above, there is insufficient information in the literature to estimate the frequency at which each pathway (or associated water quality impacts) occurs. In Section 6.4, we identify pre- and post-hydraulic fracturing water quality sampling results among the types of data that are not routinely collected that could improve our understanding of the impacts of hydraulic fracturing on water quality. However, there is insufficient information to evaluate the frequency at which this sampling is performed, and recommending this is beyond the scope of the Assessment. Also, as we note above, review of regulatory oversight was out of scope for this Assessment.

Finally, we note in Chapter 6 that the well and the geologic environment in which it is located function as a closely linked "system" that often provides multiple barriers to prevent fluid movement between oil/gas zones and drinking water resources.

Best Management Practices and Regulatory Changes

The EPA should examine, as a longer-term future activity, federal, state and tribal 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 federal, state and tribal 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 federal, state and tribal standards and regulations related to the well injection stage of the HFWC. The EPA could consider the work completed on this topic by the American Petroleum Institute (2012). The EPA should also consider hydraulic fracturing-related standards and regulations within a few key states such as Pennsylvania, Wyoming, Texas, Colorado and California which all have implemented new hydraulic fracturing-related regulations since 2012. The EPA could consider the work completed on this topic by the Interstate Oil and Gas Compact Commission, the State Review of Oil, Natural Gas, Environmental Regulations, Inc. (STRONGER) organization, the Groundwater Protection Council (GWPC), the American Petroleum Institute (2012), Freyman (2014), Horner (2013), and Richardson et al. (2013). The EPA should also more accurately describe changes in such standards and regulations as an "evolution" vs. "improvement" in these federal, state and tribal regulations. These summaries of best management practices and regulatory changes need not be an exhaustive analysis of such practices and changes, and may be prepared as a 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 the potential impacts of hydraulic fracturing well injection on drinking water resources. The recommendations in this paragraph can be considered as recommendations for longer-term future activity.

EPA Response: We included some additional information about new hydraulic fracturing injection technologies in Chapter 6 and Appendix D. However, there is insufficient information in the literature to evaluate the frequency/degree to which all existing BMPs are implemented and whether/to what degree they have reduced impacts to drinking water. Chapter 6, Chapter 10, and Appendix D describe practices that could, if implemented, reduce the frequency/severity of impacts. We limited discussion to those practices described in peer-reviewed literature; however, recommending their use is out of scope of the Assessment.

We note that review of regulatory oversight was out of scope for this Assessment. Instead, Chapter 1 provided a general overview of this topic.

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 final Assessment Report:

- Abualfaraj, N., Gurian, P.L.; and Olson, M.S. 2014. Characterization of Marcellus Shale flowback water. *Environ. Eng. Sci.* 31(9): 514-524. September 2014. doi:10.1089/ees.2014.0001.

- 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, Pennsylvania, 1982. Society of Petroleum Engineers Publication SPE-10847-MS.

- Bosquez, T. IV, D. Carmeli, J. Esterkin, M. Kieng Hau, K. Komoroski, C. Madigan, and M. 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,

- Davies, R.J., Mathias, S., Moss, J., Hustoft, S., and Newport, L. 2012. Hydraulic fractures: How far can they go?, *Marine and Petroleum Geology* 2012: 1-6. doi:10.1016/j.marpetgeo.2012.04.001

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EPA Response: We considered all literature recommended by the SAB and included new citations in the final Assessment Report where appropriate.

3.5. <u>Flowback and Produced Water Stage in the HFWC</u>

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 target geologic 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.

1) The organic content of wastewaters: 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).

> **EPA Response**: In response to SAB's comment about the chapter being "encyclopedic," we simplified the presentation of the chapter by shifting the detailed reviews of individual studies to an appendix (primarily in the produced water volume and composition sections). We presented the major points derived from the studies in the main text, and left details to the appendix.
>
> We have added references and information on the organic content of produced water. Approximately 600 compounds in shale-gas water and 300 in coalbed methane have been added to tables in Appendix H. These tables also indicate known hydraulic fracturing additives, including tracers that we found through our literature review. The elucidation of more organics in produced water has occurred because new analytical methods and advanced instruments have been used in either academic or government (i.e., USGS) settings. Many of the organics are naturally-occurring, not only from shale, but also from tight sands and coalbeds.

2) The distinction between flowback and produced waters: Within the draft Assessment Report, the EPA included discussion on the distinction between flowback and produced waters. The SAB acknowledges that distinguishing these waters may be important to do for some situations or analyses (e.g., for risk assessment purposes). In the final Assessment Report, the SAB recommends that the EPA include descriptions of the differences in composition between flowback and produced waters. The SAB recognizes 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 constituents from injection of hydraulic fracturing fluids (Vidic et al. 2013; Haluszczak et al. 2013; and Balashov et al. 2015).

In terms of distinguishing between flowback and produced water, the EPA should carefully consider whether to strengthen the definitions of flowback and produced waters as provided in Appendix J of the draft Assessment Report (e.g., perhaps to include discussion on the relevance of operational factors, pressure monitoring, water quality aspects, and other factors that may be associated with these distinctions). The EPA should also consider providing a description of the differences between millidarcy, microdarcy and nanodarcy permeability of 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 within the production casing 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).

> **EPA Response**: The discussion of flowback and produced water has been simplified to enhance understanding. Extraneous definitions have been moved to the appendix. We refer to all water flowing from the well as being produced water. Flowback definitions usually include an operational aspect (i.e., water returned within 30 days), so the main text almost always refers to produced water only. The part that could be considered flowback is now described as being the initial produced water or produced water with varying amounts of fracturing fluid and formation water.

3) <u>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 constituents or metals used for hydraulic fracturing but has not and should summarize what constituents, metal cations, and isotopes are used for these chemical and radioactive tracers. 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 successfully used include antimony, iridium, and scandium (daughters include tellurium and platinum).

The agency should also clarify that there are two types of tracers in use: minerals naturally present in the geologic formation or dissolved ions in the brine contained within the formation that can be measured in flowback or produced waters as a putative "fingerprint" of the formational waters, and elements or constituents 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 expand and clarify the discussion provided in Chapter 7 on the current use by industry of tracers for injection fluids, as well as any efforts made by the EPA or other entities to develop tracers, and describe how the use of tracers might be an approach that could allow interpretation of the source of contamination if it occurs. Within this chapter, the EPA should also explain the difference between the use of natural tracers vs. induced (injected) tracers and the description of what isotopes (natural and radioactive) are used as tracers of groundwater, brine, and fracturing fluid movement.

The State of Pennsylvania Department of Environmental Protection (PA DEP) 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 PA DEP. The EPA should check the online PA DEP database to see if companies have been cited for Notices of Violation (NOVs). 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.

> **EPA Response:** A discussion of tracers has been included. SAB supplied literature references on tracer use, but, of those, only one gave the names of specific chemicals used as tracers. Impacts from specific chemicals were the main stated concern of SAB. We discovered the identities of several tracers, but many more with undisclosed identities are likely to be in use. The available data were compiled, and as the tracers were mostly noted as constituents of hydraulic fracturing fluid, the information is presented in Chapter 5. A few haologenated tracers have been identified in produced water and are now included in the report. Additional work as suggested – checking to see if Pennsylvania has data is beyond the scope of the project, especially since the specific names of tracer chemicals are not always disclosed.

4) <u>Duration of time needed for well completion vs. 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. Well completion activities and methods (including hydraulic fracturing) are used to prepare a well for production following drilling, and the draft Assessment Report accurately states that hydraulic fracturing 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. The agency should also note in the Assessment Report that previously fractured, existing wells may be hydraulically fractured again in the future.

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 Field in east Texas work done in the 1980s. However, a number of wells in the Lost Hills and Kerridge fields in California, for example, are on 1/8 acre spacing and pumping times 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.

> **EPA Response:** In Chapter 3, we provide a discussion of the timeline of operational activities at a hydraulic fracturing well site. This discussion and accompanying figure was revised in response to SAB comments—see response to Charge Question 1.

5) The proportion of wells in conventional versus unconventional oil/gas plays and oil/gas fields, and the proportion of conventional versus unconventional wells: 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 United States, the SAB recommends that the EPA describe the percentage of hydraulically fractured wells installed in unconventional as compared to conventional oil/gas plays and oil/gas fields.

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 United States. 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 United States can be considered a longer-term future activity.

> **EPA Response:** We agree that determining the proportion of produced water production from conventional versus unconventional well across the entire United States would require longer-term research activity. Where available, we do present produced water volume and composition data for specific formations, information that may be useful for such an analysis.

6) The relationship of leaks or spills to the process of hydraulic fracturing itself: Chapter 7 discusses surface releases during hydraulic fracturing as a potential area of interest with respect to drinking water resource impacts. The final 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 or trucked 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

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[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

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 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. Also, the percentage of leakage from tens of thousands of horizontal hydraulic fracturing wells in Oklahoma and Texas were surveyed in Bachu and Valencia (2014). 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 can be considered a longer-term future activity.

> **EPA Response:** We agree with the SAB that the relationship of spills to the hydraulic fracturing process itself would require longer-term research activity. We did not have the data to examine this question in this assessment, nor was it an explicit goal. Instead, we examined the broader question of spills at hydraulic fracturing sites, whether or not they were related to the hydraulic fracturing process itself.

7) <u>The source of salt in produced water:</u> The draft Assessment Report emphasizes (from Blauch et al. 2009) that the exceptionally high concentrations (> 100,000 mg/l TDS < 350,000) of dissolved salts measured in produced waters and in naturally occurring deep-basin brines are derived from dissolution of halite and other evaporite minerals 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 high concentrations of dissolved salts in produced waters (since halite and associated evaporite minerals are not found in all or most shales). The SAB notes that while some sedimentary basins may contain subsurface halite layers that chemically interact with the exceptionally slow movement of deep-basin fluids, the high concentrations of dissolved salts are largely derived from brines that entered the target formation or in the surrounding formations including evaporite beds that may be present in the basin but not necessarily in the target formation itself. Given that the Marcellus Shale in New York, Pennsylvania and Ohio, and the Utica Shale in Ohio are approximately 400 million years old, diffusion of metal cations from overlying and/or underlying evaporite layers into the target shales is possible. 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 the dissolved salt content of production waters with time could be attributed to transport of brine from small pores in the shale into the induced fractures. Alternately, the increase could be related to the increasing percentage of deep formation waters (natural brines) moving back to the lowered production pressures in the well after the hydraulic fracturing process is completed. A paper describing a mass balance calculation on the brine salts for production wells in the Marcellus Shale showed a proof of concept for how dissolved salts enter the production 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 the draft Assessment Report.

EPA Response: Because the source of salt in produced water does not generally affect spill impacts, all of the material on salt origin has been moved to an appendix.

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 final Assessment Report provided more clarity regarding regulatory and industry response to spills, the reader 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. This summary of best management practices need not be an exhaustive analysis of such practices. The EPA may develop this summary as a longer-term future activity.

EPA Response: Best management practices and regulations were generally outside the scope of this Assessment. The exception to this was when practices were detailed in the scientific literature and shown to be effective in reducing impacts. We agree that the examination of best management practices would require longer-term research activity.

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 these water-saturated coals, which are the target zones of CBM wells, are usually part of an extensive but shallow unconfined aquifer system. As CBM wells are pumped, some amount of pore de-saturation occurs. In contrast, fluids in deep organic shales and other tight gas formations essentially occur in highly confined aquifers (i.e., reservoirs) in which all pores are saturated with fluids. As a result, the pores in these deep reservoirs never de-saturate; they are always filled with some type of fluid (oil, water, gas, brine). The SAB recommends that the EPA include these distinctions within the final Assessment Report since such distinctions impact the quantity and quality of hydraulic fracturing waters that are produced during hydraulic fracturing operations.

EPA Response: Additional background on coalbed methane (CBM) has been added to Chapter 3. A figure showing typical produced water from CBM has been added to Chapter 7.

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 be 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 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 final 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. 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 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.

> **EPA Response:** The major findings have been rewritten following the guidance given by SAB. The emphasis of the chapter has shifted to providing synthesized findings from the information provided, and either eliminating excessive detail or moving it to Appendix E. The findings have been made more specific and summarize the major results from the chapter. For example, the SAB noted that the median spill volume should be stated specifically in a finding, as it is now. We have not included timeframes for groundwater remediation as this topic was generally out-of-scope for this assessment and the limited data we have on severity of impacts do not afford an understanding of remedial efforts.

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 constituents (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 may have been rarely reported (Bair and Digel 1990; Llewellyn et al. 2015; Vidic et al. 2013), the final Assessment Report should describe the occurrence, frequency and severity of long-distance travel events, or outline a plan for such an assessment as a future activity, and recognize that such events could 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, these heterogeneities can act as discontinuities in the subsurface flow regime, and this should be discussed on lines 30-32 on page 7-42 of the final 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 final Assessment Report should note that if a hydraulic fracturing spill were to enter unconsolidated sediments, migration of the constituents 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 final Assessment Report should clarify that long-distance travel of hydraulic fracturing constituents is possible, may have been rarely reported in the published literature, 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 geologic heterogeneities and discontinuities found in the rocks in all sedimentary basins. The SAB concludes this portion of the modeling exercises is unrealistic because preferential flowpaths in the subsurface are generally important in relation to contaminant mobility. Likewise, other *interpretive* modelling cited in the draft Assessment Report (Myers 2012) is also misleading as it over-emphasizes and over-simplifies highly permeable, geologically unrealistic, subsurface heterogeneities (e.g., the model grid provides for continuous fractures 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 final Assessment Report as well as the differences between the results of *interpretive* models vs. *predictive* models. Two examples of *interpretive* models 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 modeling examples and explain why one study concluded that contamination could occur within a very short time period, whereas the other concluded such contamination was unlikely. In essence, these contradictory conclusions are related to the 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.

EPA Response: We removed the discussion of proximity from this chapter (as proximity is described in more detail in Chapter 2). The potential for a spill into heterogeneous or fractured media has been noted, but the discussion of transport in general has been minimized and the discussion focuses on features unique to produced water. This was done to minimize duplication with Chapter 5. The single modeling report, to which the SAB objected, was removed because of this simplification of the chapter. Other modeling described by SAB (Myers 2012)[1] was not relevant to Chapter 7.

As noted previously in our response about tracers, we do not have any information on releases of radioactive tracers (or other tracers) to the environment.

[1] Myers, T. (2012). Potential contaminant pathways from hydraulically fractured shale to aquifers. Ground Water 50: 872-882. http://dx.doi.org/10.1111/j.1745-6584.2012.00933.x

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 constituents from hydraulic fracturing operations occur to the environment. The EPA should provide additional context in this chapter of the final 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 constituents 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 final 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 as recommendations for longer-term future activity, but the final Assessment Report should include some discussion of general observations regarding flowback and produced water chemistry.

EPA Response: Concerning SAB's request for more information on large spill events, we added information on a large spill in North Dakota. As it occurred relatively recently (2015), the long term impacts of this spill are unknown at this time. Information on large spills was otherwise generally limited.

Discussion of regulation of construction practices and the possible impacts on spills was outside the scope of the report.

Regarding assessments after release of constituents into the environment, we added a general discussion of the issues and challenges in causal analysis to Chapter 10, since this issue is relevant to all stages of the hydraulic fracturing water cycle. A concise discussion of the approach taken to investigate three of the EPA retrospective case studies was added in Appendix E, and referenced in Chapter 7, in response to this comment. We included the limited information on environmentally-benign tracers available in the literature, in addition to the tracer discussion we added to Chapter 5.

A generalization of produced water composition was not developed because of limited data. To implement this suggestion would require a large and internally consistent data set with elucidation of inter- and intra-formation differences, temporal change, and differences in hydraulic fracturing treatments at a minimum. Also, because of same data limitations, a "generalized water chemistry" of organics and inorganics was not developed.

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 on the extent and duration of the impacts, including the following, most of which will require longer-term future activities to address fully:

- The degree to which spills and releases impact drinking water supplies.
- 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.

To understand the likely probability of releases to surface water or groundwater from hydraulic fracturing activities, the final 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, 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. For example, a professional basketball court is 94 feet long and 50 feet wide. If a 1000 gallon spill occurred and was contained within that area, it would be about 19 inches deep. 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 final 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 reader 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.

EPA Response: SAB requests additional detail on leaks and spills in a bulleted list. The material on spills in the chapter was developed from available literature that did not allow us to describe many of these aspects of spills. We did increase the emphasis on the duration of impacts, where known. The analysis we added of spills from North Dakota included the fraction of spills that were contained on site, which partially addresses SAB's request for more information on spill containment. We reviewed the wording in the spills discussion to ensure readers would not infer that all spills reach surface waters or other receptors.

Where SAB requests more information for two specific spills, we provided all the information available to us. Our available information only included the short-term impacts described in the report.

SAB requests statistical analysis and figures quantifying types of release events and their frequency. We evaluated spills data from North Dakota covering the period from 2002 to 2015. From these, we provided figures that demonstrate the spill frequency for 13 categories of spill causes, spill frequency per number of active wells, and frequency distributions of spill volumes.

Data on spills do not exist on a nationwide basis; we reported on available composited spill studies.

We agree that the statistical analysis suggested, between wells which used hydraulic fracturing versus those that did not, would require longer-term research activity.

We also agree that development of figures or tables that summarize temporal and spatial scaling would be a longer-term activity. We did, however, emphasize both the relative volume that could be released from a single truck compared against the total amount of produced water from a well. To provide additional perspective, we also concluded the truck spill discussion with a report of the local concern generated from a single truck spill.

Regarding SAB's comment on evaluation strategies and analysis, in our discussion of three of the EPA retrospective case studies, we included information on the procedures and approaches used in these cases. Baseline sampling was included as one element in these studies among several others. Even with a thoughtful approach, it may not always be possible to provide a conclusive determination of impacts, and we indicate this in the chapter and Appendix E.

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.

EPA Response: Regarding further examination of uncertainties, we agree this would require longer-term research activity. It should also be noted that of the organic compounds identified in produced water, the majority have not been quantified—a requirement for risk assessment.

Developing or summarizing approaches to reduce uncertainties was outside of the scope of this assessment, as was a review of state practices and regulation (including state databases).

SAB requests clarification if data gaps are due to data being non-existent or not easily available. We have focused on data that are readily available. We used data that were available in literature or report form and in two cases that were available electronically (North Dakota spills data and USGS produced water data). We have not compiled data held by other state agencies, for example.

3.5.5. 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 hydraulic fracturing-related wastewaters and in surface waters, best management practices (BMPs) for surface impoundments, and the natural occurrence in subsurface brines, 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 final 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 final 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 final Assessment Report, even though such cuttings are related only to hydraulic fracturing drilling.

Chapter 7 and Appendix E of the final Assessment Report should amplify discussion on the ion 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 dissolved bromide generally comes from pore fluids that have dissolved bromide minerals in the rock into which hydraulically fractured wells are drilled, and discuss whether a bromide salt is ever added as an injection constituent. The final Assessment Report should also more consistently use the terms “bromine” to refer to the element and “bromide” to refer to the metal ion. 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 same applies to the use of chlorine and chloride, and iodine and iodide.

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 and Wagner 2009; and Richardson et al. 2014), information about iodide in hydraulic fracturing-related wastewaters should be amplified in the final Assessment Report. The ratio of dissolved 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 chloride than seawater. In addition, the final Assessment Report should discuss the degree to which flowback and produced water contains bromate, chlorate, perchlorate or iodate. All of these chemical species have human toxicity endpoints and some have Maximum Contaminant Levels (MCLs) established under the Safe Drinking Water Act. Data sources that provide information on levels of bromide, bromate, iodide, chlorate and perchlorate in oil/gas and hydraulic fracturing-related wastewaters associated with different geologic formations where HF is occurring are provided in section d2 below.

In Chapter 7, the agency 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 pages 7-41 to 7-42 and impoundments are mentioned in the draft Assessment Report, impoundments are not emphasized sufficiently, nor are they clearly distinguished from containment structures used to contain leaks and spills from storage containers or from hydraulic fracturing operations. The EPA should describe best practices regarding the use of impoundments and how are they constructed, monitored, and regulated. Since the EPA notes that container leakage (i.e., leakage from pits, impoundments or tanks) is the single biggest source of leakage on an event basis, the nature and use of hydraulic fracturing impoundments and other containment structures are particularly important to fully describe in the final Assessment Report. It is especially important for EPA to clearly distinguish leaks and spills that escape containment from those that do not, and to distinguish leaks from produced water storage impoundments from leaks and spills from chemical storage containers and other containers that are typically far smaller in size than produced water storage impoundments.

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 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 (e.g., Pennsylvania), impoundments are being used less frequently than in previous years, 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 final Assessment Report. In addition, the EPA should discuss the cause of the structural lack of integrity responsible for leaks from impoundments, and whether leaks from impoundments are induced by operational conditions, poor manufacturing of materials (e.g., linings or tanks), corrosion caused by the flowback or produced water chemistry, or by seismic activity. The EPA should also concisely describe which states have laws or regulations requiring lined pits and bermed areas to manage potential spills, leaks and runoff from hydraulic fracturing operations, and include a list of best practices currently in use in industry (such as the elimination of unlined pits, and use of tanks stored over lined berm-surrounded catchment areas). This summary of best management practices and regulatory changes need not be an exhaustive analysis of such practices and changes. The EPA may develop these summaries as longer-term future activity.

In addition, the term “containment” is not adequately described in the draft Assessment Report. The EPA should describe it adequately in the final Assessment Report and also more specifically discuss whether spills are being contained or escaping containment and whether the containment structures for hydraulic fracturing materials and fluids are being adequately designed, operated, maintained, and eventually decommissioned. In addition, the terms “impoundment,” “container,” and “containment” are not defined in the Glossary (Appendix J) and the EPA should consider including such definitions in this appendix of the final Assessment Report.

The final 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 originally were contained in pores of near-surface rocks that have since been deeply buried, 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, salt springs, and salt licks. 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 (1997) 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 the region. Both the model results and the measured bottom-hole pressures indicate that the flow rates of the brines are exceptionally low 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 background and pre-existing chemistry of surface and groundwater in developing a better understanding of whether impacts from drilling and completion activities can be identified. 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, 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 constituents listed in Table 7-4. A major public concern is the appearance of contaminated or degraded drinking water in wells in areas where hydraulic fracturing occurs. Since naturally occurring contaminants and degraded drinking water in wells can occur from issues not related to hydraulic fracturing, the EPA should also discuss the importance of background and pre-existing chemistry of surface and groundwater in developing a better understanding of whether impacts from drilling and completion activities can be identified. The scientific complexity of baseline sampling and data interpretation should be clearly and concisely described. Although baseline sampling is simple in concept, it can be very difficult to obtain meaningful results in practice. Concentrations of naturally occurring contaminants, including methane, aromatic hydrocarbons, radionuclides, and disinfection by-product precursors, can vary significantly, both temporally and spatially, especially in surface water and in groundwater drawn from shallow and/or alluvial wells. Water quality can be significantly influenced by hydrological events (rainfall, flooding, drought), by water acquisition for purposes other than hydraulic fracturing, and by spills or discharges or constituents not associated with hydraulic fracturing. Obtaining representative samples, characterizing natural variations in water quality, properly collecting (and preserving and storing) samples for the analytes of interest, accurately determining the concentrations of the analytes of interest, and correctly interpreting the data can be challenging tasks. Interpretation of water chemistry data from private wells, whether from baseline sampling or subsequent sampling, and attribution of possible causes of changes in water chemistry is not straightforward and can be complex. The analysis of water chemistry data from private wells requires the water chemistry data to be integrated with water-level data and details about the construction and maintenance history of each well. Interpretation and attribution can be confounded by several factors including:

- Changes in groundwater flow directions, both vertical and lateral;
- The age of the well, type of casing, presence or absence of a well screen and water-treatment equipment, aquifer materials, competency of cement and grout seals;
- The maintenance history of the well -- routine disinfection of the wellbore, presence of mineral deposits and bacterial slimes in the well and the screen, and corrosion of the casing and screen; and
- The location and depth of the well relative to septic tanks; yard, household, and automotive chemicals; and livestock.

Chemical analyses and water levels also need to be measured periodically so that temporal and spatial trends can be assessed. Relevant information can be found in various sources, including Minnesota Department of Health (2014), and U.S. Geological Survey (1994).

As described in the EPA's research Study Plan (U.S. EPA 2011), the EPA had planned to evaluate the potential use of tracer constituents 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: minerals naturally present in the geologic formation and ions present in brines that can be measured in flowback or produced waters as a putative "fingerprint" of the formational waters, and elements or constituents injected into the fracturing fluids intentionally to allow analysis of well completion or cement squeeze processes. The EPA discusses minerals naturally present in the formation or brine in the chapter, but the EPA does not sufficiently discuss elements or constituents injected into the fracturing fluids intentionally in the chapter. The EPA should explicitly describe in the chapter whether it recommends the use of fingerprint constituents in injected fluids, and what additional information is needed to evaluate whether to use these constituents 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 constituents could elucidate such mobility, if the fingerprint constituents 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 constituents 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 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. In addition, the EPA should evaluate as a longer-term future activity the potential for using non-targeted chemical analysis to identify currently unmonitored HF constituents. In Chapter 7, the agency 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 finds that many constituents in produced waters are often categorized as BTEX constituents, and that these constituents are frequently found in hydraulic fracturing wastewaters because the constituents come out of the shales themselves. The chapter should note that while petroleum (oil/condensate) contains many hundreds of individual constituents that could be included in the dissolved phase as trace components, these constituents 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 constituents. The SAB recommends that the EPA further describe microbial processes that affect the transformation of chemicals recovered in flow back and produced water, and the transformation of chemicals that may impact ground and surface waters, 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 final 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 constituents. 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 constituents. 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 constituents 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 constituents 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 constituents, the EPA should further describe the usefulness of using EPI Suite analysis when assessing potential impacts of hydraulic fracturing constituents 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 the body of the 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 and how this practice 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. Several available references describe the reuse of flowback and produced water that the EPA should consider when developing the final Assessment Report (e.g., Balasubramanian et al. 2015; Barnes et al. 2015; Burgos and Lebas 2015; Farrell et al. 2015; Hussain et al. 2014; McMahon et al. 2015; and Seth et al. 2013).

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. 2014).

EPA Response: Regarding SAB request of more discussion on radioactivity, information on radionuclides was moved from the appendix to Chapter 7. Concerning discussion of the use of radioactive tracers, please see our prior response on this topic.

SAB recommended amplified discussion of the Cl/Br ion ratio in flowback and produced water. Detailed geochemical evaluation of the data presented in the chapter and Appendix E was beyond the scope of the effort of the assessment, as this is generally unrelated to impacts of spilled produced water. We included literature data on iodide as was available. We agree that consideration of iodide would be a longer-term activity. We included limited discussion of iodide and its implications for wastewater treatment in Chapter 8.

SAB recommends additional information be provided on impoundments. A discussion of impoundments has been added to Chapter 8.

SAB recommends additional information on natural brines. Information on brines as alternate sources of constituents was discussed with regard to the EPA retrospective case studies.

SAB recommends listing maximum contaminant levels (MCLs) in the data tables for the drinking water contaminants found in produced water. We discuss MCLs in Chapter 9 of the final assessment.

SAB recommends that EPA assess and describe the potential for development of tracers and outline a plan for organic compounds. Describing additional research is outside the scope of this report. This pertains to both tracer development and outlining a plan for analyzing organic compounds.

SAB recommends additional discussion of microbial processes. Microbial processes in transport of spilled compounds is contained in the discussion in Chapter 5. Reservoir formation microbial processes and some recent research on fate of biocides is included in Appendix E.3.8.

SAB noted the limitations of EPI suite-estimated chemical properties. As we do not have a means to improve the estimates, the discussion of these results was minimized and placed in the appendix, further noting that the properties could only be considered baseline (low TDS) values.

SAB recommended additional analysis on recycling or reuse of produced water. This is discussed in Chapter 8, and to a lesser degree Chapter 4 (use of reused water as a reducer of demand for fresh water).

SAB recommends reviewing a study from the University of Cincinnati (Botner et al., 2014)[1]. The study mentioned by SAB is only known through a conference presentation and master's thesis. The potential impacts studied were from methane and not relevant to produced water. The study was considered for inclusion in Chapter 6, but not included because of its publication status.

[1] 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)

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., J. Pechiney, R. Villaseñor, and R. Woodroof. 2015. Determining the number of contributing fractures in shale gas wells with production analysis and proppant tracer diagnostics. *Society of Petroleum Engineers*. 2015, March 1. doi:10.2118/173620-MS.

- Elahi, S.H., and , B. Jafarpour. 2015. Characterization of fracture length and conductivity from tracer test and production data with ensemble kalman filter. *Society of Petroleum Engineers*. 2015, August 4. doi:10.2118/178707-MS.

- Goswick, R.A., and , J.L. LaRue. 2014a. Utilizing oil soluble tracers to understand stimulation efficiency along the lateral. *Society of Petroleum Engineers*. 2014, January 1.

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

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

- Leong, Y., J.E. de Iongh, S. Bähring, A. K. Tuxen, and , T.B. Nielsen. (2015, September 28). Estimation of fracture volume between well pairs using deuterium tracer. *Society of Petroleum Engineers*. doi:10.2118/174832-MS.

- Roney, D., D.J. Quirk, A. Ziarani, and L.H. Burke. 2014. 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*. 2014, September 30. doi:10.2118/171605-MS

- Salman, A., B. Kurtoglu, and H. Kazemi. 2014. Analysis of chemical tracer flowback in unconventional reservoirs. *Society of Petroleum Engineers*. 2014, September 30. doi:10.2118/171656-MS.

- Scott, M.P., L.J. Raymond Jr., A. Datey, C. Vandenborn, and R.A. Woodroof Jr. 2010. Evaluating hydraulic fracture geometry from sonic anisotropy and radioactive tracer logs. *Society of Petroleum Engineers Asia Pacific Oil & Gas Conference and Exhibition.* Brisbane, Queensland, Australia, October 18-20, 2010. SPE document #SPE-133059-MS. DOI: http://dx.doi.org/10.2118/133059-MS

- Srinivasan, K., J. Krishnamurthy, R. Williams, P. Dharwadkar, T. Izykowski, and W.R. Moore. 2016. Eight-plus years of hydraulic fracturing in the Williston Basin: what have we learned? *Society of Petroleum Engineers*. 2016, February 1. doi:10.2118/179156-MS.

(2) Data sources that provide information on well fracture time are provided below.

- Fyten, G.C., R.S. Taylor, and D. Price. 2015. Viking stimulation: case history. *Society of Petroleum Engineers*. 2015, October 20. doi:10.2118/175955-MS.

- Govorushkina, A., C. Henderson, L. Castro, R. Allen, and E. Nasir. 2015. Interventionless unconventional multistage hybrid completion: fracturing longer laterals in cemented applications. S*ociety of Petroleum Engineers*. 2015, November 9. doi:10.2118/176838-MS.

- Krenger, J. T., J. Fraser, A.J. Gibson, A. Whitsett, J. Melcher, and S. Persac. 2015. Refracturing design for underperforming unconventional horizontal reservoirs. *Society of Petroleum Engineers*. 2015, October 13. doi:10.2118/177306-MS.

- Nejad, A.M., S. Sheludko, R.F. Shelley, T. Hodgson, and P.R. Mcfall. 2015. A case history: evaluating well completions in eagle ford shale using a data-driven approach. *Society of Petroleum Engineers*. 2015, February 3. doi:10.2118/173336-MS

- Qiu, F., M.M. Porcu, J. Xu, R. Malpani, P. Pankaj, and T.L. Pope. 2015. Simulation study of zipper fracturing using an unconventional fracture model. *Society of Petroleum Engineers*. 2015, October 20. doi:10.2118/175980-MS.

- Reddy, L., A. Jenkins, and E. Fathi. 2015. Dynamic assessment of induced stresses and in-situ stress reorientation during multi-stage hydraulic fracturing in unconventional reservoirs. *Society of Petroleum Engineers*. 2015, October 13. doi:10.2118/177301-MS.

- Temizel, C., S. Purwar, A. Abdullayev, K. Urrutia, and A. Tiwari. 2015. Efficient use of data analytics in optimization of hydraulic fracturing in unconventional reservoirs. *Society of Petroleum Engineers*. 2015, November 9. doi:10.2118/177549-M.

- Yousefzadeh, A., Q. Li, and R. Aguilera. 2015. Microseismic 101: monitoring and evaluating hydraulic fracturing to improve the efficiency of oil and gas recovery from unconventional reservoirs. *Society of Petroleum Engineers*. 2015, November 18. doi:10.2118/177277-M.

(3) Data sources that provide information on monitoring of well flowback are provided below.

- Rane, J.P., and L. Xu. 2015. New dynamic-surface-tension analysis yields improved residual surfactant measurements in flowback and produced waters. *Society of Petroleum Engineers*. 2015, August 1. doi:10.2118/172190-PA.

- Salman, A., B. Kurtoglu, and H. Kazemi. 2014. Analysis of chemical tracer flowback in unconventional reservoirs. *Society of Petroleum Engineers*. 2014, September 30. doi:10.2118/171656-MS.

- Vazquez, O., R. Mehta, E. Mackay, S. Linares-Samaniego, M. Jordan, and J. Fidoe. 2014. Post-frac flowback water chemistry matching in a shale development. *Society of Petroleum Engineers*. 2014, May 14. doi:10.2118/169799-MS.

- Williams-Kovacs, J.D., C.R. Clarkson, and B. Zanganeh. 2015. Case studies in quantitative flowback analysis. *Society of Petroleum Engineers*. 2015, October 20. doi:10.2118/175983-MS.

- Zhou, Q., R. Dilmore, A. Kleit, and J.Y. Wang. 2016. Evaluating fracture-fluid flowback in Marcellus using data-mining technologies. *Society of Petroleum Engineers*. 2016, February 1. doi:10.2118/173364-PA.

- Zolfaghari, A., H. Dehghanpour, E. Ghanbari, and D. Bearinger. 2015. Fracture characterization using flowback salt-concentration transient. *Society of Petroleum Engineers*. 2015, June 1. doi:10.2118/168598-PA.

- Zolfaghari, A., Y. Tang, J. Holyk, M. Binazadeh, H. Dehghanpour, and D. Bearinger. 2015. Chemical analysis of flowback water and downhole gas shale samples. *Society of Petroleum Engineers*. 2015, October 20. doi:10.2118/175925-MS.

(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.

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

- Blauch, M.E. 2010. Developing effective and environmentally suitable fracturing fluids using hydraulic fracturing flowback waters. *Society of Petroleum Engineers*. 2010, January 1. doi:10.2118/131784-MS.

- Chen, R., S. Sharma, T. Bank, D. Soeder, and H. Eastman. 2015. 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, A., K. Schreglmann, D.L. Plata, M. Elsner, N.R. Warner, A. Vengosh, K. Moore, D. Coleman, and R.B. Jackson. 2015. Pre-drilling background groundwater quality in the Deep River Triassic Basin of central North Carolina, USA. *Applied Geochemistry* 60 (3–13). September 2015. doi:10.1016/j.apgeochem.2015.01.018.

- Houston, N.A., M.E. Blauch, D.R. Weaver, D. Miller, and O'Hara, D. 2009. Fracture-stimulation in the Marcellus shale-lessons learned in fluid selection and execution. *Society of Petroleum Engineers*. 2009, January 1. doi:10.2118/125987-MS.

- Johnson, J.D., and J.R. Graney. 2015. 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, J.D., J.R. Graney, R.C. Capo, and B.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. 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*. 2012, January 1. doi:10.2118/152596-MS

- Lu, Z., S.T. Hummel, L.K. Lautz, G.D. Hoke, X. Zhou, J. Leone, and D.I. Siegel. 2015. 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, 2015. Appalachian Plateau region, USA. *Applied Geochemistry* 60 (72–77). September 2015. doi:10.1016/j.apgeochem.2015.04.013.

- Phan, T.T.; R.C. Capo, B.W. Stewart, J.R. Graney, J.D. Johnson, S. Sharma, and J. Toro. 2015. 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., and L. Xu. 2014. Monitoring residual surfactant in the flowback and produced water: a way forward to improve well productivity. *Society of Petroleum Engineers*. 2014, April 21. doi:10.2118/172190-MS

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

- Rimassa, S.M., P.R. Howard, B. MacKay, K.A. Blow, and N. Coffman. 2011. Case study: evaluation of an oxidative biocide during and after a hydraulic fracturing job in the Marcellus Shale. *Society of Petroleum Engineers*. 2011, January 1. doi:10.2118/141211-MS.

- Schachter, H.E. 2014. 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*. 2014, August 28. doi:10.15530/urtec-2014-1921626.

- Sharma, S., L. Bowman, K. Schroeder, and R. Hammack. 2015. 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, B.W., R.C. Capo, and C.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, B.W., E.C. Chapman, R.C. Capo, J.D. Johnson, J.R. Graney, C.S. Kirby, and K.T. Schroeder. 2015. 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., T.R. Woodworth, S.D. Burton, and R.D. Richards. 2009. Controlling bacteria in recycled production water for completion and workover operations. *Society of Petroleum Engineers*. 2009, January 1. 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 D.A. Yoxtheimer. 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., 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. 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., 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, 140-156, dx.doi.org/110.1016/j.coal.2013.1012.1017.

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

<u>(7) Data sources that provide information on reuse of flowback and produces water are provided below:</u>

- Balasubramanian, R., R. Ryther, R. De Paula, B. Epps, V. Keasler, J. Li, and R. Staub. 2015. Development of very low peroxide containing peracid formulation as superior treatment option for water reuse applications, *Society of Petroleum Engineers (SPE), SPE International*

Symposium on Oilfield Chemistry. The Woodlands, Texas, USA 13-15 April 2015, SPE-173780-MS.

- Barnes, C.M., R. Marshall, J. Mason, D. Skodack, G. DeFosse, D.G. Smith, S. Foreman, T. Hanna, and M. Cecchini. 2015. The new reality of hydraulic fracturing: treating produced water is cheaper than using fresh. *Society of Petroleum Engineers (SPE), SPE International Symposium on Oilfield Chemistry*. Houston, Texas, USA 28-30 September 2015, SPE-174956-MS.

- Burgos, M. and G. Lebas. 2015. Beneficial reuse of production water for irrigation. *International Petroleum Technology Conference (IPTC)*. Doha, Qatar 6-9 December 2015. IPTC-18389-MS.

- Farrell, J.W., T. Baudendlstel, and M. Kidder. 2015. Water-flexible fracturing systems. *Unconventional Resources Technology Conference.* San Antonio, Texas, USA, 20-22 July 2015. SPE-178699-MS/URTeC: 2173887.

- Hussain, A., J. Minier-Matar, A. Janson, and S. Adham. 2014. Advanced technologies for produced water treatment and reuse. *Internation Petroleum Technology Conference (IPTC).* Doha, Qatar 20-22 January 2014. IPTC 17394.

- McMahon, B., B. MacKay, and A. Mirakyan. 2015. First 100% reuse of Bakken produced water in hybrid treatments using inexpensive polysaccharide gelling agents. *Society of Petroleum Engineers (SPE), SPE International Symposium on Oilfield Chemistry.* The Woodlands, Texas, USA 13-15 April 2015, SPE-173783-MS.

- Seth, K., S. Shipman, M. McCutchan, and D. McConnell. 2013. Maximizing flowback reuse and reducing freshwater demand: Case studies from the challenging Marcellus shale. *Society of Petroleum Engineers (SPE), SPE Eastern Regional Meeting*. Pittsburgh, Pennsylvania, USA 20-22 August 2013. SPE 165693.

<u>(8) The SAB recommends that the EPA consider the following additional literature sources within this chapter of the final Assessment Report:</u>

- Akob, D.M.; I.M. Cozzarelli, D.S. Dunlap, E.L. Rowan, and M.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.

- Bachu, S. and R.L. Valencia. 2014. Well Integrity: Challenges and Risk Mitigation Measures. *The Bridge* 44(2): 28-34.

- 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.

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EPA Response: We considered all literature recommended by the SAB and included new citations in the final Assessment Report where appropriate.

3.6. Wastewater Treatment and Waste Disposal Stage in the HFWC

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 discharge, and 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 geologic formation levels, and estimation methods and their associated challenges), and hydraulic fracturing-related wastewater characteristics including a discussion on what is wastewater. The chapter presents a discussion on 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, metal cations, 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. 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 hydraulic fracturing-related wastewater management; the fundamental principles of some of the treatment technologies described; the occurrence and removal of disinfection by-product (DBP) precursors in addition to bromide; additional aspects of “waste disposal,” including cuttings, drilling muds, and treatment residuals; the locations of hydraulic fracturing-related wastewater treatment and disposal facilities relative to downstream/downgradient public water supply (PWS) intakes and wells; the impacts of water recycling on pollutant concentrations and their potential impacts on drinking water quality (increased risks) should spills of recycled water occur; trends in hydraulic fracturing-related 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 associated with hydraulic fracturing-related wastewater disposal in deep well injection wells on oil and gas production infrastructure (e.g., damage to wells and storage vessels, and also to pipelines transporting water and wastewater), and on PWS infrastructure (e.g., damage to public water supply wells).

Regulatory Framework for HF Wastewater Treatment

The regulatory framework for oversight of CWTFs and of 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 final 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 hydraulic fracturing-related 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. In addition, information dealing with deep well injection of hydraulic fracturing-related wastewater in Chapter 7 of the draft Assessment Report should be moved to and consolidated in Chapter 8 of the final Assessment Report.

> **EPA Response:** We acknowledge that regulations are important in determining how wastewater management practices are conducted. However, a comprehensive regulatory summary is beyond the scope of this Assessment Report. We have revised Text Box 8-2, added footnotes, and reviewed the text with regard to coverage of regulations. Regulations are discussed in the text where helpful and appropriate to provide context for management practices. Additionally, an overview of regulations was added in Chapter 1.

Treatment Technologies and Costs

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 for costs of hydraulic fracturing water purification technologies over the past decade, trends in hydraulic fracturing-related 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 hydraulic fracturing-related wastewater is being reduced because of regulatory changes driven by public concerns about seismic activity and its associated costs.) An assessment of these trends and costs should be included in the final Assessment Report. The EPA should consider use of the EPA's costing information developed for wastewater treatment (U.S. EPA 1979a; 1979b; 1979c). The final 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. The SAB recommends that these activities be addressed in the final Assessment Report. However, to avoid undue delay in publishing the final Assessment Report, the SAB recommends that the activities that cannot be promptly addressed without further study should be identified in the Assessment Report as research needs to be addressed as a longer-term future activity

> **EPA Response**: We have incorporated comments provided by the SAB on the descriptions of treatment technologies, either accepting suggested rewording or clarifying our original text in response to comments.
>
> With regard to trends and costs, we acknowledge the importance of costs as a driver in wastewater treatment and wastewater management in general. However, a full analysis of costs and trends in wastewater treatment over the past decade is beyond the scope of this Assessment Report and chapter. The chapter emphasizes cost as a significant consideration when discussing drivers and limited cost information is provided by way of example where available and appropriate.
>
> Discussion has been included regarding the need for operators to adjust their wastewater management practices where injection into disposal wells is curtailed due to induced seismicity (Section 8.4.1).

<u>Disposal Options and Costs</u>

The agency should clearly and accurately summarize trends in oil and gas wastewater disposal in Chapter 8. Disposal techniques have changed significantly over the past 15 years, and are likely to continue changing. There are inadequate scientific and economic descriptions 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 final Assessment Report should also discuss likely future trends in hydraulic fracturing-related wastewater disposal, and describe and assess future uncertainties. For example, the final 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.

As a longer-term future activity, the EPA should evaluate whether trends for deep well injection of hydraulic fracturing-related wastewater are being reduced because of regulatory changes driven by public concerns about seismic activity and its associated costs (as recently occurred in Oklahoma; see Wines 2016).

The final Assessment Report should clarify what is meant by "waste disposal." The title of Chapter 8 (Wastewater Treatment and Waste Disposal) is ambiguous and the text is not clear as to whether "waste" includes only those wastes generated during hydraulic fracturing-related 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 routes for these wastes, and whether drilling wastes are normally disposed in regulated landfills having low potential to leach constituents of concern into nearby drinking water sources. The final Assessment Report should also discuss how hydraulic fracturing spill-contaminated soils, pond sediments, and other solid media that are potentially impacted by hydraulic fracturing constituents are managed and disposed, and whether the EPA considers these potentially impacted media as "site reclamation" activities that the agency 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 them 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.

EPA Response: We acknowledge the importance of costs as a driver in wastewater treatment and wastewater management. A full analysis of costs and trends in wastewater treatment, however, over the past decade would be a substantial undertaking and is beyond the scope of this Assessment Report and chapter. The chapter emphasizes cost as a significant consideration when discussing drivers and limited cost information is provided by way of example where available and appropriate.

We have included discussion acknowledging the need for operators to adjust their wastewater management where injection into disposal wells is curtailed due to induced seismicity (Section 8.4.1).

Discussion has also been added noting possible changes in wastewater management should drilling decline and the demand for reuse drops (Section 8.4.4). A detailed analysis of these alternate trajectories would be a substantial effort that is beyond the scope of the chapter.

We acknowledge that drilling muds and drill cuttings are important waste streams, but these are outside of the scope of the hydraulic fracturing water cycle, as is a discussion of site reclamation activities. We changed the title of the chapter to *Wastewater Disposal and Reuse* to better reflect the focus of the chapter.

Regarding spill-contaminated sediments, we found insufficient data available for a detailed analysis of how these and other solids are disposed of, and an analysis of the relevant regulations is beyond the scope of the Assessment Report and chapter.

Organic Constituents in Wastewater

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 et al. 2014; Fan et al. 2014; Kondash et al. 2014; Lester et al. 2015; and Wang 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 constituents that are designated as confidential business information (CBI), and that a significant portion of hydraulic fracturing injection fluid constituents being used by operators are considered proprietary information. The sphere of unknown constituents is further enlarged by the fact that subsurface reactions can change the structure and toxicity of both known and unknown constituents. 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 constituents do not fall into these categories, then there may not be a concern regarding such constituents. 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 final Assessment Report. Within the final Assessment Report, the agency should also characterize in some way data on proprietary constituents that the EPA may have, and information provided in newer versions of FracFocus on chemical class and concentration (i.e., concentration of the constituent, in terms of % by mass, in the hydraulic fracturing fluid). As the FracFocus data that the agency assessed were 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.

> **EPA Response**: We have revised the text to acknowledge uncertainties in wastewater composition related to fracturing fluid chemicals and their degradation products. We also note that there may be chemicals present that are claimed as confidential business information.
>
> Because this chapter addresses wastewater management rather than the fracturing fluid, an analysis of data on proprietary constituents is out of the scope of this chapter, as is a discussion of the status of FracFocus. Chapter 5 provides discussion of the constituents in hydraulic fracturing fluids and makes use of data available in FracFocus 1.0 as analyzed in EPA research.
>
> Although this chapter briefly notes organic constituents in wastewater to provide context for management practices, more complete descriptions of the organic chemistry of wastewater is provided in Chapter 7 and Appendix E.

<u>Treatment Residuals</u>

Regarding the residuals generated from hydraulic fracturing-related 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 dissolved 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 final 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, state or tribal 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 final Assessment Report should 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 final 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.

> **EPA Response:** The chapter has been revised to include a more complete discussion of the management of residuals associated with hydraulic fracturing wastewater, especially with respect to potential impacts from technologically enhanced naturally occurring radioactive material (TENORM). However, a full discussion of regulations applicable to treatment residuals is beyond the scope of the chapter. Also, insufficient data are available to fully characterize the current management of these residuals in terms of volumes, composition, and disposal. Data on the handling of hydraulic fracturing wastewater treatment residuals is identified in the chapter as a data gap.
>
> Regarding organics, the SAB makes a valid point that a full discussion of treatment of wastewater for organic constituents would break out content by the various states. However, this appendix is not meant to be a complete guide for making treatment decisions but rather to provide general information on the processes available for various constituent types. We have left the text at the more general level for the purposes of this appendix.

<u>Bromide and Nitrosamines</u>

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 describe how significant dilution of waters containing dissolved 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 (California) 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 final Assessment Report should include 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 constituents 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 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. Bromide is converted (oxidized) to bromine by the applied disinfectant (e.g., chlorine). The bromine and the chlorine are incorporated into DBPs. The ratio of bromide to applied chlorine and bromide to organic matter affects the bromination fraction in the DBPs. The applied chlorine level is determined by the chlorine demand, water temperature and the required CT (disinfectant concentration x contact time) for the plant. Literature reports have considered bromide incorporation percentages (Luong et al. 1982; Amy et al. 1991) within THM, while incorporation into unregulated DBPs is less well studied. The dissolved Br-to-Cl ratio in the DBPs can be orders of magnitude higher than the ratio in the raw water. (e.g., Hua et al. 2006; Obolensky and Singer 2005; and Westerhoff et al. 2004).

> **EPA Response:** The descriptions of modeling studies have been clarified to better present assumptions and have been moved to Appendix F. In this Assessment, we do not use modeling to present definitive strategies for reducing impacts on public water systems (PWS). The chapter has been edited to include the potential for formation of nitrosamines.
>
> With respect to the concerns regarding more fully documenting that bromide is preferentially incorporated into halogenated DBPs, Chapter 8 and Appendix F have been revised to provide further emphasis on this issue. In order to balance educating the reader about the topic with concerns about the content being too long and too dense, the chemistry of DBP formation is only briefly discussed.

<u>Antiscalants and Other Constituents</u>

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 constituents 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. The agency should address this potential concern in Chapter 8. Data sources that would provide information on concentrations of antiscalants in HF waters are provided in section d2 below.

In addition, the final Assessment Report should discuss the degree to which bromate, chlorate, chlorite, perchlorate, and iodate are used in hydraulic fracturing fluids and are present in flowback and produced water. The SAB notes that bromates, chlorites and hypochlorites are used in fluids during HF stimulation. All of these constituents have human toxicity endpoints and some have MCLs, and the EPA should describe whether these constituents are ever found in hydraulic fracturing waters. The SAB also finds that the EPA's discussion on halogens and halogenated disinfection by-products in Chapter 8 is inadequate.

> **EPA Response**: We have focused the more substantive discussions in the chapter on those constituents for which enough literature and data are available. The chapter notes the potential for contributions to wastewater from hydraulic fracturing chemicals, but has not included separate discussions regarding individual classes of fracturing fluid chemicals.
>
> We were unable to find data on bromate, chlorate, or chlorite in flowback and produced waters.
>
> The discussion of disinfection by-products (DBPs) has been reviewed and revised to provide succinct but clear information on a wider range of DBPs without detracting from the flow of the chapter.

Additional Recommended Corrections

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 has 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 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 metal ions in the coagulation process.

- 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 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 be removed by filtration only 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, powdered activated carbon, or adsorptive media. 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. The 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." In wastewater treatment, aeration refers to the mixing of air/oxygen, through mechanical processes, in wastewater.

- On page F-7, electrocoagulation is said to be *"… less effective for removing TDS and sulfate."* This technology is 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 simply by 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 remove 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 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 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 final Assessment Report.

EPA Response: We have addressed each of the above comments on treatment technologies by either accepting the suggestions or editing the text to clarify our original content.

Regarding electrocoagulation, the SAB describes the process of electrocoagulation but then adapts it to chemical coagulation when suggesting that we do not include it under emerging technologies. While the chemical reactions may be similar, the processes are different. Furthermore, literature supports that while the concept has been around for a century, the technology has had limited success and is not considered "mainstream" by way of water treatment. In addition, the reference to the 1977 EPA document in the comment discusses chemical coagulation, not electrocoagulation. We have addressed the first part of the SAB's request to make it clear electrocoagulation is an emerging technology specific to hydraulic fracturing applications, but did not include it with chemical coagulation as a main stream technology.

Regarding “bromine” and bromide”, we have made any necessary corrections during revisions.

We recognize SAB’s point regarding coagulation and flocculation aiding in total suspended solids (TSS) removal but not the actual technology that removes TSS per se. However, Halliburton uses a patented technology that uses electrocoagulation to remove TSS. TSS is removed via flotation due to gas bubbles formed on the cathodes or, for heavier particles, settling. The text has been modified to better explain this concept.

Concerning the removal of monovalent ions, the authors cited in the reference to nanofiltration (Hammer and VanBriesen, 2012)[1] specifically list nanofiltration as one of the treatment technologies that are capable of removing monovalent ions, although the conditions must be favorable for all the treatment technologies listed (not just nanofiltration). Nonetheless, nanofiltration is not known for removing monovalent ions effectively. Therefore, we have removed nanofiltration from the statement.

Regarding media filtration and metals, a discussion of metals in dissolved vs particulate form and the requirements of pretreatment have been added to the text.

Concerning nanofiltration and removal of dissolved metals and metalloids, the authors cited in the reference to nanofiltration (Hammer and VanBriesen, 2012) specifically list nanofiltration as one of the treatment technologies that are capable of removing monovalent ions. Albeit, the conditions must be favorable for all the treatment technologies listed (not just nanofiltration). Nonetheless, nanofiltration is not known for removing monovalent ions effectively. Therefore, we agree with the commenter about removing nanofiltration from the statement.

Regarding the precipitation of radium, the text has been changed to match the SAB's suggested text.

Regarding coagulation, the term "coagulation" has been replaced with "chemical precipitation" which encompasses both coagulation and precipitation and coincides more accurately with the section referenced in the paragraph (8.5.2.4).

We have edited the text to reflect the comments on aeration, electrocoagulation, electrodialysis, and forward osmosis.

Regarding electrodialysis and organics, the cited material was misleading. The original source revealed that oil and grease were removed by a pretreatment process (induced gas flotation), not electrodialysis. The table has been edited to remove the entry in the table.

Lastly, we have identified the acronym CWT in the text as “centralized waste treatment” as per the EPA definition so as not to deviate from the established meaning (and associated regulatory context). We define the term “wastewater” as used in the assessment in the introduction to the chapter.

[1] Hammer, R; VanBriesen, J. (2012). In fracking's wake: New rules are needed to protect our health and environment from contaminated wastewater. New York, NY: Natural Resources Defense Council (NRDC). http://www.nrdc.org/energy/files/fracking-wastewater-fullReport.pdf

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 hydraulic fracturing-related 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."* This conclusion is not fully supported by the information and data presented in Chapter 8, and is also not supported by peer reviewed literature that has demonstrated contaminants from oil and gas wastewater disposal facilities have reached drinking water facilities and have had effects (e.g., see States et al. 2013, which is cited in the draft Assessment Report; and Landis et al. 2016). The agency should clearly and accurately describe the basis for this statement in Chapter 8.

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 final Assessment Report should clearly and accurately describe the basis for this estimate. The draft Assessment Report includes many disparate estimates (for different years or time periods, different groups of states, and different segments of the industry) and uses different units of volume and flowrate. These are appropriately used, but are nevertheless likely to be confusing to at least some readers. To provide more clarity, the SAB recommends that the EPA include a table in Chapter 8 that 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 hydraulic fracturing-related 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 Trihalomethane (THM) and Haloacetic Acid (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 final Assessment Report should clarify whether these statements are based on toxic effects observed in cell cultures, on animal toxicity studies, or on human toxicity data. The EPA should cite the appropriate references for human toxicity data. For example, extensive information regarding the human health impacts of DBPs is provided within the EPA's Stage 1 and Stage 2 Disinfectants and DBP rules (U.S. EPA 1998, and U.S. EPA 2006) as well as numerous EPA documents (e.g., U.S. EPA 2005).

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.

> **EPA Response:** The statement in the draft chapter *"there is no evidence that these contaminants have affected drinking water facilities"* has been removed.
>
> In the revised chapter, Section 8.6.1 reiterates Veil's (2015)[1] estimate, which is introduced in Section 8.2.1, along with a description of Veil's procedures and the data limitations. The text in Section 8.2 has also been reviewed and edited to provide better clarity on the various types of volume estimates in the chapter. Adjusting volumes for increased production over time is beyond the scope of the chapter, as is providing a validated approach to predict future wastewater generation trends.
>
> While we appreciate the importance of the underpinnings of toxicity information for DBPs, adding additional content on the specific types of toxicity studies is a level of detail not essential to the key points of the section, and would add length to an already lengthy chapter.
>
> The text on potential downstream transport of sediment has been edited to note the factors that would influence potential impacts on water quality from sediment-associated contaminants.
>
> [1] Veil, J. (2015). U.S. Produced water volumes and management practices in 2012. Oklahoma City, OK: Ground Water Protection Council. http://www.gwpc.org/sites/default/files/Produced%20Water%20Report%202014-GWPC_0.pdf

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 several issues associated with this wastewater disposal method. First, transport of wastewater from a specific wellsite to a disposal injection well poses risks for spills. Longer distances increase the likelihood of crossing surface waters, where spills could impact surface water intakes, and the likelihood of spills in general, which could impact water supply wells. Second, the final Assessment Report should summarize the extent to which permitting of injection wells in different states considers their proximity and potential impacts to water supplies (public water supply wells, private wells, surface water intakes). Third, as noted in the draft Assessment Report on pages ES-19, ES-20, and 8-20, the EPA did not investigate water quality issues nor potential impacts to drinking water from the disposal of hydraulic fracturing wastewater in underground injection control wells; the EPA should assess the potential for such issues and impacts as a longer-term future activity.

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 very recent 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 the potential for seismic activity may affect operator selection of appropriate flow rates and pressures to minimize or eliminate significant seismic events when deep well injection is used. The SAB encourages the agency to collaborate with other federal, state or tribal regulatory agencies, universities, industry and other stakeholders to update the research associated with this issue as a longer-term future activity.

HF flowback and produced waters are not always considered “wastewater” since they may be beneficially reused in the HFWC process. The final Assessment Report should note that reuse of wastewater or HF flowback and produced waters 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 final Assessment Report should note that the storage of any reused water with these elevated contaminant concentrations represents a potential source of leaks/spills that could impact 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 final 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 final Assessment Report should further describe that technologically-enhanced naturally occurring radioactive materials (TENORM) may pose a significant risk since treatment processes used to remove other constituents (such as metals, biochemical oxygen demand, 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 final Assessment Report should also acknowledge that other strategies for disposal of treated wastewater from hydraulic fracturing-related activities 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 find their way into drinking water resources if not properly managed, the final 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). Since not all constituents in HF Flowback and produced waters are known, the chapter should recognize that there are no data on the removal of unknown hydraulic fracturing constituents, and that the presence of these unknown 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 all regulated injection well sites in the United States 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 final Assessment Report would strengthen the examination of the potential impacts of hydraulic fracturing wastewaters on drinking water resources.

EPA Response: The discussion of DBPs has been reviewed and revised to provide succinct but clear information on a wider range of DBPs without detracting from the flow of the chapter.

We acknowledge the importance of wastewater spills during transit as a mechanism for impacts on drinking water resources. This topic is covered in Chapter 7. A summary of state permitting requirements for UIC Class II disposal wells is beyond the scope of Chapter 8, although the importance of the general hydrologic setting in which a spill or leak occurs is noted in the chapter in Section 8.6.2.3 in the context of impacts from pits and impoundments.

Although potential impacts from wastewater injection itself are outside the scope of this chapter, more content has been added on concerns related to induced seismicity and state responses (Section 8.4.1). The text notes the importance of disposal wells in the overall management of wastewater nationwide, and text has been added on the need for operators to adjust their wastewater management practices if use of disposal wells becomes curtailed due to concerns about induced seismicity.

We have edited the text to better describe the potential for concentration of contaminants in wastewater during successive reuse cycles and note that the storage and transport of minimally treated wastewaters provides a potential route for impacts on water resources in the event of spills or leaks.

The text has been revised to note that the concentrations of radium in publically-owned treatment works (POTW) and CWT effluents are much greater than the MCL of 5 pCi/L. Revisions to the chapter include more content overall on TENORM, including treatment. (Note that general content on spills and leaks is covered in Chapter 7.)

Revisions to the chapter include additional discuss of treatment residuals and their management. Revisions to the chapter also include acknowledgment that uncertainties in wastewater quality and treatment exist because not all constituents are known.

Because of challenges related to the completeness of locational data for disposal wells and domestic wells, it was not feasible to map the locations of these wells relative to PWS intakes.

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 occur. Within the draft Assessment Report, the EPA describes a study that assumed a 3-log (1000x) 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 final 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 constituents used in hydraulic fracturing injection fluids and to unknown subsurface reactions that affect the quality of flowback and produced water, the final 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 final Assessment Report should also assess iodide in the same manner as is recommended for bromide (see 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, 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 et al. 2009). Therefore, information about iodide in flowback or produced waters should be amplified in the final Assessment Report. The ratio of dissolved 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 chloride than in seawater.

> **EPA Response:** The chapter initially included and still includes a discussion of the PA DEP TENORM (PA DEP, 2015)[1] study that documented the presence of radionuclides in effluents from CWTs and POTWs affected by oil and gas wastewater. The chapter also includes discussion of work by Warner et al. (2013)[2] regarding radionuclides in effluents from a CWT in Pennsylvania that received Marcellus wastewater. The draft chapter also included an analysis of estimated concentrations of several constituents (including radium) that would result from various treatment processes and for different influent concentrations, with the emphasis that with

a high enough influent concentration, a high removal rate could still produce an effluent concentration that exceeds MCLs or other standards. This content is still included, with details in Appendix F. In revising the chapter, we have increased the overall content on TENORM, including residuals, and the potential for leaching from TENORM-bearing solids.

Our contaminant removal estimates (Section 8.4.3.2 and Table F-4) were used to emphasize that treatment processes may not be able to adequately reduce contaminant concentrations if the influent concentration is high enough. (Details of the analysis were kept in Appendix F and discussion in the chapter is brief.)

In revising the chapter, we looked at the National Pollutant Discharge Elimination System (NPDES) permit information for several CWTs in the eastern United States treating wastewater from the Marcellus region and one near the Fayetteville Shale in Arkansas and described the constituents monitored, whether they have limits, and the frequency and sample types.

Text on treatment processes has been revised as per SAB comments, either accepting suggested edits or clarifying our initial text to address reviewer concerns.

During revisions, we have reviewed the text to ensure that iodide is discussed appropriately. However, comparison of anion ratios in flowback and produced water relative to seawater was not considered relevant to our discussions of wastewater management strategies.

[1] PA DEP (Pennsylvania Department of Environmental Protection). (2015b). Technologically enhanced naturally occurring radioactive materials (TENORM) study report. Harrisburg, PA: Commonwealth of Pennsylvania Department of Environmental Protection.
[2] Warner, NR; Christie, CA; Jackson, RB; Vengosh, A. (2013). Impacts of shale gas wastewater disposal on water quality in western Pennsylvania. Environ Sci Technol 47: 11849-11857. http://dx.doi.org/10.1021/es402165b

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 THMs and HAAs, bromate). The ratio of dissolved 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 should be referenced regarding DBP formation in drinking water treatment plants downstream from CWTFs or from POTWs receiving hydraulic-fracturing related wastewater. For example, the State of Pennsylvania's public drinking water suppliers have been reporting full speciation data on THM and HAA in compliance data for several years. Also, the EPA's Region 3 office is conducting an ongoing study of bromide and DBPs in the Ohio River. The final Assessment Report should discuss 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 final 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 final 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 it 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 final 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 final Assessment Report should describe this scenario. Also, the final 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 (Sr) 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) dissolved 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 a 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 final Assessment Report.

> **EPA Response**: We have added discussion about the need for operators to adjust their wastewater management practices where injection into disposal wells is curtailed due to induced seismicity (Section 8.4.1). We have also noted that operators may need to find alternate ways to manage wastewater that is currently reused if hydraulic fracturing activity drops and the demand for reuse decreases (Section 8.4.4).
>
> Available data and information do not permit a quantitative assessment of frequency and severity. Furthermore, because wastewater management practices and the related logistics and environmental concerns vary geographically, a direct comparison and ranking of practices is not feasible. We have, however, brought forth those practices we believe present the greatest potential for impacts and described those factors that would influence the frequency and severity of impacts.
>
> During revisions, we have reviewed the text to ensure that bromide and iodide are discussed appropriately. However, comparison of anion ratios in flowback and produced water relative to seawater was not considered relevant to our discussions of wastewater management strategies.
>
> In Chapter 8, we more fully addressed historic information about DBP formation in drinking water systems downstream from CWTs and POTWs that received hydraulic-fracturing wastewater. We did not however find robust information regarding fluctuations in total organic halide concentrations at water treatment plants downstream from those CWTs and from POTWs that historically received hydraulic fracturing-related wastewater.
>
> In revising the chapter, we looked at NPDES permit information for several CWTs in the eastern United States treating wastewater from the Marcellus region and one near the Fayetteville Shale in Arkansas and described the constituents monitored, whether they have limits, and the frequency and sample types. Text on treatment processes has been revised as per SAB comments, either accepting suggested edits or clarifying our initial text to address reviewer concerns.
>
> Regarding the impacts of the high organic content of hydraulic fracturing wastewater, we briefly mention the role of organic material in DBP formation in Chapter 8 and Appendix F, and we also added discussion of a study regarding the impact of high dissolved organic carbon content of flowback water on DBP formation. However, as noted by the SAB, there is relatively little

published data on concentrations of naturally occurring organic material (NOM) found in hydraulic fracturing wastewaters.

We have added content regarding concerns associated with ammonium in hydraulic fracturing wastewaters potentially converting free chlorine to chloramines at downgradient drinking water treatment plants.

The chapter acknowledges the potential for discharge of strontium, and the chapter notes what can be extremely high concentrations of strontium in some hydraulic fracturing wastewaters. However, although MCLs are mentioned periodically in Chapter 8 for reference, toxicity and other potential health effects are covered in more detail in Chapter 9.

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 final 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 (as recently occurred in Oklahoma; see Wines 2016), 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. The SAB recommends a more detailed analysis of these trends, including actual and projected disposal costs, as a longer-term future activity.

A key limitation of Chapter 8 is that, although this chapter addresses potential impacts of hydraulic fracturing-related 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), and 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 in Chapter 8 would provide more insight into risks to drinking water resources.

Chapter 8 inadequately describes potential impacts on public drinking water supplies that rely upon surface water intakes located within the same watershed as, but 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). To assess this topic, a variety of information is needed including: the size and location of injection wells, CWTFs, and POTWs receiving wastewater discharges (directly or indirectly); the locations and treatment capabilities of drinking water treatment facilities; and 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 accepting wastewater associated with hydraulic fracturing.

The EPA should also consider the potential impact that treatment of any hydraulic fracturing fluids would have on the ability of a local POTW to recover resources (energy, water, nutrients) from wastewater. This is important because the EPA, DOE, other federal agencies, and some professional organizations have been organizing meetings on accelerating this aspect of the wastewater sector. In addition, the SAB notes that some POTWs are operated 24 hours per day while others are staffed only during day time operating hours, and recommends that the EPA consider the impact that treatment of any hydraulic fracturing fluids would have on local POTWs in terms of their staffing levels and operator training.

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 final Assessment Report. If these modeling results are included in the final Assessment Report, the limitations associated with the modeling should be explicitly identified and the results should be appropriately qualified in the final Assessment Report.

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 data for certain 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 final 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). The EPA should also provide adequate justification for limiting analysis to a one mile radius to define proximity of a drinking water resource to hydraulic fracturing operations. The SAB notes that the EPA used a five mile radius for potential effects of coal-fired power plant bromide discharges on downstream drinking water plants (U.S. EPA 2015b). While it is not clear that the five mile radius is sufficient as the discharged bromide is conservative in surface waters, some consistency in the proximity analysis for different sources of the same contaminant (bromide) may be expected.

The EPA should also develop maps of watersheds that have drinking water treatment plants located downgradient from active or planned hydraulic fracturing activities for oil or gas development. Limiting proximity analysis to one 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 et al. 2015; Rice and Westerhoff 2015). The EPA should conduct similar work to understand potential risks to municipal surface water drinking water intakes greater than one mile away from hydraulic fracturing-related treatment and disposal facilities.

> **EPA Response:** While the chapter and appendix cover conventional and advanced unit treatment processes as they are currently available, an analysis of trends over the past 15 years and a projection of future developments in treatment are beyond the scope of this document. However, the revised chapter discusses the need for operators to adjust their wastewater management practices if use of disposal wells becomes curtailed due to concerns about induced seismicity. Discussion has also been added noting possible changes in wastewater management should drilling decline and the demand for reuse drops.
>
> We agree with the value of assessing wastewater management from a watershed perspective. We have added a new section (Section 8.4.3.1) containing a map we developed showing the relationship between Pennsylvania potable water supplies and the CWTs in their upstream watersheds that accept or have accepted Marcellus wastewater. The map provides a general illustration of how CWTs are situated within catchments in Pennsylvania, showing their spatial and general hydrologic relationships to streams that can serve as potable water supplies. We were only able to complete this analysis for one area (Pennsylvania) and one management practice (CWTs). Limitations in the completeness of locational data for disposal wells prevented us from doing a similar analysis for disposal by injection.
>
> We appreciate the value of understanding the potential effects on a POTW in terms of resources. However, discussion of POTW operations, energy, staffing, and other issues is considered out of scope for this chapter.
>
> Given the challenges we encountered in constraining produced water volumes for hydraulic fracturing activities, estimation of produced water generation within a fixed radius of particular CWTs relative to the CWTs' capacities would be best approached as a future project. Please note that no analyses or discussions in Chapter 8 make use of a 1-mile radius.
>
> In revising the chapter, we looked at NPDES permit information for several CWTs in the eastern United States treating wastewater from the Marcellus region and one near the Fayetteville Shale in Arkansas and described the constituents monitored, whether they have limits, and the frequency and sample types.
>
> The descriptions of modeling studies related to DBP formation have been clarified to better present assumptions and have been moved to Appendix F. We do not use modeling to present definitive strategies for reducing impacts in this assessment.

3.6.5. 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 results from or status of 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, metal cations, 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 final 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 final 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; 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 hydraulic fracturing-related wastewater treatment and waste disposal. While the draft Assessment Report does briefly address hydraulic fracturing-related 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 finds that it should provide more information and analyses on these topics.

> **EPA Response:** We have included as much available data as possible on contaminant removal during treatment (from peer reviewed literature and other sources that met our criteria). Table F-4, for example, provides data from studies of removal efficiencies and influent/effluent data for various processes and facilities. At the time of this Assessment, laboratory data from EPA research specific to this topic are not available.
>
> The discussion of DBPS has been reviewed and revised to provide succinct but clear information on a wider range of DBPs without detracting from the flow of the chapter.
>
> In the revised chapter, Section 8.6.1 reiterates Veil's (2015)[1] estimate, which is introduced in Section 8.2.1, along with a description of Veil's procedures and the data limitations. The text in Section 8.2 has also been reviewed and edited to provide better clarity on the various types of volume estimates in the chapter. Adjusting volumes for increased production over time is beyond the scope of the chapter, as is providing a validated approach to predict future wastewater generation trends.

We acknowledge that drilling muds and drill cuttings are important waste streams, but these are outside of the scope of the hydraulic fracturing water cycle.

[1] Veil, J. (2015). U.S. Produced water volumes and management practices in 2012. Oklahoma City, OK: Ground Water Protection Council. http://www.gwpc.org/sites/default/files/Produced%20Water%20Report%202014-GWPC_0.pdf

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 final Assessment Report:

References on seismic activity

- 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.

References on energy in treatment plants

- 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., L. Tan, and M. Davis. 1991. The effects of ozonation and activated carbon adsorption on trihalomethane speciation. *Water Research* 25(2): 191-202. http://www.sciencedirect.com/science/article/pii/004313549190029P

- 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.

- Luong, T., C. Peters, and R. Perry. 1982. Influence of bromide and ammonia upon the formation of trihalomethanes under water-treatment conditions. *Environmental Science and Technology* 16(8): 473-479. http://pubs.acs.org/doi/abs/10.1021/es00102a009?journalCode=esthag

- U.S. EPA (U.S. Environmental Protection Agency). 2015b. Effluent Limitations Guidelines and Standards for the Steam Electric Power Generating Point Source Category. United States Environmental Protection Agency EPA-HQ-OW-2009-0819, Washington DC. https://www.epa.gov/eg/steam-electric-power-generating-effluent-guidelines-2015-final-rule

- Weaver, J., J. Xu, and S. Mravik. 2016. Scenario Analysis of the Impact on Drinking Water Intakes from Bromide in the Discharge of Treated Oil and Gas Wastewater. *ASCE Journal of Environmental Engineering* 142(1). DOI: http://ascelibrary.org/doi/abs/10.1061/%28ASCE%29EE.1943-7870.0000968

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., I. Ferrer, E.M. Thurman, K.A. Sitterley, J.A Korak, G. Aiken, and K.G Linden. 2015. Characterization of hydraulic fracturing flowback water in Colorado: Implications for water treatment. *Science of the Total Environment* 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., I. Ferrer, J. Blotevogel, and T. Borch. 2014. Analysis of hydraulic fracturing flowback and produced waters using accurate mass: identification of ethoxylated surfactants. *Analytical Chemistry* 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., J. Oppenheimer, S. Adham, and M. Kumar. 2009. Innovative beneficial reuse of reverse osmosis concentrate using bipolar membrane electrodialysis and electrochlorination processes. *J. Membrane Sci.* 326(2): p. 392-399.

- Ji, X., E. Curcio, S. Al Obaidani, G. Di Profio, E. Fontananova, and E. Drioli, 2010. Membrane distillation-crystallization of seawater reverse osmosis brines. *Separation and Purification Tech.* 71(1): p. 76-82.

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

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

- Perez-Gonzalez, A.M., R. Urtiaga, and I. Ibáñez. 2012. State of the art and review on the treatment technologies of water reverse osmosis concentrates. *Water Research* 46(2): p. 267-283.

- Zhao, S., L. Zou, and D. Mulcahy. 2012. Brackish water desalination by a hybrid forward osmosis-nanofiltration system using divalent draw solute. *Desalination* 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. 2006. An evaluation of the relationship between SUVA and NOM coagulation using the ICR database. *J. American Water Works Assn.* 98(7): p. 110-123.

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

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

- U.S. EPA (U.S. Environmental Protection Agency). 1998. National Primary Drinking Water Regulations: Stage 1 Disinfectants and Disinfection Byproducts Rule. 63 FR 69390-69476, December 16, 1998. https://www.gpo.gov/fdsys/pkg/FR-1998-12-16/pdf/98-32887.pdf#page=1

- U.S. EPA (U.S. Environmental Protection Agency). 2005. Drinking Water Criteria Document for Brominated Trihalomethanes. 2005. United States Environmental Protection Agency: EPA-822-R-05-011. Washington DC.

- U.S. EPA (U.S. Environmental Protection Agency). 2006. National Primary Drinking Water Regulations: Stage 2 Disinfectants and Disinfection Byproducts Rule. 71 FR 388-493, January 2, 2006. https://www.gpo.gov/fdsys/pkg/FR-2006-01-04/pdf/06-3.pdf

References on ammonia and chloramine chemistry

- Hayes-Larson, E.L. and W.A. Mitch. 2010. Influence of the method of reagent addition on dichloroacetonitrile formation during chloramination. *Env. Sci. & Tech.* 44(2): p. 700-706.

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

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

- Schreiber, I.M. and W.A. Mitch. 2005. Influence of chloramine speciation on NDMA formation: Implications for NDMA formation pathways. *Abstracts of Papers of the American Chemical Society* 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 (U.S. Environmental Protection Agency). 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 (U.S. Environmental Protection Agency). 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 (U.S. Environmental Protection Agency). 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

- Wines, M. 2016. Oklahoma puts limits on oil and gas wells to fight quakes. New York Times, March 7, 2016. Available at http://www.nytimes.com/2016/03/08/us/oklahoma-earthquakes-oil-gas-wells.html?rref=collection&_r=0.

EPA Response: We considered all literature recommended by the SAB and included new citations in the final Assessment Report where appropriate.

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 constituents used and encountered across the HFWC. The chapter describes constituents used in hydraulic fracturing fluids, constituents detected in flowback and produced water, toxicological and physicochemical properties of hydraulic fracturing constituents, the selection of toxicity values including reference values and oral slope factors, and physicochemical properties of such constituents, and provides a summary of additional sources of toxicity information. The chapter presents a discussion on hazard identification of reported hydraulic fracturing constituents, including how constituents were selected for hazard identification, a multi-criteria decision analysis framework for hazard evaluation, and a summary of constituents 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 set of issues 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 constituents for those which may be of most concern. The SAB finds that inclusion of both exposure and toxicity data are of paramount importance in such an approach. Physicochemical properties of constituents (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 constituents is an overstatement of the scope of the problem.

At a minimum, the EPA should explicitly indicate what fraction of the identified constituents 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

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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

and Development (OECD) (2014) hydraulic fracturing scoping project which identified 1121 “unique” hydraulic fracturing constituents based on input from OECD member countries including the United States. 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 dataset 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 constituents, but only 55% of constituents 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 constituents 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 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 constituents 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 constituents is not unique to hydraulic fracturing, and the EPA should consider developing a tiered approach for toxicological information, including read-across methods of grouping constituents 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 constituents, 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 dataset) could be just as relevant as chronic studies. The

[10] Aggregated Computational Toxicology Resource, U.S. Environmental Protection Agency

ATSDR publishes acute, intermediate, and chronic ATSDR MRLs for many constituents. 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 constituents employed in hydraulic fracturing in an inclusive manner, and not restrict the criteria for selection of hydraulic fracturing constituents of concern to those that have formal noncancer oral reference values (RfVs) and cancer oral slope factors (OSFs) for those constituents.

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 constituents 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 the physiochemical score. While it may be useful in judging a constituent's likelihood of occurrence in drinking water, this value may be a relatively poor surrogate for actual exposure. Constituents 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 constituent 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 constituents 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 constituents reported in FracFocus 3 compared to FracFocus 1.0.

The SAB recommends that the EPA 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 constituent characteristics, such as mobility when the constituent 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 the EPA to more broadly include available physicochemical data on constituents, 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 policy makers and users of the assessment to prioritize constituent exposures of greater concern.

EPA Response: Regarding the consideration of the various types of toxicity values presented in this assessment, the 2012 Progress Report clearly outlined EPA's intention to characterize toxicity by using selected sources of reference values (RfVs) and oral slope factors (OSFs). The use other sources of toxicity data that do not meet EPA's criteria for inclusion in the assessment would be outside the scope of the study plan. The EPA's Office of Solid Waste and Emergency Response (OSWER) directives on hierarchy for selecting toxicity values was used to frame our selection criteria. In the revised chapter, we clearly state that the toxicity values – chronic oral RfVs and OSFs – compiled in this report are not intended to be an exhaustive compilation of toxicological information on these chemicals. Rather, it is intended to be a reconnaissance of high-quality toxicological information that met EPA's criteria for inclusion in this study. If a source of RfVs, OSFs, or qualitative cancer classifications was not included here, that only means that it did not meet the criteria for the purposes of EPA's Study, which are described in the chapter.

The revised chapter includes a statement justifying the use of chronic toxicity values rather than less-than-chronic values. Chronic RfVs account for the potential that chemical exposure may be continuous, in low concentration, and over a longer duration. In the absence of reliable information on the potential duration of chemical exposure, this is a conservative assumption for the protection of human health. Chronic RfVs are also lower than acute and other shorter duration RfVs, and are therefore more health protective. For these reasons, chronic RfVs are generally preferred as the default by risk assessors when conducting site specific risk assessments (U.S. EPA, 1989)[1] and when developing regional screening levels (https://www.epa.gov/risk/regional-screening-levels-rsls). In contrast, acute RfVs are more applicable for single exposures and/or exposures of limited frequency to high concentration and shorter durations (e.g. emergencies). Additionally, from EPA's sources, there were very few chemicals that had acute or intermediate toxicity values that did not also have a chronic value available. Therefore, the inclusion of these less-than-chronic values in our analysis would not have provided a considerable increase in information. In the chapter, we have a paragraph discussing the number of chemicals that had less-than-chronic values available.

Although the primary focus of the chapter is on chronic oral RfVs and OSFs from selected data sources, the hazard identification section in the chapter has been expanded to include the following:

- Quantitative structure-activity relationship (QSAR)-based toxicity estimates (chronic oral LOAELs), which can be used by risk assessors to rank chemicals based on potential toxicity.
- Information on the toxicity information and data available for each chemical on EPA's Aggregated Computational Toxicology Online Resource (ACToR) database.
- Expanded discussion of carcinogenicity and qualitative cancer classifications available for these chemicals.

The inclusion of this information has helped broaden the amount of potential toxicity information available for hydraulic fracturing constituents. For example, the ACToR database includes vast and disparate amounts of chemical information. An overview of the types of data and data collections queried by ACToR has been added to the chapter. In addition, text describing the types of data relevant to the chapter queried by ACToR was added.

In addition, we added a section to Appendix G describing other approaches and tools that can be used to address chemical toxicity data gaps, including read-across concepts and the use of high throughput and emerging technologies. However, we do not use these sources to characterize the potential toxicity of chemicals in the hydraulic fracturing water cycle, as this is outside the scope of the assessment.

The revised chapter includes a statement on the number of chemicals used in hydraulic fracturing fluids that are classified as generally recognized as safe (GRAS) by the U.S. Food and Drug Administration (FDA). GRAS determinations are often specific to certain conditions as expressed in the FDA GRAS Notification Database and therefore do not indicate that the same chemical is safe for use in hydraulic fracturing fluids.

Under the Hazard Identification Section of the chapter, we added subsections that specifically address potential hazards highlighted in previous chapters. These sections include: methane in stray gas, disinfection by products in wastewater, and organic and inorganic constituents (including naturally occurring radioactive materials) in produced water.

The multi-criteria decision analysis (MCDA) framework used in Chapter 9 has been published in a peer-reviewed journal since the time of the SAB review. In the revised chapter, it is made clear that the MCDA is intended only as a preliminary analysis, and a limitations section has been added to discuss the limitations mentioned by SAB. The analysis uses experimentally measured physicochemical property values (provided in EPI Suite) whenever possible; when experimentally measured values were not available, estimated values from EPI Suite were used. The revised chapter also clearly describes the decision to use frequency of use in hydraulic fracturing fluids as the metric for chemical occurrence in the MCDA.

We attempted to locate the Organization for Economic Co-operation and Development (OECD) document recommended by SAB, but were unable to find this document online, by contacting OECD, or via a request to the SAB.

[1] U.S. EPA (U.S. Environmental Protection Agency). (1989). Risk assessment guidance for Superfund: Volume 1: Human health evaluation manual (Part A): Interim final [EPA Report]. (EPA/540/1-89/002). Washington, D.C.: U.S. Environmental Protection Agency, Office of Emergency and Remedial Response. http://www.epa.gov/oswer/riskassessment/ragsa/index.htm

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?

In the draft Assessment Report, EPA clearly identifies and describes 1,076 constituents historically used in hydraulic fracturing fluids (Appendix A-2), and 134 constituents 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 constituent listed. These lists provides a valuable starting point for further refinement and updates. The SAB encourages the EPA to reconcile its lists of constituents with the international OECD (2014) list of constituents as a further check of potential constituents of interest, although the SAB recognizes that there are differences in regulations and practices between the European Union and the United States.

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

The EPA indicates that there is a paucity of information on constituent identity and concentrations in flowback and produced water, with only three references cited in Table A-4 of the draft Assessment Report. 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 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 can be considered a recommendation for 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 constituents 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, to demonstrate how combining toxicological and physicochemical information may be informative. The 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 can be 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 constituents used in hydraulic fracturing fluids and 23 constituents detected in flowback or produced water, the EPA should explicitly state that these MCDA results should not be used to prioritize the constituents of most concern nationally nor to identify 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 constituent's likelihood of higher concentrations in drinking water, this approach may not adequately address constituents 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) of the draft Assessment Report. 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).

EPA Response: In the revised chapter, we bring forward the relevant CBI information presented in Chapter 5 and discuss how this affects the "completeness" of our chemical list. We also refer to EPA's analysis of FracFocus 1.0, which describes how many CBI chemicals had enough information to be assigned to a standardized chemical family. This resulted in the designation of 448 standardized chemical families to which these chemicals could be assigned.

Industry provided the EPA a list of 381 CBI chemicals, of which only 80 had a Chemical Abstracts Service Registry Number (CASRN) designated. Chapter 5 provides a brief analysis of the physicochemical properties of 19 of these CBI chemicals, and found that the values of the physicochemical properties of known and CBI chemicals are similar, covering similar ranges and centered on similar values. This suggests that even though these chemicals are not publicly known, their physicochemical properties are not appreciably different from the known chemicals. We did not conduct a similar analysis to determine the availability of toxicity values (RfVs and OSFs) for this set of chemicals, because it would not have been possible to present those values in the report while fully protecting the identity of the CBI chemicals. However, because there is such a large range of RfVs (0.000013 – 20 mg/kg day) for the current list of chemicals, we would not reasonably expect a toxicity value for a CBI chemical to fall outside of this range.

In the revised chapter, it is made clear that the MCDA is intended only as a preliminary analysis. A limitations section has been added to discuss the limitations mentioned by SAB. As suggested by SAB, the revised chapter explicitly states that the MCDA results should not be used to prioritize the constituents of most concern nationally, nor to identify future toxicity testing research needs. We also explicitly state 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.

We attempted to locate the OECD document recommended by SAB, but were unable to find this document online, by contacting OECD, or via a request to the SAB. Therefore, were not able to reconcile EPA's and OECD's lists of chemicals.

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 the U.S. federal government, state governments, or international non-governmental organizations used for risk assessment

purposes, or publicly available peer-reviewed data. The final Assessment Report should explicitly indicate what fraction of the constituents identified in hydraulic fracturing fluid and/or produced waters have some hazard information (e.g., toxicity data available from or used by the U.S. federal government, 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 constituents 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 constituents in multiple places in Chapter 9 of the draft Assessment Report: *"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 individual water-tap levels.

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 constituents. 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 United States and European Union government- or international non-governmental organization-based toxicity data and safety assessments, nor accepted read-across approaches for highly similar constituents).

   EPA Response: As described previously, it would be outside the scope of this Assessment to include sources of toxicity data that do not meet EPA's criteria for inclusion. However, we have made an effort to clarify that chemicals that lack chronic oral RfVs and OSFs may have other sources of toxicological information available. For example, the chapter has been revised to clarify that there are other possible sources of toxicological data (e.g. QSAR-based toxicity estimates, or data from EPA's ACToR database) that should be utilized by risk assessors and researchers when the selected RfVs and OSFs are not available. However, the lack of chronic oral RfVs and OSFs from EPA's selected sources indicates that the majority of these chemicals have not undergone significant toxicological evaluation. Several recent peer-reviewed studies (cited in the chapter) have come to similar conclusions. The revised chapter includes information on the amounts and types of data available for the list of chemicals identified in this report, as identified from a query of EPA's ACToR database.

   We did not include additional sources of toxicity data in the MCDA, but have expanded the analysis to include a "cancer MCDA" that ranks the chemicals based on OSF, in addition to the "noncancer MCDA" that ranks the chemicals based on RfV. Regarding the scope of the MCDA, we have revised the MCDA section to emphasize that the analysis is intended to put EPA's selected toxicity reference values (RfVs and OSFs) into the context of variables that may impact environmental occurrence and transport. The limitations of the MCDA are clearly described in a limitations section that has been added to this draft.

The revised chapter makes clear that the hazards discussed for these chemicals are based on chronic oral exposure, and emphasizes that effects are best assessed on a local basis.

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

In Chapter 9 of the final 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 constituents. 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, the agency can develop an 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 constituents 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 substances on the GRAS (U.S. FDA 1961) 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 constituents, as well as containment practices). These concepts and best practices should be used to the extent feasible in the final Assessment Report or be explicitly noted as gaps in the Assessment Report if not used. Since constituents that are highly diluted are less likely to produce toxic effects, the SAB suggests the TTC be used to assign lower priority to contaminants potentially present in these HF fluids. These assignments of lower priority should be 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 constituents that have the potential to be present at levels of concern.

EPA Response: Under the "Hazard Identification" section of the chapter, we added subsections that specifically address potential hazards highlighted in previous chapters. These sections include: methane in stray gas, disinfection by products in wastewater, and organic and inorganic constituents (including naturally occurring radioactive materials) in flowback or produced water. Toxicological data provided for these chemicals includes chronic oral RfVs, OSFs, qualitative cancer classifications, QSAR-based LOAEL estimates, and the availability of data from EPA's ACToR database.

For each set of chemicals discussed in the "Hazard Identification" section, we have added discussion of field studies that have detected these chemicals in groundwater or drinking water near areas of hydraulic fracturing activity. We note instances in which chemicals concentrations in these field studies exceeded MCLs.

As discussed in our responses to previous comments, the focus of the toxicological evaluation is on selected RfVs and OSFs, as outlined in the 2012 Progress Report[1]. Additional details have been added on QSAR-based toxicity estimates and EPA's ACToR database as sources that risk assessors can turn to for additional toxicological information of these chemicals, when RfVs and OSFs are not available. In addition, we added a section to Appendix G describing other approaches and tools that can be used to address chemical toxicity data gaps, including read-across concepts and the use of high throughput and emerging technologies. However, we do not use these sources to characterize the potential toxicity of chemicals in the hydraulic fracturing water cycle, as this is outside the scope of the assessment.

The revised chapter includes a statement on the number of chemicals used in hydraulic fracturing fluids that are classified as GRAS by the FDA. GRAS determinations are often specific to certain conditions as expressed in the FDA GRAS Notification Database and therefore do not indicate that the same chemical is safe for use in hydraulic fracturing fluids.

In coordination with Chapter 5, an overview of the trends in chemical use in updated versions of FracFocus has been added to the revised version of the chapter. To address concerns regarding the reliance on an early version of FracFocus data, we have added the comparative results of a recent analysis of FracFocus 2.0 conducted by Konschnik and Dayalu (2016)[2].

[1] U.S. EPA (U.S. Environmental Protection Agency). (2012). Study of the potential impacts of hydraulic fracturing on drinking water resources: Progress Report. (EPA/601/R-12/011). Washington, D.C.: U.S. Environmental Protection Agency, Office of Research and Development. https://nepis.epa.gov/exe/ZyPURL.cgi?Dockey=P100FH8M.txt

[2] Konschnik, K; Dayalu, A. (2016). Hydraulic fracturing chemicals reporting: Analysis of available data and recommendations for policymakers. Energy Policy 88: 504-514. http://dx.doi.org/10.1016/j.enpol.2015.11.002

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 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 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.

EPA Response: The introduction to our chapter includes a summary of the major pathways/events identified in other chapters of this report that may lead to the entry of these chemicals into drinking water resources. To better integrate that information from other chapters, a figure (see Figure 9-1) depicting the potential pathways by which chemicals may migrate to drinking water resources has been added. We also provide an overview of cases in which there is direct and indirect evidence of contamination of drinking water resources.

For each subset of chemicals discussed in the "Hazard Identification" section, we include a paragraph summary of the major pathways and events identified in previous chapter that may lead to the entry of this specific subset of chemicals into drinking water resources, and cite specific instances in which these chemicals have been detected in groundwater near areas of hydraulic fracturing activity. We note which chemicals detected in these studies are known to be associated with hydraulic fracturing activities and instances in which chemical concentrations in these field studies exceeded MCLs.

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 what they report as uncertainties, assumptions, and limitations. However, the SAB notes areas of disagreement with some of the assumptions, limitations, and uncertainties presented.

A major assumption was that chronic toxicity data should be the basis for identifying constituents 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 the severity of some impacts (e.g., those noted to yield transient exposures).

A major uncertainty is whether the list of constituents used for hydraulic fracturing (Table A-2), based on references listed in Table A-1 of the draft Assessment Report, is representative of current hydraulic fracturing practices. This could be better characterized by comparing constituents listed in FracFocus version1.0 with those in FracFocus 3 to help assess whether the hydraulic fracturing industry is changing constituents used within the HFWC, and whether there is movement in the United States 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 sufficient because it does not include certain CBI information which is proprietary, and lacks information on the identity, properties, and frequency of use for approximately 11% of hydraulic fracturing constituents used in HF operations (which are considered CBI; see EPA draft Assessment Report, p. 5-73). The agency should acknowledge the limitations on information about what is being injected, and should describe these concerns regarding its reliance on FracFocus version 1.0 data within the final Assessment Report. Within the final Assessment Report, the agency should also characterize data that the EPA may have on proprietary constituents, and information provided in FracFocus on chemical class and concentration (i.e., concentration of the constituent, in terms of % by mass, in the hydraulic fracturing fluid). In addition, the agency should note that the current version of FracFocus may provide some additional insights into the CBI associated with chemicals used during HF operations (for example, chemical type and categories).

EPA Response: As described above in our response to comments, the revised chapter includes a statement justifying the use of chronic toxicity values rather than less-than-chronic values. The revised chapter also brings forward the relevant CBI information presented in Chapter 5 and discusses how this effects the "completeness" of our chemical list. To address concerns regarding the reliance on an early version of FracFocus data, we have added the comparative results of a recent analysis of FracFocus 2.0 conducted by Konschnik and Dayalu (2016)[1].

[1] Konschnik, K; Dayalu, A. (2016). Hydraulic fracturing chemicals reporting: Analysis of available data and recommendations for policymakers. Energy Policy 88: 504-514. http://dx.doi.org/10.1016/j.enpol.2015.11.002

3.7.6. 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 the 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 severity of 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, state and tribal regulations that govern spills and leaks that could be employed to further mitigate potential for exposure. The SAB finds that resumption of local case studies or initiation of the originally planned studies described in the research Study Plan (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}). Two Panel members do not find the lack of such case studies to be a limitation to the draft Assessment Report, based on the perspective that investigations conducted by universities, consulting firms, and other external stakeholders could be used in lieu of the agency conducting such studies.

Additional field studies should be given a high priority, to develop a much more comprehensive chemical exposure database. It is acknowledged in several places in the draft Assessment Report 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 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 can be considered as recommendations for 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 General Laboratory Practices (GLP) guidelines (e.g., OECD screening information dataset) 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 constituents 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). In addition, the EPA should also directly consider and include exposure, use of TTC concepts, and use of best practices for mitigation of hazards identified in the course of the analysis. The SAB suggests the TTC be used to assign lower priority to contaminants potentially present in these HF fluids.

There is a gap in knowledge of constituents that are designated as confidential business information (CBI). The chemical and toxicological information for CBI constituents 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 (i.e., concentration of the constituent, in terms of % by mass, in 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 constituents without publically disclosing specific information. The EPA can characterize the toxicological and MCDA results in a manner similar to the approach used for known constituents. This would enable an assessment of the potential for significant impact (or not) from CBI constituents relative to known constituents. The EPA should also recognize the concerns regarding its reliance on an early version of FracFocus data.

The EPA should distinguish between constituents injected into a hydraulic fracturing well vs. constituents and hydrocarbons that come out of the well in produced fluids. The SAB suggests that if no constituents are added to a hydraulic fracturing well, there is still a potential for impacts to drinking water resources from constituents present naturally in the subsurface which could also be brought to the surface in produced water. In Chapter 9 and throughout the final Assessment Report, 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 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 constituents identified as being of most concern in produced water are products of the hydraulic fracturing activity, flowback, or later-stage produced water, or are constituents of concern derived from oil and gas production activities that are not unique to hydraulic fracturing activity. This will help inform the readers about the different characteristics of HF flowback and produced waters and in-situ subsurface constituents relative to formation water produced in conventional oil and gas development. To understand better the composition of these fluids, analytical methods may need to be developed, which can be considered a recommendation for longer-term future research 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 those exposure scenarios. The EPA provides a wide range of possible scenarios along the HFWC, but more emphasis is needed to identify the most likely durations and routes of exposures of concern so that the 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 finds that the selection of likely scenarios 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 from HFWC operations.

EPA Response: SAB correctly notes that additional field studies would require longer-term activity and were not possible to complete in the timeline of this report. To address potential exposure scenarios, our chapter includes a summary of the major pathways/events identified in other chapters of this report that may lead to the entry of these chemicals into drinking water resources, and provides an overview of cases in which there is direct and indirect evidence of contamination of drinking water resources.

The 2012 Progress Report[1] clearly outlined EPA's intention to characterize toxicity by using selected sources of RfVs and OSFs. See our prior response to SAB's comments above. The use of other sources of toxicity data that do not meet EPA's criteria for inclusion in the assessment would be outside the scope of the study plan. The revised chapter clearly states that the RfVs and OSFs compiled in this report are not intended to be an exhaustive compilation of toxicological information on these chemicals, but rather is intended to be a reconnaissance of high-quality toxicological information that met EPA's criteria for inclusion in this study. The revised chapter includes a statement justifying the use of chronic toxicity values rather than less-than-chronic values.

Although the primary focus of the chapter is still on chronic oral RfVs and OSFs from selected data sources, the hazard identification in the chapter has been expanded to include the following information: QSAR-based toxicity estimates (chronic oral lowest observed adverse effect level or LOAELs), which can be used by risk assessors to rank chemicals based on potential toxicity; information on how many data points each chemical has available on EPA's ACToR database; and expanded discussion of carcinogenicity and qualitative cancer classifications for these chemicals. We found that the majority (if not all) of the major toxicity databases suggested by SAB are part of ACToR's data collection, and therefore were searched as part of the ACToR query performed in this chapter.

In Appendix G, we have added a section describing the Threshold of Toxicological Concern (TTC), the OECD QSAR Toolbox, and high throughput screening data as tools and emerging technologies that have potential utility for filling chemical toxicity data gaps. However, we do not use these sources to characterize the potential toxicity of chemicals in the hydraulic fracturing water cycle, as this is outside the scope of the assessment.

As described in our prior response to SAB's comments, our revised chapter also bring forward the relevant CBI information presented in Chapter 5, and describes how this affects the "completeness" of our chemical list. To address concerns regarding the reliance on an early version of FracFocus data, we have added the comparative results of a recent analysis of FracFocus 2.0 conducted by Konschnik and Dayalu (2016)[2].

The revised chapter includes an improved discussion on the hazard of chemicals used in hydraulic fracturing fluids and those of chemicals in flowback or produced water. We point out that many organic and inorganics in flowback and produced water are naturally occurring and are not unique to hydraulic fracturing. The SAB's observation that there is potential for hazard even if no chemicals are added to hydraulic fracturing fluids has been added to the major conclusions of the chapter.

[1] U.S. EPA (U.S. Environmental Protection Agency). (2012). Study of the potential impacts of hydraulic fracturing on drinking water resources: Progress Report. (EPA/601/R-12/011). Washington, D.C.: U.S. Environmental Protection Agency, Office of Research and Development. https://nepis.epa.gov/exe/ZyPURL.cgi?Dockey=P100FH8M.txt

[2] Konschnik, K; Dayalu, A. (2016). Hydraulic fracturing chemicals reporting: Analysis of available data and recommendations for policymakers. Energy Policy 88: 504-514. http://dx.doi.org/10.1016/j.enpol.2015.11.002

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. 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, the publication 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* datasets and computational results available through ACToR and specifically state which constituents 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 impacts of highly diluted constituents (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 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 constituents 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 constituents 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 final 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 constituents.

- Judson, R.S., Martin, M.T., Reif, D.M., Houck, K.A., Knudsen, T.B., Rotroff, D.M., Xia, M., Sakamuru, S,, Huang, R., Shinn, P., Austin, C.P., Kavlock, R.J. and Dix, D.J. 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.

EPA Response: When cross-referencing these suggested databases with ACToR's data collection, we found that the majority of the major sources suggested were searched as part of the ACToR query performed in this chapter. Therefore, relevant information was captured from these data sources if available. Finally, we considered all literature recommended by the SAB and included new citations in the final Assessment Report where appropriate.

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 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 discusses 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 identified 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 the 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 final Assessment Report to make these discussions more understandable to the reader 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 final 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," "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 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 final Assessment Report should describe whether this is a dangerous level of radioactivity, and how these levels compare with levels from 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 shale plays in the United States 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 planned prospective studies were not conducted or completed. While the reasons for not conducting these studies were not described in the draft Assessment Report, 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 be construed as a lack of due diligence on the part of the EPA without further explanation, the SAB finds that the EPA should include in the Executive Summary its rationale for excluding the prospective case studies. Further the SAB finds that the agency should highlight studies by other organizations that have conducted work associated with a "prospective" view. Two Panel members do not find the lack of prospective case studies to be a limitation to the draft Assessment Report, based on the perspective that investigations conducted by universities, consulting firms, and other external stakeholders could be used in lieu of the agency conducting such studies.

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 impacts may occur infrequently, but they have the potential to 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 the response to Charge Question 8(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 final Assessment Report. Conclusions that are presented in the Synthesis should be more than results (e.g., measurements, observations, and 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 in the way of 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 that information forward, 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 final Assessment Report (as opposed to mimicking the overall organization of these chapters). The EPA should consider prioritizing 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.

EPA Response: We have revised both the Executive Summary and Chapter 10. The Executive Summary, in particular, has been revised to be more understandable to the general public. We have clarified the language in the Executive Summary and have provided numerous text boxes and figures to illustrate key concepts. One of these text boxes, Text Box ES-3, describes EPA's Hydraulic Fracturing Drinking Water Study, including the role of the Science Advisory Board. Although the prospective case studies are not discussed in the Executive Summary, they are included in Appendix A of the final Assessment Report. Appendix A provides background on EPA's study, including a list of reports and publications produced as part of the study. As noted in Appendix A, we were unable to find suitable locations for the prospective case studies that met both the scientific criteria of a rigorous study and the business needs of potential partners.

The final Assessment Report, including the Executive Summary and Chapter 10, highlights the role of local- and regional-scale factors in impacts on drinking water resources from activities in the hydraulic fracturing water cycle. We also state that identified impacts generally occurred near hydraulically fractured oil and gas production wells and ranged in severity, from temporary changes in water quality to contamination that made private drinking water wells unusable.

Chapter 10 has been significantly revised and is no longer identical to the Executive Summary. Chapter 10 presents the information behind the impact bullets presented at the beginning of the Executive Summary and within Chapter 10 (see Section 10.1.5). Chapter 10 does this by focusing on factors identified in the final Assessment Report that can increase or decrease the frequency or severity of impacts. We prioritize information decision makers could use to reduce the vulnerability of drinking water resources to activities in the hydraulic fracturing water cycle. In this way, Chapter 10 is now a synthesis and not a summary.

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 linked clearly to evidence provided in the body of the final 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 finds 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.

The SAB expresses 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." The SAB finds that the EPA did not support quantitatively its conclusion about lack of evidence for widespread, systemic impacts of hydraulic fracturing on drinking water resources, and did not clearly describe the system(s) of interest (e.g., groundwater, surface water), the scale of impacts (i.e., local or regional), nor the definitions of "systemic" and "widespread". The SAB observes that the statement has been interpreted by readers and members of the public in many different ways. The SAB concludes that if the EPA retains this conclusion, the EPA should provide quantitative analysis that supports its conclusion that hydraulic fracturing has not led to widespread, systemic impacts on drinking water resources. Most Panel members also conclude that the statement requires clarification and additional explanation (e.g., discuss what is meant by "any observed change" in the definition of "impact" in Appendix J, and consider including possible modifying adjectives before the words "widespread, systemic impact" in the statement on page ES-6). Four of the 30 Panel members find that this statement is acceptable as written, but note 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 these four Panel member's opinion are noted in Appendix B to this report.

Most members of the SAB Panel have concerns regarding the data limitations supporting the EPA's major findings. These concerns include the 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 constituents in hydraulic fracturing fluids.

Regarding the EPA's basis and support for its major finding regarding "widespread, systemic impact" in the statement on page ES-6, the SAB Panel notes that the statement is presented also in Chapter 10 in somewhat different form on pages 10-19 and 10-20, where it is stated 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 Reports that there are insufficient data, a paucity of long-term systemic studies, and other mitigating factors, the SAB concludes 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.

Regarding the recommendation from most members of the SAB Panel that the EPA provide quantitative support for its conclusion that hydraulic fracturing has not led to widespread, systemic impacts on drinking water resources, 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 encourages the agency to contact state agencies, 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 final Assessment Report. The SAB finds that the draft Assessment Report's analysis of spill data cannot be extrapolated across the entire United States. The SAB recommends that the agency revisit a broader grouping of states and "refresh" the final 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 constituents in flowback and produced water appears to be very limited. For example, only three references are cited for all of the constituents listed in Table A-4 of the draft Assessment Report. Since information could not be located on measured concentrations for many hydraulic fracturing constituents, it is not possible to estimate human exposures or begin to assess the potential risks to health associated with exposures to these constituents. The EPA should have some information, at least in terms of orders of magnitude, on how exposures to certain hydraulic fracturing constituents compare to adverse effect doses for these constituents (e.g., for a few of the most potent constituents) 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. In addition, the agency should consider including other additional benchmarks for comparison.

- 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. While the agency concluded they documented no case of stream impacts associated with the process of hydraulic fracturing, there may be impacts associated with the HFWC or other activities that may have occurred. 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. All but one Panel member are 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 SAB notes that some states (e.g., Ohio) do not require pit liners in hydraulic fracturing impoundments (Horner 2013). The agency should discuss the frequency of this occurrence, provide details on pit liner requirements, describe 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 the draft Assessment Report does not clearly, concisely, and accurately describe these major findings 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 concludes 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. Four Panel members concluded that the major finding regarding "widespread, systemic impacts" is clear as written. The SAB recommends that the EPA revise these statements of findings in the Executive Summary and elsewhere in the final Assessment Report to clearly link these statements to evidence provided in the body of the final 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 final Assessment Report, when presenting the major findings. Regarding the EPA's findings of gaps and uncertainties in publicly available data that the EPA relied upon to develop conclusions within the draft Assessment Report, the EPA should clarify and describe the different databases that contain such data and the challenges of accessing them, and make recommendations on how these databases could be improved to facilitate more efficient investigation of these databases.

EPA Response: Statements of major findings included in the Executive Summary and elsewhere in the final Assessment Report have been revised for clarity. We have also revised the Executive Summary and the technical chapters (Chapters 4-9) to more clearly link statements of major findings to observations and data that support those findings.

In particular, the SAB expressed concerns about the sentence "We did not find evidence that these mechanisms have led to widespread, systemic impacts on drinking water resources in the

United States" and recommended that EPA clarify and provide quantitative support for this conclusion. We note that the majority of SAB reviewers, but not all, held this view. EPA scientists carefully considered the SAB's recommendation and concluded that the sentence could not be quantitatively supported given the existing data gaps and uncertainties. Additionally, as noted by the SAB, the sentence was interpreted by readers and members of the public in many different ways, which showed that it did not clearly communicate the findings of the draft report. As a result, this sentence was not included in the final Assessment Report.

Throughout the final Assessment Report, we have identified data gaps and uncertainties. In particular, Chapter 10 provides perspective on data gaps and uncertainties that, if filled or reduced, could further understanding of impacts on drinking water resources from activities in the hydraulic fracturing water cycle. It was outside of the scope of this report to comprehensively investigate, gather, and organize data collected by states. It was also outside of the scope of this report to make recommendations on how existing databases could be improved for studying impacts on drinking water resources from activities in the hydraulic fracturing water cycle.

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 final 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 linked clearly to evidence provided in the body of the final 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.

EPA Response: Chapter 10, the Synthesis, has been significantly revised and is no longer identical to the Executive Summary. The material in Chapter 10 is presented by stage of the hydraulic fracturing water cycle and draws from data and information presented in the preceding chapters. Chapter 10, however, no longer repeats the conclusions presented in each of the preceding chapters. Given the uncertainties and data limitations, it was not possible to conduct an integrated assessment and compare the relative impacts across the stages of the hydraulic fracturing water cycle. Instead, we focused on factors that can either increase or decrease the frequency or severity of impacts, as wells as uncertainties and data gaps identified in the previous chapters. We see the identification of factors, uncertainties, and data gaps as particularly useful for decision makers. As noted in Section 10.1, factors can often be managed, changed, or used to identify areas for specific monitoring or the modification of practices. Thus, information on factors can help decision-makers reduce the vulnerability of drinking water resources to activities in the hydraulic fracturing water cycle.

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, many stresses to surface or groundwater resources associated with stages of the HFWC are often localized in space and temporary in time, but nevertheless can be important and significant. For example, many impacts of water acquisition will predominantly be felt locally at small space and time scales. These local-level impacts, when they occur, have the potential to be severe, and the final Assessment Report needs to better recognize 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 many members of the public have stated that hydraulic fracturing activities have caused local impacts to drinking water resources. Examination of these high-visibility, well-known cases is important so the reader 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.

EPA Response: Chapter 6 of the final Assessment Report includes text boxes on each of the locations identified by the SAB—Dimock, Pennsylvania; Pavillion, Wyoming; and Parker County, Texas. For each location, we reviewed information in publicly-available reports. Each text box describes possible pathways or sources for reported impacts on drinking water resources.

3.8.3. Information, Background or Context to be Added

d. 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). The agency should revise Chapter 10 to leverage the final Assessment Report's review of relevant literature and synthesis of knowledge gaps to identify ongoing research, and 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 final 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 concludes 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. Two Panel members do not find the lack of prospective case studies to be a limitation to the draft Assessment Report, based on the perspective that investigations conducted by universities, consulting firms, and other external stakeholders could be used in lieu of the agency conducting such studies. Given the length of time required to conduct prospective case studies and the need to finalize the Assessment Report, the SAB recommends that the EPA consider the recommendations of all but two Panel members to conduct research on expanded case studies and prospective case studies as an item for 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:

Surface activities implicated in groundwater contamination:

- 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.

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

- Warner, N.R., C.A. Christie, R.B. Jackson, and A. Vengosh. 2013. Impacts of shale gas wastewater disposal on water quality in western Pennsylvania. *Environmental Science and Technology*. 47: 11849-11857.
- Olmstead, S.M., L.A. Muehlenbachs, J.S. Shih, Z. Chu, and A.J. Krupnick. 2013. Shale gas development impacts on surface water quality in Pennsylvania. *Proceedings of the National Academy of Sciences* 110: 4962-4967, doi: 10.1073/pnas.1213871110.

Effects of gas-well drilling or improper zonal isolation on groundwater contamination.

- 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.
- Jackson, R.B., A. Vengosh, T.H. Darrah, N.R. Warner, A. Down, R.J. Poreda, S.G. Osborn, K. Zhao, and J.D. Karr. 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.
- Fontenot, B.E., L.R. Hunt, Z.L. Hildenbrand, D.D. Carlton Jr., H. Oka, J.L. Walton, D. Hopkins, A. Osorio, B. Bjorndal, Q.H. Hu, and K.A. Schug. 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.

EPA Response: The Assessment Report is a science document and does not present policy recommendations. Chapter 10 does not make recommendations or present a research agenda. Instead, we discuss the uncertainties and data gaps found in this assessment and highlight the need for further data collection and monitoring to reduce these uncertainties or to fill in data gaps (see Section 10.2). The presentation of uncertainties and data gaps draws attention to information needs that, if filled, could enhance science-based decisions to protect drinking water resources.

Finally, we considered all literature recommended by the SAB and included new citations in the final Assessment Report where appropriate.

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The following additional references were cited or included as suggested additional literature for the EPA to consider within the body of the SAB report, and are provided to improve the literature base for EPA's final Assessment Report and to help ensure a more comprehensive understanding of hydraulic fracturing activities and operations:

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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 that hydraulic fracturing for oil and gas may 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 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–DISSENTING OPINION

Prepared by Stephen Almond, Shari Dunn-Norman, John Fontana, and Walt Hufford, Members of the SAB Hydraulic Fracturing Research Advisory Panel

Preamble

In 2009, the U.S. House of Representatives Fiscal Year 2010 Appropriation Conference Committee requested the United States Environmental Protection Agency (EPA or agency) conduct an assessment on the potential impacts to drinking water from the process of hydraulic fracturing. In responding to that request, EPA assigned to the Office of Research and Development (ORD) the task of developing and executing an assessment that not only examined the process of hydraulic fracturing, but also greatly expanded the scope to include the entire life cycle of oil and natural gas development associated with the use, management and protection of water. The ORD held meetings with external stakeholders to gain an understanding of the life cycle processes of exploration and production activities. Subsequently, ORD developed a work plan detailing its proposed investigation of each of the principal areas the agency identified as being relevant to the water life cycle, including: (1) sourcing of water, (2) mixing of water with chemicals/proppant, (3) injection of water/proppant to fracture the reservoir, (4) management of the flowback/produced water, and (5) reuse, treatment/discharge and disposal of these waters. Following the development of a draft work plan in 2011, the agency initiated its investigation and has provided updates regarding those efforts.

Early in the process, the EPA designated this effort as a *Highly Influential Scientific Assessment* (HISA). Therefore, it is important that the SAB very carefully consider the wording and structure of our responses to the EPA. Both the draft report issued by the agency in June 2015 and our work in the SAB panel have been scrutinized by external stakeholders. As such, the facts and conclusions in our response to EPA should be based on the body of scientific evidence that has been produced within the agency's draft report and by other external stakeholders who have continued their work associated with life cycle water use by the oil and natural gas industry. Significant effort has been expended by these external stakeholders (academia, non-governmental organizations, other regulatory agencies and industry) to both identify and mitigate risks dealing with hydraulic fracturing activities. This has included investigations associated with water quality and quantity.

Following the release in June 2015 of the EPA draft report entitled *Assessment of the Potential Impacts of Hydraulic Fracturing for Oil and Gas on Drinking Water Resources* the SAB panel was asked to: 1) respond to certain Charge Questions (CQs) that were submitted by the EPA, and 2) provide other feedback associated with the draft report. Responses to these CQs have been developed through "face-to-face" meetings, conference calls, and working group sessions that focused on each CQ. The SAB panel heard from and reviewed comments (both oral and written) from the public as part of our deliberations with over 396 unique comments provided to the SAB. This active participation included a diverse group of individuals representing individual citizens, private property owners, environmental organizations, trade associations and other entities.

This dissent is being provided while recognizing and respecting those on the panel who may disagree with the opinions stated herein. Further, this document does not necessarily reflect the views or opinions of any organization or affiliation and are offered as conclusions resulting from our deliberations. It is in that spirit that these dissenting remarks and recommendations are offered.

<u>Dissenting Opinion</u>
<u>Major Finding of "no widespread, systemic impacts on drinking water resources within the United States"</u>

The first (January 7, 2016) draft of the SAB report provided the following text regarding this conclusion:

> *The SAB has concerns regarding the clarity and adequacy of the 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 are presented ambiguously within the Executive Summary and are 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 hydraulic fracturing mechanisms have led to widespread, systemic impacts on drinking water resources in the United States. The SAB finds this statement does not clearly describe the system(s) of interest (e.g., groundwater, surface water) nor the definitions of "systemic," "widespread" or "impacts." The SAB is concerned that this statement does not reflect the uncertainties and data limitations described in the body of the report associated with such impacts. The statement is ambiguous and 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 second (February 16, 2016) draft of the SAB report provides the following text regarding this conclusion:

> *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 there 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," "widespread". The SAB agrees that the statement has been interpreted by member of the public in many different ways and concludes that the statement requires clarification and additional explanation."*

The statement by the EPA in the draft Assessment Report issued in June, 2015 is clear, unambiguous, concise, and does not need to be changed or modified. The statement provides a "holistic" conclusion of the life cycle process of water used by the industry. While the report could have articulated the agency's statistical assessment more clearly, there has not been any facts or evidence demonstrating a systemic or widespread impact to existing drinking water resources or other water resources that may not meet the current criteria of a drinking water resource. If a systemic or widespread issue had been identified, the EPA and the state regulatory agencies would have quickly responded to such findings. In the absence of such documented events, the conclusion is clear that no systemic, widespread impact to drinking water resources is occurring. To suggest otherwise, undercuts the work and dedication by the employees of those federal and state agencies who are charged with environmental protection. The draft EPA reports estimates approximately 30,000 wells are drilled each year in the United States. Only a very small percentage of those wells have had an operational issue that may have impacted drinking water resources. Even among this small percentage, the identified impacts to drinking water resources have primarily been associated with surface spills, well construction, and well cementing – not hydraulic fracturing.

The SAB panel is correct in highlighting that localized impacts should not be discounted nor marginalized. Moreover, the SAB correctly identified that an aspect of the draft Assessment Report dealing with the actual "impact" of a spill requires further clarification. A casual reader of the draft report is left to question if impacts from all spills or releases are *permanent* or *temporary*. The agency should expand the discussion around the actual timing of "impacts" to the local environment. In many cases, including the ones referenced within the report, it is clear there is no long term demonstrated impact associated with a release. The major conclusion by EPA in their June 2015 draft Assessment Report stating "*no widespread, systemic impacts on drinking water resources in the United States*" is accurate, unambiguous, and supportable with the facts EPA has reviewed.

Conclusion

This dissent to the SAB report focuses on the wording and conclusions of certain sections of that document. With the designation of the USEPA assessment being classified as a *Highly Influential Scientific Assessment*, the SAB report needs to clearly and concisely reflect the opinions of the SAB. The structure provided by the agency and the SAB team provides an ability for panel members to provide dissenting opinions, which will be used by the Chartered SAB and the EPA in finalization of their final document.

This dissent describes that the conclusion by the EPA in the June 2015 draft Assessment Report stating "*We did not find evidence that hydraulic fracturing mechanisms have led to widespread, systemic impacts on drinking water resources in the United States*" is accurate, clear, concise, unambiguous, and supportable with the facts EPA has reviewed.