EPA Science Advisory Board Peer Review
on
EPA Office of Research and Development Draft Report,
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)

Preliminary Individual Comments from Members of the EPA Science Advisory Board (SAB) Hydraulic Fracturing Research Advisory Panel

U.S. EPA Science Advisory Board
1200 Pennsylvania Ave., N.W.
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Preliminary Individual Comments on EPA's June 2015 Draft Report, *Assessment of the Potential Impacts of Hydraulic Fracturing for Oil and Gas on Drinking Water Resources* from Members of the EPA Science Advisory Board (SAB) Hydraulic Fracturing Research Advisory Panel

INTRODUCTION

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, EPA developed a research study plan[1] that was reviewed by the Agency's Science Advisory Board (SAB) and issued in 2011. A progress report[2] on the study detailing EPA's research approaches and next steps was released in late 2012, and was followed by a consultation with individual experts convened under the auspices of the SAB in May 2013. In June 2015, EPA's Office of Research and Development (ORD) released a draft assessment report[3], entitled *Assessment of the Potential Impacts of Hydraulic Fracturing for Oil and Gas on Drinking Water Resources*. The draft Assessment report synthesizes available scientific literature and data on the potential for hydraulic fracturing for oil and gas to change the quality or quantity of drinking water resources, and identifies factors affecting the frequency or severity of any potential changes.

The draft Assessment Report follows the hydraulic fracturing water cycle 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.

ORD requested the EPA SAB conduct a peer review of EPA's draft Assessment report. Under a peer review, the SAB will develop an advisory report of consensus advice for the EPA Administrator.

The SAB Hydraulic Fracturing Research Advisory Panel will conduct an advisory meeting on October 28-30, 2015 where the members of the Panel (see Appendix A) will seek to develop consensus advice in response to charge questions associated with the research described in EPA's draft Assessment Report. The charge questions are listed below. To facilitate the discussion of the issues and charge questions during the meeting, individual Panel members have been assigned lead discussant roles and were asked to provide preliminary written comments

[1] USEPA 2011. Plan to study the potential impacts of hydraulic fracturing on drinking water resources. U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-11/122, November 2011.
[2] USEPA 2012. Study of the potential impacts of hydraulic fracturing on drinking water resources: Progress Report. U.S. Environmental Protection Agency, Washington, DC, EPA/601/R-12/011, December 2012.
[3] USEPA 2015. Assessment of the potential impacts of hydraulic fracturing for oil and gas on drinking water resources (External Review Draft). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-15/047, 2015.

before the meeting on assigned charge questions as designated on the agenda for the meeting (see Appendix B). All members of the Panel were encouraged to provide individual preliminary written comments responding to the assigned charge questions, remaining charge questions assigned to other Panel members, and any other issues they identified in the draft Assessment Report.

The SAB Staff compiled all preliminary individual Panel member written comments received from the members of the Hydraulic Fracturing Research Advisory Panel on the charge questions. These comments are presented under each charge question, in alphabetical order of the Panel member. These preliminary individual Panel member comments do not represent consensus advice from the Hydraulic Fracturing Research Advisory Panel, have not been reviewed by the Chartered SAB, and do not represent EPA policy.

CHARGE QUESTIONS

Charge Question 1: Goals, Background and History of the Assessment:

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?

Charge Question 2: Water Acquisition Step in the Hydraulic Fracturing Water Cycle:

The scope of the assessment was defined by the hydraulic fracturing water cycle, which includes a series of activities involving water that support hydraulic fracturing. The first stage in the hydraulic fracturing water cycle 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 hydraulic fracturing water cycle? 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 hydraulic fracturing water cycle? Are there relevant literature or data sources that should be added in this section of the report?

Charge Question 3: Chemical Mixing Step in the Hydraulic Fracturing Water Cycle:

The second stage in the hydraulic fracturing water cycle 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 hydraulic fracturing water cycle? 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 hydraulic fracturing water cycle? Are there relevant literature or data sources that should be added in this section of the report?

Charge Question 4: Well Injection Step in the Hydraulic Fracturing Water Cycle:

The third stage in the hydraulic fracturing water cycle 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 hydraulic fracturing water cycle? 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 hydraulic fracturing water cycle? Are there relevant literature or data sources that should be added in this section of the report?

Charge Question 5: Flowback and Produced Water Step in the Hydraulic Fracturing Water Cycle:

The fourth stage in the hydraulic fracturing water cycle 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 hydraulic fracturing water cycle? 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 hydraulic fracturing water cycle? Are there relevant literature or data sources that should be added in this section of the report?

Charge Question 6: Wastewater Treatment and Waste Disposal Step in the Hydraulic Fracturing Water Cycle:

The fifth stage in the hydraulic fracturing water cycle 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 hydraulic fracturing water cycle? 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 hydraulic fracturing water cycle? Are there relevant literature or data sources that should be added in this section of the report?

Charge Question 7: Chemicals Used or Present in Hydraulic Fracturing Fluids:

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?

Charge Question 8: Synthesis of Science on Potential Impacts of Hydraulic Fracturing on Drinking Water Resources, and Executive Summary:

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 hydraulic fracturing water cycle 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?

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Charge Question 1: Goals, Background and History of the Assessment

> 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?

Comments from Dr. E. Scott Bair

(1). Chapter 3 deals with the proximity of hydraulically fractured wells to drinking-water supplies, where distance serves as a surrogate for vulnerability. Closer is more vulnerable, further is less.

(2). Although aquifers are presented on the first page of Chapter 3 as part of the drinking-water resources of the United States, they are only superficially mentioned in the body of the chapter. More information about the ground-water resources in hydraulically fractured areas needs to be added. For example, typical depths to aquifers, confined or unconfined aquifers, aquifer thicknesses, and aquifer continuity. All of this information is available from the USGS.

(3). More information needs to be presented about the vertical distance between surface-water bodies and the target zones being fractured. Information also should be presented about the depths most aquifers compared to the depths of most hydraulically fractured wells.

It is misleading to state, as it does in Text Box 3-1, that "An estimated 6,800 public water supplies were located between 1 mile of a hydraulically fractured oil and gas well between 2000 to 2013. These PWS sources supplied water 3,924 public water systems and served more than 8.6 million people…" These statistics only tell one part of the story – lateral proximity. To be complete, this story has to also include depths to the target zones or depths of the wells. It is a three-dimensional issue that in the report is presented solely in two dimensions, which misrepresents the actual field situations.

(4). Don't be afraid to mention the rocks. The geologic aspects of the hydraulic fracturing water cycle are not presented in sufficient detail, yet it is the rocks lying between the fracked zone and shallow aquifers/surface-water supplies that provide much of the protection to our drinking water supplies.

I suggest using the incident records of UIC Class I wells to show the long-term safety record of similarly constructed wells. The construction of hydraulically fractured oil/gas wells is quickly moving to standards similar to Class I wells, where in-well pressure monitoring is required.

Specific Comments

(1). Page 3-1, line 13: The term "non-fresh bodies of water" needs to be defined and examples presented. The EPA definition of drinking water resources presented in this report is certainly non-traditional and raises a lot of questions (see below). It definitely needs clarification.

Are marshes and wetlands considered to be drinking water resources? What about water in estuaries and bays? How about permeable sands, sandstones and limestone that contain brackish water? What if these rock types occur at depths of 3,000 to 10,000 feet? Are sandstones and limestones that contain brine considered to be future water resources? What if these rocks occur at depths of 3,000 to 10,000 feet? My point is under this definition nearly all sediments and rocks are considered future water resources. Is this realistic? This definition needs to be re-thought. In its extreme, it is impractical and misguided.

(2). Page 3-1, lines 25-26: Springs are commonly used for drinking water supplies that can range from a single household or an entire town. Spring water resources should be included in this analysis. Springs are the surface manifestation of the water table and usually are counted separately.

(3). Page 3-1, line 26, Page 3-2, line 5: By definition, aquifers store and transmit ground water. Referring to them as ground water aquifers is redundant and unnecessary. Just say "aquifers."

(4). Insert the underlined word "… surface and ground water resources increases the…"

(5). Section 3.2, title: Being a geologist I am sensitive to the world being viewed as two-dimensional. The word "proximity" in this section generally only refers to the lateral distance from and oil/gas well to a drinking water supply. This is fine for surface-water bodies and wellheads, as it is 2-D. But the chapter title is "… to Hydraulic Fracturing Activity." Does this refer to the wellhead, which I think is what is meant? Or, does it also refer to the distance from the production zone up to surface water bodies? Or, is it also the proximity between a wellhead and the bottom of an aquifer, which is also problematic under the definition of drinking water supplies used in this report because many rocks not presently considered to be aquifers are classified as such under the EPA definition.

There is nothing in this section pertaining to aquifers and vertical distances across rock layers. I suggest changing to title to "Distances from Surface Water Resources to Wellheads of Hydraulically Fractured Wells," or something shorter but equally explicit.

(6). Page 3-6, line 9: Springs are usually considered the outflowing of ground-water resources.

(7). Figures 3-2, 3-4, 3-5, and 3-6: These maps are too small but could be substantially enlarged by cutting off all of Mexico below Texas and putting the legend in the upper left corner covering part of Washington and Oregon.

(8). Page 3-11, Conclusion: A statement should be added to the effect that, "Hydraulically fractured wells usually are constructed at depths of approximately 3,000 to 10,000 feet, although some older wells are shallower. This is done, in part, to create vertical zone of protection between the hydraulically fractured zone and nearby surface-water supplies. This zone also provides protection between the hydraulically fractured zone and shallow, fresh-water supplies in aquifers. The average depth of a fracked well should be restated herein.

(9). Text Box 3-1. Major Findings, Current and Future Drinking water Supplies, Bullet 6: I understand the technological advances that enable us to reclaim wastewaters, recycle storm water, and desalinate seawater. This sentence and, perhaps, this entire section are written from the viewpoint of surface waters resources. Ground water resources are skimmed over at best or often don't fit into the outlined sections.

I suggest adding a qualifying statement to this effect at the beginning of the chapter or changing the title of the chapter to reflect that it refers to surface water resources.

The third dimension, depth, and the rocks that occur between the fracked zone and the wellhead or surface water supplies are not adequately accounted for.

(10). Text Box 3-1, bottom: None of these bullets contains any information about the depth differences between the fracked zones and surface water resources. I suspect that many of the private systems described in the last bullet are ground-water supplies. If this is so, it is misleading to solely present the lateral distance between the wellhead and these private systems. The vertical distance is equally important, if not more important.

Comments from Dr. Peter Bloomfield

Chapter 1 covers the background, scope, and intended use of the report in some detail, and clearly articulates them. It does not, however, contain an explicit statement of the goals of the assessment. They may be inferred from the text from the background (Section 1.1):

> ...we review and synthesize scientific literature, including the publications resulting from the EPA's research and information provided by stakeholders, to assess the potential for hydraulic fracturing for oil and gas to change the quality or quantity of drinking water resources. This report also identifies factors affecting the frequency or severity of any potential impacts.

Evidently the two-fold goals are:

- Assess the potential for hydraulic fracturing for oil and gas to change the quality or quantity of drinking water resources;
- Identify factors affecting the frequency or severity of any potential impacts.

Section 1.3 discusses the approach that was taken in the assessment, with much detail on the search for and evaluation of relevant parts of the literature. This approach seems well suited to the first goal, since the literature contains reports of actual impacts and of mechanisms with the potential for impact. However, as far as "factors affecting the frequency or severity of any potential impacts" are concerned, its adequacy is less clear. For example, proximity of a drinking water source to a hydraulically fractured well could be such a factor, but does it actually affect frequency or severity? That would seem to require a study involving baseline (pre-fracking) and post-fracking water quality, of a kind that is described elsewhere in the report as lacking.

Chapters 2 and 3 give good background on hydraulic fracturing and drinking water resources, respectively. I am not aware of any topics that need to be added to those two chapters.

Comments from Dr. Elizabeth W. Boyer

Chapter 1 provides a detailed overview of the goals, background, scope, approach, and intended use of this EPA assessment report. The statement of goals should be made more explicit and clarified, and used consistently throughout the document. Here is how the objectives are currently worded -- embedded in the last sentence of the background section, in Chapter 1-1 (p 1-1). "In this report, we review and synthesize scientific literature, including the publications resulting from the EPA's research and information provided by stakeholders, to assess the potential for hydraulic fracturing for oil and gas to change the quality or quantity of drinking water resources. This report also identifies factors affecting the frequency or severity of any potential impacts." From my perspective, the review, synthesis, and analysis of scientific literature and information provided by stakeholders should be stated as part of the approach, not the goal. Further, the use of EPA sponsored research projects, technical input from agencies, industries, NGOs and other stakeholders can be highlighted as part of the approach. The goals of the assessment seem to be: 1) To assess the potential for hydraulic fracturing for oil and gas to change the quality or quantity of drinking water resources; and 2) To identify factors affecting the frequency or severity of any potential impacts. (to water resources).

Numerous public commenters were concerned with the narrow scope of the report. The report does note that the assessment does not discuss the potential impacts of the HF process on other water uses (e.g., agriculture or industry), other aspects of the environment (e.g., seismicity, air quality, or ecosystems). However, I suggest that EPA further acknowledge the deliberate aim to stay focused on drinking water resources, yet emphasizing that they recognize the need for additional assessment. Further research and assessment needs include: 1) detailed case studies, for example those that were proposed in the research plan yet not completed); 2) studies of impacts of the HF process on human health, ecosystem health, and aquatic life. Documenting

future needs for these will help to further address limitations of the current report and identifying future directions for synthesis and assessment by EPA or other agencies.

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

One public commenter had issue with the EPA conclusion (on page 3-11) that "the colocation of hydraulic fracturing activities with surface and ground water increases the potential for impacts to current and future drinking water resources." The commenter states that "by using the term colocation, EPA risks giving a false impression to users of the study report that there is little protection if HF occurs at a wellsite that is in close proximity to surface or ground water. This would be an inaccurate impression for several reasons. First, wells are generally set back from surface water resources – particularly those used by public water systems – in accordance with state and local regulations…. " I agree that this conclusion should be carefully reworded.

Comments from Dr. Katherine Bennett Ensor

Chapter 1 articulates well the goals and objectives of the study, the intended audience, intended uses, as well as the limitations of the science and questions considered.

Specific limitations of the report that are noted in Chapter 1 include:

- A discussion of the actual "frequency and severity of changes" due to hydraulic fracturing.
- The quantity of wastewater from hydraulic facturing (see Table 1-1).
- The "reclamation and well closure" or the impact of hydraulic fracturing on the total national water use.

For example, beginning with line 23 of chapter 1: "In this assessment, we also identify and discuss factors affecting the frequency or severity of changes to avoid a simple inventory of all specific situations in which hydraulic fracturing might alter drinking water quality or quantity." From this sentence I discern that the report does not address the quantity and severity of "specific situations", even though specific situations may be key to understanding the *what if* aspects of when operations go wrong. I note, however, that there is specific consideration given to the frequency and severity of spills for two states in Chapter 5. This aspect of the report appears to contradict the statement above in chapter 1. While I appreciate the focus on "systemic problems", it is important to characterize and discuss the frequency and severity of "outliers" that have occurred. Recognizing the extent to which this has been done in chapter 1 is important.

I am reminded that studying the environment is often a study of extremes or outliers. On average systems and practices may operate as planned, but it is those cases when all activities do not fall into place correctly that strong consequences manifest in direct impact to human life and well being. It is also, those cases from which improvements in technologies and operational

procedures may. To this end, I find lacking in chapter one acknowledgement of the presence of such events, even though the report itself does highlight specific events. It is important to acknowledge and provide sufficient information to understand the level of concern to communities on the "outliers" that notably exist in the overall efforts of hydraulic fracturing. There is indication that this information is available, however, it is not fully captured or discussed in the document nor acknowledge in chapter 1.

Further, as noted in chapter 1 Table 1-1, the quantity of wastewater is not addressed in the report, although the quality is addressed. The study also does not address "reclamation; and well closure. " (page 1-6). The activities are considered
"outside the scope of the hydraulic fracturing water cycle and, therefore, their impacts are not addressed in this assessment. Additionally, this report does not discuss the potential impacts of hydraulic fracturing on other water uses (e.g., agriculture or industry)".

Although not indicated in Chapter 1 as a limitation, the report does not directly address projected population growth and future water use requirements, or at least I missed it if this issue is discussed.

It is important to recognize these limitations of the study when considering the overall water quality and quantity for the United States, but to some extent chapter 1 may overstate the limitations of what is actually considered in the report.

Chapters 2 and 3:

I very much appreciate the care with which the hydraulic fracturing water process is described in chapter 2. The description also further defines the boundaries for consideration of the impact of hydraulic fracturing on the impact of water quality and quantity. One question I have, is the impact of well spacings on the potential impact of drinking water and water quality? I do not see where this question is directly addressed but I expect there is a significant impact. If you advance to chapter 3, there are PWS within 1 mile of 49 to 144 active wells (figure 3-5) providing additional merit for this specific question.

A few suggestions for additions to Chapter 3 are:

- A discussion highlighting communities experiencing water constraints and the presence or absence of fracturing activities in those regions.
- A high level discussion of population growth and future water needs by communities. It is not the expertise nor focus of the report, however, acknowledging future growth using general projections is an important aspect of the challenge.
- Are there aquifers that are particularly impacted by hydraulic fracturing activities, and if so, is there quantifiable information that could be included? Possibly maps by aquifer similar to the county specific maps of chapter 3.

Include further discretization for figure 3-5, dividing further the 49-144 category. (With at least one PWS sitting within 1 mile of 144 hydraulically fractured wells, distance between wells must have an impact.)

Comments from Dr. Dawn S. Kaback

In Chapter 1, I believe the goals, background, scope, approach and intended use of the assessment are clearly articulated. Overall the document is well written and appears to be thorough and as complete as can be done given the limitation of the existing data.

In Chapters 2 and 3, the description of hydraulic fracturing and drinking water resources are clear and informative as background material. However, I do provide some specific comments as included below. I do not suggest any additional topics be added to Chapters 2 and 3.

One primary comment for Chapter 1 is the current explanation that technologies for hydraulic fracturing and directional (horizontal) drilling are recently developed and that is why the sudden explosion in the industry using this approach. I do not believe this is correct and hope that it can be corrected. The recent explosion in hydraulic fracturing and horizontal drilling was primarily driven by the search for new oil and gas resources within the United States and resulted from the efforts of numerous exploration geologists who developed the concept to extract resources from geologic formations previously considered as source zones. Prior to the development of this concept oil and gas exploration focused on porous/permeable reservoir units that had trapped oil or gas either stratigraphically or structurally. The new focus on exploring within potential source rocks was the new driver for the explosion. Of course the need for the hydraulic fracturing and horizontal drilling technology was critical to make the new plays economic. Be sure to make edits within Text Box 2-1 and fix Conclusions Section 2.4.

The above discussion is directed at Section 1-1, especially targeting lines 2, 5, 7-9, which had too much focus on the technology development rather than including the key importance of development of new exploration targets.

A primary comment in Chapter 2 is that there may be a discussion missing on the fact that the new geological source rock targets being produced by hydraulic fracturing and horizontal drilling require closer well spacing that can provide significantly greater potential impacts on drinking water resources. In addition, many areas currently being explored and produced are located in close proximity to populations. I am not sure where this needs to go or whether it needs to be a new subsection, but it is a key fact.

A primary comment in Chapter 3 is that there should be more discussion about potential future water supplies and where they might come from. For example, if deeper aquifers in the West, then that should be discussed. Also some of the measures shown in Text Box 3-1 may not be as good as they could be. See comments below and focus on last two bullets. Also it would be good to have a better summary of where the more vulnerable areas are in the major plays across the country using some type of criteria? Or is this too complex. Maybe you could just list some examples of vulnerabilities…such as in the East, maybe proximity of surface water resources to

be have surface water quality impacts, in the West, maybe potential impacts to water quantity, but surface water and groundwater.

Ch. 1 p. 1-1, lines 12-18: should you include some description of additional concerns beyond drinking water? This is written as if drinking water is the only concern.

p. 1-2, footnote 3: add "after the production phase is initiated" to the end.

p. 2-1, line 13, after "proppant," add "(typically sand)."

Ch. 2 The section on the number of wells, Section 2.2.1, is quite long. Could it be an appendix or shortened in some way?

p. 2-1, line 22, use "old" or "were existing," not "older."
Text Box 2-1, line 12 says that the first horizontal wells were drilled in the mid-1980s. The first horizontal well was drilled in 1929 in Texon Texas, but in the mid-1980s the technology was more widely used in the Austin Chalk and began its more widespread application. In the late 1980s horizontal drilling was first combined with hydraulic fracturing. As the technology further developed, it was more widely applied. A variety of horizontal drilling approaches were tested and longer laterals were drilled over time.

p. 2-2, lines 24 and 25 focus too much on the technology. See above and make edits to the entire page.

p. 2-3, Figure 2-1, The "blobs" representing the various targets are not realistic and should be drawn to look more geological (are they stratigraphy, structural, or what?). If it is a stratigraphic play with a tight then the oil probably extends laterally but the vertical fractures intersect it to produce the product. This same figure and the "blobs" are in many other places throughout.

p. 2-3, line 14-15, says primary purpose is to increase surface area but may be a better way to explain it as the surface area also needs to provide pathways to get the resource from the formation to the well bore.

p.2-8, Figure 2-5. This figure spans from 5-60 years but I am not sure 60 years is realistic for shale gas. I know we don't have examples of fracked horizontal wells producing for long enough to say but you might want to tone that down to make it more realistic for shale gas. Also the diagram should consider edits to "surveys," are these "seismic?" If so say so. Also it implies drilling of a test well and collecting core, but I don't know what percentage of wells have that, unless they always call the first well a test well and then they use it for production if it is economic? Use of the term "test well logging" would benefit from changing to "downhole geophysical logging."

p. 2-9, line 4, change "including" to "primarily." Plus again you are implying that rock core samples are always available. Suggest softening a little. Also if you are going to use

the word "test hole," I suggest replacing with "exploratory borehole." You should also be careful about the use of well vs borehole. The hole is not a well until it starts producing theoretically.

p. 2-9, line 10: Use "geophysical logging" instead of "well logging." Line 31: change "Indian Country" to "Native American lands."

p. 2-10, line 11 and line 14: consider using term "borehole" instead of "hole or wellbore." Line 23: not sure about the first clause….seems strange here and recommend to delete. Line 31: change "portion" to "percentage." Line 32: change "growing" to "increasing." Line 32-33: I believe this statement only applies to California, but the way it is written implies everywhere. I suggest constraining it to make it accurate.

p. 2-19, lines 18-26: why use "unconventional" when earlier you state that it is no longer appropriate or commonly used? Use of the word "gas" should possible be "shale gas." Line 38, add "plugged" before the word "well."

p. 2-20, line 15, add "horizontal wells after hydraulic fracturing or "in shale reservoirs" after the word "well."

p. 2-24, Figure 2-16: Need to explain that this figure does not provide cumulative information but each year is stand alone.

p. 2-26, footnote 3: replace "dirt" with soil or just say "removing surficial and shallow subsurface material." This is way too dumbed down. Line 27 add "onshore" to US?

p. 2-31, line 10, perhaps define tight oil and refer back to earlier section. Does it mean only those wells that are fracked and horizontal? I know it is used in the figures and needs to be defined more clearly.

p. 2-32 line 16-17 gives all the credit to the hydraulic fracturing and not the geologists' new exploration play and concept. Fix this according to discussion above.

Ch. 3, Section 3.3 should include more discussion on water supplies in the future and where they would likely come from. If there are new aquifers likely to be tapped in the West, that should be explained.

p. 3-12, Text Box 3-1; Next to last bullet is not that critical as the important thing is how close the wells are to the drinking water supplies/systems, as we are only talking about drinking water impacts. Last bullet is a little extreme as it says at least one well in a whole county. Seems like there should have been a better measure.

Comments from Dr. Azra N. Tutuncu

The EPA scientists who conducted the research and put together the report entitled "*Assessment of the Potential Impacts of Hydraulic Fracturing for Oil and Gas on Drinking Water Resources"* have produced a well written scientific reference document that will benefit public and scientists alike. The authors have conducted extensive literature review to incorporate up to date scientific facts using engineering and science journals, EPA research project results, federal and state agency reports, oil and gas industry publications and the data provided by the oil and gas industry throughout the report. The readers have been provided with good understanding of EPA's goals for the assessment, intended use and approaches taken to reach their objectives and limitations in Chapter 1. The hydraulic fracturing process and the resources for drinking water were clearly described and distinct effort was made to inform and engage the readers for clear description of the hydraulic fracturing process and evaluating potential sources of water in Chapters 2 and 3. The maps utilized in Chapter 3 combining EPA data with the other Federal and State agency and industry provided databases including USGS, US Census Bureau, EIA, ESRI and Drilling Info delivered an exceptional review of the states and counties where the hydraulic fracturing activities are concentrated on and their proximities to the metropolitan and micropolitan areas. The major findings were recapped in a unique "Text Box" format.

The induced seismicity topic has become another significant challenge for hydraulic fracturing is noteworthy to comprise briefly here for informing the public. Since 2009, there has been significant increase on the number of induced earthquakes in Texas, Oklahoma and other seismically inactive states. While the scientific reasons behind these induced seismic events are under extensive investigation, most preliminary findings indicate the high rate and high volume waste disposal wells and resulting activation of existing unknown nearby faults. It will be beneficial to include the disposal wells in an analogous arrangement to the hydraulic fracturing well location maps presented to introduce even higher potential nature of the disposal operations as an alternate probable source for drinking water contamination. The maps and explanation can be included in a short subsection in either Chapter 3 along with the sites for the hydraulic fracturing wells also highlighting the induced seismicity epicenter locations or in Chapter 5 where Well Injection detailed review is covered.

The following USGS website and a recent article published is a credible reference for the extent of the induced seismicity increase throughout the Central and Eastern US in recent years as a link to be considered for potential impact on drinking water resources.

USGS, 2015. http://earthquake.usgs.gov/research/induced/.

Weingarten M., Ge S., Godt J., Bekins B.A. and Rubinstein J.L. 2015. High-rate injection is associated with the increase in U.S. mid-continent seismicity. Science, V. 348. Issue 6236. 1336-1339.

Charge Question 2: Water Acquisition Step in the Hydraulic Fracturing Water Cycle

The scope of the assessment was defined by the hydraulic fracturing water cycle, which includes a series of activities involving water that support hydraulic fracturing. The first stage in the hydraulic fracturing water cycle 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 hydraulic fracturing water cycle? 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 hydraulic fracturing water cycle? Are there relevant literature or data sources that should be added in this section of the report?

Comments from Dr. E. Scott Bair

(1). This chapter contains several examples of linked events within the hydraulic fracturing water cycle that occur on different time scales. Water acquisition for an oil/gas or a group of oil/gas wells is a one-time occurrence – when the well(s) is constructed. It is not an issue after the well begins producing oil/gas. Water acquisition of several wells in multiple fields will stress surface water supplies and, if used, ground water supplies. Inn terms of surface water supplies, this stress likely returns to normal conditions the following year (calendar or water year). In other words, it can be a significant stress but it will always be temporary.

This needs to be stated explicitly in several sections of this chapter. The conclusions should include these qualifications.

It is also important to note that the stress on water resources is local, likely on a county by county basis within a region. The entire watershed of a major river is not likely to be impacted all at the same time.

(2). Section 4.2.2: Much more general information and data about the chemistry, density, and other properties of brines in the pores of the reservoir rocks needs to be added. Going forward from the time an oil/gas well is fracked, the produced water from well chemically becomes more and more like the brine as less and less frack water remains in the production zone and brine flows into the well from the fractured zone and beyond it. As such, brine is an important component of produced water and its chemical characteristics need to be presented so the public has a complete view of the composition of the wastewater that is reused, treated, and/or injected into disposal wells. At present, the descriptions and presentation of brine chemistry is inadequately treated in the report.

(3). The word "cumulative" is used in several places in this chapter. Cumulative means to add together successive parts. In this sense, it is misused in Chapter 4. In general, it should be replaced by the word "total."

(4). There are several places in this chapter where a time frame (e.g., a year, a month, from 2003 to 2010) needs to be added to put a numeric value in the proper time perspective.

Specific Comments

(1). Page 4-3, line 4: Add the underlined phrase, "…formations and the depth and density of induced fractures…"

(2). Page 4-3, line 3: Replace the word "values" with the word "amounts" and replace the word "across" with the phrase "due to the physical properties of the…"

(3). Page 4-6, line 18: The term "upstream portion" is oil/gas jargon and won't be understood by most of the people reading the report. Insert an in-text definition or find another way to phrase this concept.

(4). Page 4-9, line 22-23: This sentence needs a time frame. Insert the proper time frame for the underlined text, "Cumulative water use and consumption by year for hydraulic…"

(5). Figures 4-2, 4-3, Text Box 4-2, Figure 4-6: The maps on these pages are too small to be helpful to the reader. Consider putting each graph on a separate page.

(6). Page 4-17, Figure 4-3, subtitle: The acronym "EIA" needs to be defined in the text.

(7). Page 4-25, Figure 4-6, subtitle: The acronym HUC needs to be defined in the text.

(8). Page 4-25, Figure 4-6: The subtitles need to explain that these two figures are based on data that have been normalized by watershed (HUC unit) and are not based on county-by-county data.

(9). Page 4-32, line 18: Replace the word "overlying" with the word "within". The geologic basin is the rocks that fill it. The basin does not underlie the rocks. It is the thickening of the rock strata in an area that is slowly subsiding that forms the basin.

(10). Page 4-34, paragraph 3: This is a place where the temporary or seasonal time frames of surface water withdrawals needs to be pointed out.

(11). Page 4-35, line 24: Insert the underlined word, "… have the potential to temporarily affect both water…"

(12). Page 4-35, line 30: Insert the underlined words, "Short-term surface water quality impacts…"

(13). Page 4-36, Figure 4-9, title: Define the acronym EIA in the text.

Comments from Dr. Elizabeth W. Boyer

Chapter 4 focuses on water acquisition: the withdrawal of surface and ground water needed to support the hydraulic fracturing process. The goals of the chapter were clearly stated… considering potential effects of water acquisition for hydraulic fracturing on quality and quantity of drinking waters, and to identify factors that affect the frequency or severity of impacts. Though outside of the scope of these goals, a number of the public commenters raised concerns about the need to consider impacts of water use for fracking on aquatic life and ecosystem services in addition to the drinking water resources, that EPA should further acknowledge in terms of future research needs.

To achieve their goals, EPA reviewed publicly available data on sources of water used for HF from surface water, ground water, and reused wastewaters (section 4.2). Overall, I this portion of the assessment was relatively clear and concise summarizing the surface and ground water sources using the limited data and case studies available. The graphics were informative.

Considering accuracy, some prose in this EPA report, as well as numerous public commenters and committee panel members all noted the gaps in the data available to assess water use, and there were numerous concerns expressed with heavy reliance on the industry supported frack focus database.

EPA considered the amount of water used per well (Section 4.3); and cumulative water use and consumption estimates at national, state, and county scales (Section 4.4). (EPA concluded that cumulative water use nationally for HF is at least 44 BG/year; Median water use for a well is approximately 1.5 MG.). Some reviewers noted the inaccurate use of the term cumulative suggesting that it be replaced with the term total use throughout the chapter.

EPA considered water use for HF in 15 individual states where hydraulic fracturing currently occurs and consider the potential for hydraulic fracturing water withdrawals to affect water

quantity and quality in localities within those states (Section 4.5). They present results mostly at state and county level due to the availability of data at those scales (and representing heterogeneity – where states and localities often differ in industry activity, formation type, and water availability, all of which affect potential impacts). They use statistics to extrapolate results nationally.

There were several very useful case studies presented in the report, presented to illustrate how water withdrawals may affect short- and long-term water availability in areas experiencing high rates of hydraulic fracturing. The study found that water imbalances from HF operations have not occurred in either the Susquehanna River basin (page 4-35, box 4-5), or the upper Colorado River basin (page 4-31, box 4-4). These studies demonstrated that many local factors and local heterogeneity explain whether water imbalances occur. A limitation was that with only a few river basins under study, the role of factors such as climate, geology, water management, and water sources could not be fully explored.

The report noted that the potential for impacts on drinking water resources greatest in areas with high HF water use, low water availability and frequent drought. For example, the report documented some areas where it is problematic. In a study in southern Texas, there is a lot of demand from the dense array of natural gas wells tapping the Eagle Ford Shale, and there isn't much of a water supply available. Groundwater use there is causing change in water storage and drawdown of the local water table. There were some particularly useful public comments from hydrogeologist Bridget Scanlon toward clarifying that section.

Several of the public comments expressed concern with surface waters taken from small rivers or streams. In such cases the timing with relation to flow conditions is important, and withdrawals during low flow periods resulting in dewatering and severe impacts on small streams and aquatic life. It should be more clearly noted that the stresses on water resources are expected to be local and temporary, and not to understate the potential for localized problems. More attention needs to be given to describing the potential impacts on water resources at "hot spots" in space (e.g., headwater streams) and time (low flow conditions, seasonally).

There are several places in this chapter where a time or units need to be clarified.

A further discussion of key data limitations – such as the need for specific local data useful for modeling; and needs for better regional data from state/national (USGS) water use statistics reporting are needed and may help the states and federal agencies to understand what is needed for continued assessment. For example, how should USGS track county-level "mining" and other categories of water use, to best facilitate understanding of the role of water use for HF compared to other water uses? There are challenges with regard to the way the use categories are defined, the reliability of the information reported by the states, and consistency of reporting. Similarly, a further description of how the FracFocus database should be impoved, or how such information could be acquired operationally by state or federal agencies, would add to the utility of this section.

Relevant new reference: The Depths of Hydraulic Fracturing and Accompanying Water Use Across the United States. RB Jackson, ER Lowry, A Pickle, M Kang, D DiGiulio, and K Zhao. Environmental Science & Technology; 2015, 49, 8969−8976. DOI: 10.1021/acs.est.5b01228.

Comments from Dr. Katherine Bennett Ensor

I became aware of this recently published paper today. It is not referenced in the current version of the report, but does address issues.

Zacariah L. Hildenbrand, Doug D. CarltonJr., Brian E. Fontenot, Jesse M. Meik, Jayme L. Walton, Josh T. Taylor, Jonathan B. Thacker, Stephanie Korlie, C. Phillip Shelor, Drew Henderson, Akinde F. Kadjo, Corey E. Roelke, Paul F. Hudak, Taylour Burton, Hanadi S. Rifai, and Kevin A. Schug, A Comprehensive Analysis of Groundwater Quality in The Barnett Shale Region, *Environ. Sci. Technol.*, 2015, *49* (13), pp 8254–8262, DOI: 10.1021/acs.est.5b01526, Publication Date (Web): June 26, 2015

Comments from Mr. John V. Fontana

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

   The report does a good job of characterizing and classifying the different types of water sources available for use/consumption and points out that while overall, nationally, there appears to be plenty of supply for conducting hydraulic fracturing, 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. The report includes references on the use or re-use of wastewater as well as non-drinking sources (eg. Brackish water) that lessen the impacts by reducing the need for fresh drinking water sources. I like the many footnotes explaining industry terms and relationships for the reader that may be less familiar with industry lingo.

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?

   Yes, it is clear from the report that there are competing uses for this water and especially in more arid parts of the country, but also possibly at local spatial scales, and that irrigation is one of the larger competing uses of the sources of drinking water. The available data is mainly at county scale and larger. This limits the ability of the report to distinguish smaller scale and local impacts at points of withdrawal, which is made clear and explained in the report.

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 hydraulic fracturing water cycle?

Yes, the major findings identify the major sources of water used, types of sources, range of amounts used in a well and nationally, and regions or types of regions and conditions where potential for impacts may occur.

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

Section 4.2.3 Quality (of source water)

This section is very brief on the topic of types of water used. Freshwater is described as the most common quality type. Reuse of wastewater, *which should state also includes produced formation water*, is described. I think this section would benefit by an expanded discussion on the technologies for re-sue of produced water or other non-drinking sources. Most areas show very low percentage of reuse of these sources. However, locally, some are 5-20% range reused wastewater and in Colorado – Garfield County, Piceance Basin - 100% wastewater used for fracturing. The report (and the users of this information) would benefit from describing in more detail how it is that this area is able to use 100% waste waters. (Perhaps an expansion of the information offered in Text Box 4-4.) It may be a combination of not only the wastewater quality in this area, but also the fact that the area has been unitized (all operators are sharing infrastructure to produce the fields), the area is mature (one of the early areas of unconventional tight gas sand development), all of which may have allowed time for the technology to develop for reuse of produced waste water. Even though this is a local scale occurrence, I think this is a major finding that could help push development of this technology in other areas. What are the trends in this technology and where can they be applied that they currently have not been applied? This could be a major finding.

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

Yes. The report states that there have been no direct impacts from the acquisition stage that can be directly attributed to withdrawal of water for hydraulic fracturing documented in the report, but the combination with other uses and drought conditions may have cause some impacts to availability. Still, the report explains thoroughly the potential for impacts and the types of conditions that warrant caution of both quantity and quality impacts at local scales. The report proposes that proper water management in these areas may be able to reduce the potential impacts, which may include adding the use on non-drinking sources, and examples of this are shown.

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

A major uncertainty/limitation is from the lack of available data at local scales and this is explained thoroughly in the report, and is addressed by stating the potential impacts at local spatial scales. Even though the intent of the report was to be "national" in scale and not local, the EPA did a good job using available data down to the smallest scale available (mainly county level) to evaluate regional potential impacts.

Once the 2015 USGS water census usages data is complete, this section would benefit greatly from an update using that data combined with the large Frac Focus database since the report was only able to use 2010 census usage data and compare it to fracture water usages from the 2011-2012 FracFocus data.

<u>Section 4.4.2 (Cumulative Use/Consumption) County Scale and Table 4-2.</u>

I see the difficulty of using available data. The FracFocus database started in 2011, and the last USGS census for total water data is only available ever 5 years with the last report in 2010. However, comparing this data to each other as the % of hydraulic fracturing water used compared to total used results in % values greater than 100%. This is likely due to the fact that significant increases of hydraulic fracturing in those areas occurred between those dates relative to the 2010 water usage reports. Obviously it would be better if there was a way to compare the 2011-2012 annual average fracture water to the 2011-2012 annual average total water, but it appears that this data is not available and I assume this is the best we have, and other means of getting that data were exhausted, or were they? If not, perhaps these odd % values should be explained in terms of this method of calculation being used.

<u>Page 4-3, Lines 1-4,</u>

It might be helpful to mention briefly how these flowback returns are estimated due to mixing with other formation fluids (produced water, etc.), and that this is described more in CH 7.

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 hydraulic fracturing water cycle? Are there relevant literature or data sources that should be added in this section of the report?

<u>UNITS</u>

Throughout CH-4, water quantity units are reported as million gallons or billion gallons. While a single gallon is easy for anyone to visualize in terms of quantity, I doubt many of

the eventual readers of this report, including our politicians, and the general public, will have an idea of what a million or billion gallons looks like, or what that means relative to other uses. Much of the industry reports water in barrels, because oil is reported that way. However, in the water resources industry, the acre-foot is a more common unit for describing water usage from both surface and ground water sources. An acre area of water by one foot deep is easier to visualize than a billion gallon jugs of water. 1 acre-foot = 325,853 gallons, and therefore 1 million gallons = 3 acre feet, and one billion gallons = 3,068 acre-feet. A short discussion on how much water a corn field uses, or a household uses, might also help put this perspective in scale for the less technical reader of this document.

<u>Section 4.5, Water Use Impacts by State, p. 4-21, Lines 7-27</u>

This predictive information on water usage is now outdated due to the severe drop in drilling activity since the end of 2014. Rigs counts have dropped >60% since that time and projections of water uses should be adjusted or a comment should be made as to the change in activity which will affect these predictions made in the Nicot et. Al., 2012 paper and other references in Lines 15-27. Similar data is quoted in 4.5.4, p4-38, lines 17-24. I think most in the industry see these lower activity rates are likely to stay for a long period of time.

<u>4.5.4, North Dakota & Montana (use/consumption), p.4-37, lines 27-34</u>

I looked up the NDDMR 2013 presentation reference this is supposed to state an average use of 660 gallons per day of "maintenance water" being used in addition to initial water on each well due to the salinity of the produced water. Even though this may be beyond the scope of the report (part of production, not hydraulic fracturing), I think this is still important to include if it is accurate. However, I looked up the reference, which is a power point, and the data stating this is not there in the slides. Is there an abstract or verbal transcript? It has also apparently been quoted in other references but there is no "original source of data" provided for the actual data itself and it almost appears to be a word of mouth quote. Perhaps I missed something? This information should be either confirmed as to the actual source of this statistic or deleted from the report.

Comments from Dr. Daniel J. Goode

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

EPA has collected, analyzed, and summarized a wide range of information about the sources and quantities of water used in hydraulic fracturing (HF), or hydraulic fracturing water acquisition (HF-WA). This study has primarily relied on existing databases. EPA

has also summarized a number of journal articles and technical reports describing sources and quantities in HF-WA. Other information in media reports and technical presentations at conferences has also been summarized. Some of this information, especially technical reports, media reports, and presentations at conferences, does not appear to have been peer reviewed.

EPA has produced a number of very informative graphics and tables that substantially improve the availability of information characterizing the sources and quantities of water used in HF, and the relationship between that use and drinking water. This information should be very useful for focusing future efforts to fill information gaps on sources and quantities of water used in HF. Although some of the information sources are not peer reviewed, these limitations are generally clearly identified.

EPA's 2012 Progress Report identified the Well File Review as a key data source for many aspects of the relationship between HF and DW, including water acquisition, as a "secondary" source (Table 21 on page 46 of Progress Report), but the Well File Review Report (2015o) does not contain any information about water acquisition. That report is not cited in Chapter 4 of the draft assessment. So, a possible interpretation is that the Well File Review was not used because it was not useful as a source of information about water acquisition. It is recommended that EPA add at least a brief summary of the information about water acquisition that was provided by the Well File and an explanation of why that information was not included in the study, if not already included.

The clarity of the summary of available information is reduced by use of ambiguous and inconsistent terminology in several instances. Some examples:

- The proportion of FracFocus disclosures from Texas (48%) is described, clearly, as "almost half" on p. 28 of the FracFocus report, but is, less clearly, "the bulk of" disclosures on p. 4-17 of the main report.
- The adjective "cumulative" is used in many places for HF water use and water consumption to mean "total" or "overall" (e.g. line 16 on p. 4-1). The more common technical use of "cumulative" as the sum of parts, especially in time, is used in Figure 4-5. Removing "cumulative" (as done in line 17 on p. 4-48, e.g.), except to mean summing in time, would improve the clarity of the description of HF water use and consumption.
- For use of treated HF wastewater, the 'source' is described as "reused" HF wastewater (e.g. line 2 on p. 4-2). Clarity would be improved by describing a 'source' as "treated" HF wastewater because "reused" only applies if and when this 'source' is actually used. If all treated HF wastewater is not actually used, but some is discharged, then a proportion of the treated HF wastewater source is NOT "reused". (An analogy would be describing the source of drinking water (from a river) as "treated surface water", as opposed to just "surface water" as is done in

this report. The surface water 'source' is not "treated" unless it is actually used, hence it would be misleading to describe the source as "treated surface water".)

The clarity of EPA's summary of sources and quantities in HF-WA could be improved by use of clearer, more consistent, technically accurate wording throughout the study reports.

Reference Konikow (2013b) p. 4-24 is not in ref list for Chap 4. (should it be 2013a?)

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

See comment above about use of "cumulative" in HF water use and consumption text.

EPA's information presented on the relationship between quantities of water used and consumed in HF is highly informative, but is limited by the lack of information on water use and availability at the local or site scale, as noted in the study documents. This limitation could have possibly been addressed by EPA data collection and monitoring at sites of existing HF water use, possibly as part of prospective studies that were in the study plan, but which were not conducted. It is unclear if any information of the Well File Review included descriptions of HF-WA at local and site scales. EPA appropriately acknowledges that its county-level assessment of water use and availability "does not indicate where impacts will occur at the local scale." (line 15 on p. 4-53)

The 2 national maps comparing HF water use/consumption to total water use/consumption (figs. 4-2(a) and 4-2(b)) at the county scale should be each shown as full-page maps (like fig. 4-1). These maps are important products of the study and they cannot be clearly understood as currently presented in the report. In particular, the top 2 categories, dark blue and dark green, cannot be clearly distinguished as shown in the PDF file.

The 2 national maps comparing HF water use to fresh/total water availability (figs. 4-5(a) and 4-5(b)) at the county scale should be each shown as full-page maps (like fig. 4-1). These maps, especially fig. 4-5(a), are important products of the study and they cannot be clearly understood as currently presented in the report PDF file.

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 step of the hydraulic fracturing water cycle? Are the factors affecting the frequency and severity of any impacts described to the extent possible and fully supported?

The report does not focus adequate attention on local experiences of water "impacts" actually experienced prior to and during the study period. Such attention would have provided more information on the frequency and severity of impacts, based on actual

experiences. For example the groundwater emergency in LA may have been partially blamed on HF water use to the proportion of HF groundwater use relative to total groundwater use (p 4-44). As noted in the report, water use management in the Susquehanna River Basin and other areas is credited with minimizing the impact of HF withdrawals on stream flow. More detail could have been presented using monitoring data from industry and SRBC (in this case) to understand how HF could have impacted the drinking water due to temporal dynamics and local scale. As noted in the report, these dynamics and local scale are not fully understood due to the lack of data at this scale. The EPA missed an opportunity to explore these dynamics and local scale by examination of these and other water use management events.

The clarity of the major findings is reduced by use of ambiguous and inconsistent terminology in several instances. Some examples:

- "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 (U.S. EPA, 2015c)." (emphasis added)
  However, the case study report cited includes:
  "*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." (p. 1, *emphasis* added)
  "Minimal impacts" is NOT the same as "NO IMPACTS", and:
- "In SRB there are times or locations when water can be stressed, but water is managed to prevent overuse and minimize risk at individual sources." (p. 1).
  One would think that "stressed" would be categorized as "impact", recognizing that other uses, if any, also contribute to the "stress".

The clarity of EPA's major finding about potential impacts in HF-WA could be improved by use of clearer, more consistent, technically accurate wording throughout the study reports.

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

EPA fully and clearly describes the uncertainties, assumptions, and limitations about HF-WA and drinking water. However, some of these limitations could have been reduced by focusing more of the study on examining the Well File and other information not in databases, and less on hypothetical scenarios and modeling. EPA missed an opportunity to provide more new information about actual HF-WA and its relationship to drinking water through the study research.

Many of the existing data sources used in the report are not transparent and peer reviewed.

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 hydraulic fracturing water cycle? Are there relevant literature or data sources that should be added in this section of the report?

Prospective Case Studies are missing from EPA's study. This was a major recommendation of the Study Plan SAB Panel, and members of this panel highlighted this deficiency during review of the 2012 Progress Report. This remains a major limitation of the study. Such studies would allow EPA to monitor water acquisition and the effects of such acquisition to a level of detail not practiced by industry or required by state regulation. These detailed new data would allow EPA to reduce current uncertainties and research gaps about the relation between HF-WA and DW.

Gaps in understanding the relationship between HF-WA and drinking water could be reduced by examining the Well File and other information not in databases, but already collected by the states. Such studies would provide new information about actual HF-WA and its relation to DW in a fully transparent and peer-review process.

EPA should conduct further research explaining how reported (or purported) cases of HF-WA impacts on DW 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. If EPA finds that the actual impacts to DW were not significantly related to HF-WA, then that 'negative' result should also be explained fully and transparently in peer-reviewed reports. Controversial or contentious sites should not be ignored, but addressed directly and resolved. This research would be part of the natural process of learning from our mistakes, and improving the protection of DW while providing water supply for HF industry.

Comments from Dr. Stephen J. Randtke

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

The draft report does a reasonably good job of accurately and clearly summarizing an enormous amount of information pertaining to the water acquisition stage of the hydraulic fracturing (HF) water cycle, and putting it in the proper context. It does an equally good job of identifying and characterizing perhaps an even greater amount of information that is either nonexistent or not readily available, and properly taking this into account in assessing the potential impacts of water acquisition and qualifying the report's findings and conclusions in regard to water acquisition.

Minor improvements in clarity will presumably be made as the report is edited in response to questions, comments, and suggestions by panel members, the public, and various others who review the draft report. Adding some terms to the glossary might help in this regard. For example, the term "directional drilling" does not appear in the glossary, and the distinction between directional drilling and horizontal drilling (e.g., on p. 4-31) may not be immediately clear to some readers. The term "total water use" is used extensively in Chapters 3 and 4, but is not defined in the glossary, so a reader uncertain what total water use includes would presumably need to follow one of the many references to Maupin *et al.* (2014) linked to this term and then go online to view a copy of the USGS report. The statement that "Passby flows can reduce the frequency of high consumption-to-stream flow events, particularly in the smallest streams" (p. 4-34) is completely logical to knowledgeable readers but might be a bit difficult for others to digest. The term "high consumption-to-stream flow events" would be clearer if written as "high-consumption-to-stream-flow events."

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

The draft report thoroughly examines and nicely summarizes water use and consumption at various scales and clearly notes, in several places, the difficulty in assessing impacts at the local scale, where the greatest impacts are likely to occur but for which reliable data is generally lacking and site-specific factors strongly influence both water use and water management decisions.

To put water use for hydraulic fracturing in context, presumably with the intent of providing a context readily understood by the average citizen, the draft report summarizes water use by the average American on p. 3-1. This is a good approach and several relatively minor changes would help the readers gain an even clearer perspective. Specifically, I recommend that EPA: 1) clarify what is included and not included in water used for "household purposes" and what uses are supported by public water systems (PWSs); and 2) summarize the amounts of water withdrawn for all uses relative to total annual streamflow.

The word "household" should be inserted as the first word in Line 15 to clarify that the average American uses about 90 gal. per day for "household purposes." Notes should be added to clarify three things: 1) 90 gal. per day does not include water supplied by public water supply systems to commercial establishments, schools, office buildings, etc., places where water is used (by average Americans) for many of the same purposes for which they use it at home; 2) many public water supply systems also provide water for industrial and other uses, i.e., the term "public" in "public water supply" is not meant to imply that the water is used only for household purposes; and 3) the average American indirectly use far more water to produce the energy they use, the food they eat (and export), the products they purchase, etc. For example, a recent article in the New York Times (Buchanan, L., J. Keller, and H. Park, "Your Contribution to the California Drought," NYT, May 21, 2015) notes that the "average American consumes more than

300 gallons of California water each week [43 gallons per day] by eating food that was produced there."

Chapters 3 and 4 compare water use for hydraulic fracturing to water use for domestic purposes and to total water use for all purposes. Although these comparisons provide helpful perspectives, a more complete picture of water availability and use would be even more helpful to most readers. My concern is that many readers will fail to realize just how much water is used, directly and indirectly, by the average American. Also, in many sparsely populated areas, water use for hydraulic fracturing may represent only a minute fraction of total water use or total water availability, even when it exceeds 1% of water use by PWSs. Examples of information that could help readers better understand the bigger picture, especially if illustrated using pie charts or similar visual aids, include:

- Withdrawals by PWSs (30 BGD*) are dwarfed by withdrawals by industry (260 BGD when withdrawals for thermo-electric power generation are included) and agriculture (150 BGD), uses that indirectly serve the needs and interests of the average American (food, energy, jobs, export income, etc.).
- Withdrawals by PWSs (30 BGD) represent only a small fraction (2.5%) of the total annual average streamflow of the U.S. (1,200 BGD). Of this, about 21 BGD is withdrawn from surface sources (1.75% of average streamflow) and 9 BGD is withdrawn from the ground, which contains a fresh water volume equal to approximately 50 years of streamflow.
- Water consumption by PWSs (7) is dwarfed by agricultural consumption (83 BGD), less than industrial consumption (10 BGD), and a small fraction of consumption for all purposes (104 BGD).

* The flow rates shown parenthetically here are in billion gallons per day (BGD) for 1980 and were taken from an old USGS report. Water used for hydro-electric power generation (2,800 BGD) was not considered to be withdrawn and was not consumed. If additional information is added to the draft report, more recent data (e.g., data for 2010 from Maupin et al., 2014) should be used instead.

The units used in the draft report appear to be reasonably clear to readers with a technical background, but other readers may be confused, at least momentarily and in certain places in the report, by changes in units from millions to billions of gallons, from days to years, from flowrates to annual volumes, and from volumes or flowrates to percentages relative to some other flowrate or volume. Overall, the report appears to use the most appropriate units to summarize a given data set, switching to other units as needed to address various spatial and time scales. For example, the volumes of water involved in water acquisition and wastewater production are expressed in "billions of gallons per year," to convey to the reader the fact that very large volumes are involved, but they are then expressed as a percentage of "total water use" to convey to the reader that these volumes and their associated flowrates are actually very small relative to the amounts of

water used for other purposes – at least at national and state scales, but not necessarily at local scales.

As final edits are made to the report, EPA should consider reviewing the units of volume and flowrate used in each section the 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. Perhaps even more importantly, volumes or flowrates expressed as percentages of other volumes or flowrates should be given a final check to see if the information is being accurately conveyed. This is especially true when using the words "less than" (or the equivalent symbol). For example,

1) The report states (in Chapter 4, "Major Findings," p. 4-48, lines 15-18): "Cumulatively, hydraulic fracturing uses billions of gallons of water every year at the national and state scales, and even in some counties. When expressed as a percentage compared to total water use or consumption at these scales, however, hydraulic fracturing water use and consumption is most often a small percentage, generally less than 1%." While this statement is true, actual HF water use, on a national basis, is clearly more than an order of magnitude less than 1%. A high-end estimate of HF water use of 80 billion gallons per year (p. 4-8, line 34) represents only 0.79% of the 27.6 BGD used by PWSs and private water supplies for domestic purposes (24 BGD and 3.6 BGD, respectively, p. 3-1). Water use by PWSs represents less than 10% of total water use, so even a high-end estimate of HF water use actually represents less than 0.08% of total national water use. Water used for HF is consumed to a greater extent than water for other uses, so these above statement is less in error with respect to water consumption; nevertheless, a more accurate statement is warranted given the extent to which this report is likely to be cited.

2) The report states (p. 4-9, lines 3-7): "All of these estimates of cumulative water use for hydraulic fracturing are small relative to total water use and consumption at the national scale. For example, in the combined 20 states where operators reported water use to FracFocus in 2011 and 2012 (U.S. EPA, 2015b), annual hydraulic fracturing water use and consumption averaged over those two years was less than 1% of total annual water use and consumption in 2010 (see Appendix Table B-1)." Again, this statement is true, but inaccurate with respect to HF water use as a fraction of total water use. In fact, HF water use was less than 0.5% of total water use for every one of the 20 states listed in the Table B-1, and averaged only 0.065% for all 20 states combined.

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 step of the hydraulic fracturing water cycle? Are the factors affecting the frequency and severity of any impacts described to the extent possible and fully supported?

My initial impression is that the draft report does a reasonably good job on all three counts, with one exception described in the following paragraphs. I look forward to hearing the comments of other panel members and the public who might have other thoughts about the major findings of the report regarding known of potential impacts of water acquisition for hydraulic fracturing on the quantity and quality of our nation's water resources.

The draft report notes that water use for hydraulic fracturing can cause "excessive drawdown" of nearby water levels, as illustrated in Text Box 4-3 (p. 4-27) for the Eagle Ford Play I Texas. The report suggests, several times, that the impacts of drawdown can be minimized by switching to other sources of water; but it pays scant attention to the potential impacts of drawdown on water quality. It suggests that water acquisition for hydraulic fracturing has potential to cause localized drawdown and potential impacts to water quality (p. 4-27, line 35), but cites just a few examples, including salinization of the Trinity and Woodbine aquifers underlying much of the Barnett play (p. 4-27) and elevated levels of some constituents (e.g., nitrate) in the Ogallala (p. 4-41). Some of the same information in repeated later in Chapter 4.

There may be few published reports directly linking drawdown associated with hydraulic fracturing to water quality impacts, but much is known about the potential impacts of drawdown on groundwater and surface resources, and these impacts are independent of the purpose for which the water is used. Increased pumping costs can be readily estimated from the drawdown depth and average energy costs ($ per MGD per foot of drawdown). Much is known about contaminant migration (towards or away from water supply wells) based on drawdown depth, aquifer permeability, and the proximity of various sources of contaminants; and at least some of this information is readily available in literature pertaining to such topics as groundwater modeling, contaminant transport, and wellhead protection. A common impact of aquifer drawdown, affecting water quality in both wells and streams, is increased salinity. In many locations, increased salinity is correlated with decreased streamflow (increased flow of saline groundwater into streams). For both ground and surface waters, the costs associated with increased salinity (e.g., increased corrosion of equipment, water mains, water heaters, etc.) can be readily estimated using various rules of thumb (e.g., $ of damage per customer or MGD for each 100 mg/L increase in chloride) developed by those who have previously studied these impacts.

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

I commend EPA's decision to more broadly define water resources in the draft report. While it made sense more than 40 years ago to consider waters containing high concentrations of total dissolved solids (TDS) to be unsuitable as sources of drinking water – and therefore to afford them less protection from pollution – that is clearly no longer the case. Seawater desalination plants have been built in many locations around the world, including several in the US, and more are in the planning stages. Brackish waters are considered as potential future sources of water supply in a number of inland locations, and in some locations even produced waters are being viewed as potential sources of drinking water. While it makes good sense in many locations to dispose of produced water by injecting it into deep formations already containing water of similar or lower quality, it also makes sense to protect relatively saline water sources that may one day prove useful as sources of drinking water.

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 hydraulic fracturing water? Are there relevant literature or data sources that should be added in this section of the report?

I do not wish to make any recommendations at this time regarding additional source of information EPA should consider, but may offer some suggestions during the upcoming panel meeting.

Comments from Dr. James E. Saiers

The Report's analysis of water acquisition for hydraulic fracturing is, from a geographical standpoint, the most comprehensive to date. The assessment leverages peer-reviewed literature to supplement and strengthen EPA's own analyses on water usage and stress within the major unconventional plays of Texas, Oklahoma, and Pennsylvania. The report also explores, in a lower level of detail, water usage in shale and tight-oil plays of Arkansas, California, Colorado, Louisiana, North Dakota, and Utah.

The overall conclusion of the chapter is that withdrawals for hydraulic fracturing represent a small proportion of freshwater usage at state-wide levels. At local scales, on the other hand, frac-water withdrawals can contribute significantly to groundwater depletion, particularly in arid environments (e.g. west Texas). Frac-water withdrawals are also capable of altering the flow regimes of small streams, even in regions of rainfall abundance (e.g., Pennsylvania). In my view, these are reasonable conclusions that are consistent with current knowledge and available data.

The report goes onto identify sources of uncertainty in the EPA analysis. Chief among these is the dearth of information on 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 not recorded, or is at least inaccessible, for several states included within EPA's analysis. The availability or absence of data reflects differences in regulations and regulatory oversight. This chapter could be meaningfully extended through review of the regulatory landscape governing water withdrawals for hydraulic fracturing and by evaluating the various regulatory approaches for their efficacy in safeguarding against freshwater depletion at local scales.

In the paragraphs below, I've made additional suggestions for revisions.

Page 4-16, lines 6-18: This paragraph touches on potential effects of frac-water withdrawals on water quality, but the effects of withdrawals on aquatic habit, and stream ecology in general, are critical and seem to be overlooked. There is a small literature on this topic:

> 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.
>
> Entrekin SA, Maloney KO, Kapo KE, Walters AW, Evans-White MA, Klemow KM (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

Page 4-21, Line 7 and Appendix Table B-7: I recommend that the report direct the reader to interpret the county-by-county projections in frac-water use with caution. The predictions ultimately rely on many uncertain assumptions governing the future of oil-and-gas production.

The following journal article was published after the release of the EPA draft report, but may be useful for strengthening the report's inferences on freshwater use in PA for hydraulic fracturing:

> Barth-Naftilan, E., N. Aloysius, andJ. 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.

Page 4-38, Lines 10-24: The information provided in in these two paragraphs appears to be conflicting. In the first paragraph, it is written that "potential impacts (in western ND?) appear to be low" provided the Missouri River can be used as a source of water, while in the next paragraph, a USACE study is cited that concludes groundwater resources in western ND are insufficient to meet the needs of the oil and gas industry. Please clarify.

Comments from Dr. Azra N. Tutuncu

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

> The assessment presented in Chapter 4 is clear and concise summarizing the surface and ground water sources using data from various states where available, then extrapolating the results to come up with statistics for nationwide implementation.

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?

> EPA researchers evaluated fresh water availability for each county, then compared it to the reported water use for hydraulic fracturing showing that in most counties, there is no shortage in water availability. Case studies and recent publications were utilized with examples from operations in Texas at Barnett, Eagle Ford and Permian basin, to present the availability of brackish water as a source for fracturing water use in minimizing potential future impacts on the drinking water resources.

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 hydraulic fracturing water cycle? 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?

> The EPA researchers clearly stated the assumptions they made and the dataset used to define their major findings.

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

> Yes, the information provided highlights in detail the uncertainties and limitations regarding the acquisition of water.

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 hydraulic fracturing water cycle? Are there relevant literature or data sources that should be added in this section of the report?

> The anisotropic properties of the formations have not been discussed in detail that is one of the controlling factors for flow in porous media. The anisotropic permeability will also impact the contamination potential and the amount of brackish water available for use as fracturing fluid that can minimize the use of total available water for the hydraulic fracturing operations.

Charge Question 3: Chemical Mixing Step in the Hydraulic Fracturing Water Cycle

The second stage in the hydraulic fracturing water cycle 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 hydraulic fracturing water cycle? 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 hydraulic fracturing water cycle? Are there relevant literature or data sources that should be added in this section of the report?

Comments from Dr. Stephen W. Almond

The layout of Chapter 5 on chemical mixing has been nicely improved since the first report last year. The breakdown into the overarching factors for determining the potential for a spill to affect the quality of drinking water of fluid characteristics, chemical management & spill characteristics followed by chemical fate and transport puts the section into a logic progression.

The chemical mixing phases in Section 5.2 which I think could be labeled "fluid pumping process" provides a good breakdown/description of the pumping process on a typical well treatment (i.e., Figure 5-3) but does not describe the actual chemical mixing process where a significant portion of the spill or leakage can occur before the fluid pumping process begins . In many cases, the chemical process can occur hours and sometimes days before the fluid pumping process. A breakdown of the actual chemical mixing process and and explanation of the equipment used would be a good addition to the section. Possible spills associated with running over the blender / mixer tup, changes hoses to the fracturing tanks, etc can be a source of significant spills and leakage onto the ground.

On the caption description on Figure 5-3, line 5 that stars with "proppant size may change within each stage" should be corrected to read "proppant concentration or volume may change within each stage" as the term "proppant size" normally refers to the actual size of the proppant material itself (i.e., 20/40 mesh or 12/20 mesh, for example. At the end of the caption, the end of the last sentence should read "in as many as 59 stages on a single well." Also, on page 5-5, lines 5-7

contain an error by stating that "Acid is typically pumped directly from acid storage tanks or tanker trucks, without being mixed with other additives." In fact, the additives such as corrosion inhibitor, surfactant, asphaltene inhibitor, iron control additives, etc have already been mixed into the acid prior to arrival to the fracturing location. Although the mixing occurs at a different location, if acid is leaked or spilled on location, it contains some of the most potentially hazardous chemicals at the fracturing location (i.e., corrosion inhibitor). An additional text box to explain the details / composition of the acid that is brought to location should be considered to insure the fluids used in the pumping phases are described completely. This will also help explain to the reader the need to have "corrosion inhibitor" listed as an additive in Table 5-1.

In Table 5-1, the additive category of gel stabilizers was not included. These additives are typically, sodium thiosulfate, methanol and isopropyl alcohol. These additives are used in the majority of wells above 225 degF but since FracFocus seems to have had more entries on the lower temperature unconventional wells, it was most likely not found there.

A very nice job in putting together descriptions of water based fracturing fluids (5.3.1), alternate fracturing fluids 95.3.2 and proppants (5.3.3). It is important to know that there are several types of fluids and proppants used in hydraulic fracturing and the details and references are complete.

One of the things that stood out in Chapter 5 was the seeming focus on unconventional wells in both the treatment volume, chemical volumes used, . In relation to the number of wells drilled in the US, what is the percent of unconventional compared to the number of conventional wells? The unconventional wells have definitely caught more attention in not only this report but in the public's eyes. The fear is this report seems to have responded more to the public's voice to focus on unconventional wells than the true nature and distribution of all conventional and unconventional wells fractured in the US. Table 5-4 is an example of this which lists 4,000,000 gallons of water as a common fracturing fluid volume and 1,5000,000 lbs of proppant. These volumes and weights do not accurately represent the average volumes and weights of materials used in an average fracturing treatment across the US but rather in isolated fields and basins. This can be seen in Figure 5-5 where the mean additive volumes are shown.

On Table 5-4 under gelling agents, the most popular ones used are guar gum, hydroxypropyl guar (HPG), carboxymethyl hydroxypropyl guar (CMHPG), carboxymethyl hydroxyethyl cellulose (CMHEC) and hydroxyethyl cellulose (HEC). Very little, if any, hydroxymethyl cellulose (HMC) is used and not sure why this is listed as a gelling agent.

On page 5-32, lines17-18 describe proppant stored on-site in large tanks or bins with typical capacities of 220 to 440 lbs which is incorrect. A more typical large bin or tank is in the neighborhood of 2500 ft3 or closer to 185,000 lbs of sand (i.e., see Halliburton Mountain Mover Model FSR-2500 details, http://www.halliburton.com/public/pe/contents/Data_Sheets/web/H/H09429.pdf).

The inclusion of Section 5.9 on trends in chemical used in hydraulic fracturing is very much appreciated as in fact the industry has made great strides in developing chemicals with better environmental properties. For example, when you compare, the liquid carriers for the base gel concentrates from the 1980's which were typically diesel to today's non-diesel, hydrotreated

light petroleum distillates it is clear we are moving in the right direction even though the cost of the replacement solvent is more expensive than the older diesel material. One thing that is discouraging as a researcher who has been involved in the development of a number of more environmentally friendly chemicals, only to have their use in hydraulic fracturing and other well treatment fluids not accepted/used due to a higher cost of the material. I'm not sure if this can somehow be brought into this report but to move towards a "best-in-class" type of requirement environmentally for chemicals system in the US would be a great help in encouraging the development and focus on new classes "greener" fracturing chemicals. This same discussion links to the comments made in Section 9.6.4 in lines 28-32. Even if the industry uses the prioritized chemicals to focus on for replacement, if there is no driver for the operating companies to use the better class of chemicals due to an additional cost, history has shown the most likely they will not be replaced.

Comments from Dr. Shari Dunn-Norman

The information presented in Chapter 5 is a good explanation of the process for mixing and pumping fluids used in hydraulic fracturing. The chapter provides a useful summary of the names of chemicals used in the hydraulic fracturing process and illustrates where spills may end up, if they occur. However, the chapter has no practical information on spill mitigation practices employed, for example building berms around a tank battery.

There can be no doubt that spills present the highest risk of release in hydraulic fracturing, as in many other industrial processes. Data presented in this chapter is consistent with this, showing approximately 1.3 spills per 100 fracturing treatments, or .987 success rate. This is worse than the release risks due to well construction, as expected.

The caption on Figure 5-14 is very misleading. This caption indicates the figure displays spill volumes for 151 HF related spills from the EPA data base. But on page 5-45, line 1, the text states that only 125 of the 151 reported events had reported spill volumes. This needs correction. Figure 5-14 would also be better displayed in histograms displaying the range of magnitude for each type of release. As it stands now, Figure 5-14 could be misconstrued to be a typical size release, which it is not. It seems misleading to include histograms related to chemical mobility in water and fail to do this for the spill data analyzed.

Some of the chemicals listed in Table 5-2 are used in food or other daily use products. This really should be noted. Vinegar is 4-18% acetic acid. Guar gum is many foods. In fact, the largest market for guar gum is the food industry, not the hydraulic fracturing industry. I suggest EPA add an asterisk to all the chemicals listed in Table 5-2 that are used in food, or daily use products.

There is much emphasis on describing the potential release pathways and what *may* occur, but the chapter lacks strong examples. Two of the examples cites have minimal release volumes with no impact to water. The other example cited, and illustrated in Figure 5-19, demonstrated an impact to surface waters but there was no verified evidence of groundwater contamination.

Yet that possibility is speculated in Figure 5-19. Such speculation should be removed. Casual readers may not be able to differentiate substantive evidence versus speculative thoughts.

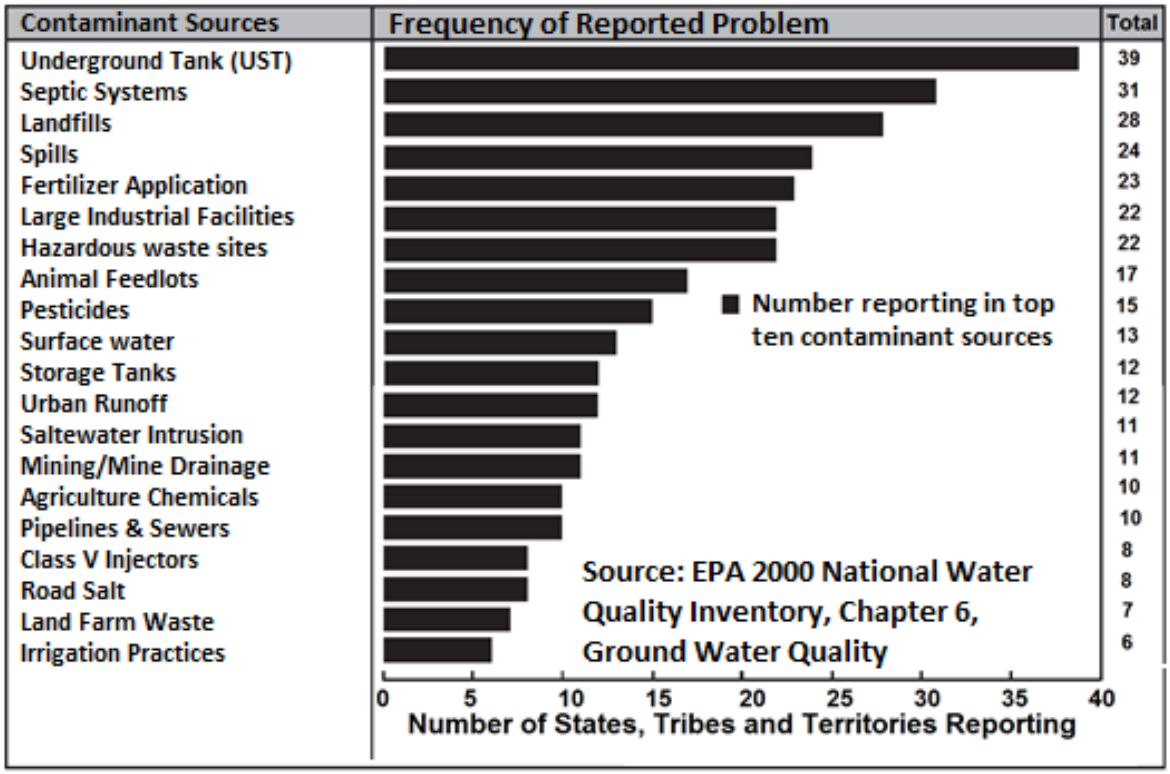
Much of what is written in chapter 5 on fate and transport is highly speculative, again because there are no real studies of large releases and health effects studies are in their infancy. Most of the health effects studies are currently relying on proximity to oil/gas wells as the causal link, which may or may not ultimately prove a health effect. Industry has been fracture stimulating wells in west Kansas for 50 years with no known impacts.

How do releases found in this study fall compare to other releases, for example, events shown in this release frequency table (Table 1, provided below) produced by EPA in 2000? Would this chapter be more helpful if it established a frame of reference for the reader? Perhaps there should be a reference to the groundwater.org website and their discussion on contamination.

http://www.groundwater.org/get-informed/groundwater/contamination.html

Finally it should be emphasized there are very limited studies on baseline water quality. Understanding the pre-existing water quality is critical in identifying potential contamination. Most of the rural water wells in the US are rural, private wells. These rural wells are outside the SDWA and are not tested. Many of these wells might fail testing simply due to metals or other elements that leach from rocks. What if 25% of the rural water wells didn't meet EPA standards just on background quality?

Table 1. Frequency of Reported Water Contamination Source



Also, I request that the Yale study results are referenced in the EPA study. Marcellus is a major area of concern and this study focuses on those concerns. I don't have Yale's full study but here is a link to the paper published in the national academy of sciences. http://www.pnas.org/content/112/43/13184.abstract I think their work helps to address a number of issues we discussed during the Panel's 10/29/15 meeting.

Comments from Dr. Katherine Bennett Ensor

The chapter summarizes the available information regarding the composition, volume, and management of chemicals used to create hydraulic fracturing fluids. While there is a good summary by state as represented by table 5-3, is it possible to provide a similar analysis by distinct shale play? In this way, communities would be closer to understanding what is present in their region, while still protecting the intellectual property of specific companies.

It seems prudent to summarize the frequency and severity of spills clearly and distinctly, preferably through appropriate mapping and/or expert statistical graphics. Although the information provided clearly identifies this concern, I find and clear and concise overall picture missing. Is there information on industry best practices, and the prevalence to which these best practices are adhered to by the industry as a whole available? If this information is available, it would be worthwhile to bring it forward in this chapter.

Although it is not the scope of the report to highlight industry best practices, do documents or resources exist to which readers should be directed? It is clear from chapter 5 that spills and accidents will occur in hydraulic fracturing, thus it is imperative to quantify, document and mitigate the impact of such incidents on drinking water.

Comments from Dr. Daniel J. Goode

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?

The assessment provides a comprehensive and useful summary of the chemical characteristics of HF fluids, respective volumes, and management of fluids during HF operations.

EPA's study of spill reports associated with HF (EPA 2015n) provided analysis and figures for 457 spills. However, the draft report presents analysis and figures for a sub-set of only 151 of these spills. The 151 were selected because those spill reports were categorized as "Fracturing Fluid" or "Chemicals and Products" (Table 3, EPA 2015n). However, several of the other categories of Material Type could also include chemicals used for HF, including "Frac Water", "Hydrocarbons", and "Unknown" (Table 3, EPA

2015n). As noted by EPA (2015n), "frac water *may* not include individual chemicals and/or chemical products" (Table 3 footnote; *emphasis* added), implying, reasonably, that "frac water" *may* include such additives. Obviously a category of "Unknown" could also include HF fluids. While I think it reasonable to analyze spills associated with the HF Treatment separately from spills associated with "Flowback and Produced Water", it would have been much clearer if the set of spills analyzed in the draft report corresponded directly to that used in EPA's report on the spill data analysis (EPA 2015n). As presented, none of the figures in the draft report on this analysis (figs. 5-12 through 5-15) correspond directly to those presented in EPA (2015n).

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 hydraulic fracturing water cycle? 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?

The major finding of the study is that there is not enough information available to assess the relationship between the chemical mixing stage of hydraulic fracturing and drinking water: "In addition to limited information on chemical usage, we cannot complete a thorough assessment of the potential impact of chemical spills due to limited information on actual spills." and "There are documented chemical spills at fracturing sites, but a lack of available data limits our ability to determine impacts." (p. 5-74) and other statements in the Synthesis section. This major finding does not identify the potential impacts to drinking water resources from the chemical mixing stage.

The Synthesis (Section 5.10) identifies "three overarching factors: (1) fluid characteristics, (2) chemical management and spill characteristics, and (3) chemical fate and transport." (p. 5-71). However, the Summary of Findings (Section 5.10.1) discusses only factors (1) and (2), and does not provide any findings about factor (3), chemical fate and transport.

The factors affecting the frequency or severity of impacts include chemical fate and transport, but those are summarized in only the most basic manner. General statements such as "Precipitation can re-mobilize trapped chemicals and move them over land or through the subsurface." (p. 5-72) can be found in any introductory environmental science textbook, and do not represent synthesis of research on the relationship between the chemical mixing stage of HF and drinking water.

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 hydraulic fracturing water cycle? Are there relevant literature or data sources that should be added in this section of the report?

EPA should conduct detailed analysis of actual spills that may have affected drinking water to understand the factors determining the relationship between the chemical mixing

stage of HF and drinking water. Such a study should begin with construction of databases from information already at state regulatory agencies.

EPA should conduct 'prospective' studies that would provide more detailed information on chemical mixing and the impact of spills than is normally available from industry or required by regulation.

Comments from Dr. Bruce D. Honeyman

Chapter 5, Chemical Mixing, of the *Hydraulic Fracturing Drinking Water Assessment*, is essentially a critical review of well-field-site hydraulic fracturing (HF) fluids. My overall impression is two fold: 1) the EPA staff examined a tremendous amount of data in compiling the report; and 2) the lack of reporting of data by industries conducting HF inherently created substantial uncertainties in EPA's ability to bound the question of 'severity' (3b). As stated in Section 5.10.3 Uncertainties, 'The lack of information regarding the composition of chemical additives and HF fluids, containment and mitigation measures in use and the fate and transport of spilled fluids greatly limits our ability to assess potential impacts to drinking water resources.' Lack of reporting, underreporting and Confidential Business Information (CBI) assignment of data by State and local governments and industry hampered firm conclusions about potential effects on drinking water from HF fluids. More to the point (pg. 5-2), 'Data limitations also preclude a quantitative analysis of the likelihood or magnitude of chemical spills or impacts.'

a. The report appears to be an accurate summary of data acquired via various sources (e.g., FracFocus 1.0; CBI data provide directly to the EPA) as represented in the various EPA reports hot-linked from the summary report. A notable effort by report writers was to estimate the volume of HF fluids on-site (Section 5.4.4; Fig. 5.5); this is a crucial parameter as it can bound the potential for impacts to the environment through spillage. Unfortunately, on-site volumes are highly variable (e.g., throughout the HF process at a single well site) and one of the least known aspects of the potential for drinking water contamination. The footnotes on pg. 5-27 are helpful in understanding the constraints and logic put into the estimation. However, Figure 5-5 needs some more explanation to make it accessible to readers: it reflects substantial creativity and hard work on the part of EPA staff but for many readers will be a head-scratcher.

b. An assessment of the potential impact of HF fluids requires at least the following: 1) an accurate assessment of the chemicals used in HF operations; 2) their on-site volumes; 3) likely concentrations after the point of mixing; 4) real data on the effectiveness of containment strategies; and 5) an understanding of the potential imposed by chemicals (in this case sometimes enormous volumes of concentrated exotic formulations) in complex geomedia. We know that during the reporting period 692 chemicals were reported to FracFocus 1.0 from a total of 35,957 disclosures. Of the 692, 35 were reported in at least 10% of the FracFocus 1.0 disclosures and statistically there was an average of 5 CBI chemicals per disclosure. The chemical data is proximally inclusive but skewed toward Texas operations and voluntary compliance and therefore retains a substantial uncertainty. Uncertainly about the identity of chemicals used in a particular operation is compounded by a paucity of knowledge about on-site stockpiles and after-

mixing formulations and the effectiveness of spill-containment. Chapter 10 ('Synthesis') includes the observation that while there appears to not be evidence of widespread, systemic contamination of drinking water as a consequence of the processes and mechanisms described in Chapter 5. However, the data record is insufficient to provide any certainly to the observation. An examination of the spill record table[4] alone gives sufficient pause to reconsider the statement.

The above leads me to the following point: while the draft HF assessment report is not 'a human health, exposure or risk assessment'[5], I believe that the public needs more guidance from this document than the uncertainty with which they are left. For example, the draft report includes the estimate of 3.3 to 12.2 spills per 100 HF wells installed in PA. There is no additional assessment regarding an estimate of the potential impacts to drinking water in terms of potential severity. In other words, there is considerable uncertainty among stakeholder groups about the potential impact of HF fluids on drinking water: to what extent can this report reduce some of that uncertainty?

c. Of the three elements contributing to the potential impact of chemical mixing on drinking water (fluid characteristics, chemical management and spill characteristics and chemical fate and transport) the discussion of the latter has, in my opinion, the least critical assessment. The listing of the chemical properties of 42% of the 1,076 chemicals used in HF is an interesting addendum but the central issue is that we have a markedly limited ability to assess the environmental impact of large quantities of chemicals in mixture (Section 5.8.5) in contact with complex geomedia. The background sections on mobility only can set a context for the scenarios but there needs to be a critical assessment of our abilities to 'predict' where a spill might go and, to be honest, we need to conclude that it is limited. As stated (p. 5.73): 'The most successful way to prevent impacts to drinking water resources is to prevent spills from occurring in the first place'.

d. The EPA group tasked with developing this section appears to have done a thorough job at gleaning whatever data was available publically on HF 'chemical mixing' during the evaluation period. Although the report is 'not designed to inform specific policy decisions' (Presentation to the SAB on 9/30/15), public interest in the report, and the substantial resources and effort the EPA has dedicated to its production, stakeholder groups will no doubt use the report to support whatever action is believed needed by them. With respect to 'chemical mixing', the substantial task is to act to <u>reduce or better constrain the uncertainty</u> that looms over the question of potential impact by: 1) improving the critical data sets (e.g., spills, HF fluid composition); 2) developing risk assessment models based on the current data sets; and 3) research in the management of spill-containment systems.

[4] http://www2.epa.gov/hfstudy/review-state-and-industry-spill-data-characterization-hydraulic-fracturing-related-spills-1, Appendix B

[5] Presentation to the EPA Science Advisory Board on 9/30/2015

Comments from Dr. Richard F. Jack

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?

> Yes. This chapter begins by describing the fate of chemical mixing and its affect on drinking water resources being affected by 1) chemical composition, 2) management of spills, 3) chemical fate and transport. The volume of chemicals used is described in chapter 5.2, the composition of hydraulic fracturing fluids are described in chapter 5.3, and chapter 5.4 describes the composition frequency in volume of hydraulic fracturing chemicals used, management of potential spills are described in chapter 5.5 for chapter 5.7. Chapter 5.8 describes the fate and transport of any potentially spilled chemicals. And finally chapter 5.9 discuss is potential changes underway within the industry to reduce potential impacts from spills.

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

> Yes. Though it is well understood that many factors affect the hydraulic fracturing process, such as geology, skill of the operator, cost, etc. The report is a good job in explaining the steps involved in hydraulic fracturing. This information is readily available and verified by many hydraulic fracturing consultants and operators.

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

Do these major findings identify the potential impacts to drinking water resources due to this step of the hydraulic fracturing water cycle?

> Yes. Chapter 5-2 and figure 5-3 describes the chemical mixing phases along with the complexity of the equipment, plumbing, and storage tanks. The chapter also does a very good job explaining how all of these steps to interact with one another to generate the optimum chemical mixture and pressures required for the hydraulic fracturing process. This chapt that er gives a very good general understanding to better comprehend what potentially may occur to cause spillage and seepage into the ground water. Chapter 5.5 Chemical management and spill potential discusses the equipment, processes and vulnerabilities effectively. Importantly 1/3 of all spills result from equipment failure, thus spills will eventually happen. The mobility, complex connectivity, re-connectivity make spills not just highly likely, but almost impossible to avoid. Table 5-5 provides a good overview of the likely causes of spills.

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

> Yes. Factors affecting the frequency and severity of impacts are described <u>to the extent possible.</u>

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

Yes. Text box 5-2 describes the FracFocus database. Though the data submitted is mandatory for many states, especially for the predominant states for hydraulic fracturing is occurring, nonetheless there are limitations to the database itself. For example, said meters to FracFocus were able to apply for a disclaimer known as the confidential business information (CBI). CBI is basically confidential, proprietary information than a vendor does not wish to disclose. As stated in text box 5-3, submission of 39,000 chemicals from January to march in 2013 70% of the disclosures contained at least 1 CBI. Now there are a large number of chemicals mentioned in the frack focus database it can easily be argued that there is still a significant limitation to our overall understanding of the chemicals used in hydraulic fracturing. This is well stated in the report:

"In general, then, we are limited in our ability to fully assess potential impacts to drinking water resources from chemical spills, based on available current information. To improve our understanding we need: more information on the chemical composition of additives and fracturing fluid; the physicochemical properties of chemicals used; baseline monitoring and field studies of spilled chemicals; drinking water resources quality conditions before and after hydraulic fracturing is performed; detailed site-specific environmental conditions; more information on the containment and mitigation measures and their effectiveness; and the types and volumes of spills."

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 hydraulic fracturing water cycle?

The EPA report describes important research gaps in their analysis. These are described below:

- Due to the limitations of available data and the scope of this assessment, it is not possible to provide a detailed analysis of all of the factors listed above.
- Data limitations also preclude a quantitative analysis of the likelihood or magnitude of chemical spills or impacts.
- Spills that occur off-site, such as those during transportation of chemicals or storage of chemicals in staging areas, are out of scope.
- The data contain 6 few post-spill analyses, so ground water contamination may have occurred but have not been identified. Additionally, several years may be required for a spilled fluid to leach into the ground water and therefore impact on a ground water receptor may not be immediately apparent. Page 5-46
- Surface spills related to hydraulic fracturing activities are not well documented in the scientific literature, though some evidence of spills and impacts to environmental media exists, chapter 5 page 47.
- Conclusion on spills:

GAP BioTransformation Processes

Bacterial biodegradation processes are, in general, well understood. However a gap exist in our knowledge of biotransformation of chemicals used in hydraulic fracturing under a variety of environmental conditions. Including mixtures, site conditions, etc. This is especially important for the biocides that are added to prevent bacterial growth. Though, when a spill occurs the entire hydraulic fracturing chemical mixture is diluted, degraded and its migration maybe relatively slow, the eventual impact over long time periods is very little understood. For example, page 70 of chapter five, second paragraph, "The second documented spill (U.S. EPA, 2015n, line 144), shown in Figure 5-20," states that there was no documented impact to the ground water. In addition the next page states that there is no documented information as to the composition of the hydraulic fracturing chemicals. Thus the conclusion that there was no impact to simply cannot be made because 1) there is no baseline data, 2) there is no definition of "impact", 3) there is no mention of any tests performed for the contaminants themselves.

The same conclusion can be made for the third documented spill on page 5-69. Due to the lack of information of the chemicals used, base-line monitoring, documentation of compounds tested or lack thereof one cannot make the conclusion that there is no impact from this spill.

Summary of Findings

The conclusion cannot be made that there were no impacts to the ground water from chemical spills when there is little information on post-spill testing and sampling.

The EPA cannot make conclusions as to the nature of the chemicals present when they rely on a database of such as FracFocus which does not realistically contain a full disclosure of the chemical type and concentration of hydraulic fracturing chemicals used.

Uncertainties

This section is well written and highlights the many uncertainties in the data available to the EPA to truly assess if hydraulic fracturing chemicals impact drinking water sources.

This statement itself summarizes very well the uncertainties that can occur from hydraulic fracturing spills. 5-74

"In general, then, we are limited in our ability to fully assess potential impacts to drinking water resources from chemical spills, based on available current information. To improve our understanding we need: more information on the chemical composition of additives and fracturing fluid; the physicochemical properties of chemicals used; baseline monitoring and field studies of spilled chemicals; drinking water resources quality conditions before and after hydraulic fracturing is performed; detailed site-specific environmental conditions; more information on the containment and mitigation measures and their effectiveness; and the types and volumes of spills."

Research Gaps to be addressed:

This study does not and cannot bring together all of the chemical, geological, toxicological, spatial, and longevity aspects of hydraulic fracturing concerning chemical spills.

In order to fully understand the facts of hydraulic fracturing a series of studies need to be undertaken that encompass different a series of hydraulic fracturing chemicals, migration and Bio degradation in Situ for different geological formations, base-line groundwater monitoring, onsite sampling of hydraulic fracturing chemicals pre and post injection, and flowback and produced waters. Monitoring wells need to be installed in the aquifer at several locations and monitored over a longer term (up to 5 to 10 Years), for pre and post-fracking characterization of ground water as well as eliminate any possible seasonal variation that can occur.

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

And ACS articles of the tracers, radioisotopes, Vengosh

Comments from Dr. Dawn S. Kaback

The report answers the above questions in a positive way in Chapter 5. However, I have provided some comments below that make suggestions as to how to clarify certain parts of the document and to fill in missing information.

Ch 5. p. 5-4, Figure 5-3 doesn't really explain the 4 stages well enough. It states that fracturing starts on the left at the "toe of the well." I don't recommend that term unless it is widely used. We would be more likely to say something like "at total depth" or at the "distal end." Also make similar change on page 5-6, line 1. Plus it mentions fractures being elongated but doesn't really explain how the proppant works but uses the term "proppant gradient?" Also it doesn't explain the term "pre-pad." I think part of the problem is that you look at this figure before you read the text on the next page.

p. 5-5, line 4, change "from" to "during." Line 5, change "pieces of rock' to "formation material" or "cuttings." Line 14, change "channels" to "fractures and bedding planes." Line 28: add the words "carry the proppant further into the formation."

p. 5-6 line 4: remove "site." Line 5: shouldn't you also say "the geology?" Line 32, remove "what" and "is."Line 35, add "geologic" before "formation."

p. 5-8, Figure 5-4, need to explain the acronyms or add them below.

p. 5-9, Table 5-1: there is much discussion about water being the primary frack fluid but also discussed in Section 3.

p. 5-11, line 30: explain the problem with the residual breakers.

p. 5-12, line 1 – what are unconventional fluids? Not explained at all. p. 5-12. Line 7, somewhere in this section need to explain water sensitive formations, give some examples and explain how they may affect production goals.

p. 5-24, Table 5-4, change "and" to "an" in the sentence just below the Table Caption.

p. 5-29 Table 5-5, first two rows should use same tense of verb "transport;" proppant function should use verb "store" instead of "hold;" high pressure fracturing pumps should use work "inject" and not "injected." Manifold trailer should be better explained as it doesn't seem to match what is on Figure 5-6.

p. 5-30, Figure 5-6 has hydration units and water tanks but these aren't mentioned in Table 5-5. Make the Table and Figure match better.

p. 5-35, line 28, Define the term "base fluid" as it shows up in multiple places including (5-36 lines 9 and 10; 5-50, line 31; 5-71, line 6, 26, 27-28. Need to know whether it means base as the "bottom" or the opposite of "acidic."

p. 5-40, Text Box 5-12: this is a great case study but need to explain the new wells and which ones are removed from the baseline study and why. Maybe need a map of the well locations, etc. It is a little hard to follow when you use words such as "these wells." I suggest the whole box be revised a little to explain why you sampled the wells, where they were located and where they were completed, then that you wanted to determine background and compare potentially impacted wells to the background.

p. 5-51, Figure 5-16: don't like the term chemical ground water plume. I am not sure how to fix it….not sure about contaminant, constituent, COC? I know this figure is in more than one place as well. Footnotes 1, 2, and 4 all misuse the term "soil." For footnote 1, I recommend changing "soil" to "solid, grain, or particle" in the first sentence. Second sentence you need to add something and say "soil and formation or geologic media or?" Footnote 2 remove the word "soil." Footnote 3 replace "chemical" with "constituent." Footnote 4 replace "soil" with "solid." Again I don't like the term "chemical."

p. 5-52, line 4: should the verb after "fate and transport" be singular or plural? Line 12-13, discuss surface water groundwater interaction more and just don't use the terms gain or loss in flow, as you are trying to describe chemical reactions as well. *Also the entire section 5.8.1 needs to be rewritten as it is not as technical as it should be.* Lines 14-18 talk about soluble vs insoluble as if there were two endmembers but that isn't the

situation. Line 27 CHANGE "SOIL" to something like "the subsurface is divided into two zones: unsaturated and saturated based upon….."

p.5-53, line 1-2 must say something like "infiltration vertically downwards toward the water table or horizontally towards an area of low topography to intersect surface water." Line 7: is Dissolved Organic Carbon a chemical or a compound? I hate thinking of it as a chemical. Sounds too harsh. Line 26, explain this sentence about the "desalting."

p. 5-55, line 4 change "soil" to "solid."

Comments from Mr. Dean Malouta

The chapter regarding chemical mixing at the well pad adequately addresses the issues of chemical concentrations, ranges of types of chemicals used, possibilities for spillage and at what stage, processes involved in mixing and what could potentially go wrong, and most likely sites of spillage. The chapter also mentions many of the steps taken by industry to prevent spills or retard spills if they occur (liners, berms etc.) Many of the public written comments wish there were more about potential for spillage at other steps of the hydraulic fracturing process (i.e. transportation of chemicals to the well pad and of flow-back waste post fracturing.) This is clearly beyond the scope of the present study but it may be worth repeating in this chapter introduction that it is beyond our scope and more particularly why. This seems to be of particular concern to the public so we should probably be more specific in addressing this concern.

While the chapter very fully covers the range of possibilities of spills, what is less well discussed are 1) the likelihood or probability of an occurrence or some indication as to how frequent or volumetric spills have been in the past. It would be helpful to characterize the majority of spills as to whether they were small and easily remediated or if they exceeded standard preventative measures to deal with such spills. Most would agree that spills are undesirable but if we could have some sense how frequently they were generally caught and contained vs. how frequently they were were uncontained, then the public would gain a better understanding of the level of risk being discussed.

One specific paragraph begs a question: Page 5-48 line 6 cites a 2013 study (which obviously preceded 2013, however, when the events took actually took place is not mentioned) in which BTEX chemicals were spilled. While past industry practices may have used such chemicals in the hydraulic fracturing process, it is my understanding (which I would like to have confirmed or contradicted) that BTEX chemicals are no longer used in industry for fracturing purposes. This comment would apply to the chapter on chemicals used as well. If such chemicals are actually still in use, I would like to know what level, amount and/ or concentration they are used.

In general, additional summary with respect to context, frequency and severity is needed for clarification. In this chapter as well as in chapters 6 and 7, additional summary of the likelihood or probability of unwanted events should be discussed. Currently, the text reads as if anything

could happen and it is left to the readers to decipher for themselves how worrisome such events are. Also, in this chapter and chapters 6 and 7, I would like to see specific mention of industry best practices, and, where applicable, recommendations for such practices or even recommendations in certain extreme cases for a call for legal requirements to adhere to certain specific best practices which may be agreed by knowledgeable experts.

Comments from Dr. Cass T. Miller

a. The available information regarding composition, volume, and management of chemicals used to create hydraulic fracturing fluids is characterized. The nature of the data sources used, including FracFocus and confidential business information (CBI) non-disclosure result in an incomplete record.

b. Potential risks to drinking water are described in a very general sense, which basically amounts to pathways and factors of leading order importance in assessing transport and fate. Because fracking sites are not routinely monitored before, during, and after fracking operations assessing the impacts on the environment are usually difficult to prove. If one doesn't look for something, you are less likely to find it. A good example, is the last case study of the effect of spills, which really wasn't very informative. The use of the word soil for all subsurface solid material is not scientifically accurate. See for example the USDA definition, which limits soils to the top 2 meters of material below ground surface. A more comprehensive approach could be taken to classify the physicochemical parameters of all identified species than simply relying on just the EPI Suite.

c. The uncertainties, assumptions, and limitation of this analysis are articulated in section 5.10.3. These limitations are severe and correct. Assessing the potential for environmental contamination of drinking water resources would require much more data than is currently available.

d. The chemical properties should be more completely characterized using other sources of information. Best practices for preventing contamination can be more thoroughly characterized. Quantification of the fraction of sites that use best practices should be quantified to the extent possible. Stronger support for the development and use of fracking additives that pose a lower risk to the environmental is recommended.

Comments from Dr. Azra N. Tutuncu

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?

EPA established a database providing comprehensive insight into total water use in hydraulic fracturing operations. The database contains data reported from the first version of FracFocus Chemical Disclosure Registry for a selected study period. FracFocus had been

initiated as a voluntary data reporting registry. Therefore, the database has limitations capturing the earlier operations everywhere in the US and even within the participating states the data was used for the analysis reported. It does not represent a full picture for all hydraulic fracturing operations in US in the specific timeframe the study has been conducted. The confidential nature of the CBI ingredients from the disclosures, and input errors during the development of the database have also forced EPA researchers to make approximations using the available data in determining the chemical volumes and other critical input needed to evaluate the potential drinking water contamination as clearly stated in the report. Using more recent versions of the FracFocus Chemical Disclosure registry along with the GWPC upgrades will provide continuous improvement of the data accuracy and transparency for the nationwide analysis.

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 hydraulic fracturing water cycle? 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?

Major findings have been supported by information and data in Chapter 5. Spilled fluids were reported to be not reaching surface or ground water for 41% of the spills analyzed. Researchers have not determined how spilled fluids may have affected surface or ground water quality. Yet, they have provided information about the responses to hydraulic fracturing related spills to contain the spilled fluids and to remediate the affected area. Hence, the spill characteristics and containment offer detailed insight into the hydraulic fracturing associated spills in several states.

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

All assumptions and steps followed have been clearly presented.

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 hydraulic fracturing water cycle? Are there relevant literature or data sources that should be added in this section of the report?

A portion of the total number of hydraulic fracturing related spills occurred in the United States have been included in the report concentrating on the available data from nine states that are among the top oil and gas producing states. Inclusion of similar data from other oil and gas producing states will provide a more complete picture. The data used from nine states was also partial spill data available for the analysis due to the unreported source of the spills. Emphasize should be given to conduct additional research incorporating larger populated data from the recent versions of the complete dataset.

The ranking of the 20 most and least mobile organic chemicals using their physicochemical properties covered in Table 5.7 and Table 5.8 is valuable insight toward short and long term potential impact of these chemicals on the drinking water resources. Adding another column

to these tables with information containing their toxicity and other relevant MSDS information will provide an influential integrated manuscript increasing the value of the assessment.

Comments from Dr. Thomas M. Young

Chapter 5 of the report attempts to summarize risks to water resources posed by releases that occur during the chemical mixing phase of hydraulic fracturing. The report does a good job of describing the diverse activities that occur during this operational phase including how chemicals are stored on site and handled during blending operations. The report also does a good job of analyzing available data on the frequency, size and causes of releases during this operating stage. However, the completeness of this data set leaves something to be desired. There is no national system for reporting or collecting spill reports. At the state level, reporting requirements related to spills varies with respect to the size and nature of a reportable spill and the information that is collected about it. Most of the spills discussed in the report included little or no field investigation of the impacts of the release, such as follow-up soil and/or groundwater testing for chemicals. Even when testing was performed, such as in the Killdeer case, it is not clear what chemicals should be monitored for given the difficulties defining and characterizing the chemicals used at a given site. Therefore, when there are "limited detections of other organic compounds," (p. 5-40, line 31) it is not clear if that is because the compounds were absent or because the analytical method employed was not capable of recovering and detecting the unrecognized compounds.

There are many holes in the information about the chemicals used in hydraulic fracturing. The importance of the missing information is obviously difficult to gauge, but it is clearly a significant number of chemicals that are affected. First, the source of the majority of the chemical usage data is FracFocus, a database that, except in a few jurisdictions, collects voluntary submissions from industry. It is not clear either how much care is put into the accuracy of submissions or whether any data curation is applied to it at any point. As noted in the summary, the "[a]ccuracy and completeness of original FracFocus disclosure information was not verified" (p. 5-73, lines 19-20) as part of this research. The FracFocus database, along with other sources were used to identify 1076 chemicals. These do not include an unknown number of chemicals claimed as "confidential business information" by industry. The report analyzes physicochemical properties for 19 CBI compounds, but it is unclear how many more such compounds are known to EPA. FracFocus disclosures indicate that 11% of ingredients are CBI (p. 5-73, line 28). A large fraction of the chemicals that have been included in industry disclosures and that are in the public domain are not amenable to the application of standard physicochemical property estimation packages such as EPISuite. Physicochemical parameters were determined for only 42% (453) of the compounds, and the fate and transport of the remaining 58% of the compounds do not seem to be further considered (p. 5-53, lines 20-28). The exact number of compounds included in the analysis of physicochemical properties is sometimes confusing as well, with 515 (rather than 453) cited as the number of compounds which had estimated properties (p. 5-56, line 1). The omission of the majority of the chemicals known to be used in hydraulic fracturing from the analysis makes all statements about how "most" of the chemicals behave problematic. In the most obvious example, the report states that

the "log Kow values are skewed positively, indicating less mobile chemicals…" (p. 5-55, lines 7-8). Since EPISuite does a good job of estimating physicochemical properties for nonpolar chemicals but has a much more difficult time (or cannot be applied at all) for ionic species or species with unusual heteroatoms such as organometallic compounds, there is a strong chance that inclusion of these in the analysis would shift the conclusion from "skewed positive" to "skewed negative." Given that this is the main basis for concluding anything about mobility of these compounds, this is an important point.

Use of Log Kow (and aqueous solubility) as the determinant of contaminant mobility will lead to erroneous conclusions for a number of chemical structures, some of which are likely important in fracturing fluids. Glyphosate (CASRN: 1071-83-6; chosen because data widely available) is a good example of a chemical with a small Kow (Log Kow -4.0 (expt), -4.47 (EPISuite est)), a high water solubility (12 g/L (expt)) but limited subsurface mobility (Log Koc 3.3, USDA pesticide properties database preferred value). Consequently, despite its widespread application, groundwater contamination with glyphosate is relatively infrequent (although some of its degradation products are more commonly found). Compounds that adsorb to soils via interactions other than hydrophobic (such as some amines or phosphates like glyphosate) often have stronger sorption to soils than predicted based on Log Kow alone.

In addition to uncertainties related to the identity of chemical constituents present in typical fracturing fluids, another key information gap relates to the concentrations of the additives. The FracFocus database lists maximum concentrations for additives, but it is difficult to tell how representative these maxima are of the varied conditions occurring during fracturing operations at one site or across different sites. A variety of scenarios and calculations in the report are based on volume fractions of additives of 2% or less (p. 5-6, line 18, p. 5-26, footnote 1, p. 5-27, line 6). Table 5-4, for example, suggests that total amounts of additives are between 0.21% and 0.49% of the fracturing fluids. Spilled "aqueous" fracturing fluids are assumed to contain 2% or lower additive fractions at several points in the document (p. 5-36, lines 17-18). The 2% limit is hard to reconcile with the fact that acids are listed as being present at 3-28% concentrations (p. 5-5, line 3) and maximum concentrations of methanol range from 0.4 to 100% with a median maximum of 30%, with methanol being used at 72% of sites. I assume that this occurs because at high (higher than 2%) concentrations of acid and/or methanol, that the fluids are no longer "water based" but are something else instead. But these alternative fluids are subsequently largely ignored during the impact assessment efforts in the report. As a final point, impacts are

Given the incomplete data described above, a critical question in this report, which is largely not addressed here, is how the findings in the chapter should influence future research on spills from hydraulic fracturing operations. There are few reports of stark and obvious impacts to water resources from these operations, but it is similarly clear that there has been little systematic investigation of the question. It seems plausible that significant and important impacts are occurring but cannot be detected with current approaches. This is especially true of groundwater and soil impacts. Some targeted further research or data collection in this area seems warranted.

Charge Question 4: Well Injection Step in the Hydraulic Fracturing Water Cycle

The third stage in the hydraulic fracturing water cycle 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 hydraulic fracturing water cycle? 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 hydraulic fracturing water cycle? Are there relevant literature or data sources that should be added in this section of the report?

Comments from Dr. E. Scott Bair

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?

1. As a teacher, I struggle with the manner in which the potential pathways of fracturing fluids are presented in section 6.2.2. As a researcher, I struggle with the title of this section, "Evidence of the Existence of Fluid Movement Pathways or of Fluid Movement". Little evidence is presented -- indicators are presented and simulation results from interpretive models are presented, but little direct evidence from measured fluid pressures or measured contaminant or tracer concentrations are presented, which is anticipated from the title. The word '<u>evidence</u>' should be reserved for measured field or lab data that demonstrate a specific fluid pathway. Herein, '<u>evidence</u>' should express the same standard used in a courtroom.

There are several case studies where actual field data were used to establish a fluid pathway or the lack of one. Such studies and their conclusions should be emphasized to

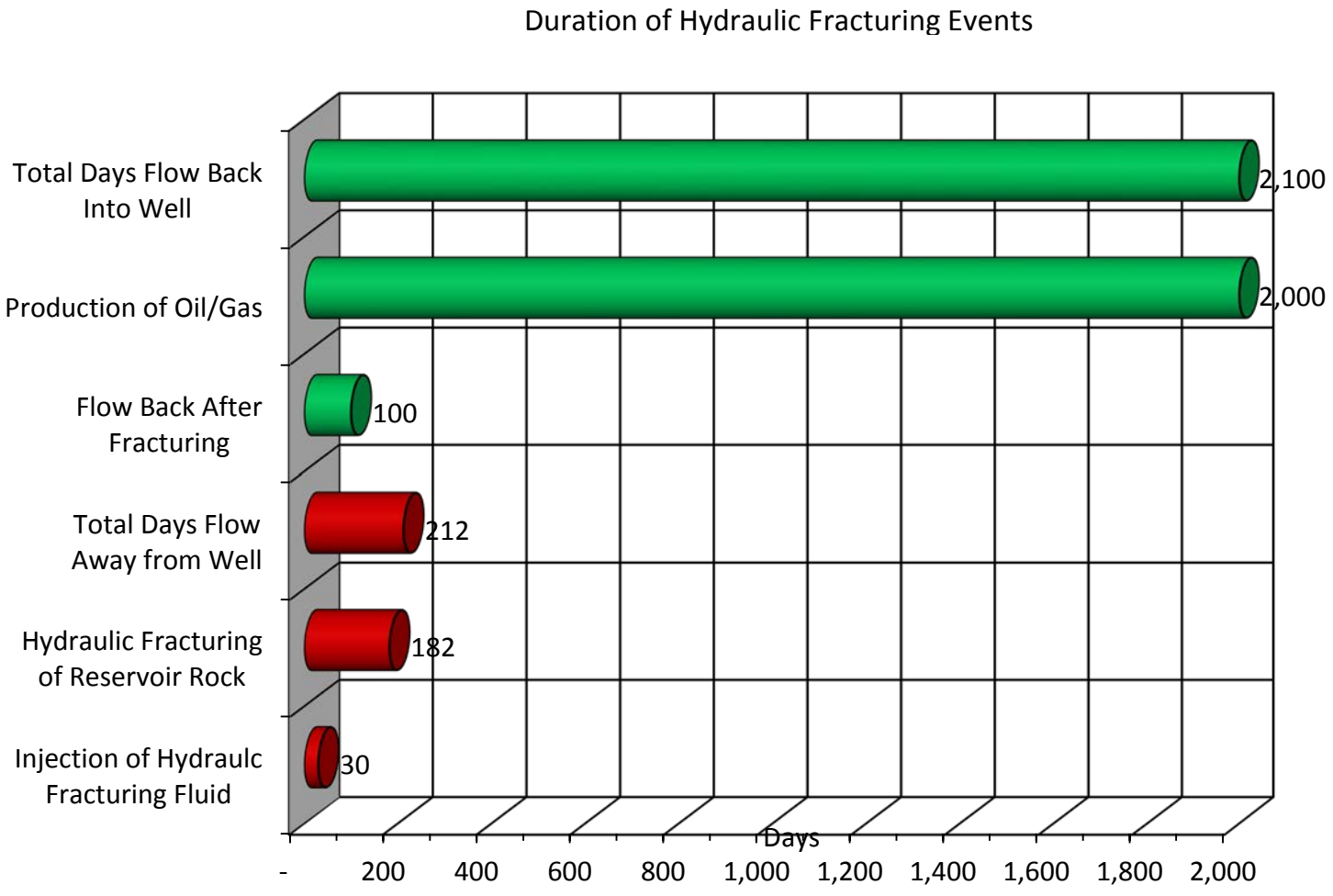
the reader. Similarly, pathway analyses based on interpretive models should be explicitly described as such, their limitations presented, and their conclusions appropriately qualified.

2. By merely describing the various studies that have been performed and then referencing the article in the appropriate technical journal or report, the public is one-step removed from actually reading the article with its assumptions, limitations, graphs, tables and explanations. I understand the need for brevity when so much research has been performed to identify and examine potential pathways. My suggestion is to add several (many) figures from the original articles. Even as a modeler, I found the task of reading the 14 pages in section 6.2.2 difficult in terms of its content and sheer volume of text. I can't imagine how challenging it would be to the general public. I suspect this is one reason so few public comments were submitted about the fluid flow modeling.

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 hydraulic fracturing water cycle? 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?

1. Not all impacts of well injection activities will cause the same severity or occur at the same frequency. Yet, the text contains no hierarchical language differentiating a short-term or an acute impact from a long-term or chronic impact. There also is no language informing the public whether one type of impact is more or less probable than another. In its present form, the text, more often than not, treats all impacts as equals in frequency and severity. This treatment presents an unrealistic, scary perspective and does not provide the public with reasonable information to assess potential risks.

2. Nowhere in Chapter 6 or elsewhere in the final draft document is there a table or a graph summarizing the duration of different hydraulic fracturing events. For example, the period of fluid injection to fracture the source rock may be hours or days for each fractured well segment and weeks to months for the entire length of a well. Other than when the well is constructed, this is the only period of time when the flow of fracturing fluids is radially outward from the well. 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.
It is important, in terms of assessing the impact of fracturing fluids on overlying USDWs to understand and appreciate the difference in the duration of these stresses and



the difference in the duration of fluid flow directions oriented away from and into the well. To this end, a graph like the one below should be added to Chapter 6, as well as to the Executive Summary and the Synthesis, to inform the public about these very important differences in stress duration and fluid flow direction.

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

1. There are many types of models (physical, electrical analog, statistical, mathematical) and many types of model applications (predictive, interpretive, generic or hypothetical). The models described and cited in Chapter 6 are mathematically-based, interpretive models -- meaning the models were used as a framework for studying the dynamics of a specific flow system or systems. Interpretive models usually are based on a generic hydrogeologic setting or settings, non-controlling boundary conditions, representative values of pertinent parameters, and lack the calibration and history-matching processes to be useful in making predictive simulations.

These limitations are not made clear to the reader and should be described for each modeling study before results of a model are described. A short paragraph needs to be inserted near the beginning of Chapter 6 describing the types of models and their applications (e.g., see Anderson and Woessner, 1992, pgs. 4-5.) The fact that few, if any, of the models described in Chapter 6 have been calibrated to measured field values of fluid pressure, intrinsic permeability, solute concentrations, etc. renders them helpful but not correct and not necessarily realistic under other boundary and initial conditions.

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 hydraulic fracturing water cycle? Are there relevant literature or data sources that should be added in this section of the report?

1. As mentioned in our meeting in April 2013, there is a great deal of information readily available from the UIC group at USEPA about the number of incidents of leaky tubing, poor cement jobs, and potential leakage of fluids to USDWs along fractures that could (should) be used to describe how more rigorous well construction standards and monitoring can diminish these risks.

2. Section 6.3 deals with fluid migration associated with induced fractures with subsurface formations and with the potential for subsurface fluid migration into drinking water resources. The latter topic deals with fluid movement along naturally occurring fractures within the geologic units overlying the hydraulically fractured source rock. I struggle with this section because no information, none, nada, zip, zero information is presented about the occurrence and distribution of natural fractures, which is of first-order importance to the migration of fracturing fluids to USDWs. Yet, third-order topics such as geochemical and biogeochemical reactions among injected fluids, formation fluids, subsurface microbes, and rock formations are discussed. This is the same exactly the same oversight that was identified in the original draft report.

I am dismayed by how much effort has gone into explaining the fracture mechanics of induced fracturing and how little information is provided to the public regarding the existence, size, spacing, and density of naturally occurring fractures. To put this in perspective, assume a target zone occurs at a depth of 7,000 feet and the nearest USDW extends to a depth of 500 feet. Assume the fractures induced by hydraulic fracturing extend vertically 500 feet, a generous distance. In this case, fracturing fluids have to travel vertically through 6,000 feet of differing types of sedimentary rock along existing, natural fractures. It is essential to understand the characteristics and of natural fractures in this case as 90% of the vertical distance of flow to the USDW occurs along them.

This is a major shortcoming of this section of Chapter 6 and one that was broached at the draft review session in April 2013. As stated at that time, it would not be difficult to address this deficiency as almost all undergraduate texts on structural geology describe naturally occurring fracture patterns, aperture sizes, orientations, and distributions in different sedimentary rocks. There are numerous diagrams and photographs in these texts and in USGS reports that could be used

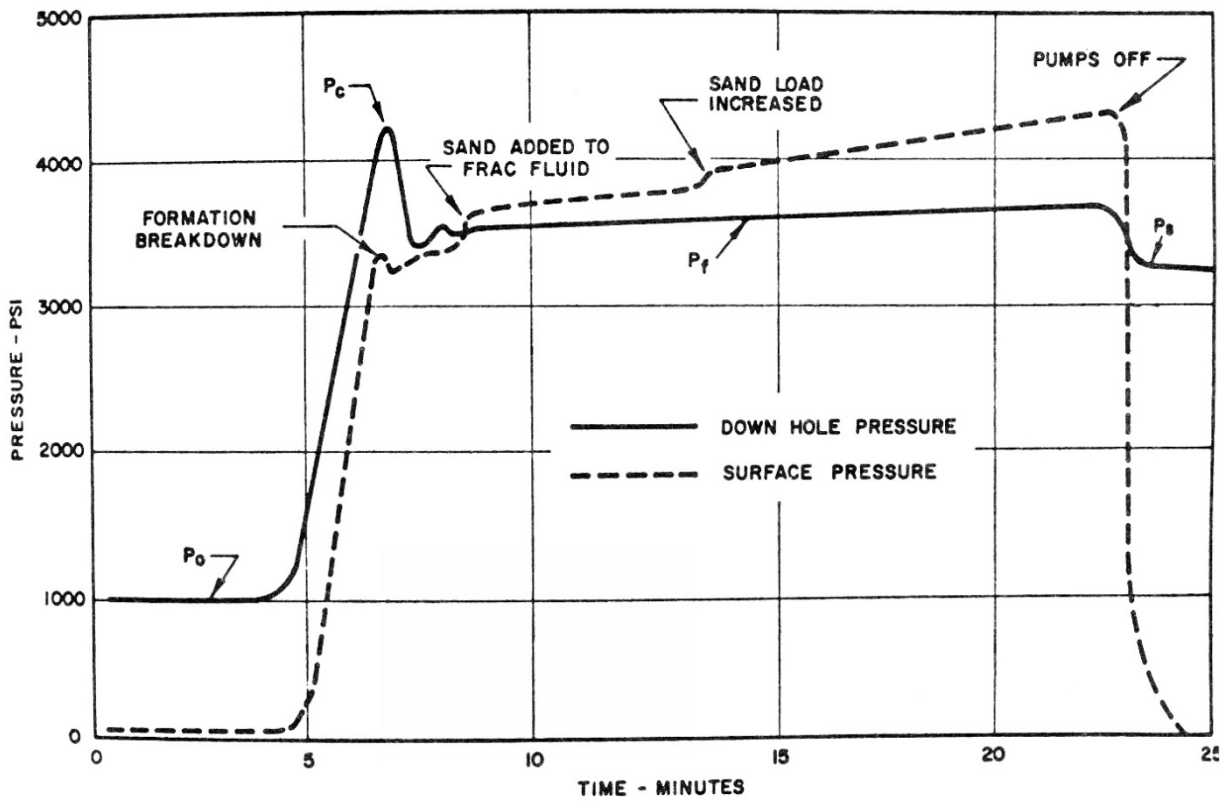
Without knowledge of the characteristics of natural fractures, the public is ill-informed and could be easily mislead about the dynamics of fracturing fluid flowing thousands of feet upward into USDWs, as well as misinformed about the likelihood and severity of such an occurrence.

3. Additional information regarding nature of deep hydraulic gradients, those overlying and underlying hydrocarbon source rocks, must be included in this chapter. The universal existence of upward hydraulic gradients from source rocks to USDWs is a major misconception and a significant limitation to many of the interpretive modeling studies cited in Chapter 6. This omission also misleads the public. It, too, can be addressed by adding some explanative text and figures from a few of the numerous deep-basin conceptual and flow modeling studies in oil/gas regions (e.g. Toth 2009, 1988; Senger et al., 1987) and studies based on deep, measured subsurface fluid pressures above and below oil/gas zones (Gupta and Bair, 1997).

4. Another fundamental piece of information that needs to be added to Chapter 6 is a simple graph of pressure vs. time during an hydraulic fracturing event. No such diagram appears anywhere in the final draft report. An example from the USEPA report by Warner and Lehr (1977) and the subsequent book (Warner and Lehr, 1981) is shown below. This diagram enables the public to visualize how quickly the bottom-hole pressure builds up in a well undergoing hydraulic fracturing and how quickly the pressure decreases after the rock is fractured. The diagram also shows when sand typically is added to the fracturing fluid and how the sand impacts bottom-hole pressures. Another aspect important to the public's understanding of the fracturing process shown on this diagram is how quickly the

bottom-hole pressure returns to pre-fracturing conditions. The outward pressure does not last long and dissipates nearly as quickly as it takes for the pressure buildup in the well.

Schematic Diagram of Pressure Versus Time During Hydraulic Fracturing



Specific Comments on Chapter 6

(1). A list of acronyms used in Chapter 6 should be inserted at the very beginning of the chapter.

(2). Page 6-1, line 6: replace the word 'laterally,' which implies horizontal movement only, with the word 'radially.'

(3). Page 6-1, paragraph 2: This would be a good place to insert information about the isolation of hazardous liquid wastes using UIC Class I injection wells as a successful program and methodology to remove short-term and long-term risk of underground injection of deleterious fluids.

(4). Page 6-1, paragraph 3, lines21 and 22: In order not scare or mislead the public, I highly recommend qualifying the conditions that may cause fracturing fluids to enter UDWS by inserting the words 'an upward' before the words 'physical force' and inserting the word 'upward' after the word 'fluid' at the end of the line. As explained above an upward gradient is but one possible background flow direction. Other directions do occur in nature.

(5). Page 6-1, line 23: The words 'throughout the life of the well, including during and after hydraulic fracturing.' are grossly misleading and incorrect under many subsurface conditions. However, if meant to instill fear and scare the general public, they are highly effective.

(6). Page 6-2, line 25: Please refrain from using the word 'conduit' for expressing how fluids flow through subsurface fractures. Conduits carry trains and subways. Conduits carry electrical cables. Conduits carry cars beneath rivers. Conduits only occur in karstic limestone like Mammoth Caves. If the intent is to grossly overstate, mislead, or frighten the public regarding how fluids flow along minute, discontinuous natural fractures in sedimentary rocks, you have succeeded. If this is not the intent, don't use the word, which is used by many types of engineers but not by geologists.

(7). Page 6-35. It should be pointed out the reader that permeable rock units (sandstones, some limestones) overlying oil/gas production zones will act as pressure bleed off zones that facilitate more horizontal flow of oil/gas/water and reducing vertical hydraulic gradients to overlying USDWs.

(8). Page 6-35 and 36. It should be pointed out that Myers (2012a) did not simulate variable-density flow conditions, nor did he simulate anything other than an upward hydraulic gradient. As a consequence, his counter arguments to published criticisms (Myers, 2012b) of his interpretive modeling study should be discounted, if not disregarded.

(9). Figures 6-5, 6-6, and 6-7 need to have an approximate vertical and horizontal scale. Simply noting that the figure is not to scale provides no useful information. Much more information and a better sense of scale could be provided by adding a horizontal arrow along the bottom margin indicating that the length of the well could be 500 to 5000 feet and adding a vertical arrow along the left margin indicating that the depth of the hydraulically fractured zone could be hundreds to several thousand feet.

(10). Page 6-40, line 34: As this sentence refers to the results of an <u>interpretive</u> modeling study, the phrase "…was also observed." is misleading. No observations were made but gas breakthrough times were <u>seen</u> in the simulations.

I have many more specific comments to help improve the report and the public's understanding of it.

Comments from Dr. Elizabeth W. Boyer

Many of the public commenters had issue with the fact that the case studies of Dimock, PA; Pavillion, WY, and Parker County, TX were not included in any depth in the report. This leads to animosity against the EPA and gives the appearance of a lack of credibility of the report. I suggest that these studies be described in some detail in the report, reviewing what happened in these areas and what is known; articulating the role of state agencies in addition to EPA in these areas, and so forth.

Comments from Dr. Susan L. Brantley

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?

I think the discussion in Table 6-1 is not quite accurate with respect to our paper (Vidic et al., 2013): 3.4% of the wells in PA between 2008 and March 2013 were cited for well construction problems (i.e. such as casing or cement problems); only 0.24% were cited for gas moving into groundwater. Ingraffea et al. looked at the same data we looked at and came up with 6.2% of inspected gas wells between 2004 and 2012 had a comment about well integrity issues (see my summary, Brantley, S.L., 2015. Drinking Water While Fracking: Now and in the Future. Ground Water, doi:10.1111/gwat.12307). The values of 3.4 and 6.2 % should be considered as lower and upper limits based on the dataset and different criteria for the estimates. We only counted problems where a Notice of Violation was issued whereas Ingraffea et al. included any incident where an inspector wrote a comment about bubbling or pressures, etc. We also reported in Vidic et al. that Considine et al. reported that between 1 and 2% of wells had casing or cement problems …this could be reported in Table 6-1 as well. Furthermore, in my NGWA paper cited above I point out that the incidence of rates reported by PA DEP for conventional wells increased from 2000 to 2012. I have inferred that this is not because of increasing problems but because of increasing scrutiny. Looking at my plot in Figure 1 in Groundwater, I infer that the rates of problems for unconventional wells peaked in PA around 2010 (ignoring the earlier peak when very few wells had been drilled) and that there is not a lot of difference between conventional and unconventional once you look at more recent years. I think the discussion in the report around Table 6-1 is inadequate. I think that Ingraffea's conclusion about higher rates of integrity problems in unconventional is not strongly supported given Figure 1 in my Groundwater paper.

The report should include discussion of our paper, Llewellyn, G., Dorman, F.L., Westland, J.L., Yoxtheimer, D., Grieve, P., Sowers, T., Humston-Flumer, E., Brantley, S.L., 2015. A drinking water contamination incident attributed to Marcellus Shale gas development. Proceedings of the National Academy of Sciences, 112(20), 6325-6330. For example, on p 6-25 the report discusses Dimock. The Paradise Road problem discussed by Llewellyn et al. could be discussed in the context of gas migration and SCP.

Also, the problems may have involved gas at intermediate depths and the lack of intermediate depth casing, all mentioned in this chapter. Gas migration was documented, probably along faults and bedding planes in PA, with migration of organic compounds derived either from i) drilling fluids, ii) frack fluids being pumped down while fracking one well, or iii) a spill from a pit at one well pad, probably containing drilling fluids.

In terms of sequestration of fluids in shales, the chapter authors might want to look at our paper Balashov, V.N., Engelder, T., Gu, X., Fantle, M.S., Brantley, S.L., 2015. A model describing flowback chemistry changes with time after Marcellus Shale hydraulic fracturing. AAPG Bulletin, 99(1), 143-154, doi: 110.1306/06041413119. This paper presents and tests a model for how water can become saltier with time even though not all injected water returns to the surface in PA wells.

The report discusses Myers 2012b without emphasizing enough that the distribution of permeability in the subsurface is wildly unknown. This simple idea (that we do not know the permeability distribution in the subsurface) should be made much more clear throughout the EPA report. Myers made assumptions about permeability and these permeabilities could easily be changed by many orders of magnitude…vastly affecting the outcomes. This must be emphasized more clearly throughout this chapter.

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 hydraulic fracturing water cycle? 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?

I suggest that throughout the EPA report, that findings be labelled with a heading, Findings.

One major finding is "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". This is a big conclusion – frack fluids leaving a wellbore and entering groundwater -- and is buried in the report. It is listed under conclusions but not under the part that looks like it has the findings. The story of problems with fracked wells is a story of outliers – a very small number of problems have occurred when ratioed to wells and yet it is extremely difficult to get info about the problems. The public hears about problems and hears that on average that fracking is safe – and then does not want to allow fracking because they cannot square the incongruity of these two lines of evidence (hearsay about individual problems and estimates of averages). The EPA needs to be forthright about the info about incidents, even when they are infrequent or when we do not know all the answers, and this info needs to come out before the public clearly as a finding. The overall situation is not unlike airplane accidents: they happen but if we study them and if data are available we can make them even less frequent.

One major finding is that in some cases HF is used in potential aquifers or close to potential aquifers. This should be emphasized more clearly in the findings of the report as i) something that has happened and ii) a problem. The range of distance to aquifers should be summarized as a major finding in this same finding.

One major finding is the importance of cement in obviating against gas migration. This should be emphasized. This is especially alarming in the context of how little we know about presence or absence of cement and its distribution in wells. For example, 3% of wells lack complete cement in zones of groundwater (p 6-19) and 7% of wells are not fully cemented over the surface casing A(p 6-8). This is clearly a problem and should be emphasized especially because cement is largely what keeps contaminating fluids from moving vertically. A major finding should emphasize the importance of cement with an implication that data about depth of cement and full versus partial cement should be available for the public for all wells.

Another major finding should be that overall, data are hard to get. I was surprised that it is even hard to find out how many wells and which wells have been fracked.

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

Given the concerns with respect to well integrity of pressure cycling, what will happen when companies want to re frack these wells? I don't think the report discusses re-fracking. I believe that the desire for re-fracking is looming on the horizon and should be mentioned or discussed.

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 hydraulic fracturing water cycle? Are there relevant literature or data sources that should be added in this section of the report?

The chapter authors could consider emphasizing the following topics more fully in the report.

1) The presence of natural gas at shallow depths can create significant problems. When a lot of drilling in an area has already been accomplished, we have a lot of knowledge of the presence of this gas but where drilling has not been completed previously, we do not. This should be emphasized in the chapter as a piece of information that is needed in order to design wells effectively. Furthermore, I am under the impression that the presence of gas at mid level depths can make it hard to cement a well correctly. A good cement seal is very important to protect from problems and yet (I believe) it is hard sometimes to get a good seal when an intermediate zone is encountered with a lot of gas. This problem

should be considered and discussed. Gas leakage in PA is often related to intermediate depth gas.

2) The report does not emphasize the potential for long term issues. We have little data about whether well seals stand up over time. This aspect should be emphasized.

3) The report should do a better job of emphasizing heterogeneities in the subsurface. See discussion above about Myers.

4) The report should do a better job of emphasizing how problems are fixed when problems occur. There is a big difference between fixing a gas well that is leaking natural gas versus fixing a situation where a significant spill of organic compounds has entered an aquifer. This context is important to make clear. When some sorts of contaminants enter an aquifer, it is almost impossible to get it out.

5) The report should make it clear why a well operator would only partially cement a zone. If cement is being put in, why would they not fully cement the zone ?

6) We provide a lot of data about a gas migration problem here: Llewellyn, G., Dorman, F.L., Westland, J.L., Yoxtheimer, D., Grieve, P., Sowers, T., Humston-Flumer, E., Brantley, S.L., 2015. A drinking water contamination incident attributed to Marcellus Shale gas development. Proceedings of the National Academy of Sciences, 112(20), 6325-6330.

Comments from Dr. Thomas L. Davis

I am writing to express my sincere appreciation to the ORD for a job well done. They have taken the feedback from the previous meetings of the SAB and have treated a difficult subject in a rigorous scientific and understandable manner. The latter is of vast importance because of societal concerns with the process of hydraulic fracturing and its potential impact on drinking water resources.

I believe the report serves as a foundation in that it contains credible findings based on sound scientific methods and principles. The findings are supported by information that are data-limited largely because of the time-frame mandated by the charge brought to EPA. Substantially more data have become available since the time the charge to EPA was delivered. These additional data would go a long ways to establish metrics pertaining to frequency and severity of potential impacts, but should not limit the findings of this report.

This report will help establish parameters and potential guidelines for assessing and mitigating risks especially associated with well injection. My individual comments relative to this study under the topic of well injection and summary findings of this study include:

1. It may or may not be the purview of this study but the technology evolution in the industry since this time of initiation of this study has been impressive. That evolution is not captured in this report and yet it has a profound bearing on the relevance and findings of this report especially as it pertains to the main public concern of the injection process itself and well integrity.
2. The modeling studies conducted to support the findings of the report relative to understanding pressures/stresses in the subsurface and the influence of faults and natural fractures are not brought to the forefront in this report. The modeling is an integral part of the scientific process and is a basis for evaluating risk and uncertainty. Although never perfect, modeling can tell us a great deal about the injection process and the way the subsurface responds to this process.
3. Incorporation of items 1 and 2 would help the overall scope of this study and would lend more clarity to the conclusions and findings of this report.

Comments from Dr. Shari Dunn-Norman

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?

This is a very complex topic, with potential sources of information from EPA sponsored studies and the literature of numerous technical societies. The assessment has an extensive range of literature cited and it would truly be impossible to cite every source related to the range of topics covered.

The assessment provides a general discussion of the basic elements of well construction, including casing, cement, perforating, and openhole completions that incorporate sleeves for fracturing. Appendix D has more specific information but there are no principles of design included in the discussion. This is a limitation of the work.

Figure 6-1 provides a good graphical overview of well construction, but is misleading in that it shows a water zone that is not cemented behind the intermediate casing string. This water zone has the same appearance as the water zone behind surface casing and may give the reader the impression that industry is constructing wells in which a USDW is not cemented. <u>The water zone behind the intermediate casing should be changed to a simple rock strata</u>.

Because industry best practices were omitted from the EPA study, none of the operational practices of industry or regulatory practices of state authorities are captured in this chapter. For example, after cementing, it is required that the mechanical integrity of the cement seal be pressure tested. These tests may be witnessed by the State and the test results must be reported in a timely manner. If the seal fails to hold the prescribed pressure, then the cement must be repaired before the next deeper section can be drilled.

The role of state regulations is mentioned briefly on page 6-8, lines 11-3, but the role of state regulations on wellbore construction/verification should be integrated more completely in the assessment report.

Top of cement is typically known by CBL and temperature logs although cement bond logs are not particularly for shallow cementing evaluation and will give a number of false positives. Again, operators typically follow well construction standards specified by the State. The specific geology of that state is well known to the State regulators and acceptable well designs within a state will vary widely to address the specific geology. The results from the Well File study are consistent with this for the most part. Wells that deviated from design standards did not appear to have been investigated in the statistical well review. That is also a limitation of the work, as there may be specific reasons for a waiver from well construction standards.

I feel that the discussion of flexible and self-healing cement could be strengthened. Additional references have been added at the end of these comments. Industry practices and technology is changing rapidly, particularly throughout the course of this EPA study. This should be noted.

The term 'over-pressured' well is used without defining what is meant by this. It would be helpful if this is defined. Does this mean a pressure beyond the design limits of the well construction or a naturally occurring higher pore pressure?

Operators design casing strings based on the 'mud weight window' between formation pore pressure and formation fracturing pressure. The use of an intermediate casing string is dictated by reaching a point where the mud weight, limited by the fracture gradient, becomes insufficient to contain pore pressure. Further correction may be necessary to insure wellbore stability in some formations. Near the point where an adjustment to fluid density will no longer maintain well control, a casing string is run and cemented. Deepwater wells and some deep land wells in high pressure formations may have many casing strings, due to the reduced overburden of the water. The way this assessment report reads it almost seems as if the use of the intermediate casing is discretionary. Again, mentioning design standards would be beneficial.

Fractures intersecting a producing or abandoned well are discussed in detail. There is significant discussion regarding 'frac hits' as evidence of the possibility of a fracture growing into another well, or another well's fracture network. Most operators place a frac plug in the other pad wells, or shut them in or load them with water while fracturing a new well. If a plug is used, the plug is positioned above the uppermost zone, to seal the wellbore and protect against 'frac hits'. In some fields offset operators routinely notify their operating neighbors about fracturing schedules. In low permeability, naturally fractured shale environments where well spacing is necessarily close, lateral fracture connections between wells are common and in some instances regional fractures may connect several wells in a field even before fracturing commences. These well-to-well

connections may persist where propped planar fractures dominate or may disappear in a few hours, days or weeks. These things are not even mentioned in the assessment report.

'Frac hits' really refer to lateral intersections, not intersections with significant height growth. This is stated once, but for the public this point should be emphasized so the reader doesn't confuse this with fracture height growth into a shallow well.

In general, the citations support the assessments noted in the chapter. But again, this is a large, complex topic making it challenging to cite all possible opinions.

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 hydraulic fracturing water cycle? 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?

Findings of the report are divided according to contamination pathways.

<u>Fluid Migration Pathways Within and Along the Production Well</u>

Evidence of fluid movement along the production well and into sources of drinking water is supported by the instance cited after hydraulic fracturing at Bainbridge, Ohio. This was due to poor cementing practices, and the authorities ascertained this was not related to hydraulic fracturing operations (see public comments from the Division of Oil and Gas Resources Management, Ohio Department of Natural Resources). Similarly a cementing failure at East Mamm Creek in Colorado was cited as causing fluids to move through a subsurface fault and into a nearby creek.

The assessment report has an extensive discussion of sustained casing pressure and suggests this may cause fluid movement into sources of drinking water. However there is no clear evidence of this. <u>This should be removed from the conclusions section as it is inconclusive. Sustained annular pressure is most commonly the result of seep-type leaks in the connections of the inner tubing and the build-up of pressure in the tubing-by-casing annulus is proof that the casing and cement of the outward casing strings are containing the pressure and the fluids. Well design relies on a nested group of casing and cement barriers. Actual leakage occurrence from a well is very low as demonstrated in a review of studies of 650,000 wells documented by King & King (Nov. 2013 – SPE Production Operations, Vol. 28, No. 04, pp323-344)</u>

The instance of casing and cement failure in Killdeer, Dunn County, ND presents the strongest case for impacts to drinking water sources when both the surface casing and cement failed during fracturing operations.

With the exception of the discussion of sustained casing pressure, the three cases presented do explain situations which allowed fracturing fluid to spill or contact a source of drinking water, due to well construction failures exacerbated by elevated injection pressures during hydraulic fracturing.

The assessment concludes that by finding a few examples, the potential for contamination exists. These are only three examples found in a population of over 850,000 US wells (0.00035% of wells) – that is a success rate of 99.99965%. One is hard pressed to find a better engineering success rate in any industry. Compared to the thousands of groundwater pollution incidents from the roughly one million Class V injection wells that EPA has permitted, the performance of fracturing is stellar. There will always be some failures in any industry. Technology is changing rapidly to address some of the problems noted. No failure rate data is cited and should be added to the work.

Fluid Migration Associated with Induced Fractures within Subsurface Formations

There are no case studies to support the simulations that model hydraulic fracture growth into subsurface faults that connect to sources of drinking water. All of the modeling indicates that fracture height growth is modest (~328 ft). Tracking and observations of fracturing in multiple Marcellus wells showed no growth out of zone. Even simulations emplacing a fracture between a water well and a producing well indicate the pressure gradients created during production would keep gas moving toward the producing well. All of the modeling tends to support that gas will not move into sources of drinking water from the pathways in this section of the assessment.

The one significant case study presented in the section is from Alberta Canada, when the fractures from a horizontal completion came within 423 feet of a vertical well at 6070 feet, presumably completed in the same zone. The increased pressure from the fractured well was transmitted through the formation (the fracture did not intersect the wellbore). This is difficult to realize from the description of the event and it would be helpful to better explain this. The increased pressure transmitted to the vertical well caused the surface equipment to fail. It was not stated if drinking water contamination occurred, and this should be clarified.

Most operators in the US conduct areal studies of existing wells prior to hydraulic fracturing operations to identify risks such as this. A personal review of this practice showed that many operators use the same area of review criteria used for Class II injection wells, before undertaking fracturing in a new well. Again, this assessment report makes no mention of such industry practices.

The summary findings include a section which discusses factors affecting frequency and severity of impacts. Notable factors include casing and cement quality, site geological and geomechanical characteristics, vertical separation between the production zone and drinking water resource. It is then suggested that findings of this chapter indicate an

increased opportunity for pathways to develop and impact drinking water resources. This is a statement with no supporting statistical evidence and the entire discussion should be removed from the conclusions.

There are no statistical occurrence information or probability findings in this study. This is important to convey this to the reader. A study on the probability of these events should be undertaken to quantify frequency and risk. George King provides rough estimates in the paper cited by this assessment yet there is no mention of those frequency numbers. His work is cited in Chapter 6, and it is suggested that EPA mention his assessment of failure frequency. (see attached Tech Notes from George King, posted with permission from George King).

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

The main assumptions are provided or can be found in the references.

The conclusions introduce a discussion regarding the lack of data to support this work. I felt that this should have been mentioned much earlier in the chapter, in addition to the end of the study. It is an important limitation.

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 hydraulic fracturing water cycle? Are there relevant literature or data sources that should be added in this section of the report?

The cement section should strengthen a discussion of flexible cement and the use of swellable packer material with cement (SPE 11062, "Swellable Packers for Well Fracturing and Stimulation") Another example paper is SPE/IADC 173065, "A Case Study of Flexible/Expandable and Self-Healing Cement for Ensuring Zonal Isolation in a Shallow, Hydraulically Fracture Gas Well, Onshore Thailand" (March 2015). IADC/SPE 112715 is a basic description of self-healing cement.

Industry practices and technology are moving rapidly. Well construction practices have been improved since the 2009-2010 well review, and some discussion should be devoted to this.

SPE 168642 presents a modeling of cement sheath integrity during hydraulic fracturing. This may be a useful reference in understanding the initiation of cracks in cement sheaths.

George King published a useful paper on plugged and abandoned wells and their environmental risk. Many fracture stimulated wells are near abandoned wells. It may be useful to review SPE 170949, 'Environmental Risk and Well Integrity of Plugged and Abandoned Wells", 2014.

Closing Remarks:

In general the chapter covers the topic well. It demonstrates the importance of well construction in the hydraulic fracturing process. However, the conclusions are vague and should be written with more specificity to reflect on the exact conclusions for each scenario. The way the findings read now, it appears to be a universal pronouncement that injection for hydraulic fracturing can/may/could cause harm to drinking water through any of the pathways. In particular the following paragraph might be quoted to support any legal condemnation of fracturing:

"Potential pathways for impacts on drinking water (i.e., the movement of hydrocarbons, formation brines, or other fracturing-related fluids into drinking water resources), may be linked to one or more components of the well and/or features of the subsurface system. If present, these potential pathways can, in combination with the high pressures under which fluids are injected and pressure changes within the subsurface, have an impact on drinking water resources." 6-51, lines 9 to 13

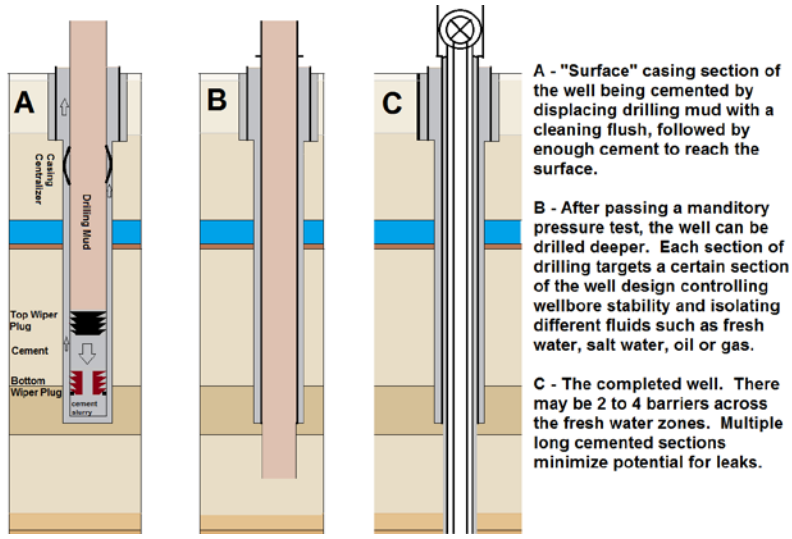
Modeling and microseismic data clearly show that frac height growth is limited (~ 328 ft) and fractures are unlikely to grow into overlying sources of drinking water. Limited frac growth/frac containment was supported by the monitored Marcellus fracture treatments. The report needs to make stronger statements when several scientific indicators give the same result.

From the work conducted in this EPA assessment, I feel we can safely state that computational modeling, microseisms, and active well monitoring indicates hydraulic fractures will not grow into overlying sources of drinking water. However, when separation between the two zones is small, then microseismic monitoring is suggested as precaution in the early development of an area.

The Basics of Wells - How is an Oil or Gas Well Built? (G. King)

Throughout the 150+ year history of oil and gas production, technologies used for well construction have changed enormously. In 1821, William Hart's first shale gas well near Fredonia New York, struck flowing gas at 28 ft. In 1859, Edwin Drake's first purpose-drilled oil well in near Titusville, Pennsylvania, reached an oil bearing sandstone layer at a depth of 69-1/2 feet. These wells, drilled and constructed with primitive tools, roughly a century before fracturing was invented, illustrate the near surface location of some gas and oil, which sometimes are found in the same zones as fresh water.

Oil and gas producing wells are built with steel pipe, cement, and other mechanical seals in a pipe-in-pipe design that puts several barriers between the producing fluids and earth or water sources outside the well. If a well's inside pipe barrier fails from a corrosion leak in the innermost tubing, the next steel and cement barrier will prevent leakage outside of the well. Modern well design uses more barriers at the surface and across protected water zones and fewer barriers toward the bottom of the well where oil and gas flow into the well. For a well to pollute, a leak must form and extend from inside the well to the outside environment, past all the steel and cement barriers, and the pressure inside the well must be higher than the pressure outside the well at the depth of the leak.



Construction of a well's barrier system begins during drilling as each section is drilled and each casing string of the well is put in place and cemented. The completed well is a system of interactive barriers formed by steel pipe and cement. The number of barrier sets is matched to the needs of isolation for a specific section of the well.

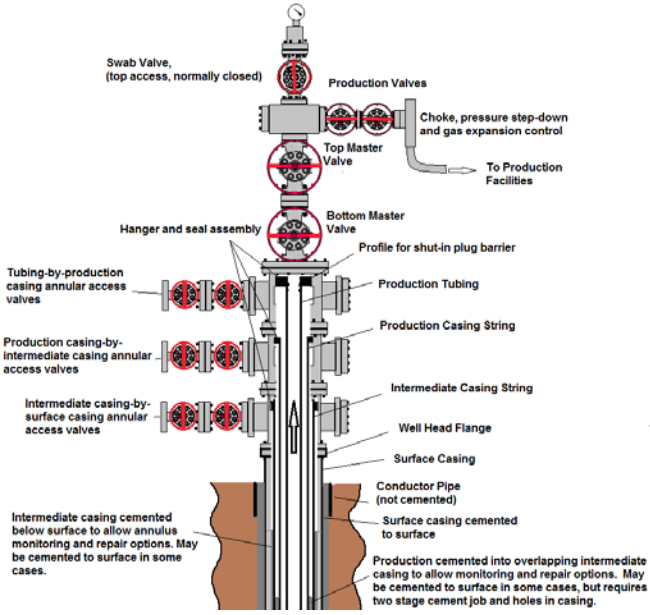
Cementing for Isolation

Once a section of a well has been drilled, a steel pipe (casing) is run to bottom and cement (powdered cement, mixed with water – no sand or gravel) is pumped down the casing to the bottom and then up around the area between the casing and the drilled hole, forming a strong bond with very high resistance to pressures and flow. Once the cement hardens (a few hours) it has similar strength and leak resistance to the rocks through which the hole was drilled. A required pressure test and other monitoring tests insure that the seal is in place and preventing leaks. The effectiveness of a cement seal depends on well design, which considers local engineering and chemical factors. Cement is as strong as the rock that has kept gas, oil and

saltwater isolated underground for millennia. There are many records of cemented wells that are still effectively sealed after 100 years.

Control at the Surface - The Well Head

The wellhead is the only part of a well that is visible in most cases and is the access point for further well operations such as production, treating and workovers to modify the well as pressures in the reservoir decline. After the deepest casing is set and cemented, the blowout preventer used during drilling is replaced by a set of valves that can be used for surface control and routing of pressure and produced fluids. The wellhead is an intricate control center using multiple valves and seals barriers to enable maximum control of fluids flowing from the formation. Wellheads and their control systems may be simple on low pressure wells or very complex on high pressure wells.



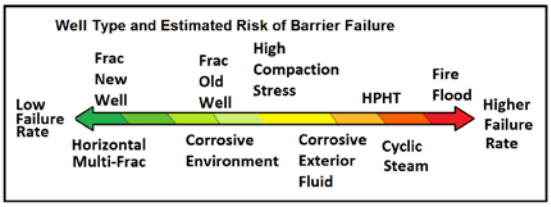
Well Integrity and Leak Potential

Data from studies of over 650,000 wells worldwide have been examined to give a clearer picture of the leak potential for wells and the difference between a single barrier failure that is contained by the next barrier without leaking and an isolation failure that results from failure of multiple barriers. Older era vertical well leak rates are about 0.02%, but the newer generation of horizontal wells have leak rates of less than 0.004% (4 detected leaks in a hundred thousand wells) and this leak rate continues to be reduced through improvements in design and cementing and an on-going goal is to locate and correct a single barrier failure before it becomes a leak.

The technology in practice at the time of well construction is a reflection of how well operators and regulators are doing their jobs in applying and checking for use of the best technologies. Early drilling methods, such as cable tools, allowed blowouts and old-time "gushers", a practice that is extinct in modern completions. Texas established cementing and abandonment rules in 1919, and over 15,000 "orphaned" wells have been identified and been plugged in 25 years by a state-run program funded by operator permitting fees.

Well Type may be one of the largest factors in well-to-well variances in well failures and risk. Wells that operate at the extremes of temperature, pressure, corrosion tolerance, high erosion potential or are in areas of tectonic induced movement or active subsidence will usually have shorter well life or more integrity problems than wells in less extreme or lower stress

environments. All wells require periodic maintenance to control production deposits such as scales, paraffins and asphaltenes or require corrosion protection or other issues.



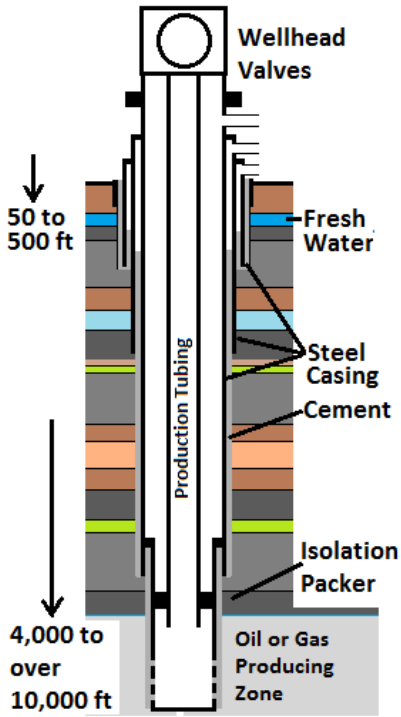
Disclosure: George E. King is a Texas Registered Professional Engineer with over 44 years oilfield experience. His technical background includes fracturing, workovers, chemicals, acidizing, well integrity and horizontal wells. www.GEKengineering.com

Basics of Wells – Cementing: How Effective is Cement in Creating Barriers? (G King).

During drilling, each section of a well is cased (a length of pipe is place to cover the well from surface to the bottom of a section) and liquid cement is pumped down the pipe and forced up the annulus between the outside of the pipe and the drilled hole wall. Within hours of placement, the cement sets or hardens into a stone-like seal between the pipe and the rock. Near the surface, where the wellbore penetrates a fresh water zone, the cement must pass a pressure test showing that it has sealed the annulus against leaks from the next phase of drilling. If the cement in a section of the well fails to pass testing requirements, the zone seal must be repaired and the pressure test passed before drilling of the next section can commence. Steel casing provides burst, collapse and tension strength and the cement provides the seal that isolates fluids and pressures. Cement on the outside of the casing string may come to the surface or to a lower level, depending on local regulations, requirements of the completion and the threat level of an isolation failure in the overall design. The isolation provided by cement and pipe depends on the quality of the cement, the pipe-to-cement bond and the cement-to-rock bond.

The vertical thickness of cement required in the annulus to form a seal to protect the environment and the well is surprisingly small. Field tests of high pressure gas wells, which are often the most difficult to effectively isolate, shows only 25 to 50 feet of high quality cement is needed to isolate zones that have over 6,000 psi differential pressure. Common practice in the industry is to use a cement sheath that comes completely to the surface for casing that covers groundwater sources, but deeper pipe and cement pairs may use a design for a partial open annulus that allows for improved monitoring and even possible repair if a leak is detected.

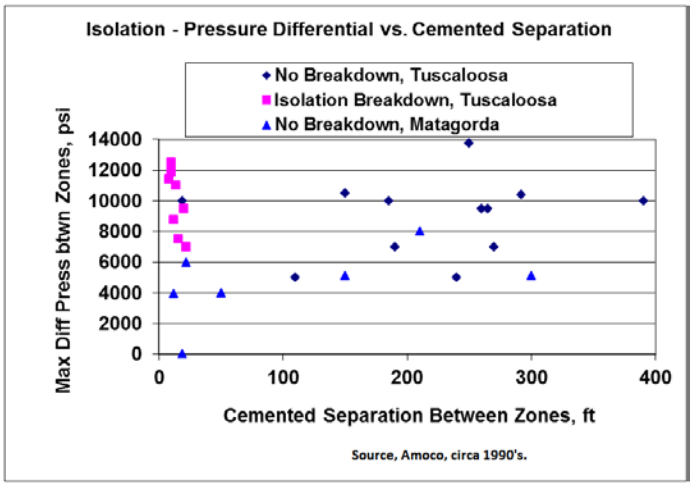
Cement does not need to be perfect over every foot of the cemented area, but at least part of the cement column must form a durable, dense and permanent seal sufficient to prevent fluids from moving behind the pipe. As a safety factor, Industry commonly uses from 200 to 600 ft of cement in overlap sections between pipe strings and above zones of widely different strength or pressure.



A US government study of subsurface water-injection operations in the Bakken area of North Dakota showed that the maximum quantifiable risk that water from water injection wells would reach an underground source of drinking water was seven chances in 1 million well-years where casing and cement adequately covered the drinking-water aquifers. Where surface casings and cement do not cover the USDW's, the probability is six chances in one-thousand well years (Michle, 1991). The 1000-to-1 improvement is a testimony to the efficiency of the cement seal in a well.

The question of how much cement to use in a well is often misunderstood. Regular cements, when mixed properly with water, have a slurry density of about 16 lb./gal., depending on cement type. This density translates into a vertical pressure application of roughly 0.83 psi for every vertical foot of cement slurry. When friction pressure from pumping is added, a full column of liquid cement may fracture formations along the drilled hole, damaging the rock and ruining the cement isolation attempt. For this reason, lower density cement or open annular spaces are often part of a deeper well design.

Cement Bond Logs (CBL), are often proposed as a need for every well, but these tools, while useful in early cement design or to help find problems, can give false readings, will miss small channels completely and are often difficult to run in a repeatable manner. A false reading by a CBL may cause a cement repair attempt where none is needed and repair operations may weaken the casing and leave a potential leak path where none existed before. For well rework and suspected changes in well integrity, other leak detection methods such as noise logs and borax logs offer more accurate determination of leaks than can be produced with a CBL.



With the exception of a pressure test, requiring cement evaluation on every cement job appears to be a questionable decision, with possible detrimental structural consequences.

Best indicators of quality cement job are pumping records showing:

- steady density mixing,
- displacement pressures and returns within expectations, and
- drilling mud displacement by cement in line with expectations of time and volume.

An experienced operator can often predict cement quality from these records alone.

There are several critical and other important steps prior-to, during and after a cement job. The table has these items in rough order.

Factor	Reason	Casing String Target
Pressures within operation limits	Cement density & equivalent circulating density must be less than fracture gradient for exposed zones.	All strings
Casing centralization	Hold casing off borehole wall. Solid body centralizers preferred. 70% standoff is customary.	All strings
Wellbore & annulus cleaning	Mud thinning, filter cake removal & dispersal, separation of mud from cement.	All strings
Pump Chart Monitoring	Keep cement density, pressure, returns within job design.	All strings
Two plug system	Separation of mud/cement/flush – no contamination	Where isolation is critical
Gas migration prevention	Prevents gas channels in the cement.	Any casing string across a gas charged formation.
Pipe Movement	Important, but difficult to achieve in horizontal well	Vertical, near surface pipe
Float shoe & collar	Insures strong uncontaminated cement around the bottom of the well.	All strings where isolation is critical.
Pressure Test	Important for construction info. Critical for isolation.	Vertical casing isolation across fresh water zones.

Disclosure: George E. King is a Texas Registered Professional Engineer with over 44 years oilfield experience. His technical background includes fracturing, workovers, chemicals, acidizing, well integrity and horizontal wells.

Comments from Dr. Katherine Bennett Ensor

As a non-expert, but often a collaborator in the area of fate and transport of chemicals in groundwater, I found chapter 6 one of the most difficult to read. At the same time I believe the issues addressed in chapter 6 are critically important. I do not have specific recommendations but rather a general recommendation. As I read this very detailed and expertly constructed discussion of potential fate and transport of hydraulic fracturing fluids and gases to drinking water resources I am struck by the lack of data or information available to make this assessment. It may be that this information is there in key references, but I do not find the material readily

available when I read the chapter. If the information truly does not exist, then serious effort must be taken to measure and quantify the impact now and in the future.

Further, while it is important to all that the necessary data is brought to bear on this important problem, I also wonder if there is an opportunity to glean more from the available data through inclusion of strong statistical expertise in modeling complex information flows with missing and irregularly observed data. I do not know of anyone taking on this challenge for hydraulic fracturing, however, I see a critical need to develop a community to do so. When individuals expertly trained in the science of statistics are included in complex problems, the solutions to those problems improve dramatically.

Comments from Mr. John V. Fontana

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?

> Yes – the report accurately describes the general state of the art of technology present well including variations with different types of oil and gas production (ex. Coal bed methane). However, the issue and science of stray gas migration and analysis is brought up in this section and needs a greater level of clarification. (see comments below)

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 hydraulic fracturing water cycle? 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?

> The report makes no attempt to quantify the relative number of impacts described in the literature. The report basically says that there is inadequate data to quantify the frequency or severity of impacts. However, the research did uncovered a limited number of impacts. There is also the Well File Review (Text Box 6.1, p. 6-6) that examine a number of well files statistically representing over 20,000 wells. This information should be used in the concluding sections to state the frequency of impacts found in the literature by the EPA relative to the number of wells that have been hydraulically fractured.
>
> Care needs to be taken to distinguish studies that presume impacts are from anthropogenic causes when natural causes (fault seepage) or historical events (old abandoned wells) could still be the cause of the symptoms and findings, such as in the mention of Darrah et al. (2014), on p. 6-19, lines 6-16. Many of the of the peer review cited papers like this one have great science in terms of identifying the source of migrated gases using sophisticated isotopic and compositional analysis, but then attempt to

eliminate natural pathways in their conclusions by using assumptions, and even though the statements sound sensible, they are not always scientifically justified.

Section 6.4.1.3 describes several cases of documented impacts, and clarifies that the cause may be inconclusive. Perhaps the frequency relative to the number of wells should be noted in here as well, even though some of these are not documented to have occurred from hydraulic fracturing activities.

Since stray gas is such a significant concern in the public's eye, I agree with comments at our panel meeting that this section more careful and detailed coverage. Published cases should be discussed and evaluated in greater detail to evaluate where conclusions correct or overreaching.

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

Page 6-2

Good job identifying complexity of identifying stray gas migration due to numerous potential natural and anthropogenic causes. This is the reason for not being able to easily quantify confirmed impacts from drilling/HF activities. This section admits there are many potential natural occurring or man-made routes and it is challenging to distinguish one from the other.

Pages 6-2, 6-16 to 6-19; STRAY GAS ISSUES:

Recommended expanding on the comment on Page 6-2 about the complexity of identifying stray gas migration due to numerous potential natural and anthropogenic causes. This is the reason for not being able to easily quantify confirmed impacts from drilling/HF activities. This section admits there are many potential naturally occurring or man-made routes and it is challenging to distinguish one from the other. This is truly the case with this topic.

Starting on page 6-16, (in 6.2.2.1 and Text Box 6-2), the reports states that new noble gas and hydrocarbon stable isotope data can be used to distinguish casing failure gas signatures from natural migration up faults, or unknown abandoned wells, et.. While they make a strong argument, all of these authors have had their results disputed because of conclusions of impacts that are partially based on the assumption of certain pathways without clear proof. In text box 6-2 on Stray Gas Migration, the EPA later states that even though the science of identifying the source of gases and alterations can be performed, the pathway for the contamination is not always clear, and this IS the common issue in interpretation that leads to many conflicts among the experts.

The report states that methane occurs naturally in many aquifers and discussed that methane from different sources (i.e., significantly different formations and/or depths) can often be distinguished isotopically or compositionally, but it should be clarified that the increase of just methane in a well is not a good indicator of a release from a well. The

best method for confirming cause and effect is the pre-drilling baseline sampling and post drilling sampling combined with these sophisticated isotope and analytical interpretation methods, and in a court of law, even this becomes challenging with the natural pathways.

BASELINE STUDIES

A section on examining existing practices or recommended procedures for baseline (before and after drilling) studies could be added. These exist in (ex. Colorado and Pennsylvania) in terms of required and/or recommended (minimum guidelines) programs, but should be tailored regionally for different geologic and reservoir conditions (ex., higher than typical NORMs.)

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 hydraulic fracturing water cycle? Are there relevant literature or data sources that should be added in this section of the report?

WELL INTEGRITY TESTING. In addition to cement bond logs, there is acoustic technology - **Spectral noise logging (SNL)** is used to listen to movement of gas and fluids behind the pipe and cement. This was mentioned as "ultra-sonic testing" in Appendix D, but not in the report (only bond logs mentioned). This can be an additional tool to help find the source of "casing gas seepage", or Braden Head gas, as it is also known. From Wikipedia:

Spectral noise logging (SNL) is an acoustic noise measuring technique used in oil and gas wells for well integrity analysis, identification of production and injection intervals and hydrodynamic characterization of the reservoir. SNL records acoustic noise generated by fluid or gas flow through the reservoir or leaks in downhole well components.

Noise logging tools have been used in the petroleum industry for several decades. As far back as 1955, an acoustic detector was proposed for use in well integrity analysis to identify casing holes.[14] Over many years, downhole noise logging tools proved effective in inflow and injectivity profiling of operating wells,[15][16] leak detection,[17][18] location of cross-flows behind casing,[19] and even in determining reservoir fluid compositions.[20] Robinson (1974) described how noise logging can be used to determine effective reservoir thickness.[21]

In the conclusions section (6.4.4) **t**here should be a better summary of the documented frequency of impacts relative to the number of wells drilled, rather than just saying "

*"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."*

Suggest EPA reviews and quantifies the number of cases, perhaps classified into categories of how the type of data was used (cited violations based simply on methane qty in well, site specific investigations using chemical composition, etc..) Some cases may need to be carefully considered and stated in separate groups, such as the Pennsylvania rule that cite a company for an increase in CH4 but must prove it's NOT from wellsite activities.

Public comments emphasized the issues with general statements such as lack systemic wide issues. These types of statements need to be better qualified and where at all possible, quantified.

FOR VARIABLE GAS CONCENTRATIONS IN WATER WELLS:

SEE - 2014, Brent Wilson, Geologic and baseline groundwater evidence for naturally occurring, shallowly sourced, thermogenic gas in northeastern Pennsylvania, AAPG Bulletin, v. 98, no. 2 (February 2014), pp. 373–394 (This paper documents geology that results in many water wells in NE PA that are impacted by naturally occurring coal bed methane in the aquifers above the Marcellus producing wells. The industry has been cited for exceedances of methane in water wells caused by draw down in the water well and unrelated to releases from O&G operations. These citations appear or may be counted as releases from drilling activities.)

Comments from Dr. Daniel J. Goode

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?

The report provides an excellent overview of factors affecting the relationship between hydraulic fracturing (HF) well injection and drinking water (DW) during the HF and gas-production phases of a HF well's life. The summary of actual experiences and occurrences related to well injection, and to fluid pathways to DW sources, is very useful.

Individual comments by members of this panel on EPA's 2012 Progress Report urged expansion of the Well Field Review to include more than 323 (about 1.4 percent) of the more than 24,000 Well Files submitted by operators, but this was not done. Furthermore (Text Box 6-1), "EPA did not attempt to independently and systematically verify data supplied by well operators." EPA missed an opportunity to peer-review, make more transparent, and improve the statistical representativeness of its analysis of this primary, original source of information about HF well injection and DW.

The clarity of the summary of available information is reduced by use of ambiguous and inconsistent terminology in several instances. Some examples:

- Well "communication" is a common word that is used in the oil and gas community in a specific and uncommon way, to refer to evidence of fluid pathways from a well to other wells, or to other permeable subsurface features. The wells 'communicate' because a pressure change in one changes the pressure in the other, due to fluid migration along permeable pathways. I recommend explaining what "well communication" means (fluid pathways from wells to permeable subsurface features, including other wells) in the report context by adding a footnote where it is first used in Chapter 6, on line 15 of page 6-2. Alternatively, "communication" could be replaced with more explicit, and less ambiguous, language such as "fluid pathways" or "fluid migration".
- Text on lines 29-32 of page 6-4 indicates that liners do not extend to the land surface, while casing does. Fig. 6-1 labels "7" as production casing, but it does not extend to land surface. Isn't a production "liner" actually the feature labeled "7", and not production "casing"?
- If there is no difference between "casings" and "strings" (e.g. lines 3 & 4 on p. 6-6), then only one term should be used. If they are different, then this difference should be explained, perhaps with a footnote.
- The Well Field Review (WFR) analyzed only the "spatial" relationship of DW to hydraulic fracturing (HF) wells (p. 22 of EPA, 2015o). This included geospatial analysis of distances between HF wells and streams, and comparison of depths of protected groundwater resources to well characteristics (p. 23 of EPA, 2015o). Insert "spatial" before "relationship" in line 12 of p. 6-6 to properly describe the limited extent of EPA's use of the WFR in its study on the relationship between HF well injection and DW.
- Text on line 8 p. 6-7 implies that a good cement seal is not needed across brackish water-bearing zones, regardless of their potential use as drinking water sources. From the choice of wording in the first (topic) sentence of the paragraph, the paragraph seems to be written as justification for non-continuous cement, rather than description of the importance of good cement seal across zones of drinking water resources. I recommend re-writing the paragraph to focus on the importance of good cement seals across DW and hydrocarbon-bearing zones. Noting that continuous cement is not necessarily required to protect DW can be included later in the paragraph. If "good cement seals" and "high-quality cement" are the same thing, then use of identical wording would be clearer.
- Chap. 6 uses both "hydraulic fracturing" (e.g. line 1 p. 6-1) and "hydraulic fracturing operations" (e.g. line 26 p. 6-1). It would be more consistent to delete "operations", which seems extraneous in nearly all uses.
- The single use of "spudded" in Chap. 6 (line 12 p. 6-23) could be changed to "drilled", for consistency.
- Terminology "communication problems" (line 33 p. 6-26) is ambiguous.
- Microseismic and microdeformation monitoring are powerful methods for "far-field" estimation of heights and lengths of fractures induced by HF. However, these methods are not direct "measurements" of those dimensions. I recommend that discussion of use of these methods to "measure" fracture dimensions include

"indirect" or "indirectly", or otherwise indicate that these methods provide "estimates" of induced fracture dimensions, albeit probably the best estimates currently available.

- Use of "wellbore swelling" (line 25 p. 6-14) to refer to an uncemented wellbore pathway closing due to formation swelling *into* the wellbore may be confusing to many readers. "Formation swelling" may be clearer.

The clarity of EPA's summary of well injection could be improved by use of clearer, more consistent, technically accurate wording throughout the study reports.

The report cites Vincent (2011) on line 32-34 p. 6-11 as noting "that the mechanical integrity of the well was a key factor in determining the success or failure of the fracturing." While the finding seems reasonable, I could not find any statement along these lines in the cited paper. One of the sources for Vincent's (2011) meta study, Paper 6361 by J. Greene (1976), *did* report that some re-fractured wells "had to be plugged and abandoned due to poor mechanical integrity" (as reported by Vincent, 2011). Otherwise, Vincent (2011) seems to focus more on using mechanical integrity as a pre-existing condition to be considered *before* re-fracturing (during "candidate selection"). As to concerns about "older wells", Vincent (2011) reports that "Gutor et al (2003) showed that well age is a poor criterion to select restimulation candidates, presuming the mechanical wellbore condition is acceptable." The citation of Vincent (2011) at this point in the report seems only marginally related to the topic of the section, or to factors associated with older wells, as far as I can tell.

A paragraph about case study results (starting on line 20 p. 6-17) does not cite the Northeast Pennsylvania case study report (EPA 2014i), but instead cites the Well File Review (EPA 2015o) on lines 27-28. The Well File Review does not contain information about methane sources detected in groundwater, which is the subject of the relevant sentence, so I suspect the correct citation is EPA (2014i). (Note that the citation date in the draft report of the NE-Pa case study report is (2014i), but the current edition of that case study report is dated May 2015 [http://www2.epa.gov/hfstudy/report-retrospective-case-study-northeastern-pennsylvania-pdf].)

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 hydraulic fracturing water cycle? 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??

The first sentence in section 6.4.1.2 lists "subsurface pathways for fluid migration", and the list includes "fractures . . ., intersections of fractures . . ., and fractures intersecting with faults . . .". However, the first item in the list is "flow of fluids out of the production zone into formations above and below it" which does not seem to fit as a "pathway".

Perhaps this first item is intended to represent a pathway via the *permeability of the matrix* of the production zone formation? This sentence should be re-worded for clarity.

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

The primary limitation of the study is appropriately identified as lack of data altogether, or lack of databases that allow analysis of the relationship between HF well injection and DW. EPA missed an opportunity to improve the availability of such data related to HF well injection by concentrated efforts to build databases of the "large amounts of operator-submitted data" (p. 6-56) at state agencies.

Almost no mention is made in the study of the long-term risks to DW associated with post-production HF wells. As noted in the report, many abandoned (non HF) oil and gas wells exist and some of these wells have been pathways for unintended migration of HF fluids and natural gas to DW sources. In the future, how will hundreds of thousands of abandoned HF wells affect DW sources over very long time scales? Although the actual HF treatment occurs over a very short duration, a key difference between HF wells and 'conventional' wells is that the HF treatment has altered, probably permanently, the fluid migration properties of the subsurface. The fact that production and overlying formations have 'trapped' or 'capped' the oil/gas resource does not mean that the HF-treated formations will continue to prevent fluid migration to DW sources.

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 hydraulic fracturing water cycle? Are there relevant literature or data sources that should be added in this section of the report?

The draft report states that "In order to more conclusively determine sources and migration pathways, . . . studies in which data are collected on well integrity and ground water methane concentrations both before and after hydraulic fracturing operations . . . would be needed." p. 6-18. Such 'prospective' studies were recommended by the SAB during its review of EPA's study plan, and were included in EPA's final study plan, but were not conducted. This remains a major deficiency of EPA's study.

EPA model studies evaluated the potential for subsurface fluid migration from HF wells during HF treatment (i.e. during fracture initiation) and during resource production (p. 6-28). However, migration potential was not modeled for the post-production period, after the HF well is closed or abandoned. In contrast to the reduction of pressure within the well during production, subsurface pressures rise after the flow of fluids to the surface is halted. This will alter the gradients in and around the production zone, including within fractures, and these gradients are a major factor in fluid migration. Long-term model simulations, constrained as much as possible using detailed monitoring data, should be conducted to evaluate the potential for fluid migration to DW sources after HF wells are abandoned.

Other Comments:

The Paper that Jim Saiers mentioned during the October 28-30, 2015 Panel meeting discussion regarding hydraulic fracturing and well bores is cited as follows:

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

Comments from Dr. Bruce D. Honeyman

a. This chapter appears to be a thorough review of oil and gas well injection operations but limited in its ability to conclude specifically about HF operations due to a lack of publically-available data.

b. Potential origins of contamination of drinking water form the 'injection' processes are well described. It is much more problematic to extend what is in many cases a qualitative assessment, based largely on non-HF well data sets, to frequency and severity for HF operations (essentially a risk calculations) but this, in my opinion, needs to be attempted. It's clear that a small fraction of wells leak to drinking water supplies but the severity question (potential impact) is not directly addressed.

c. Although thousands of wells are established for hydraulic fracturing each year, there is limited data specific to these types of operations. As a consequence, this section must rely on information from non-HF oil and gas wells to deduce the impact of HF on drinking water. Given this constraint, it would be helpful for the staff to provide a critical assessment of the relative risk of each of the injection process factors to the potential of impacting drinking water from wells. For example, what can we control (i.e., the extent of control-- cementing); what are the substantial unknowns?

d. Cementing operations are one of the crucial steps in maintaining well integrity. Presumably most cements were developed for traditional oil and gas operations. While it seems reasonable that HF fluids (e.g., acids) could degrade the integrity of cements, little information has been provided to suggest that HF operations have modified cements to the conditions of HF fluids. Is this any sort of issue?

Comments from Mr. Dean Malouta

With respect to Chapter 6, Charge Question #4: A) The description of available data and information is well documented. B) Further, conclusions drawn and inferences made as to potential issues arising from the well injection phase of hydraulic fracturing are reasonable and consistent with common observations. It is not clear from the chapter, nor from the summary of the data at the end of the chapter, that either the frequency or the severity have been adequately addressed, or dismissed as unable to assess such impact or severity. The anecdotal data, while

well described and very fully documented, is not statistical in nature, and therefore conclusions as to severity and true risk are difficult to assess. C) Perhaps the area most in need of additional assessment is the background and context needed to characterize the impact of the data as described. For example, the cited references are dated according to when they were written, but we cannot tell from the summaries the time period for which the incidents actually occurred. This may be significant in that there may have been certain practices (for example, uses of a particular chemical, a cementation practice, a well integrity testing policy, etc.) that may have been poorly executed or commonly done one way a decade or more ago, but which are no longer practiced, or even legally allowed today. One does not get that sense of possible temporal variation from the current draft. At a minimum, I would suggest adding the dates of occurrence from the collected data and from the literature review, so that such conclusions may be drawn or inferred. Possibly less variable, but unspecified in the writing, are any spatial variations in the adverse practices. For example, are all known occurrences identified in a single basin or state? This might be significant, as there may be unusually complex structural geology or an unusual geothermal gradient in an area, requiring additional diligence in that basin but which may be a far lesser risk or unheard of in others. Tom Spencer in comment number EPA-HQ-OA-2015-0245-0086, as well as many other commenters, mentions a desire to understand more about such spatial and temporal variations in these practices as well. Further clarification along these lines would be useful.

Overall, I commend the authors for a very thorough compilation of existing available data, and for their summaries and conclusions. The addition of a summary of temporal and spatial variations in the observations will go a long way to address many of the public's concerns.

Comments from Dr. Cass T. Miller

a. The assessment does a thorough and careful job of describing available information regarding well construction, injection, well integrity, and movement of hydraulic fracturing fluids and other materials in the subsurface. The key point here is available information, which is lacking from what is desirable. In general monitoring information of conditions before, during, and after fracking is not available. Well construction details and operational data is not available. An important aspect for potential contaminant risk is old and abandoned wells, which exist in large numbers, are not located, and in many cases have not been adequately plugged. This issue should be more carefully acknowledged and described as the environmental threat that it poses.

b. The major findings are supported to the extent possible by available information. The role of abandoned and old wells should be a major finding that is highlighted, since such wells occur commonly and are major factor in assessing and controlling risk to drinking waters.

c. The uncertainties are many, and these are acknowledged and detailed.

d. Significant gaps in knowledge exist. The report would be strengthened by outlining steps that could be taken in the spirit of the precautionary principle to prevent contaminant risks from fracking and yield the sorts of data currently missing from the record to allow a more mature understanding of risks to drinking water resources.

Comments from Dr. Laura J. Pyrak-Nolte

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?

This chapter underplays the interaction of induced fractures with natural pre-existing fractures/fracture networks in the subsurface. The existence of natural fractures/fracture networks affects the extent and orientation of hydraulically induced fractures (e.g. references 1-4) and affects whether an induced fracture will or will not link and/or reopen fractures/faults. For example, on page 6-30 lines 1-11, mentions many properties and processes that affect fracture creation but do not explicitly mention pre-existing fractures.

The role of pre-existing fracture fractures and formation irregularity on the integrity of cement bonds is not discussed. While poor cement implacement is mentioned, it is never defined. Debonding can occur form cement heterogeneity, cement contamination, and complex formation surfaces/composition (especially under hydraulic fracturing pressure conditions and even at low pressures, e.g. reference 5) which can drive fractures in an annulus around the casing as well as longitudinally and transversely. A short summary of geomechanical and geochemical compatibility of cement with a formation is needed to summarize fully cement integrity.

In Chapter 6, the phrases "induced fractures or other features within subsurface formations" or "other geologic features" is too vague and needs to be expanded. The phrase tends to masks the importance of pre-exisitng fractures, fracture networks, planes/zones of weakness and faults along which fluids can move. This occurs throughout this chapter.

In Figure 6.1, the locations of the cement in heal and along the horizontal portion of the borehole need to be labeled.

It is not clear why a reference to the Gulf of Mexico is used in a discussion about well integrity and protecting drinking water (page 6-7 lines 6-9 to page 6-8 line 1-2) or the definition of "high quality cement".

On page 6-15 lines 2-3, the statement "Some of the oil and gas wells with shallow surface casing had elevated gas pressures in their annuli" needs an explanation as to whether this implies a leak or containment.

On page 6-16 lines 38-39, the statement on glacial history needs an explanation.

On page 6-19 lines 14-16, what did Heilweil (2014) find? All this sentences states is that a techniques was used….but not what it found or why it is important.

On page 6-23 line 12, "spudded"?

On page 6-30 in footnote 2, Young's Modulus is not the ratio of stress to strain. Young's Modulus is a constant of proportionality that defines the relationship between an applied stress and the resulting strain.

On page 6-34 lines 12-22, No mention is made why TDS is important, what a good value of TDS is or if before and after comparisons were made. Otherwise, one cannot judge the significance of this information.

On page 6-35 lines 1-9, in the discussion of flow of fluids out of the production zone, one potential pathway is "through the formation matrix". Does this include pre-existing fractures? Based on the other sections, it does not. The role of pre-existing fractures, fracture networks and other mechanical discontinuities is not adequately addressed in terms of the movement of fluids and geomechanical interactions with the induced fractures.

On page 6-48 line 28: A reference is made to Figure 6.4. But Figure 6.4 does not illustrate what is stated in the text.

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 hydraulic fracturing water cycle? 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?

This is the major finding of the Chapter: "Potential pathways for impacts on drinking water (i.e., the movement of hydrocarbons, formation brines, or other fracturing-related fluids into drinking water resources), may be linked to one or more components of the well and/or features of the subsurface system. If present, these potential pathways can, in combination with the high pressures under which fluids are injected and pressure changes within the subsurface, have an impact on drinking water resources."

The fact that 50-80% of the injected fluid is currently unaccounted for during flowback needs to be highlighted in the introductory paragraph above.

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

The discussion of robustness of the cement bond logs cannot be judged without mentioning the frequency of the acoustic signal and the spacing the measurements. Are the measurements made every millimeter over the entire borehole surface? Are the measurements affected by rock anisotropy?

Definition of "old wells" is used rather loosely and a clear definition is not given. From the report, an "old "well" can be anything over 1 year. How is this determined? Is "time" really the correct way to characterize a less than new well? Shouldn't there be measurements of degradation (e.g., cement bond log)? For example, on page 6-25 lines 13-14, "…becomes worse as a well ages" is this aging because of high usage (cyclic pressures) or the passage of time?

On page 6-31 line 17, an average value for 2-3 well diameters for a typical well for hydraulic fracturing is needed. As the dimensions of a well are not given in this chapter and the figures are not drawn to scale, this might be misleading to the public.

The uncertainty in the interpretation of micro-seismic event interpretation and the interpretation of fracture height/extent is not given.

On page 6-38 lines 18-26: It states that "in 3 out of 6 wells, fractures extending…", Where the actual fractures detected or was it just a cloud of microseismic events?

Text Box 6-3: The fracture heights are needed.

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 hydraulic fracturing water cycle? Are there relevant literature or data sources that should be added in this section of the report?

A very large gap in the report is the lack of adequate discussion on the non-recovered fluids. Where do the fluids go? It is hard to believe that 50%-80% of the injected fluid is trapped through capillary processes in the shale matrix or trapped on clay surfaces (see page 6-35 –lines 10-19 are not very clear). If it was adsorption onto clay minerals, swelling would occur causing a volume change in the rock…which for 750,000 to 1.2 million gallons of water would be significant. Others have suggested that the capillary trapping happens in the induced fractures (e.g. 6-7). I think this is a source of great uncertainty in the potential impact of fracturing fluids on drinking water because it is an "unknown". The impact of this "unknown" could be significant and needs to be clearly stated. What if any role do pre-existing fracture networks play this loss of fluid. While several paragraphs are given to buoyancy and pressure gradient effects, those discussions once again neglect pre-existing fracture networks/ faults.

Note: on pages 6-35 lines 20-31 to page 6-36 lines 1-4: 2-3 sentences are repeated as you go between these pages.

References

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

3. Zoback, M.D, Rummel, F., Jung, R. and C.B. Raleigh, Laboratory hydraulic fracturing experiments in intact and pre-fractured rock, International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts, volume 14, issue 2, March 1977, pages 49-58.

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

5. Wang, W. and A. Dahi Taleghani, Cement sheath integrity during hydraulic fracturing; An integrated modeling approach, SPE-168642-MS, SPE Hydraulic Fracturing Technology Conference, 4-6 February, The Woodlands, Texas, USA. 2014.

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

7. Parmar, J., Dehghanpour, H. and E. Kuru, Displacement of water by gas in propped fractures: Combined effects of gravity, surface tension, and wettability, Journal of Unconventional Oil and Gas Resources, Volume 5, March 2014, pages 10-21.

Comments from Dr. Joseph N. Ryan

p. 6-1, lines 5-6: "The fractures, which typically extend hundreds of feet laterally from the well…" The fractures do not extend laterally only. From microseismic monitoring, it is know that fractures extend vertically from the well also.

p. 6-1, lines 13-15: "…problems with the well's components or improperly sited, designed, or executed hydraulic fracturing operations (or combinations of these) could lead to adverse effects on drinking water resources." These problems not only "could lead to adverse effects;" such problems have led to adverse effects. Likewise, p. 6-2, lines 1-2, "…inadequate construction or degradation of the casing or cement can allow fluid movement that can change the quality of drinking water resources;" such problems *have* changed the quality of drinking water resources.

p. 6-2: Another pathway for fluid movement pathway not mentioned is along or through active or inactive wells tapping nearby formations. Substantial effort is put into preventing movement of fracturing fluids along these flow paths, but such movement has been documented in at least a couple of cases. An aspect of this is covered in the third bullet of the following "induced fractures" flowpath (p. 6-2, lines 22-24), but a scenario could be readily envisioned by which fluid movement occurs via other wells without the need for fractures.

p. 6-3, lines 9-11: "We do not attempt to predict which of these pathways is most likely to occur or to lead to a drinking water impact, or the magnitude of an impact that might occur as a result of migration via any single pathway, unless the information is available and documented based on collected data." We need these predictions, these assessments of potential risks of the various flow paths. If we rely on collected data, we can only assess the likelihood of drinking water impacts that have already occurred and been detected. But tying drinking water impacts to oil and gas development is obviously challenging, and groundwater moves slowly, so impacts may have not yet occurred. We need predictions of what could happen.

p. 6-6, lines 4-7: "All of the production wells used in hydraulic fracturing operations in the Well File Review had surface casing, while approximately 39% of the wells (an estimated 9,100 wells) had intermediate casing, and 94% (an estimated 21,900 wells) had production casing." This explanation should specify the well condition if the intermediate or production casing is absent – presumably, the borehole is open under those conditions. Also, it should be emphasized that this well construction status pertains to 323 wells that were hydraulically fractured in 2009 and 2010 – there is no assessment of well construction before or after this relatively short time period. An assessment of changes in well construction over time should be provided.

p. 6-6, lines 32-35: "Casing strength can be increased by using high-strength alloys or by increasing the thickness of the casing. In addition, the casing must be resistant to corrosion from contact with the formations and any fluids that might be transported through the casing, including hydraulic fracturing fluids, brines, and oil or gas." These statements describe what *can* and *must* be done, but these statements do not describe what *was* done. Where casings of greater thickness or stronger alloys used? Did casings resist corrosion?

p. 6-8, lines 3-4: "Most wells have cement behind the surface casing, which is a key barrier to contamination of drinking water resources." Did a lack of cement behind the surface casing lead to groundwater contamination? Is there any greater incidence of groundwater contamination in the 7% of wells that were not fully cemented?

p. 6-13, lines 5-6: "High pressures associated with hydraulic fracturing operations can damage the casing and lead to fluid movement that can change the quality of drinking water resources." This statement is an example of numerous statements about what *can* occur. To state that something can occur, the EPA must have evidence that it has occurred, but that standard has not been met for many of these statements. This statement, for example – no evidence is provided that hydraulic fracturing has damaged casing and led to fluid movement, presumably out of the

well and into an adjoining aquifer. The EPA can speculate that this is possible, and then move on to assess the probability, but the EPA should not state that such things *can* occur.

Comments from Dr. Azra N. Tutuncu

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?

The EPA researchers have accomplished preparing a highly comprehensive chapter covering complicated operational challenges for well construction, well integrity and well injection. The movement of the fluids hydraulic fracturing as well as other formation fluids was clearly described. The researchers have used valuable data provided by operators and case studies complimenting the technical concepts discussed.

While natural fractures and induced fractures were mentioned separately to indicate their importance in the fluid movement, the presence of natural fractures and their heterogeneity and distributions were not discussed in detail. Adding a section specifically discussing the role of natural fractures in permeability and how hydraulic fracturing process may enable to link these existing fractures in addition to creating new fractures that will have significant impact on how the fluid movement will take place in the formation through porous media and if these fluids can create a potential harm to aquifers.

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 hydraulic fracturing water cycle? 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?

Yes, the prepared section is well designed and covers very detailed version of well injection issues from many different perspectives using examples, data and literature reported case studies. The major findings identified many potential impacts of the overall injection operations on drinking water resources, not necessarily hydraulic fracturing fluid impact as stated in this question as well as in the report. Please see my note below on the Injection well types for better description of the all injection operations. The factors affecting the frequency covered relatively well. However, the severity of the impacts are not described with the same precision.

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

Yes, the EPA researchers were very keen on explaining that the data used are not checked for QAC by them since it was very difficult to obtain any data from industry, there were

high limitations and the data provided to them were used without QC. There are many uncertainties in the assumptions used in the models as well as in the data. It was clearly noted by the scientists preparing the report.

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 hydraulic fracturing water cycle? Are there relevant literature or data sources that should be added in this section of the report?

The topic "Well Injection" goes beyond the hydraulic fracturing operations, it also includes Enhanced Oil Recovery and Waste Disposal operations that contains all Underground Injection Control (UIC) wells that is well covered under Underground Injection Control Program (http://water.epa.gov/type/groundwater/uic/) in EPA website.

- Industrial and Municipal Waste Disposal Wells (Class I)
- Oil and Gas Related Wells (Class II)
- Mining Wells (Class III)
- Shallow Hazardous and Radioactive Injection Wells (Class IV)
- Shallow Non-Hazardous Injection Wells (Class V)
- Geologic Sequestration Wells (Class VI).

Waste Disposal wells (Class I) are particularly critical to include in this report as the injection rates and volumes are significantly higher than the hydraulic fracturing operations and unlike fracturing that is completed in 1-2 day timeframe and typically closely monitored using pressure, microseismic, sometimes surface microseismic in addition to in-well microseismic to determine if any undesirable incident will take place during the operations. The waste disposal injections, on the other hand, continue for many years and currently there are over 190,000 disposal wells in the US (See Figure on "Active and Associated Class II Injection wells in Central and Easter United States" in Weingarten et al., 2015 for a close look at the distribution of the disposal wells). The Figure notes that there are almost 189,000 disposal wells just in the Central and Easter US. The yellow well locations in the figure indicate the wells less than 15 Km to an occurred earthquake.

Weingarten M., Ge S., Godt J., Bekins B.A. and Rubinstein J.L. 2015. High-rate injection is associated with the increase in U.S. mid-continent seismicity. Science, V. 348. Issue 6236. 1336-1339.

Similar to the all oil and gas well operations, operators are required to report to the State Inspection agencies (like Texas Rail Road Commission in Texas or Colorado oil and Gas Conservation Commission in Colorado) monthly average injection rates, total monthly volumes, and maximum wellhead injection pressures for these wells in order to assure that the injection rates and pressures are consistent with amounts specified in the agency's injection/disposal permit. If a significant pressure change takes place and a leak is determined, the operator is required to notify the State Agency in 24 hours. Depending on the severity, the state regulatory agency may require well to be shut in and repaired. The oil and gas well hydraulic fracturing operations are closely monitored with further additional

monitoring techniques such as microseismic, seismic, logging, cement bond logs,…and continued to be monitored with Mechanical Integrity Tests (MIT) for their integrity for lifecycle duration.

This is a quote stating the difference between Injection and Disposal wells in Texas Rail Road Commission Website:

(http://www.rrc.state.tx.us/about-us/resource-center/faqs/oil-gas-faqs/faq-injection-and-disposal-wells/):

"What is the difference between a disposal well and an injection well?

Disposal wells may be used to inject mineralized water produced with oil and gas into underground zones for the purpose of safely and efficiently disposing of the fluid. Typically, the underground interval is one that is not productive of oil and gas. In some cases, however, the disposal interval is a productive zone from which oil or natural gas has been produced or is currently produced. In either case, the disposal interval must be sealed above and below by unbroken, impermeable rock layers.

Injection wells inject fluids into a reservoir for the purpose of enhanced oil recovery from the reservoir. The vast majority of wells in Texas are injection wells. Operators use injection wells to increase or maintain pressure in an oil field that has been depleted by oil production and also to displace or sweep more oil toward producing wells. This type of secondary recovery is sometimes referred to as waterflooding.

Texas is the nation's number one oil and gas producer with more than 315,618 active oil and gas wells statewide according to oil and gas well proration schedules (as of June 30, 2015). Injection and disposal wells are also located throughout the state to improve oil and gas recovery and to safely dispose of the produced water and hydraulic fracturing flowback fluid from oil and gas wells. Texas has more than 54,700 permitted oil and gas injection and disposal wells with approximately 34,200 currently active as of July 2015. Of these 34,200 active injection and disposal wells, about 8,100 are wells that are used for disposal, the remainder (about 26,100) are injection wells.

SOURCE: Distribution of Wells Monitored by the Railroad Commission, updated August 29, 2014 and online Oil and Gas Data Query-Injection/ Disposal Permit Query.

Operators are required to follow the Railroad Commission of Texas (Commission) disposal regulations administered by the agency's Technical Permitting Section - Underground Injection Control (UIC) Program. Underground Injection Control is a program that is federally delegated by the U.S. Environmental Protection Agency (EPA) to Texas, and it follows national guidelines under the federal Safe Drinking Water Act for surface and groundwater protection. EPA awarded the Commission primary enforcement responsibility over oil and gas injection and disposal wells on April 23, 1982. "

Introducing different types of injection wells, not limiting the reader to hydraulic fracturing related well injection will be beneficial providing transparency to all operations requiring well injection.

Adding a section on natural fractures and hydraulic fracture interactions and their impact on the changes in the Stimulated Reservoir Volumes (SRV) as well as the strength and mechanical properties of formations being fractured, their overburden and underburden formations and the in situ stress state and fluid pressures in these formations will be other important factors that can be described better.

The ground water depth variation in the US (see the Figure below obtained from USGS) will also make a difference how the well design needs to be made to protect further the drinking water resources. An identical well design should not be implemented using only surface, intermediate and production casing at everywhere in the US since the formation characteristics in the reservoirs and aquifers and overburden layers are different.

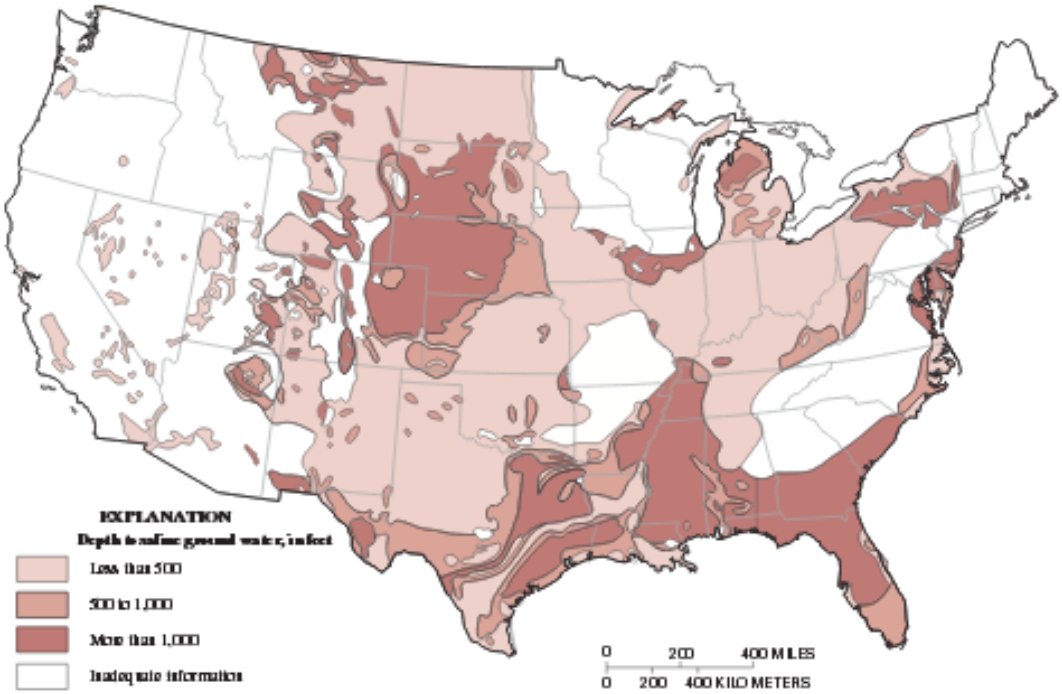


Figure is from USGS report in desalinization of ground water (http://pubs.usgs.gov/fs/fs075-03/pdf/AlleyFS.pdf)

Comments from Dr. Paul K. Westerhoff

Clear evidence is provided that hydraulic fracturing can impact drinking water supplies. The assessment lacks at least four critical aspects:

1. A comprehensive list of chemicals (Table 5-1 and others) is presented, however some of these are used as high molecular weight polymers, yet only the monomer is reported. Notation of which are polymers and representative molecular weights should be added.

2. What is the lifetime of the casings, and what decommission processes are in place to prevent impacts to drinking water aquifers? This is important, because the number of issues (e.g., sustained casing pressures as indicators of risk) increased to nearly 50% for wells over 15 years old.

3. What techniques are used, other than pressure tests, to assess casing integrity before fracturing, after fracturing or long after initial fracturing? Specifically in the vertical shaft section of the wells that pass through drinking water aquifers? For example, various x-ray systems or UAV systems are used to inspect concrete pipelines for structural integrity in other applications.

4. Methane or other gas isotopic tracing appears to emerge as a good monitoring tool. Page 6-56 identifies this as a research need. More specifically, based upon modeling or spatial impacts of horizontal wells, what radial distance (zone of influence) should be considered as potentially impacted? Should pre-drilling samples be collected for analysis from homes? What type of sampling frequency and duration before drilling is needed to provide baseline information on isotopic tracing to provide a high level of confidence that if gases are detected years after drilling that they could be associated with the well rather than other natural background variations?

5. A reduction in PA DEP violations from 52% in 2008 to 20% in 2011 is good, but 20% remains a high level. What are the best practices that have reduced these numbers of violations? What new regulations or practices exist around the country that could reduce the number of violations even lower?

Charge Question 5: Flowback and Produced Water Step in the Hydraulic Fracturing Water Cycle

The fourth stage in the hydraulic fracturing water cycle 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 hydraulic fracturing water cycle? 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 hydraulic fracturing water cycle? Are there relevant literature or data sources that should be added in this section of the report?

Comments from Dr. Stephen W. Almond

A nice job was done in setting up the definitions of the terms "flowback" and "produced" water to help differentiate between each one as it relates to overall well flow. This is very important as in fact, there are many times more releases of "produced" water in the overall timeline of the establishment and operation of a single well and an entire field or basin. It would be nice to see a statistical comparison between the number of leaks, spills, etc between the very short time period where actually "flowback" water is a component of the "produced" water and the life of the well for the produced water and other well production components (i.e., oil and gas). In many of the sections describing the nature and type of spills/released in Chapter 7, the examples site the inability to identify the interface between flowback and produced water raised doubt between the effect of flowback or produced water. The fact is that the time for spills, leaks and releases involving flowback fluid is very small compared to the time and volume of spills, leaks and releases for produced fluids and I don't think this perspective is brought out in the report.

One of the things that stood out in this study was the seeming focus on unconventional wells. In relation to the number of wells drilled in the US, what is the percent of unconventional compared to the number of conventional wells? The unconventional wells have definitely caught more attention in not only this report but in the public's eyes. The fear is this report seems to have

responded more to the public's voice to focus on unconventional wells than the true nature and distribution of all conventional and unconventional wells fractured in the US.

The identification of the sources for flowback and produced water spills, leaks, releases, etc are nicely identified and described in Chapter 7. Dividing the types of spills and leaks into sections makes it very easy to see the cause and effect relationships of each type. It would be helpful to see these types of release events summed up in each section to show the actual probability statistics. There are a number of local statistics from specific studies but it would be nice to summarize these in the conclusion Section 7.8.4. For example, there were X number of wells drilling the US, Y number of these well fractured in the US and is there a statistical difference between the number of releases between those fractured and those unfractured for a specific time period? That is, is there a statistical difference between the two types of well completions?

In the conclusion section, it would be nice to see mention of the areas of improvement which could help to reduce the number of actual spills, leaks, releases, etc. For example, it appears there are a number of leaks which could be addressed by closer regulation of the construction practices for containment areas (Page 7-35, line 29) and for monitoring the condition of production flow lines and other fluid transport lines.

Comments from Dr. Elizabeth W. Boyer

Relevant new reference: The Depths of Hydraulic Fracturing and Accompanying Water Use

Across the United States. RB Jackson, ER Lowry, A Pickle, M Kang, D DiGiulio, and K Zhao. Environmental Science & Technology; 2015, 49, 8969−8976. DOI: 10.1021/acs.est.5b01228.

Comments from Dr. Susan L. Brantley

This chapter 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 p. 7-30. In this regard, the chapter does a very good job answering the question, "*What is the composition of HF flowback and produced water, and what factors might influence this composition*?" However, it is odd that only 16 pages of the chapter are devoted to analysis and discussion of impacts, modes of impacts, and analysis of these data. My major negative criticism is therefore that the authors did not adequately synthesize the implications of the data in order to emphasize what is important and answer the question, *Are the factors affecting the frequency or severity of any impacts described to the extent possible and fully supported?*. I fear that there is a lot of information here but very little attempt to show or emphasize what is really important. Detailed comments from large to small are listed below.

1. The encyclopedia part of the chapter is very thorough and to my eyes, accurate. One quibble is that the report emphasizes the idea from Blauch et al. (2009) that brine salts in

produced waters derives from dissolution of halite and other evaporate salts in the target shale. I think this has largely been discredited: in some places in some fields there may be subsurface halite that interacts with fluids, but at least in the Marcellus I believe that most people think that the salts are largely derived from brines in the formation itself. We wrote a paper that described a mass balance calculation on the brine salt for wells in Marcellus showing a proof of concept for how the salt enters the return water and why it changes with time *(Balashov, V.N., Engelder, T., Gu, X., Fantle, M.S., Brantley, S.L., 2015. A model describing flowback chemistry changes with time after Marcellus Shale hydraulic fracturing. AAPG Bulletin, 99(1), 143-154, doi: 110.1306/06041413119).* It is clear to me (and I think to many others) that there is enough brine in the Marcellus to explain salt we see on the surface. I believe, from leaching studies, that there is even a small amount of brine in Marcellus rocks that are sampled at the surface. The Balashov paper could also be cited on p 7-7, Section 7.3, 7.4.1, lines 3-16 in p 7-26; p 7-26.. Furthermore, the list of causes of increasing solutes are not exhaustive on lines 25, 26 p 7-16 because, as Balashov et al. argue, the increasing salts could be attributed to transport of brine from small pores in the shale into the fractures.

2. One of the public's major worries is transport of fluid from subsurface to groundwater or surface water. The chapter hardly mentions connections between the subsurface and surface with respect to waste water: this is one potential pathway for contamination and the chapter does not assess it. *I believe this chapter could discuss natural brines and what is known about them and how this relates to the potential for contamination by wastewaters (how did natural brines get to the surface?).* For example, of the 161 positive determination letters in PA between 2008 and 2012 that we assessed where the state could not eliminate oil and gas activity as a possible cause, 23 cases reported contamination by brine salts (*Brantley, S.L., Yoxtheimer, D., Arjmand, S., Grieve, P., Vidic, R., Pollak, J., Llewellyn, G.T., Abad, J., Simon, C., 2014. Water resource impacts during unconventional shale gas development: The Pennsylvania experience. International Journal of Coal Geology, 126, 140-156, dx.doi.org/110.1016/j.coal.2013.1012.1017.*) As far as I know, it has not been determined where these salts came from. Furthermore, one well sampled and reported by Boyer et al. (*Boyer, E.W., Swistock, B.R., Clark, J., Madden, M., Rizzo, D.E., 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*) reported contamination with brine for a short period of time. These brine contaminants probably come from shallow brine in the subsurface but this shallow brine was not discussed in the chapter at all. Do these shallow brines imply transport upward from depth?

3. The report does not do an adequate job of emphasizing the importance of heterogeneities in the subsurface: joints, fractures, bedding, lithologic contrasts, etc.: see, for example, p 7-40 where the authors emphasize distance from the spill to the receptor. Sometimes, if a spill is into a fractured reservoir, the movement of the spill could occur over quite long

distances. I believe that this chapter needs to emphasize the importance of heterogeneities in the subsurface. Another example: The API modelling which is discussed is disingenuous because it did not include any heterogeneities. This is very unrealistic because preferential flow paths are generally very important. Heterogeneities should again be mentioned on lines 30-32 on p 7-42. Furthermore, the report appropriately emphasizes large volume spills of long duration but the report also needs to mention that small volume spills into specific types of areas (e.g. ridgetops with joints that interconnect in subsurface) could also be important because contaminants could travel easily into DW resources *(Llewellyn, G., Dorman, F.L., Westland, J.L., Yoxtheimer, D., Grieve, P., Sowers, T., Humston-Flumer, E., Brantley, S.L., 2015. A drinking water contamination incident attributed to Marcellus Shale gas development. Proceedings of the National Academy of Sciences, 112(20), 6325-6330.*). Another example: P 7-48…impacts to DW systems depend on proximity. This is not necessarily true because of the heterogeneities in the subsurface. This idea must be made abundantly clear.

4. Section 7.4.5: probably should cite Llewellyn et al., 2015. Llewellyn et al. argue that a better approach will be to look for suites of organic compounds that provide fingerprints as patterns, rather than to search of individual compounds? Identifying individual compounds may be too difficult. Llewellyn et al. should also be cited on p 7-45. *Llewellyn, G., Dorman, F.L., Westland, J.L., Yoxtheimer, D., Grieve, P., Sowers, T., Humston-Flumer, E., Brantley, S.L., 2015. A drinking water contamination incident attributed to Marcellus Shale gas development. Proceedings of the National Academy of Sciences, 112(20), 6325-6330.* Furthermore, analysis of flowback for organic compounds should be completed, but will it really help us answer the question of impacts on DW? I think not. The easiest way to see an impact of PW would be to analyze for salts. Therefore: why highlight data gaps about organics in PW in the context of this chapter, unless the chapter also points out that such analysis is extraordinarily hard and may not solve many problems in the long run? Do these ideas lead to the need for use of tracers?

5. Is it true that the fewest number of spills are due to blowouts/wellheads (p 7-33) but they cause the biggest impacts? This seems important to mention explicitly. For example, could something like this be put in the summary: The category of spill that was least likely was that of blowouts; however, this category tended to release the largest volume of contaminating fluids into the environment.

6. I think that impoundments have not been well summarized here. The report points to USGS studies (at the end, p 7-44) but are these cited (I don't see the USGS studies called out explicitly as such in 7.7.2.3)? Unlined impoundments are clearly a problem in PA and somehow this does not come through in the report. An impoundment example is given on p 7-42: impoundments are mentioned in the report, but they are not emphasized appropriately.

7. The steps needed in a study of an impact, p 7-35 and -36, make it explicitly clear how hard it is to figure out what happened and what was to blame. I believe this idea should

be emphasized as a major finding: attribution of the cause of contamination is very very difficult AND data are hard to come by for such attribution AND contamination in subsurface can be very hard to clean up. Given all these characteristics -- what does this mean about our evaluation of impacts or how to proceed? For example, does it have implications for the use of tracers during drilling or fracking?

8. The report does not do an adequate job of mentioning, reviewing, or dealing with microbial processes. In particular, fate and transport of contaminants will be very dependent on microbial reactions, especially for organic contaminants. For example, microbial processes should be mentioned along with adsorption, absorption, and precipitation on line 26 of p 7-42.

9. Text Box 7-1 seems to be the part of the report that has findings. This should be made more clear – that this is where the findings are summarized for this chapter -- and the general formatting of findings should be made more consistent throughout the report from chapter to chapter.

10. The first finding is that spills have happened and have affected drinking water resources. The EPA should put more detail into this finding: how many reports have been identified over what period or what region? The report should also probably emphasize container failures as the biggest source of contaminants when considered on a volume basis. Could the EPA write a sentence such as "To lessen the rate of spills of waste waters, xxx needs attention; to lessen the severity of the largest volume events, xxx needs attention".

11. The report makes several statements that are so general as to be almost unhelpful: for example… "Conclusive determination of impacts to water resources depends on commitment of resources to the implementation of sampling analysis and evaluation strategies." P 7-46. After synthesizing all this information, what specifically do we actually need? Do we need baseline data to understand the background + targetted campaigns that extensively characterize spilled material? If so, this is exactly what EPA should clearly call for.

12. The problem of temporal and spatial scaling needs to be mentioned explicitly. The report shows that the truck accident rate is low and the likelihood of spills related to trucks is low: but truck spills could still be important in a small local area. The "local effect" should be emphasized throughout. This is important for the public to understand why personal experience may differ from broad average observations.

13. Many public comments were about the use of the "median" as a metric for estimates of impacts. The report, perhaps in each chapter, should explain why a median is used when it is used. What is a median and why is it used?

14. Lines 9-22 on p 7-3 are not very clear or elucidating.

15. Is the Barnett the only formation where more water comes back than goes in? I believe this topic is important enough that it deserves more explanation and more highlighting. Why does more water come back and where does it come from? Why is the Barnett different than almost all the other shales?

16. Page 7-13 lines 22-29, the ideas here are not clear.

17. Incorrect callout to section 7.6.4 on p 7-17: should it be 7.5.4?

18. How is alkalinity presented in table 7-4: ppm as CaCO3?

19. The report says Brantley et al. summarized details about the XTO spill in PA…but we only gave a few details, not some of the details mentioned herein. P 7-37

20. Information should be added to the report that indicates to the reader what mechanisms or factors EPASuites does not treat. The report mentions that high salinity is not adequately incorporated into those calculations (p 7-43), but what about other possibly important factors such as microbiological reactions?

21. Section 7.5.4: the different components in PW are discussed in order of importance. Is this on a molar basis? It should be on a molar basis and it should be made clear that is it on a molar basis.

Comments from Dr. Joel Ducoste

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

The chapter tries to articulate what is known in the literature about the composition, volume, and management of flowback and produced waters. However, since the literature and data available are still coming in and the reporting are from limited observations from a small subset of spatial locations and temporal conditions, I don't think we can make any broad reaching conclusions at this time. The chapter does try to make statements where it emphasizes the lack of data, lack of analytical techniques to produce the data necessary on potential pollutants, lack of complete knowledge of all potential pollutants, and unknown subsurface reactions that transform known and unknown pollutants, to suggest that more information is needed before a definitive or even preliminary conclusion can be made related to composition, volume and management.

The chapter does try to mention the important findings from the literature reported. However, I am concerned that they did not try to articulate any weaknesses in the data reported in the literature. For example, in terms of leaks from pits or impoundments, I wonder what the cause of the structural integrity that eventually led to the leak. Were

they induced by operational conditions, poor manufacturing of the container, corrosion caused by the flowback or produced water chemistry, or seismic activity. The same can be said of well blowouts and pipeline leaks in terms of the root cause of the blowout or pipeline leak. I know 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." However, it's these secondary analyses of the data described earlier that are not being done to dig deeper and think about what new data needs to be generated along with more data in areas already being collected.

Related to roadway release of produced water from truck accidents, the EPA used a formula to calculate the number of potential crashes that may release these contaminants into a drinking water resource. This calculation has an extremely high degree of uncertainty that it is almost ridiculous to use it as an upper limit for determining roadway release of produced water on drinking water resources. Although the EPA articulated the limitations inherent in this approach, I think the report should either strike the calculation from the next version of the report or remove the comment that it represents "an upper bound on impact".

Another area that raised a red flag to me was there analysis of the extent of mobility of subsurface contaminants. While the approach they used to determine how mobile certain chemicals will be, it is based on very limited data. Further, there is the complication of subsurface reactions changing the properties of these chemicals and making them more mobile than their original state. Yet, I do not recall the report stating that these stated mobility indicators may change due to subsurface reactions or different for the specific unknown chemicals used in fracking fluids. I understand that the EPA developed an approach to help study sites where there may be potential contamination on a drinking water resource. It utilizes a model that would be calibrated and refine with more data. However, the model cited is quite complex with probably significant uncertainty and parameters that require detailed sensitivity analysis to see if the model will provide any meaningful results. Given so much uncertainty already with the unknown contaminants and unknown subsurface reactions that may change the contaminant mobility, I really don't see how this approach will truly be useful.

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 hydraulic fracturing water cycle? 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?

In the summary of findings (7.8.1), the EPA state that the amount of fracturing fluid returned to the surface ranges between 10-25 percent. But in the report, it states:

"Estimates vary but in composite indicate on average that between 5% and 75% (see Table 7-1, Table 7-2, and Table 7-3) of the volume of injected fracturing fluid may flow back to the surface". So there is some confusion here. In addition, this section mentions nothing about the occurrence of radionuclides, which is a major concern with produced water. The summary also downplays the occurrence of spills due to trucking accidents, which I believe is based on an equation with too much uncertainty tied to it. The summary also does not describe the extent of pollutant mobility in subsurface flow nor does it describe the findings related to leaks.

In terms of factors affecting the frequency and severity, the section states that produced water with lower concentrations may produce less impact. However, since we are unfamiliar with subsurface interactions and reactions, it is impossible to make that statement with certainty. In addition, there is no mention on how recycled produced water used onsite without treatment can change the severity of potential contamination of surrounding drinking water resources. This is a major concern for me as I think we are trading between balancing fresh water withdrawals to subsequent spills associated with a more contaminated flowback/produced water. Further, the extent of subsurface migration is also not discussed. As I mentioned earlier, we do not know what is happening below ground once a spill happens. We do not know how much will adsorb, react (biotically or abiotically), move readily, desorb slowly over time. All of these mechanisms will influence the severity and frequency of release.

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

The EPA finally tried to articulate the uncertainties in section 7.8.3. While I think there are some items not discussed as I mentioned earlier, the EPA mentioned some of the major uncertainties in the reported information. However, I was disappointed on the strength of need statements such as "Further sampling and investigation may be used to develop the linkage between a release and a documented drinking water impact.". On the contrary, further sampling must be used to develop linkage. We must continue to encourage the generation of data that can only help reduce uncertainty.

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 hydraulic fracturing water cycle? Are there relevant literature or data sources that should be added in this section of the report?

Data continues to be reported in the literature. A simple search on Google Scholar produced 6040 results just for 2015. While not all of them are directly applicable, it demonstrates the continued interest in developing important data to help the field understand the impact of hydraulic fracturing on water resources. The EPA must continue to scour this data and create their own data on this important topic.

Comments from Dr. Shari Dunn-Norman

Chapter 7 seems to be more an educational chapter within this study. The chapter provides a very detailed explanation of flowback water versus produced water. But it wasn't clear to me exactly *why* it was important to distinguish between flowback and produced water *from a drinking water contamination standpoint*. None of the examples releases cited made use of the distinction. Was the goal to show that releases of *flowbac*k would be more harmful than releases of *produced* water due to higher salinity? If so, that was not achieved. All cases cite elevated chlorides after the release, which would be expected from any higher brine concentration fluids being released (flowback or produced).

Flowback is a relatively short duration compared to the producing life of the well.

One example is confusing. Undersection 7.7.3.2 it is stated that there was a wellhead flange failure during fracturing operations (lines 10, 11 page 7-38), and later in the term 'blowout' is used (page 7-39, line 7). But the spill is attributed to flowback fluids. This is confusing in that a flange failure during fracturing would be at much higher pressure and suggest that is when the leak happened. When did the leak occur? This needs a bit of clarification based on the terms used. It is important so to ensure the example is really an example of flowback water spilled.

It is important to realize that fluid leaks through surface pipes *have no unique association with, or any causal relationship to, hydraulic fracturing*. For every barrel of oil the industry produces, there are many barrels of water that are co-produced. This is simply a function of the sedimentary rocks being formed in marine environments, and the nature of fluid flow through porous media. Industry has been pumping oil and water from wells to production facilities since the early part of last century. Once at a production facility, oil and water are separated, and the produced brine is pumped to a salt water disposal well (Class II injection well). All of the surface lines are subject to leaks, and there is nothing about hydraulic fracturing that impacts frequency or severity of surface line leaks. Line age and corrosion are the major factors in developing leaks. I strongly suspect that if we were to compare leak statistics for older oil and gas facilities associated with conventional wells, to those for the fractured unconventional wells, we'd likely see the surface line leak rate for the unconventional wells would be lower, because the facilities are newer. Studies like this should be undertaken.

Chapter 7 refers back to Chapter 5 (Text box 5-14) for spill rate data. This is described in text on page 7-33, lines 10 through 21. Again, these data should be shown in histograms, to illustrate the size of leaks as well as frequency. Half of the 457 spills found were 1000 gallons or less. It is an important learning of the study, and deserves an illustration in addition to the text.

The chapter seems to indicate every spill cleaned up quickly with little impact. It didn't seem that even the larger spills had significant, long-term impact. That point might be strengthened in the conclusions.

Also, I request that the Yale study results are referenced in the EPA study. Marcellus is a major area of concern and this study focuses on those concerns. I don't have Yale's full study but here is a link to the paper published in the national academy of sciences.

http://www.pnas.org/content/112/43/13184.abstract I think their work helps to address a number of issues we discussed during the Panel's 10/29/15 meeting.

Comments from Mr. John V. Fontana

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

> In general, yes. Including the fact that different definitions are used for flow back and produced waters in terms of them being a mixture of returned fracturing fluids and formation waters, and these are typically mixed and the data is not always available that can distinguish these two types of waters. Since the literature uses various definitions, the EPA wisely elected to just refer to the type of definition used with each author's data examined. The wide range of chemical compositions, TDS values and NORMs are thoroughly summarized. Interactions of injected and formation waters are also covered.
>
> Page 7.1.2, Produced Water, Page 7-13, Lines 12-16; It might help to note that CBM wells produce more water because saturated coals are the targets, since it is the head pressure of the water causing the coals to retain the gas, and once the water head pressure is lifted, the coals de-gas. Whereas shale and tight gas formation are better producers of oil and gas in areas with lower water saturation values, because the water impedes the flow in those formations. Also, the reason for different production rates of water should simply be related to reservoir properties, such as permeability, etc., and should not be stated as "… vary for unknown reasons" as the one quoted reference (US GAO, 2012)may state.

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 hydraulic fracturing water cycle? 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?

> Page 7-35; The report reiterates the need for baseline sampling which can show in some cases that water wells exceed MCLs before drilling activity commences, in this case relative to surface spills and inorganic constituents.
>
> 7.8.1, Summary of Findings (p 7-44) Something should be said about the relative frequency of impacts discussed. In the Summary of Findings and in Text Box 7-1, frequency of impacts should be discussed at least in a way relative to the data source or region that was used or available. Numerous state and other data sources summarized a variety of reported spills. The number of spills should be put into context relative to the number of wells drilled, truck trips, pipelines miles, etc.

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 hydraulic fracturing water cycle? Are there relevant literature or data sources that should be added in this section of the report?

The statement in Text Box 7-1, lines 21-26, are not clear. While a large number of chemicals have been used in HF overall, in any individual well there are not that many chemicals typically in the injection fluids. Routine analysis of produced water is typically done for major constituents rather than trace constituents which are harder to analyze, and more typical of environmental analysis methods.

Composition data were limited. Most of the available data on produced water content were for shale formations and CBM basins, while little data were available for sandstone formations. Additionally, the majority of data were for inorganics, and little data were available for organics. Many more organic chemicals have been reported to have been used in hydraulic fracturing fluid than have been identified in produced water. The difference may be due to analytical limitations, limited study scopes, and undocumented subsurface reactions.

In 7.8.4 Conclusions, and in Text Box 7-1, in response to the Research Question: *What is currently known about the frequency, severity, and causes of spills of flowback and produced water?*

The severity of spills are mentioned, as typically < 1,000 gallons, but the frequency of these spills is not.

The statement in Text Box 7-1, p 7-14, lines 21-26, are not clear. While a large number of chemicals have been used in HF overall, in any individual well there are not that many chemicals typically in the injection fluids. There is no reason to compare the number of chemicals of injection fluids to the number of chemicals in produced (formation) water. Routine analysis of produced water is typically done for major constituents rather than trace constituents which are harder to analyze in high TDS solutions, and more typical of environmental analysis methods. Petroleum (oil/condensate) contain many hundreds of individual compounds that could be included in the dissolved phase as trace components but are generally just classified as BTEX and total petroleum hydrocarbons.

Composition data were limited. Most of the available data on produced water content were for shale formations and CBM basins, while little data were available for sandstone formations. Additionally, the majority of data were for inorganics, and little data were available for organics. Many more organic chemicals have been reported to have been used in hydraulic fracturing fluid than have been identified in produced water. The difference may be due to analytical limitations, limited study scopes, and undocumented subsurface reactions.

7.4.5, Footnote on Page 7-19; I believe this is inaccurate in that "immature" methane is not produced from the Kerogen (original organic material in place) but itself is already in place as a biogenic source of methane (which can be distinguished by its C and H isotopes.)

□□ With increasing subsurface temperature after burial, petroleum source material (kerogen) produces hydrocarbons in a sequence from methane (immature), to oil (more mature), to gas (mature). Gas is produced by thermal cracking of oil (PA DCNR, 2015). □

Page 7-29, Lines 18-21, - Sentence Fragment: injected and formation fluids. Produced water containing bothAlthough some constituents of hydraulic fracturing fluids are known to readily degrade in the environment, little is known regarding how the subsurface degradation proceeds or how the constituents interact within a complex matrix of organics (Mouser et al., In Press).

Comments from Mr. Walter R. Hufford

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

From the onset, the Report entitled *Assessment of the Potential Impacts of Hydraulic Fracturing for Oil and Gas on Drinking Water Resources* would lead many readers to conclude that the entire **life cycle** of a well including; site acquisition, drilling, completing, producing and plugging is related to the process of hydraulic fracturing. While the report casually references that the actual process to hydraulic fracturing a well takes only a few days to complete, and that a well may produce for decades, the report continues to refer to hydraulic fracturing throughout the report and lifecycle, as if the process is a continuous operation. This structural disconnect within the report continues to confuse external stakeholders on the hydraulic fracturing process and exhibits a lack of clarity in educating external stakeholders regarding the process of hydraulic fracturing within the oil and gas industry.

The section provides a broad overview of the information, albeit somewhat dated, but lacks details that would provide a reader enough information to understand best management practices used by industry, regulatory requirements (i.e. secondary containment, reporting, remediation) and more clarity regarding regulatory and industry response to spills if they occur.

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 hydraulic fracturing water cycle? 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?

Chapter 7 provides a description of where *potential* releases of flowback and produced water *could* happen, with a satisfactory presentation of composition, physical properties, and migration in the event a release does occur. However, the section lacks a quantitative analysis of the frequency and impacts of spills associated with this aspect of operations. The chapter references reported spills but fails to clearly articulate that many spills are contained within secondary containment barriers installed in the event of a release. A reader is left to assume that all spills are impacting soil/groundwater/surface water which is simply not accurate.

It is disappointing that the team referenced preexisting conditions in groundwater and surface waters in only one paragraph on page 7-35. The team should present a more complete discussion of pre-existing conditions in groundwater and surface waters so readers are more informed about "background" conditions associated with their water. Moreover, there is simply no reference whatsoever of pre-existing methane concentrations in numerous potable wells from geologic zones that are not targeted for horizontal drilling and completion. Some readers may believe that any constituent that is in detected groundwater results from oil and gas operations.

Additionally, suggestions that during operation of a well that production water containing free phase hydrocarbons, dissolved phase hydrocarbons and emulsified hydrocarbons is stored in pits is not accurate. Produced water is rarely stored in open pits. Rather this media is managed in tanks or pumped to UIC wells.

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

The section should indicate what improvements have/or are being taken by regulatory agencies to improve database systems which provide more information on operational activities associated with the oil and gas industry. States have made considerable advancements in electronic database systems that allows for increased reviews and assessments by external stakeholders.

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 hydraulic fracturing water cycle? Are there relevant literature or data sources that should be added in this section of the report?

The section lacks details on spills that are referenced, specifically around response measures and monitoring, leading the reader to believe that these events cause a *permanent* condition. For example, a close read of the section regarding the Penn

Township, Lycoming County, PA incident (pg. 7-37) confirms that the impact was temporary – "*By January 2011, stream chloride concentrations had dropped below the limit established by Pennsylvania's surface water quality standards*". Further, a review of the technical reports associated with the Leroy Township, Bradford County, Pennsylvania event documented no efforts on the potable water wells with only localized surface water impacts. The team should revisit the issue regarding spills and discuss in more detail how spills are remediated and the timeframes associated with restoration to pre-existing conditions. As written the report leads a reader to believe these events, while regrettable, are permanent impacts.

Comments from Dr. Richard F. Jack

I would like to add the following pdf as a reference document for charge question 5.

Appendix K Sampling and Analysis Procedures for the Wyoming Oil and Gas Conservation Commission Groundwater Baseline Sampling, Analysis, and Monitoring Program, found at the following website: http://www.marcellus-shale.us/pdf/Wyoming_Baseline-Sampling.pdf

Additional information and Background
The State of Wyoming has recently enacted legislation for baseline parameters than can help distinguish water impacts from hydraulic fracturing and/or drilling impacts to water resources. Including action levels, sampling procedures, chain of custody etc.

This gives a rational approach to baseline monitoring as well.

Distinguishing or using indicator compounds based on chemicals is problematic due to the large number of possibilities compounded with the fact that most are not used or their use is variable across shale plays and user preferences.

Comments from Mr. Dean Malouta

In response to Charge question 5 regarding Chapter 7, A) the flow back and produced water section does an excellent job of distinguishing between various definitions of produced water and flow-back water as well as describing the range of composition, volumes and management of the flow back and produced waters. B) There is more that could be done to show how the findings and conclusions relate to the data gathered. For example, BTEX chemicals and radio-nuclides may appear in flow back and produced waters even if those items had not been pumped into a well because they exist in the hydrocarbon bearing zones already. Further, such elements and compounds often appear in produced waters from wells that a not hydraulically fractured, as well as from those that are. Given the range of public comments related to this chapter, the public needs to have these issues better articulated. The charts and discussion regarding amounts

or percentages of fluids flowed back as a function of different basins was quite well done. I would like to see better descriptions/summary of which states have laws or regulations requiring lined pits and berms to manage potential spills, leaks and runoff. Perhaps also a list of best practices currently in use in industry (elimination of pits, tanks stored over lined berm-surrounded catchment areas, etc.) could serve as recommendations for lawmakers. C) The conclusions are thorough in discussing the severity, potential, composition, chemical and physical properties of produced and flow-back waters. As in other chapters, the public needs, and I believe we should provide, some discussion as to the probability or likelihood or degree of risk involved with the statements in the conclusions. For example the last sentence of the conclusions states that produced waters have affected drinking waters. That statement, while correct, is too broad and needs to be placed in better context with the degree and probability of risk better articulated.

Comments from Dr. Cass T. Miller

a. The assessment adequately documents the known information regarding composition, volume, and management of flowback and produced water.

b. The major findings are supported and do identify potential risks to drinking water sources. The occurrence of such contamination is documented and acknowledged.

c. Uncertainties are acknowledged, but these uncertainties could be stated more forcefully. In essence, the uncertainties are so expansive that at best a rough, general indication of some of risks can be assessed. Risks from organic contaminants, such as benzene, are real and should be more clearly articulated. The CBI contaminants also pose an unknown risk. It would be helpful to not only acknowledge uncertainties, but to summarize approaches that could be used to reduce these uncertainties and help protect drinking water quality.

d. Severe gaps in our knowledge exist and practices are not in place to protect water quality uniformly. It would be useful to see a section outlining the additional information that is needed to more fully understand the risks and approaches that can be taken to control these risks.

Comments from Dr. Azra N. Tutuncu

a. 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 hydraulic fracturing water cycle? Are there relevant literature or data sources that should be added in this section of the report?

   The EPA scientists have described flowback and produced water well and used numerous examples from various unconventional plays to compare the volumes of the flow back

and produced waters, their compositions and management. Due to the continuing operations and research, there is ever improving dataset and publications becoming available every day. Hence, while it is impossible to include all publications, continuation of the effort for updating the existing database and include all new data from most recent operations will provide a more precise statistically more accurate analysis for this research.

b. 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 hydraulic fracturing water cycle? Are there relevant literature or data sources that should be added in this section of the report?

Most chemicals quoted here for hydraulically fractured wells, due to the hydrocarbon presence in conventional and unconventional reservoirs, certain chemicals will be present regardless of hydraulic fracture in o the reservoir (for example BTEX).

c. 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 hydraulic fracturing water cycle? Are there relevant literature or data sources that should be added in this section of the report?

In the return fluids statistics, the formation type and the formation fluid type for compatibility was not discussed. The return fluids are also highly dependent on the presence or absence of natural fractures and their distributions and densities and how well the hydraulic fracture intersects these pre-existing fractures, in another words, how much permeability improvement is accomplished. The composition of the water as well as chemicals will impact the interaction level between the formation, injected fluid and native formation fluid based on how compatible fluids are selected as fracturing. This aspect was not emphasized enough in the report.

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 hydraulic fracturing water cycle? Are there relevant literature or data sources that should be added in this section of the report?

The explanation of distinction between produced and flowback waters were very well accomplished. However, while uncertainties are known and highlighted, their impacts on the potential severity level was not properly covered. Spills were discussed and the volumes from spills vs. blowouts were compared, yet an historical evaluation of the regulatory effort on the amount of spills were not discussed. There are many spills not necessarily occurs during the fracturing, but during the transportation of the fluids which were also not included in the report. Any transportation related spills is also prone penetrating into soil and potential impact to drinking water through propagation to the near-surface environment.

Comments from Dr. Paul K. Westerhoff

The chapter provides valuable information, but more interpretation and data would be helpful. This includes the following:

1. There is inadequate information and analysis related to bromide and iodide in the report, including Appendix E. Bromide is important for drinking water because upon addition of oxidants or disinfectants (chlorine, ozone) brominated disinfection-byproducts form in drinking water (e.g., brominated THM or HAA, bromate). The ratio of Cl/Br in Table E-4 is roughly 200/1, which is lower than seawater (~300/1) and lower than the ~300/1 ratio observed in a AWWA national survey on bromide in drinking waters (Amy et al, AWWARF Final Report - Survey on bromide in drinking water and impacts on DBP formation, 1994). What is the reason for elevated bromide in the these flowback and produced waters, relative to chloride? Some places report "bromine" whereas other places report "bromide"; this should be more consistent. Same is true for iodide, although the report has very little data on iodide in flowback or produced waters. 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. The ratio of Cl/I in table E-4 is around 5000/1 which is much lower (i.e., more iodide) than the ratio in seawater which is 35,000/1. Why is there more I in flowback and produced water, relative to Cl, than seawater? While nitrate is reported in the report, there is no data on bromate, chlorate/chlorite, perchlorate or iodate – all of which have human toxicity endpoints and some have MCLs. Overall, the handling of halogens in the report is limited to chloride, and that is inadequate.

2. The list of water quality parameters in Table 7-4 is useful. However, some of the chemicals identified in Table 5-1 are present as polymers. However – there is no mention of this, nor of the average molecular weights or means of detection / occurrence.

3. The report has a disconnect between reporting *volumes* of water and *concentration* of water quality parameters associated with disposal and spills. For both returned chemicals in flowback or produced waters, and for spills, it would be far more helpful to calculate *mass* of chemicals. While <30% of the injected water is recovered, what percentage of the fracturing chemical mass is recovered? During spills, while direct discharge to surface water is possible and concentrations could be important, it is mass loadings and dilution which are far more helpful. Even for discharges to soils, the mass of salts and other chemicals are important because they can have long term leaching potential. Many EPA regulations are based upon mass loadings rather than concentrations (e.g., TMDL, hazardous waste characterization, etc.)

4. Various chemical concentrations are provided, as is DOC levels. It would be extremely helpful to calculate the percentage of DOC accounted for by measured organic chemical concentrations.

5. There is inadequate mention of "color" or other UV/VIS absorbance parameters of the produced or flowback water. These are important for drinking waters, specifically because the EPA uses SUVA (UVA/DOC) as one part of the Enhanced Coagulation Rule.

6. The tiered assessment (Table 7-35) is interesting. However, its discussion and implementation is inadequate. Exactly which chemicals would be measured, by whom, who would pay, at what frequency, and for how long would samples be collected? Has the EPA actually implemented this strategy on any residences? What was the outcome? An entire section could be dedicated to this tiered assessment.

7. There is inadequate discussion associated with the number and proximity of municipal surface water intakes located downstream, within watersheds, of geographic areas where hydraulic fracturing is conducted. This would be an important risk factor for these facilities.

8. Overall, the chapter inadequately addressed the potential impacts on drinking water supplies. There was not a comparison between chemicals reported in various databases and complete drinking water MCL and SMCLs (and standard levels).

Charge Question 6: Wastewater Treatment and Waste Disposal Step in the Hydraulic Fracturing Water Cycle

The fifth stage in the hydraulic fracturing water cycle 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 hydraulic fracturing water cycle? 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 hydraulic fracturing water cycle? Are there relevant literature or data sources that should be added in this section of the report?

Comments from Dr. Joel Ducoste

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

In this chapter, the EPA does provide a reasonable description of how the amount of wastewater changes over time with the initial returned water during production is primarily made of flowback water with different water characteristics and then over a longer period of time, consists of water that contains more of the subsurface geological properties. They show that the total amount of wastewater continues to increase as long as the well is in production but at a slower rate. The amount of wastewater varies by state and is hard to predict in terms of future productions due to data type as described in the report. The EPA noted that empirical water/hydrocarbon ratios or per well estimates of production rates times number of wells could be used. However, neither method would provide accurate information to compute wastewater pollutant loading to determine the extent of treatment effectiveness.

EPA then describes what are the typical wastewater characteristics for flowback and produced water with major categories including organics, inorganics, residuals, dissolved solids, and radionuclides. While I am ok with the description provided for TDS and inorganics, I continue to be concerned about the organics characteristics of

flowback/produced water given that we do not know the proprietary injection fluid chemicals being used by companies. Further, the unknown sphere of chemicals is more complicated as subsurface reactions can change the toxicity of even known compounds. The EPA tried to express some of that uncertainty but it gets confusing as they make comments as follows:

"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".

Statements like the above would suggest that if organic compounds do not fall in this category, then we may not need to be concerned. We just do not have enough information and I am not sure if we ever will without complete transparency on what is being injected and then conducting experimental tests to determine the toxicity of the wastewater produced.

Another complicating contaminant group are the residuals generated from wastewater treatment. Given the processes used to remove much of the contaminants discussed in the chapter, these contaminants would become highly concentrated in the residuals. I am surprised that residuals with some of the potential high concentrations of metals, TDS, radionuclides, and organics would not be classified under RCRA rules. The only explanation for exclusion would be that these oil and gas operations have an existing exclusion from RCRA (EPA 40 CFR 261.4(b)). However, these residuals can be a significant source of leaching into the environment if not properly managed in a very strict manner. The report does not stress this concern enough.

In terms of liquid residuals, again, any discharge or mixture with solids to then be land applied is risky again due to potential leaching of these toxic compounds. As mentioned in the report, these liquid residuals are unlikely to be discharged into a local water body even after additional treatment to meet discharge permits. Further, the higher TDS concentrations would significantly impact POTWs leaving only deep well injection as the only likely disposal route. However, I have additional concerns about deep well injection, which I will discuss later.

The chapter describes the different wastewater management practices, stating that the most common approach is deep well injection followed by water reuse (not all of it at the same level of treatment) and onsite treatment at a CWT that would then either be discharged into a receiving water body or sent to a POTW. Residuals potentially land applied, landfilled, or incinerated. As the report states, selection of management strategy will depend on wastewater characteristics, wastewater loading, and cost (transportation,

storage, and disposal). Strategies can also change with time with changes in wastewater characteristics and loading as well as potential regulations.

Deep well injection, as the report mentions, are not uniformly distributed among the different states. Siting proximity to the production well also plays a role along with the other factors mentioned earlier. While spill concerns may increase in risk if the wastewater needs to be transported to a disposal well, my additional concern would be related to potential seismic activity. The current chapter does not mention anything about reporting of seismic activity discussed in the literature (Yeck et al., 2015; Weingartern et al., 2015; McNamara et al., 2015) related to deep well injection and should be raised to help guide appropriate rates and pressures that reduce these events if this management approach is selected.

In terms of water reuse, whether partially or extensively treated, the report does raise concerns about the additional need to properly manage the flowback/produced water from a well that utilizes reuse injection water due to the potential accumulation of TDS and radionuclides. The process may be worsen by new fracturing fluid technology that can tolerate significantly higher TDS concentrations that would possibly alleviate the need to even partially treat wastewater for its reuse. Storage of any reused water with these elevated contaminant concentrations is a concern as a potential leak/spill route for impacting local drinking water resources.

Centralized waste treatment (CWT) facilities are a management strategy to reduce the pollutant load from flowback and produced wastewater. While the report discusses the unit processes typically used at these facilities (I will discuss those later), it is clear that they may not be able to reduce the concentrations to levels that allow for discharge to a drinking water resource. More importantly, due to the non-disclosure of hydraulic fracturing injection fluid as well as unknown subsurface reactions, the EPA does not have any definitive way of knowing whether the effluent water from these facilities provide sufficient environmental and public health protection. In addition, radionuclides still pose a significant risk as treatment processes may not remove to levels that are required for the protection of public health (depending on the influent concentration). The report does mention these concerns but it needs to be stressed. Although much of the existing strategies involves taking treated wastewater from CWTs for deep well injection or reuse, concerns of increased injection fluid contaminant concentrations during reuse may become a problem in terms of leakage from onsite storage.

In terms of road spreading and evaporation pits, the EPA does identify potential risks associated with runoff of contaminants from road spreading or possible pit breaches that release contaminants to a local drinking water source. POTWs were discussed as a possible option for wastewater management. As discussed in the report, conventional treatment processes at POTWs cannot remove these highly concentrated flowback/produced wastewater flows as they will disrupt biological processes. Other contaminants will essentially pass on through the treatment system. As a management

strategy, if a POTW is part of the process, prior treatment through a CWT with advance unit treatment processes are necessary. The EPA does report that even with prior CWT treatment, contaminants are still not being removed and are being measured in the effluent of POTWs.

The chapter does provide a limited review of the different unit processes that can be used to reduce different types of pollutants that are known in hydraulic fracturing flowback water and produced water (Table 8-6). The document also mentions that there are known chemical constituents in the flowback/produced water that conventional industrial wastewater treatment cannot effectively remove that then requires advance treatment technologies to possibly meet effluent permit standards for discharge into local water bodies (Note: meeting the effluent standard will also depend on the magnitude of the influent concentration). Of course, we do not have any data on the effectiveness of the removal of unknown constituents. These unknown chemical constituents clearly produces a significant amount of uncertainty in the selection of a management strategy that involves discharge into a drinking water resource, land application, and road spreading.

Table 8-7 provides more detail on CWTs with an actual list of the treatment processes employed at that facility. Unfortunately, the EPA was not able to provide influent and effluent concentrations of at least the known HF contaminants to correlate the removal performance with these treatment plant systems. Many of these advance treatment processes require significant energy input, which raises the question about the amount of greenhouse gas (GHG) emissions. While the concern here is to safeguard our drinking water resources, the EPA should not completely allow these CWTs to setup systems without some consideration of the energy requirements that could lead to higher regional GHGs (USEPA, 2013; McGucken et al., 2013).

The EPA in section 8.6.1.2 used modeling to determine how to reduce the impact of bromide on downstream users. While a description of the model was not provided along with its assumptions, it is risky to use it as a definitive strategy given that experimental data that was reported earlier in this section discusses how significant dilution of waters containing bromide may not reduce levels to background concentrations.

I continue to raise concern about radionuclides from these fracking operations. The EPA reports on a limited study that investigated these compounds from POTWs, CWTs, and zero liquid discharge facilities. Based on their reporting of the data, the EPA noted that discharge data from POTWs on radionuclides concentration were inconclusive as those receiving wastewater from fracking CWTs did not show higher effluent values compared to those not receiving this waste stream. Yet, the values they reported were all significantly elevated above the MCL and several orders of magnitude above background river levels.

Effluent radium concentrations from CWTs and zero discharge facilities were on the order 1000s pCi/L. Frightening are the zero discharge facilities that will reuse these

wastewaters with such a high radium concentration and consequently pose an elevated risk if leaks or spills occur. While the EPA noted a study that assumed a 3 log reduction in radium concentration using co-precipitation with barium sulfate, the study did not actually measure the influent concentration. The potential accumulation of radium on pipe scales, in sediments, in residuals, and the potential for leaching into drinking water resources raises significant public health risks not being stressed in this report.

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 hydraulic fracturing water cycle? 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?

In terms of wastewater quantity, the summary of findings is properly brought forward based on the limited data provided. In terms of wastewater management practices, the summary does not raise the concerns associated with high concentrations of TDS, radionuclides, and other known and unknown contaminants in reuse practices. I continue to worry about onsite storage for reuse applications. As technologies allow for increasing TDS concentrations in fracturing fluids, there will be a need to better safeguard storage facilities from leaks or spills.

In terms of treatment and discharge, on page 8-70, the summary states that modeling was used to determine the impact of small percentages of hydraulic fracturing wastewater in a river may cause an increase in DBP formation. Experimental data from a literature study described that effect. Modeling was used to propose strategies on possible dilution of bromide impacts on downstream drinking water resources. I do not support the use of modeling here since I am not familiar with the modeling approach, parameters involved, assumptions made, and whether any sensitivity or uncertainty analysis performed to provide the range of possible answers. The summary does not mention that the elevated radionuclides in treatment effluents are likely and that the study they used cited another study to prove significant removal and not direct evidence.

In the factors affecting frequency and severity section, the report states that hydraulic fracturing management can consider blending to reduce the TDS concentration in the receiving water to reduce DBP formation. This strategy is very risky and was also stated in the report as an approach that did not limit the brominated DBP formation.

Under the uncertainty section, the report states that limited data could be provided from CWTs with NPDES permits. Although they note that monitored constituents may be limited, the discharge permits may not test for, even a small fraction of the constituents found in fracking wastewater. I do not want the readers of this report feel comfortable with requirements of NPDES permits as a way of monitoring these facilities.

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

There are concerns raised earlier in part (a) that are not fully articulated or stressed.

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 hydraulic fracturing water cycle? Are there relevant literature or data sources that should be added in this section of the report?

In terms of management strategies, as I mentioned earlier, there is no mention in this chapter related to seismic activity and deep well injection. This documented relationship found in the literature needs to be assessed by the EPA as this is the predominant method of fracking wastewater management. The references provided here are only a starting point. I also want some discussion on the consequence of high energy processes potentially used in CWTs to treat difficult HF wastewater. The reference provided here allows the EPA to consider optimization of unit processes to reduce energy input.

<u>References on Seismic Activity</u>

Yeck, W.L., Block, L.V., Wood, C.K., King, V.M., 2015, Maximum magnitude estimations of induced earthquakes at Paradox Valley, Colorado, from cumulative injection volume and geometry of seismicity clusters, *Geophys. J. Int.* 200, 322–336

Weingartern, M., Ge, S., Godt, J.W., Bekins, B.A., Rubinstein, J.L., 2015, High-rate injection is associated with the increase in U.S. mid-continent seismicity, Science, vol 348 issue 6241, pp 1336-1340

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

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

USEPA, 2013, Energy Efficiency in Water and Wastewater Facilities: A Guide to Developing and Implementing Greenhouse Gas Reduction Programs, http://www3.epa.gov/statelocalclimate/documents/pdf/wastewater-guide.pdf

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

Comments from Dr. Stephen J. Randtke

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

Overall the report does a reasonably good job summarizing large amounts of information on a rapidly evolving topic (taking into consideration that there are significant information gaps, uncertainties, incomplete data sets, etc.) and drawing reasonable and adequately supported conclusions. The following comments and suggestions are offered for consideration in efforts to improve the clarity and accuracy of the report, specifically Chapter 8 and Appendix F and any related statements incorporated into Chapter 10 and the Executive Summary:

- Clarify what is meant by "waste disposal." The title of Chapter 8 (Wastewater Treatment and Waste Disposal) is a bit ambiguous in that it is not immediately whether "waste" includes only those wastes generated during wastewater treatment or is more broadly construed to include other wastes associated with hydraulic fracturing (HF). The draft report does address treatment residuals, but says little about other wastes, such as "drill cuttings" and "drilling muds," and the potential of these materials to contaminate drinking water resources. Perhaps that is because they are normally disposed of in regulated landfills having little or no potential to leach chemicals of concern into nearby drinking water sources. If so, the report should explicitly say so and provide supporting information. I do not recall seeing any discussion of spill-contaminated soils, pond sediments, or other wastes in this section of the report, but perhaps they are addressed in other sections of the report or were included in the "site reclamation" activities excluded from this report as noted on p. ES-4. If so, the report is long enough that it would not hurt to reiterate this in Chapter 8 for the sake of the readers.

- On p. 8-38, electrocoagulation is characterized as an "emerging technology." Perhaps it has only recently begun to be used (or tested for use) to treat HF wastewater, but the technology is a niche technology that been available for decades. Fundamentally, it is simply another way to add metal salt coagulants to water, which has been a common water treatment process for well over a century. Coagulation has long been used to treat wastewaters containing emulsified oils or small droplets of oil (p. 8-68), such as refinery wastewaters. It seems inappropriate to lump this technology together with technologies that are clearly both new and emerging, such forward osmosis. Also, the report notes (p. 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, EPA-600/8-77/005 (Manual of Treatment Technologies for Meeting the Interim Primary Drinking Water Regulations) for information on the effects of pH and chemical dosage on removal of selected metals by coagulation.

- On p. 8-46, the 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." Coagulation, flocculation, and electrocoagulation do not "remove" TSS. Coagulation and electrocoagulation destabilize colloidal particles (often by neutralizing their charge), allowing them to aggregate into larger particles so they can be aggregated (flocculated) into larger particles that are more readily removed by processes designed to remove particles, such as sedimentation, filtration, and dissolved air flotation.

- On page 8-46,47, the statement is made that monovalent ions are not removed by basic treatment processes and require more advanced treatment such as … nanofiltration …." Nanofiltration removes divalent ions well, but typically achieves little or no removal of monovalent ions.

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

- On p. 8-47, the draft report states that "Advanced treatment processes such as … nanofiltration can remove dissolved metals and metalloids." Nanofiltration is normally effective only for those present in multivalent form.

- The draft report states (p. 8-60) that "… brominated and iodinated [DBPs] are considered more toxic than other types of DBPs (Richardson et al., 2007)" and later (p. 8-70) that "Brominated DBPs (and iodinated DBPs) are more toxic than other species of DBPs." The report should clarify whether these statements are based on toxic effects observed in cell cultures or on human toxicity data. If the former, the type of cells tested should be noted; if the latter, supporting references should be cited. Humans differ greatly from cell cultures, and chemicals that cause toxicity in cell cultures (cytotoxicity) may not be toxic to humans. It might be appropriate to say that "some scientists are concerned that brominated and iodinated DBPs may be more toxic to humans than DBPs containing chlorine as the only halogen species, based on their toxicity to [specific types of] cells (references); but no data are currently available to prove that this is the case for humans."

If human toxicity data are available, perhaps some of the toxicologists on the panel can recommend appropriate references to cite.

- On p. 8-64, the draft report states that "Radium … and 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 carbonate, would also be expected to work reasonably well. It is 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. Perhaps the intent was to say: "Radium … can also be removed by co-precipitation if sulfate or carbonate is added to HF wastewater to precipitate calcium, barium, or strontium.

- On p. 8-65, the draft 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 p. 8-66, line 23, aeration is listed as a process able to remove VOCs. Although the term "aeration" is often used to describe this process, it is more accurately referred to as "air stripping."

- On p. 8-68, the "Summary of Findings" 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 (p. 8-9). However, the basis for this estimate is not very clear, and efforts to find it in the report were complicated by the many disparate estimates (for different years or time periods, different groups of states, different segments of the industry, etc.) in various places in the report and by the different units of volume and flowrate used in the report (appropriately used, but nevertheless confusing to the readers). It might help to include a table somewhere in Chapter 8 that more 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.

- On p. 8-70, line 29, bromide is said to be of "concern due to the formation of disinfection by-products (DBPs)." Bromide does not simply form DBPs; it also increases both the rate and extent of THM and HAA formation.

- On p. 8-72, lines 3-4, the draft report states: "There may be consequences for downstream drinking water systems if the sediments are disturbed or entrained due to dredging or flood events." An example or two would help clarify this statement. Since water treatment plants are general well equipped to remove suspended solids, and since the sediments would already have been sitting in water for an extended period of time, what adverse impacts would entrained or disturbed sediments potentially have on drinking water quality?

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

- On p. F-9, electrodialysis is said to rely on "positively and negatively charged particles and coated membranes to separate contaminants from the water." This 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-water stream.

- On p. F-10: "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, p. F-15, "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. Lumping them all together oversimplifies things and will almost certainly cause confusion in the minds of at least some readers.

- In Table F-2, p. F-16, electrodialysis (ED) is shown as being very effective for removing organics. It is very ineffective for nearly all organics. Particulate organics, oil & grease, and high molecular weight organic anions foul ED membranes (which are ion-exchange membranes) and either ruin them or significantly shorten their life. Only small, charged organic ions could potentially be removed, but removal would probably be rather poor in most cases.

- On p. F-28, lines 19-20, the report 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, this statement is misleading in that bromide is preferentially incorporated into halogenated DBPs, i.e., it is grossly overrepresented. It would not be surprising for up to half of the bromide in a given raw water to be incorporated into halogenated DBPs while less than one percent of the chloride was consumed in this way. The Br-to-Cl ratio in the DBPs can be orders of magnitude higher than the ratio in the raw water.

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 step of the hydraulic fracturing water cycle? Are the factors affecting the frequency and severity of any impacts described to the extent possible and fully supported?

The major findings generally appear to this reader to be internally consistent with (fully supported by) the information and data presented in the assessment, insofar as that is possible given the variability of the data, data gaps, incomplete records, etc. Several potential impacts and/or factors affecting them seem to have received little mention, perhaps due to lack of data or because they were deemed to be relatively minor. These impacts are as follows:

- Strontium is mentioned a number of times in Chapter 8. If there was any discussion of EPA's plans to regulate (establish an MCL for) Sr, as the agency announced in 2014, this reviewer missed it. The current Health Reference Level is only 4 mg/L. Since HF wastewater can contain hundreds to over a thousand mg/L of Sr (p. 8-65), discharge of even of small amount of inadequately treated HF wastewater to a drinking water source could compromise a water utility's ability to comply with the anticipated MCL for strontium. This merits explicit mention in the report.

- The draft report makes frequent mention of bromide and notes in several places (e.g., on p. 8-59) that bromide contributes to formation of brominated THMs. Bromide is also an essential precursor for bromate formation. Bromate, another regulated DBP, is readily formed when water containing bromide is ozonated, and the yield can be rather high relative to the MCL of 10 µg/L. Bromate formation associated with bromide in HF wastewaters could pose an even greater threat to human health than brominated or iodinated THMs and HAAs.

- Naturally occurring organic matter, typically measured as TOC or DOC, is a well known major precursor for formation of a broad spectrum of disinfection byproducts, including THMs and HAAs. HF 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). This reviewer found no mention of the potential for the organic matter in HF wastewater to form THMs and HAAs, which could be readily evaluated using simple DBP formation potential tests.

- Although NDMA is mentioned in an Appendix (p. F-28), the discussion focuses on the possible role of bromide in forming NDMA and on possible future regulation of NDMA and other nitrosamines. The potential for HF wastewaters to form nitrosamines is otherwise ignored. There was no mention of NDMA in Chapter 8. Since HF wastewaters may contain high levels of known NDMA precursors (including bromide, ammonia, and amines), since industrial discharges have been found to pose significant problems with respect to NDMA formation (e.g., for the Orange County Water District's Ground Water Replenishment System), and since disinfection of water and wastewater can potentially result in formation of problematic levels of NDMA, increased NDMA formation is a potentially significant impact of HF wastewater discharges on drinking water resources. The high levels of TKN reported for some samples (e.g., on p. E-8) are also of concern, since TKN includes nitrogenous organic compounds that may also be NDMA precursors.

- HF wastewaters can contain high concentrations of ammonium (e.g., as shown on p. 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. Also, along the same lines, this reviewer found no mention in the report of the chlorine demand associated with HF wastewaters, which if significant could also adversely impact drinking water treatment plants.

- Some HF wastewaters presumably contain significant concentrations of antiscalants, if antiscalants were used to prepare the HF fluid, and some may contain various complexing agents used for other purposes besides scale control. Such chemicals may, if added to drinking water in sufficient amounts, influence the transport and fate of metal ions, and can adversely impact metal ion removal by various treatment processes. This reviewer found no mention or assessment of this in the report.

c. Are the uncertainties, assumptions, and limitations concerning wastewater treatment and waste disposal fully and clearly described? What additional information, background, or context should be added, or research gaps should be assessed, to better characterize this phase of the hydraulic fracturing water cycle? Are there relevant literature or data sources that should be added in this section of the report?

Except as noted above, the uncertainties, assumptions, and limitations concerning this aspect of the HF water cycle appeared to be reasonably well described and appropriately taken into consideration in stating the findings of the report. This reviewer's suggestions for additional information, etc., were included above in response to the earlier questions. One additional source of information that may be appropriate to cite in this report is:

> Thorp, L.W., and J. Noël, "Aquifer Exemptions: Program Overview and Emerging Concerns," *Journal of the American Water Works Association, 107*, 9, 53-59 (2015).

This recently published article describes EPA's aquifer exemption program, which may be highly relevant to the discussion in the report related to hydraulic fracturing activities found to be occurring in some locations in formations also used, or having to potential to be used, as drinking water sources.

Another recently published paper that merits consideration for inclusion in the report is:

> Jackson, R.B., E.R. Lowry, A. Pickle. M. Kang, D. DiGiulio, and K. Zhao, "The Depths of Hydraulic Fracturing and Accompanying Water Use Across the United States," *Environmental Science & Technology, 49*, 8969−8976 (2015).

Minor Editorial Notes

The abbreviations CWT (centralized waste water treatment) and CWTF (CWT facility) are both included in the list of abbreviations in the front matter of the report. However, in many places in the report the term CWT facility is used rather than CWTF and, more importantly, CWT is frequently used to refer to treatment facilities when CWTF or CWTFs should be used instead.

On p. 8-50, the title of Figure 8-8 describes the diagram as a "process" rather than a treatment scheme or sequence of treatment processes.

It might be appropriate to include the terms "unconventional resources" (p. 8-68) and "unconventional plays" (p. 8-72) in the glossary, for the benefit of readers unfamiliar with these terms. "Unconventional resources" may not be the best term to use on p. 8-68 (lines 9-10); "unconventional wells" or "unconventional oil and gas extraction methods" might be better.

On p. F-23, line 10 should read: "… if TDS should **need to** be reduced ~~as required by~~ **for** the intended disposal option, advanced processes such as RO, thermal distillation, or evaporation are necessary."

Comments from Dr. Paul K. Westerhoff

Much of Chapter 8 relates to Chapter 7, and comments from there are appropriate to address this charge question too. The following points need improved clarification:

1. Greater extent of information is required on the composition and fate of solid residuals from CWTs and POTWs that receive wastewaters. Disposal of these materials to landfills may impact nearby water sources. Page 8-26 is too short. There is not enough discussion of where the residuals from zero-liquid discharge facilities or reuse facilities end up. Furthermore, many POTWs land apply sewage sludges. Existing regulations may not have adequate sampling frequency to address short-term loadings from fracturing wastewaters which contain elevated levels of radionuclides and other pollutants.

2. There is some discussion of halogens (Cl and Br only) in section 8.6.1.1, but the comments from Chapter 7 are also important to address:

   > *There is inadequate information and analysis related to bromide and iodide in the report, including Appendix E. Bromide is important for drinking water because upon addition of oxidants or disinfectants (chlorine, ozone) brominated disinfection-byproducts form in drinking water (e.g., brominated THM or HAA, bromate). The ratio of Cl/Br in Table E-4 is roughly 200/1, which is lower than seawater (~300/1) and lower than the ~300/1 ratio observed in a AWWA national survey on bromide in drinking waters (Amy et al, AWWARF Final Report - Survey on bromide in drinking water and impacts on DBP formation, 1994). What is the reason for elevated bromide in the these flowback and produced waters, relative to chloride? Some places report "bromine" whereas other places report "bromide"; this should be more consistent. Same is true for iodide, although the report has very little data on iodide in flowback or produced waters. 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. The ratio of Cl/I in table E-4 is around 5000/1 which is much lower (i.e., more iodide) than the ratio in seawater which is 35,000/1. Why is there more I in flowback and produced water, relative to Cl, than seawater? While nitrate is reported in the report, there is no data on bromate, chlorate/chlorite, perchlorate or iodate – all of which have human toxicity endpoints and some have MCLs. Overall, the handling of halogens in the report is limited to chloride, and that is inadequate.*

3. Additional DBP data is needed. What are the fluctuations in total organic halide (TOX) at water treatment plants? Upstream POTWs likely receive "pulses" or "extended lower releases" of high salinity water. How are the NPDES permits written? Do they regulate based upon grab samples? Should impacted POTWs install real-time conductivity meters? 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 acute health risks to sensitive populations (e.g., pregnant women) from exposure to high levels of DBPs.

4. In table 8-2, specify the calendar years considered as "recent years".

5. Mapping of all regulated injection sites in the USA would be helpful, relative to locations of WTP intakes and population of domestic wells. Discussion on page 8-24 is too brief.

6. What is the treatment capacity (MGD) of the CWTs identified in Table 8-4, relative to the annual produced water volume within a mixed distance (e.g., 100 miles).

7. It is unclear who regulates CWTs? Page 8-25 implies this data is difficult to obtain – why?

8. The report talks about "trends" in wastewater treatment. These trends are likely to continue changing in response to availability of disposal options. What would be the likely trajectory if deep well injection is curtailed for unforeseen reasons (e.g., capacity, distance from wastewater source, earthquakes, etc.)? What would be the next likely option, based upon trends in other states? It is clear that this technology selection is fluid.

9. Trends in wastewater treatment and/or disposal will likely be impacted by the associated costs. The report inadequately addresses costs (page 8-25 or 8-36). The EPA should develop relative costs per unit volume to treat wastewaters, and costs per unit volume to dispose of wastewater to different sources. The EPA has a history, dating back to the 1970's to estimate capital and O&M costs associated with treatment and disposal options. This information would be crucial in understanding likely choices different regions make to treat wastewaters recently and in the coming years.

10. It is unclear which regulations (CWT, NPDES, SDWA, CWA) need to be augmented at the state or national level to address the significant increase in salts, nutrients and other parameters to surface waters and groundwaters to protect those ecosystems, but also to specifically protect drinking water treatment plants.

11. The EPA should develop maps of watersheds that have WTPs and active or planned upland fracturing activities.

Charge Question 7: Chemicals Used or Present in Hydraulic Fracturing Fluids

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?

Comments from Dr. Stephen W. Almond

The identification and hazard evaluation of chemicals across the hydraulic fracturing water cycle (Chapter 9) contains a very good collection of the chemicals used today in fracturing fluids being reported in FracFocus. associated with the hydraulic fracture water cycle. In addition, it points out the issue of discrepancy that arises between the chemicals which have been detected in hydraulic fracturing flowback and produced water and those listed in FracFocus, that is the CBI materials where no chemical compositions are reported.

The gathering of the chemicals used in hydraulic fracturing and providing information on their toxicological properties in this chapter will serve as base to expand from as more information is gained on specific chemical components used. It is clear that additional toxicological data on even the current list of chemicals used in hydraulic fracturing. However, the information gathered in this chapter will serve as a base to expand from as we continue to gain more knowledge of the chemicals used.

Comments from Dr. Peter Bloomfield

To the best of my knowledge, the assessment presents a clear and accurate characterization of the available information. It also goes a long way to delineate the information that is unavailable, both information about the chemical constituents of fracturing fluids that is withheld as "confidential business information" (CIB), and information about the toxicology of the chemicals that are disclosed.

As to whether the assessment identifies the constituents of concern, that cannot be answered without knowledge of the constituents, 30% of which are withheld as CIB, and without information about the toxicology of the disclosed constituents.

The stated major findings are indeed supported by the information in the body of the chapter, and I am not aware of findings that should be added. The factors affecting frequency or severity are not explicitly identified, but are discussed in the relevant section. The associated uncertainties are well described in the section with that title, but to my mind are minimized in the closing remark: *"This collection of data provides a tool to inform decisions about protection of drinking water resources."*

I can believe that the analysis tools will be useful in that endeavor, but the "collection of data" is clearly not up to the task.

Comments from Dr. James V. Bruckner

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

   This document reflects: considerable thought and planning; screening and compilation of pertinent data from key sources; organization and presentation of summary data; and concise listing of chemicals of primary interest, as well as the chemicals' toxic potential, occurrence and physicochemical properties. The authors are to be commended for formulating a quite logical approach to assess the scope and potential impacts of hydraulic fracturing on national drinking water resources-- given the very limited and fragmentary information available.

   Methods used to identify chemical constituents of hydraulic fracturing fluids (Frac Focus), as well as sources utilized to characterize their physiochemical and toxicological properties, were adequately described. It is unfortunate that so many constituents are proprietary, and that companies are allowed to freely utilize unknown chemicals of unknown hazard potential in large quantities. It does not appear there is an accurate characterization of the identity or concentrations of chemicals in flowback or produced water, due to the meager amount of information available. As noted in the text of the

document, it is essential to have information on potential levels of exposure to chemicals of primary concern and their toxicity, in order to assess potential health risks they pose.

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

Integration of toxicity, occurrence and physicochemical data for the Multi-Criteria Decision Analysis (MCDA) required that all three types of information be available for utilization of the approach. This resulted in identification of some of the chemicals that may have an impact nationally. The document's authors do tabulate 147 of the 1,173 chemicals used in fracking that have chronic RfDs and OSFs. Such values are lacking for the other 87% of the 1,173. It might be worthwhile for the EPA to compile a database for members of the 87% for which peer-reviewed toxicology or QSAR studies are available that indicate particular reasons for concern. Subchronic RfVs could also be utilized. Such information could prove quite useful in hazard assessments in local situations where such chemicals are present. It is not clear whether ACToR or another existing database fulfills this need.

c. Are the major findings fully presented 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?

I believe the document's authors have done a good job describing the assumptions, construction, use, and limitations of the MCDA approach. I do wonder whether the three criteria (i.e., toxicity, occurrence and physicochemical data) should be weighted equally, particularly when some numerical values (e.g., occurrence or levels) are based on very limited information. RfDs/RfVs may often be the most robust values. Weighting with OSFs, where applicable, seems logical, although MCLs based on noncancer endpoints may not be too different.

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

The document's authors have done a good job, in a number of places in the text, relating the number of chemicals identified in different media to the number of chemicals with toxicity, occurrence and physicochemical information. I like that the authors have highlighted (and included in Tables 9-6, 9-7, 9-8, & 9-9) in parentheses the chemicals identified for hazard evaluation and MCDA analysis. Furthermore, 10 of these chemicals (benzene, toluene, ethylbenzene, xylenes, naphthalene, 1, 4-dioxane, acetone, acetophenone, cumene and phenol) are singled out for their toxic potential and frequency of occurrence.

Limitations and uncertainties are clearly presented in subsections 9.6.1 and 9.6.3. I am most concerned about: (a) the lack of toxicity data for the majority of chemicals used in hydraulic fracturing; (b) the absence of any knowledge of the identity or toxicity of proprietary chemicals; and (c) the paucity of the studies/data on chemical identity in flowback and produced water.

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 to this section of the report?

It is acknowledged in several places in the document that chemical hazard evaluations would be most useful to conduct on a regional or site-specific basis. Has the EPA conducted any such local evaluations? I would like to have seen inclusion of a couple of such examples, perhaps assessments of more well-documented or contaminated sites, in the current document. After reading chapter 9, I am left wondering whether hydraulic fracturing may really present a significant risk to our drinking water supplies, on a nationwide scale or on a local basis-- and if so under what circumstances?

Comments from Dr. Joseph J. DeGeorge

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

While in general the report clearly discusses what chemical and toxicological data it relies on and what compounds it identified as present in hydraulic fracturing (HF) fluids and produced water (PW), it is not clear that all reasonably relevant data are discussed. Numerous comments to the docket cited the extremely limited knowledge of the hazard and toxicity information, a view derived from repeated representations in the report. Yet, the report fails to note or make clear where noted that for a number of the identified chemicals without reported toxicity information they 1) are food additives, dietary supplements or by FDA criteria GRAS with known human safety profiles, 2) 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, 3) have hazard/toxicity data that, while not meeting the stringent standards specifically defined by the authors for inclusion in the report, are of high quality, used internationally, and used by EPA in other setting. The report should explicitly indicate what fraction of the identified chemicals have hazard/toxicity information if all sources from States (in addition to CA), other Federal Agencies, and International Bodies were employed, even if not meeting the very stringent criteria used for the report. The lack of clarity or exclusion of such information without clear delineation of the impact on the assessment inflates the "unknown" hazard information, rather than making clear that there is

substantial unused hazard information. This could misdirect policy makers in their attempt to encourage closing the hazard information gap.

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

The report does clearly identify and describe some constituents of concern that could potentially impact drinking water (DW) resources as defined by the report. However, for the following reasons this cannot be viewed as comprehensive within the context of the report.

1) Given the absence of integration of "exposure" information (i.e., specific volumes and/or concentrations) for most chemicals composing HFF or PW that may impact DW resources (or failure to use such information where it is known), it is not possible to assess potential impacts (or absence thereof) on DW resources. For example, identified toxicants that are present under conditions of exposure where the exposure is below the Threshold of Toxicological Concern (TTC) would pose no potential impact. This is not discussed within the report nor in the context of the constituents of concern.

2) The uncertainty factors used in calculations of toxic potential and subsequently used to derive the compounds of concern under the MCDA framework often appear to be the drivers for inclusion in the grouping of constituents of concern. For example, propargyl alcohol is named as a chemical of concern, largely driven by the uncertainty factor (3000X) applied in deriving the RfV, rather than an identified hazard. Such calculations used in determining the MCDA, could distort the identified list of compounds with most potential concern. While the methodology is provided, the impact of some of the assumptions are not clearly articulated.

3) It is not explicit within the assessment which of the many pathways for impacting DW resources as described, are of greatest potential or likelihood. Absent such directional information it is not feasible to conclude which constituents, each differing in occurrence, concentration, and volume during the various phases of HF gas and oil extraction are of greatest concern. For example, if spills of HF fluids at pad sites were considered of substantially greater likelihood of occurrence and impact than spills of PW, then the constituents of concern would differ, based on the substantial chemical compositional differences in HF fluids and PW.

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

EPA has done an outstanding job in identifying the chemical components associated with HF gas and oil extraction. To the extent that a major conclusion of the Chapter 9 as on defined lines 26- 35 is that there are data gaps, this is supported. However, the extent of the data gaps on the hazard posed by the chemical constituents appears to be magnified

by the failure to consider information on the chemicals that did not meet the extremely stringent criteria for consideration (see 7a above). The methodologies used to determine the chemicals of most concern (selected from those chemicals which did have data to meet the reports criteria) could skew the analysis and may not identify those chemicals with the greatest potential impact on DW resources.

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

The failure to directly consider and include exposure, use of TTC concepts, and best practices for mitigation of hazards identified in the course of the analysis (e.g., any information on trends in substitution of less hazardous chemicals as well as containment practices) , should be addressed to the extent feasible or be noted as gaps in the assessment report. That there is substantially more information available on many of the chemicals than was used in the report needs to be brought forward to the conclusions in section 9.6.4.

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 and discussion of factors influencing frequency or severity of potential impacts. For example, while there is some information on HF fluids used in a various volumes and storage containers, as well as some mention of variations in secondary containment, there is no discussion on how this could impact the spill conditions despite noting container failure as a substantial contribution to spills. Likewise, while there is discussion of well failures as an impact on DW resources, there is limited discussion of the likelihood of the failure at different development stages and the types of chemical constituents that would be released (e.g., well communication failures, over pressuring failures, structural failures during operation). Each of these elements (and numerous others) are discussed in the report, but there is limited synthesis with the chemical constituents as defined in chapter 9 and how this may affect the severity of DW resource impacts.

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

The existing uncertainties, assumptions, and limitations are generally well defined within the context of the report. However, importantly as noted above, there is minimal information of the impact of the excluded data sources, with exception of what fraction of chemicals have hazard information in the ACToR database (55%) versus the 13% based on the stringent criteria applied in the assessment report.

Additionally, there is an inherent assumption in the analysis that chronic toxicity data should be the basis for the identification of chemicals of potential concern. It is not clear based on the nature of the exposures, for example, local surface spills, that in all cases exposures/impacts are likely to 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 over estimations for some impacts (those noted yielding transient exposures).

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?

In addition to the data/research gaps noted above and broader data inclusion of additional hazard identification (as one docket comment suggested, "tiered" application of data sources not meeting the report's stringent criteria) the following should be considered. Understanding for those chemicals present and identified in PW, based on TTC concepts and established limits where they exist, what levels can be excluded as presenting an impact on DW resource quality. For those chemicals not identified but suspected in PW, what analytical thresholds would be necessary to achieve such that the absence of detection constitutes no "impact" (based on TTC concepts for those without toxicity data and established limits for those with such values)? In both cases exposure consideration needs to be included in the assessment.

There is a major gap in knowledge of CBI chemicals. The absence of disclosure to the public and exclusion from the assessment report of any aggregate information on the potential hazard posed by these chemicals is a significant information gap. This has been identified many of the contributors to the docket as a source of concern. EPA could provide aggregate information for the CBI chemicals disclosed to them which could generally inform on the potential for significant impact (or not) from CBI chemicals. For example, based on case information shared confidentially with EPA, EPA is aware of a spectrum of chemicals that are considered CBI, their similarity or overlap with publically disclosed chemicals, the known toxicity/hazard (or absence thereof) considering all hazard information available, the number/fraction of unique chemicals covered by CBI without any hazard information, or the fraction that would reasonably be considered to pose a potential impact on DW resources. Consideration should be given to provision of such information within the report. It would be a valuable contribution to the report conclusions without publically disclosing any CBI chemicals and would enable an assessment of the extent this gap in public information engenders.

In this Chapter and throughout the report, chemical constituents and potential impacts unique to HF oil and gas extraction should be clearly delineated from those which also exist as a component of conventional oil and gas development. This is not to say that those which overlap both production methods should not be included, but rather that those which pose unique potential impacts from the specific methods of HF production should be highlighted. For example, it is not clear from this chapter or the report to what extent HF PW through its chemical constituents poses significant, unique potential impacts to DW resources (other than over the first few days when flowback water contains HF fluid constituents). As such it is not clear that the compounds in produced

water identified as of most concern are the product of the HF activity, flowback, late stage PW, or chemicals of concern derived from oil and gas production irrespective of HF activity.

Are there relevant literature or data sources that should be added in this section of the report? EPA should extend its analysis of hazard to include other sources of information on the safety or hazard of all of the listed chemicals/constituents in it list of identified chemicals in HF fluids and PW. While EPA can and should provide its high stringency analysis for the most definitive answer (noting the liabilities in the approach as indicated, see answer b above), it should also provide analysis that includes data from any State chemical assessment, other US Regulatory Agency assessments and declarations (such as GRAS status or allowed food or dietary supplement uses), publications by credible international bodies, its own data not considered for inclusion in this report, or other accepted toxicology principles (e.g., TTC) to understand the true extent of the gap in toxicity knowledge. EPA appears to have done a scan of such data noting it only found California data meeting its requirements, and that an examination of ACToR yielded information on many additional compounds. EPA should revisit this activity and find ways to use the expanded information in the assessment. Perhaps as suggested in one of the docket comments, this additional hazard information could be used in a "tiered" evaluation. This would substantially reduce the number of chemicals with unknown hazards and could better identify chemicals of concern used in HF activities with potential to impact DW resources.

Comments from Dr. Elaine M. Faustman

"The purpose of this assessment[6], entitled *Assessment of the Potential Impacts of Hydraulic Fracturing for Oil and Gas on Drinking Water Resources*, was to synthesize available scientific literature and data on the potential for hydraulic fracturing for oil and gas to change the quality or quantity of drinking water resources, and to identify factors affecting the frequency or severity of any potential changes."

Overall the document provides an extraordinarily clear and detailed assessment of the processes involved in Hydraulic fracturing, where these activities take place and how the process may differ by location. It provides a very clear inside view of how these activities impact the amount and source of water and how hydraulic fracturing activities link with the overall cycle of water use. In this context the document is excellent and provides an extraordinary resource.

However it is the opinion of this reviewer that the document doses not adequately address the factors affecting the frequency or severity of any potential health impacts. Thus the full purpose of report was not met by specific chapters of this document. In particular this purpose was not

met in Chapter 9 "Identification and Hazard Evaluation of Chemicals across the Hydraulic Fracturing Water Cycle".

This is reflected in multiple ways that I will delineate below but does include:

1. Disconnect from what the public comments are requesting for impact information
2. Evaluate appropriate tools for the majority of the data. Provide additional assessment methods that use tools that evaluate more of the available data rather than focus on data that fits into the specific Decision tool chosen for this analysis. Focus on other decision models that can use the data that was available and include these assessments as well.
3. Inconsistent application and inclusion of peered and non-peered review data between chapters

Specifc Charge Questions:

2. The assessment used available information and data to identify chemicals used in hydraulic fracturing fluids and/or present in flow back 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?

There are many major findings that have not been adequately brought forward. This reviewer was not in agreement with how this "Identification and Hazard Evaluation of Chemicals across the Hydraulic Fracturing Water Cycle was presented and analyzed. Note that this reviewer combined responses across some of the charge question subsets.

Detailed comments for Chapter 9:

Section 9.1 introduction provides some details on what process was used to evaluate potential impacts on drinking water resources. Although the overall document emphasizes that this document does not include a risk assessment this section would be the place to clearly delineate what is a risk assessment. Add a few more specific definitions here to help general reader and stakeholders who still think this is the anticipated outcome.

Good emphasis on missing data in Page 9-2 lines 3 to 11 and the potential for missing potential health impacts.

Section 9.2 Identification of chemicals… through Section 9.3 Summary of toxicological and physiochemical property data…

These sections clearly present a process that EPA used to identify 1, 173 chemicals and this is available in the Appendices A and B. A summary figure 9-1 summarizes a part of this process and information.

This reviewer feels that this assessment process was not adequate and was not consistent with the other chapters in how peer reviewed versus non-peer viewed information was used. For example in Chapter

Why wasn't a general vulnerability analysis conducted where each of the 1,173 chemicals were assessed if any peer –reviewed article identified these chemicals as potential toxicants. Since this was not a risk assessment it appears that to set the context for needed follow-up that this initial vulnerability analysis is needed for each of these identified chemicals. This is a straight-forward and well accepted approach for initial scoping of potential for impacts during hazard evaluations. Requiring that a specific RfV or OSF be required seems to be a very high initial hurdle in this process.

Use of FracFocus as key check point for inclusion of health information in further analysis also should be discussed and questioned. Note that is not a peer reviewed database but a "..national hydraulic fracturing registry for oil and gas well operators to disclose information about hydraulic fracturing well locations and water and chemical use during hydraulic fracturing operations developed by the Ground Water Protection Council and the Interstate Oil and Gas Compact Commission " See page 4-5 and Text Box 4-1 on page 4-15. These section goes on to discuss that it is largely voluntary and emphasized only a few regions of the US were included in this assessment (lines 5- 8, page 4-15). This text states that : "Estimates based on the EPA's FracFocus project database likely form an incomplete picture of hydraulic fracturing water use because most states with data in the project data base (14 out of 20) did not require discloser to RacFocus during the time period analyzed." This should not be used to set the potential exposure considerations for Chapter nine assessments.

Chapter 4 also provides important considerations lost in the assessments conducted in Chapter 9. For example, page 4-16 discusses the potential for drinking water impacts such as "For instance, in the absence of controls surface water withdrawls can lower water levels and alter stream flows, potentially decreasing a stream's capacity to dilute contaminants… further more ground

water withdrawals exceeding natural recharge rates may lower the water level in aquifers, potentially mobilizing contaminants or allowing the infiltration of lower-quality water from the land surface or adjacent formations.."

This information or at least possibilities need to be discussed in the context of Chapter 9 as well.

Handling confidential information—missing in discussion of approaches and context for Chapter 9

Without revealing exact compounds has EPA reviewed their CBI data to see some statistics of potential hazard? For example, does EPA have number of known carcinogens, reproductive or potentially toxic chemicals that are a part of the CBI data for fracking related products? EPA could still do an assessment of total chemicals of concern that are present in CBI data without specific chemical info. Could a figure like 9-2 or review of broader data sets be done? This would help open this door without giving away business secrets. It also would go towards a more transparent process to know that hazards are being considered as part of our PMN process.

Inconsistent application of peered and non-peered review data between chapters

This reviewer applauds the report and the approach to be inclusive of data sources. The quote below from the review document is excellent and represents a monumental approach to compiling relevant data from many sources some of which have been extremely difficult to obtain and locate in one place. This is a great success of this document. The EPA has met its intent as stated below:

"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 EPA. The assessment also included citation of relevant literature developed as part of the Study Plan. "

However given this statement and approach this reviewer feels that the EPA assessment is not a consistent "synthesis of the science." For example in Chapter 5, there is extensive use of all data sources and many non-peer reviewed documents are listed –see page 5-70, lines 4 to 13 and discussion of strategies for reducing toxic chemical use across these documents.

Yet in Chapter 9 a very strict criteria for data use and access in provided (see pages 9-16 through 9-18). In fact for this chapter's assessment, the lack of formal risk evaluation numbers such as oral RfV,or lack of available data on frequency of use negated the review of those chemicals and resulted in a dramatic drop in the number of the chemicals to be assessed from 1,076 and 134

representing chemicals used in hydraulic fracturing fluid and flowback and produced water respectively to only 37 and 23 respectively for further health impact. This only represented 3 percent of the total chemicals of interest and found present in these fluids under review to be assessed as few chemicals met this criteria not that the other chemicals were without hazard. This reviewer feels strongly that other health impact assessment approaches should have been presented perhaps in parallel.

Figure 9-2 presents the fraction of chemicals that appears in ACTor but what are these numbers if the criteria is shifted and each chemical searched on whether that are any peer-reviewed reports on these chemicals that provides assessment of toxicity. It is difficult to determine from such analyses as presented is it that ACTor did not assess these chemicals or is the data for most of the chemicals missing. Additional assessments such as 9-2 could be available for systematic review of the literature not just info in the ACTor database.

As limited as they are Table 9-6 and Table 9-8 are useful for the chemicals that passed the data hurdle. What is less clear is what I would do with the Hazard potential score for these very few chemicals given the larger proportion of chemical over 97% that are not being included. Can EPA provide some context for what to do or future steps especially for the report users—how to deal with this uncertainty.

This reviewer is very supportive of multi-criteria decision models and there are many options available for these methods that would be more appropriate for these data limited situations. Some of these maybe more qualitative but this reviewer feels that it is essential that the data drives the tools and not the reverse that the tool drives the data as appears in this case.

The EPA clearly states in multiple places that it is not "[I] t 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. ". It is the opinion of this reviewer that the document does not meet this later purpose since so many chemicals were excluded from the evaluations that were conducted.

Comments from Dr. Richard F. Jack

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

> Yes, the EPA uses available information in light of the fact there is a lack of published peer-reviewed epidemiological and toxicological studies and have their health effects as a result of hydraulic fracturing.

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

Yes, the EPA report identifies and describes constituents of concern that can potentially impact drinking water resources based on available information. This is highlighted

"The U.S. House of Representatives' Committee on Energy and Commerce Minority Staff released a report in 2011 noting that more than 650 products (i.e., 16 chemical mixtures) used in hydraulic fracturing contain 29 chemicals that are either known or possible human carcinogens or are currently regulated under the Safe Drinking Water Act (House 18 of Representatives, 2011). However, that report did not characterize the potential toxicity of many of the other compounds known to occur in hydraulic fracturing fluids or wastewater. "

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

Yes. The uncertainties and limitations are well described. Namely that the majority of chemicals used in hydraulic fracturing lack sufficient epidemiological and Toxicological information. Also quote above.

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

The limitations are mentioned several times throughout this chapter, a few examples include:

Lines 19-20"…However, that report did not characterize the potential toxicity of many of the other compounds known to occur in hydraulic fracturing fluids or wastewater "

Line 24 "this study only reported acute toxicity (from lethal doses), which may differ from the effects of low-dose, chronic exposure to these chemicals"

Among others describing limitations.

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?

There are significant research and information gaps that limit the ability to make clear, comprehensive conclusions about HF chemicals and the ability to protect the public and its impacts on drinking water sources. This is best illustrated in figure 9-1. Of the 1076 chemicals potentially use in hydraulic fracturing, only 134 chemicals have been detected. The report is correct in pointing out the fact that there are trade secrets as well as a lack of analytical methods and laboratories able to perform the specific analyses required. This is further exemplified that of the 692 chemicals reported in frac focus only 75 have been measured in flowback or produced waters. There's also a lack of use data for 384 chemicals used in hydraulic fracturing.

This same example of lack of available information occurs when the report discusses toxicological and physiochemical data. Again in table 9-1 highlights this gap. There is data lacking for oral Rfv or OSF for 1026 chemicals. In addition, there is a lack of physiochemical data for 658 chemicals used in hydraulic fracturing.

Without this crucial information, it is virtually impossible to claim that hydraulic fracturing does not have the potential to cause epidemiological or toxicological affects in humans.

Additional information

This chapter should include a discussion mean of radiation from FlowBack and produced waters. It is well known that radium ^{226} and radium ^{228} are known to occur in the Marcellus shale. In a steady from the state of Pennsylvania titled " TECHNOLOGICALLY ENHANCED NATURALLY OCCURRING RADIOACTIVE MATERIALS (TENORM) STUDY REPORT" was recently published in January 2015.

The observations from this report mentioned if you instances where radiation can affect the public.

"There is little potential for radiological exposure to workers and members of the public from handling and temporary storage of hydraulic fracturing fluid on natural gas well sites.

However, there is a potential for radiological environmental impacts from spills of hydraulic fracturing fluid on natural gas well sites and from spills that could occur from the transportation and delivery of this fluid."

Radium-226 was detected within the hydraulic fracturing fluid ranging from 64.0 – 21,000 pCi/L. Radium-228 was also detected ranging from 4.5 – 1,640 pCi/L. The hydraulic fracturing fluid was made up of a combination of fresh water, produced water, and reuse flowback fluid. (Section 3.3.2)

"

There is potential for internal radiation exposure to workers and members of the public from α and β surface radioactivity at CWTs that treat O&G wastewater. Fixed α and β surface radioactivity may present a potential inhalation and ingestion hazard if disturbed during routine system maintenance. "

"*…However, there is a potential for radiological environmental impacts from spills and the long-term disposal of landfill filter cake from landfills that accept O&G waste for disposal."*

Add sampling and analyses for Ra-226, Ra-228, and additional man-made radionuclides such as tracers used in the O&G industry to Pennsylvania spill response protocol for spills of flowback fluid, hydraulic fracturing fluid, or produced water. Field survey instrumentation should also be available for surveys of areas impacted by the spill.

TECHNOLOGICALLY ENHANCED NATURALLY OCCURRING RADIOACTIVE MATERIALS (TENORM) STUDY REPORT Pennsylvania Department of Environmental Protection, Rachel Carson State Office Building 400 Market Street Harrisburg, PA 17101

Context to be addressed

Additional toxicological studies on HF chemicals collected prior to injection and their biotransformation, (degradation) products.

A section should be written that describes endocrine disruption (chemicals that affect hormone function) in the environment. These chemicals can also affect drinking water supplies. Below are references that discuss endocrine disruption from personal Care Products:

Kumar A, Xagoraraki I. 2010. Pharmaceuticals, personal care products and endocrine disrupting chemicals in U.S. surface and finished drinking waters: A proposed ranking system. *Sci Total Environ* 408:5972–5989.

Hannah R, D'Aco VJ, Anderson PD, Buzby, ME, Caldwell DJ, Cunningham VL, Ericson JF, Johnson AC, Parke NJ, Samuelian JH, et al. 2009. Exposure assessment of 17alpha-ethinyl estradiol in surface waters of the United States and Europe. *Environ Toxicol Chem* 28:2725–2732.

Kumar A, Xagoraraki I. 2010. Pharmaceuticals, personal care products and endocrine disrupting chemicals in U.S. surface and finished drinking waters: A proposed ranking system. *Sci Total Environ* 408:5972–5989.

Comments from Dr. Abby A. Li

Question 7a. Does the assessment present a clear and accurate characterization of the available chemical and toxicological information concerning chemicals used in hydraulic fracturing?

EPA clearly explains the steps they took to identify chemicals used in or released by hydraulic fracturing (HF) operations, and provides tables in Chapters 5, 7, and 9 and related appendices that characterize physicochemical properties (most and least volatile), occurrence in HF fluids as reported in FracFocus, estimated volumes and chronic reference values meeting EPA's criteria. EPA identifies several important sources of toxicological information, but they set stringent criteria for acceptable reference values. Consequently, EPA does not appear to be fully utilizing the available toxicological data. To more accurately characterize the available toxicology information, EPA could include additional columns in Appendix A-2 that list whether peer-reviewed toxicology reference values are available that may not have met all of EPA's criteria, or the existence of a relevant *in vivo* guideline assay that has been used by a federal agency for risk assessment.

EPA proposes a multi-criteria decision analysis (MCDA) framework for hazard evaluation that integrates toxicity, occurrence (or concentration), and physicochemical data. EPA clearly explains the approach, which is a reasonable starting place for prioritizing potential hazards. EPA's MCDA framework moves in the right direction toward considering both toxicology and potential exposure when prioritizing level of concern. However, EPA did not test whether "occurrence" is a reasonable surrogate for concentration based on data they may have for some of the chemicals.

Section 9.2: It would be helpful if EPA would integrate and briefly summarize information from earlier chapters and add such a summary to Section 9.2. The following information provides perspective on relative concentrations:

- The median total volume of HF fluid used per well (P.4-48)
- A brief overview of components of HF, and use of concentrated acid in the initial cleaning phase (P. 5-6 line 14-20)
- The range of volumes for each chemical used in HF (P. 5-24) and that might be stored on site (P. 5-28).
- The estimated volumes of most frequently reported chemicals, noting the large variability in median values.
- It may be helpful for EPA to provide background information on the regulations already in place that HF companies must comply with to address transport, storage, spills, and worker safety, and the type of regulatory toxicology levels and reporting requirements that are already in place if there are incidents.

Section 9.3: Section 9.3 and Appendix G provide clear explanations of the criteria that EPA used to evaluate the quality of reference values (RfVs) and oral slope factors (OSFs). EPA does not discuss the possible utility of acute and shorter term toxicity data or evaluations that may be relevant to addressing exposure to HF fluids from spills and blowouts.

EPA lists QSAR (quantitative structure-activity relationship) modeling and the ACToR database as potential sources of toxicology information that is needed, because so few chronic RfVs were available (8.4% of HF fluid chemicals and 62% of chemicals reported in flowback/produced water). Before moving so quickly to QSAR or the ACToR database, some of the sources that EPA rejected (EPA MCLG or MCL, TERA ITER, and VCCEP) should be reconsidered. ACTor includes a wide range of toxicology information based on *in vivo* data that is not peer reviewed, and at present, it is premature to use the *in vitro* data if adequate *in vivo* data are available. The TERA VCCEP program was commissioned by EPA and has provided peer-reviewed assessment of many of the HF chemicals, with an emphasis on children's health. EPA excluded MCLs, because they are treatment based (P. 9-6), but given all the uncertainty associated with using "occurrence," EPA could consider MCLs or MCLGs when prioritizing concern levels using the proposed multi-criteria decision analysis (MCDA) approach.

The problem of availability of toxicology data for chemicals is not unique to HF, and EPA might consider approaches used by other regulatory agencies, such as read-across and GRAS (generally recognized as safe) for some of the chemical substances.

Question 7b: Does the assessment clearly identify and describe the constituents of concern that potentially impact drinking water resources?

Section 9.4.1 clearly explains the four subsets of chemicals that were identified as being of interest in chemical mixing and flowback/produced water. In earlier chapters, EPA provides estimates of volumes and concentrations in HF fluids and flowback/produced water.

Table 9-2 lists 32 most frequently used chemicals in HF. This is reasonable in the absence of data on volume, but EPA might test how the reliability of this information by comparing with published data on volume.

EPA focuses this chapter exclusively on chronic hazards. EPA may want to include discussion of whether acute or shorter term environmental exposure risks might be more likely to exist than chronic risks, for some realistic worst-case scenarios. This will inform decisions on the most relevant toxicology data to include, and there many more potentially useful short-term studies may be available than chronic RfVs.

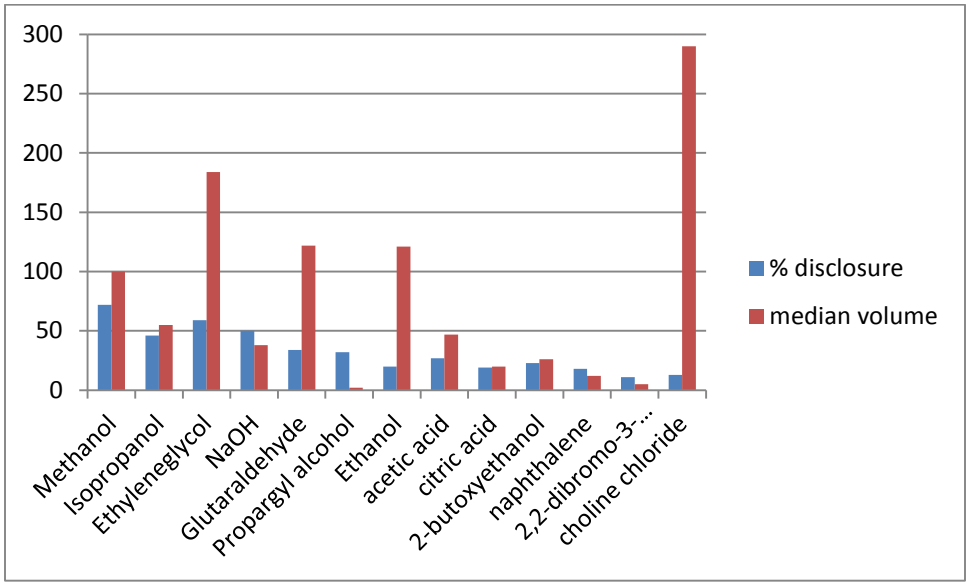
Question 7c: Are the major findings fully supported by the information and data presented in the assessment? Are there other major findings that have not been brought forward? Are the factors affecting the frequency or severity of any impacts described to the extent possible and fully supported?

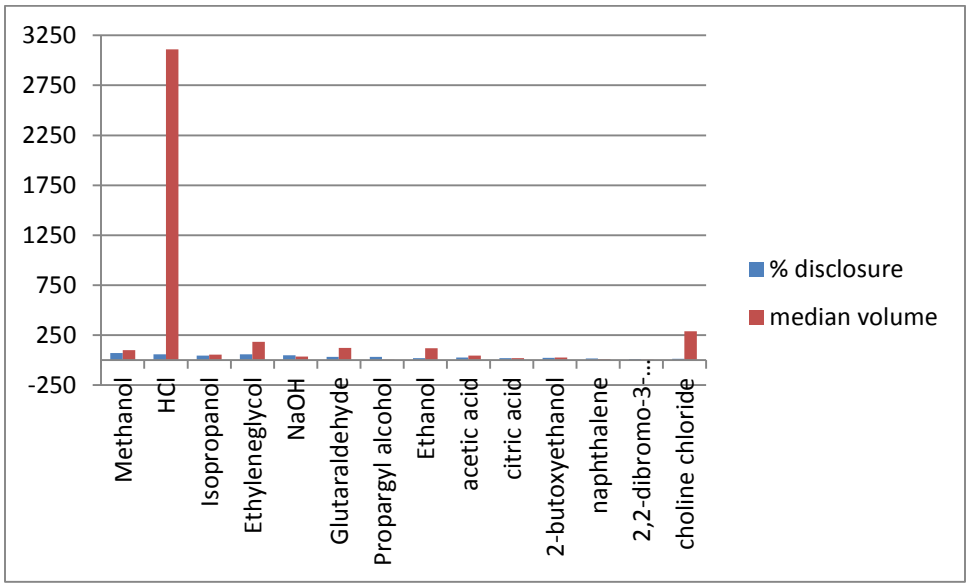
The major conclusions of this chapter are that the MCDA approach is a tool that can be used to inform decisions about protection of drinking-water resources—decisions that can be adapted to include different variables, different weights for those variables, and site-specific considerations. The MCDA approach is a reasonable starting place to identify potential priorities for further investigation of chemicals of concern as drinking-water contaminants from HF. Chapter 9 also concludes that the information therein would allow industry to prioritize chemicals for replacement with less toxic, persistent, and mobile alternatives. This depends on whether "occurrence" is a reliable estimate of potential exposure, and on EPA making use of all the toxicological data available.

Question 7d. Are the uncertainties, assumptions, and limitations concerning chemical and toxicological properties fully and clearly described?

EPA discusses several notable uncertainties in the chemical and toxicological data in Section 9.6.3. One uncertainty that EPA does not address is that frequency of disclosure is not necessarily correlated with volume of chemical per well. This is illustrated by the following graph of frequency reported in Table C-2, and estimated volume from Table C-

4, for chemicals that had both values (the first figure without HCl, and the second with HCl).





Question 7e. What additional information, background, or context should be added, or research gaps 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?

Additional information on available toxicology data:

- See response to Question 1a.

- The REACH/ECHA chemical database has test data for a large spectrum of chemicals that may be useful.

Charge Question 8: Synthesis of Science on Potential Impacts of Hydraulic Fracturing on Drinking Water Resources, and Executive Summary

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 hydraulic fracturing water cycle 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?

Comments from Dr. E. Scott Bair

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

Preface. I see a difference in the purpose and goal of the Executive Summary and those of the Synthesis. The Executive Summary, because it likely will be read by more people having more diverse backgrounds and knowledge than any other chapter of the report, needs to present materials in a manner that instructs (teaches). This entails defining terms within the text, avoiding acronyms, greater use of figures and graphs, and avoidance of long, jargon-rich sentences. In contrast, I think the Synthesis is most likely to be read by people who have expertise in one of more topics associated with hydraulic fracturing, who will read those chapters in detail, but will read the Synthesis sections to get a deeper scientific overview than is presented in the Executive Summary.

The differences in the goals and purposes between the Executive Summary and the Synthesis should be a topic of general discussion and should be described to the reader in appropriate places.

1. The majority of the Executive Summary and Chapter 10 are well-written and organized in a logical manner. I have two primary criticisms. The first is that too many synonyms are used, which often confuses broader audiences. Other terms are misused or need to be clarified or defined within the context of the report. The second is presented below.

For example (pg. ES-18, line 7): in general, sandstones are not tight formations and commonly serve as major reservoirs for oil/gas plays and groundwater resources. Use

of the phrase "gas-tight sandstone" is a recent development and should be defined in the body of the report as well as in the Executive Summary

2. Another example is use of the term "chemical" to refer to dissolved ions in water (see pg. ES-18, lines 11, 23, and in many other lines). In terms of flowback water, groundwater and brines naturally occur in the pore spaces of deep sedimentary rocks, these "chemicals" are dissolved solutes (cations and anions) in water, the solvent. To the general public, the term "chemical" implies a manufactured compound (liquid or solid). I suggest defining the term "chemical" within the body of the report to refer to manufactured compounds (solids and liquids), such as those mixed chemicals with surface, groundwater, and/or wastewater for injection into an oil/gas zone to be hydraulically fractured. This avoids the confusion with naturally-occurring dissolved ions.

3. The term "compound" is also a source of confusion. It is used to refer to dissolved, ionic components in water. To me, a compound can be natural or manufactured – minerals are naturally occurring compounds. Mineral compounds that hydrolyze (dissolve in water) become anions and cations (solutes) in the solvent water. To clarify this in the report, the terms "manufactured compounds" and naturally-occurring compounds" could be used in the report. As it stands, many places in the text give the impression that naturally occurring surface waters, ground waters, springs contain large concentrations of chemicals and compounds.

4. Another example is the use of the term "oral reference value" or slope factors. These terms are not defined or explained to the reader in the Executive Summary. The term "chronic reference value" needs to be defined and explained, particularly in light of the fact that most of these exposures are likely to be acute, not chronic. Text also needs to be added describing the (large?) uncertainties in calculating oral references values. Without these explanations and text, the paragraphs at the bottom of page ES-18 and the top of ES-19 may cause unnecessary and unjustified alarm. Just look at the list of <u>potential</u> health effects on page ES-18, lines 35-37 (see below). To me, it is misleadingly frightening.

> "Of the chemicals that had [oral reference] values available, noted health effects include the potential for carcinogenesis, immune system effects, changes in body weight, changes in blood chemistry, pulmonary toxicity, neurotoxicity, liver and kidney toxicity, and reproductive and developmental toxicity."

5. Another point of confusion that exists in the Executive Summary, the Synthesis, and in other chapters that deal with water wells and oil/gas wells is the need to periodically qualify the type of well that is being described. Often the word "well" is used multiple times in the same sentence or in sequential sentences where it refers to

water wells and to oil/gas wells. The potential for this confusion can be mitigated by occasionally inserting the word "water" well or "oil/gas" well where appropriate.

6. Page ES-5, lines 27-28 show the need to also include depth when describing the proximity of hydraulically fractured wells to residences, towns, and drinking-water resources. To me, yes, the lateral distance that a well is away these structures is an important safety measure, but equally important is the depth of the well and its production zones from underlying aquifers (USDWs). The remarks made on pages ES-5 and 6 needs to be tempered to remind the reader that the production zones are most commonly thousands of feet deep, sometimes more than a mile deep, which also provides an important measure of safety, especially if construction of the well adheres to modern regulatory guidelines and state-of-the art methods.

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?

1. Yes and no. Whenever the target for a report is a broad audience (i.e., the general public) it is critical to include lots of pictures, diagrams, and graphs. It is a great example of a where a picture is worth a thousand words. Most people are visual learners. As a result, many people get frustrated by reading page after page of text, particularly when it is deeply embedded with scientific jargon. The Executive Summary would especially benefit from the addition of several diagrams and graphs. I do not think this is necessary for the Synthesis.

2. In terms of the major findings of the report, which are described on ES-6, I am left wanting more detailed information than given in the last sentence of the second paragraph (see lines 20-21). "The number of cases, however, was small compared to the number of hydraulically fractured wells."

To me, this major finding came out of left field. It was a big surprise because the following sections of the Executive Summary and within the report do not lead the reader to even contemplate this result. It is a non-sequitur relative to the body of the report. Perhaps, too much of the report addresses the potentials for impacting water resources and human health without including any qualifying statements about the likelihood that these potential impacts may or may not occur. Lacking these qualifying statements, I think the findings in several chapters to be somewhat frightening and not consistent the major finding on lines 20-21.

Put another way, there are about 700 pages (24,000 lines) presenting the potential impacts of hydraulic fracturing on water resources and human health but only 2 lines concluding that it is not a universal problem. Talk about a surprise ending!

Somehow, a way has to be adopted that describes the likelihood (probability) and severity of the potential impacts. Without such an approach, I can appreciate the sometimes irrational fears of fracking that some people possess.

To this end, I think it would help if this sentence (lines 20-21) and other concluding remarks could include some quantitative measure of frequency, likelihood, and/or severity. For example, how many cases represent a "small" subgroup? How many cases in total were included in the total group?

3. Another common point of confusion is created by describing potential risks caused by natural phenomena that occur at far different time scales. For example, ES-10, lines 12-18 describe the possible impacts of water withdrawals for hydraulic fracturing on water quality. What is not presented to the reader is that water withdrawal is a short-term (a month, maybe two per well) and changes in local water quality are natural (normal), occur quickly in streams and rivers, and occur very slowly in groundwater. As a result, changes in water quality from water withdrawal most likely will be seen in the short-term, especially if no monitoring wells are required.

To me, more emphasis and detail needs to be added to the report describing the differences in time scales and time durations of many of the possible impacts.

4. Also, see D below.

c. In Chapter 10, have interrelationships and major findings for the major stages of the hydraulic fracturing water cycle been adequately explored and identified? Are there other major findings that have not been brought forward?

No comments at this time.

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

1. Nowhere in the Executive Summary or in the Synthesis is there a description of naturally-occurring fractures in rocks. The movement of fracturing fluids from the target oil/gas well, hundreds to thousands of feet upward to an USDW (underground source of drinking water), is by far, in terms of distance and time, along natural fractures and bedding planes in the overlying rocks. The public needs to be informed about the properties of these fractures, not just the induced fractures from hydraulic fracturing.

I suggest that a couple pictures of natural fractures at outcrops or in cores and one or more diagrams from structural geology books be added to the Executive Summary and Synthesis so the general public understands that the upward path to a USDW is tortuous, occurs in geologic formations that have far different permeabilities and porosities along a network of discontinuous fractures that can be inches to ten of feet long with apertures that can change from the width of a hair to the width of a silver dollar.

Without this type of description and visuals, the general public may fallaciously believe that the fracturing fluids travel vertically upward in a continuous tube the size of a water pipe.

2. Much of the information presented in the report is old, at least in terms of changes in the extraction of oil/gas from shales and tight sandstones. As a result, the reader (public) does not get an appreciation of what changes have occurred in terms of technological advances and in terms of regulatory advances. Adding such a section to the Executive Summary, main report, and the Synthesis would enable readers of all shapes and sizes to appreciate how environmental issues from the early years of fracking horizontal wells have been addressed over the course of time. Personally, I think this is an important section one that might allay some of the irrational fears about hydraulic fracturing, water resources, and health issues.

Specific comments

1. Page ES-7, line 2: "…at this scale." is too nebulous. Change it to "across the United States" so the reader remembers the scale being described.

2. Figure ES-3, Title description, line 1: Replace the word "flows" with the word "goes." Water does not actually flow through the USEPA-defined hydraulic fracturing water cycle. Define in the text the acronyms CWT and UIC, or have a list of acronyms at the beginning of the section.

3. Page ES-10, line 36: Insert the words "in part" so the sentence reads "…chemicals depend in part on the characteristics of…" The potential impacts also depend on rainfall, runoff, infiltration, etc.

4. Page ES-10, line 28: Insert the typical percentage of water in typical hydraulic fracturing fluids. I think it is 98 to 99 percent. This makes the statement less nebulous and helps quantify the concept for the reader.

5. Page ES-11, lines 8-10: Gosh, this is such a horribly speculative, linear extrapolation of such limited data that its sole purpose seems to be to scare the reader. Such wild speculation should not be included in an EPA report – leave it to the tabloids.

6. ES-12, line 21: The word "quickly" should be removed from the sentence. Many organic solvents are retarded, relative to groundwater flow, due to sorption onto organic matter in soil and in sediments. As a result, they move much more slowly than the groundwater. The environment should be qualified by calling it the "shallow environment" because spills of these fluids also will be subject to dilution from rainfall and snowmelt, dispersion in soil water and ground water, and possible degradation or consumption by soil bacteria. To me, the concept presented in lines 24-26 is too nebulous

and does not mention any of the possibilities that some of these 453 compounds may not remain in groundwater for prolonged times, which is inferred by the text.

7. ES-13, line 29: This is another place where the duration of a potential impact should be presented. The word "temporarily" needs to be inserted so that sentence reads as "…temporarily reducing the water's pH and increasing it conductivity." The word "significantly" should be dropped. Significance without the testing of a statistically valid population lies in the mind of the writer.

8. ES-13 and 14: There needs to be a paragraph or two added describing the nature of natural fractures, their occurrence and characteristics in different sedimentary rock types, and the fact that most of the path from the fracked zone to the land surface will occur in a network of natural fractures that are discontinuous and vary in aperture, length, and density. It is also a great place to insert a diagram or two so the reader can digest the preceding text and concepts, and visualize what such a long, disjointed, heterogeneous path looks like.

9. Page ES-14, lines 6-24: This section with all the description of how a well is constructed (various types and lengths of casing) is a great place to insert a diagram showing the different types and lengths of casing, cement in the annular spaces, and the production casing. The reader will understand what a well looks like far better if it is presented in a diagram.

10. ES-15, lines 15 on: This section which addresses the question whether liquids and gases can migrate to overlying drinking water resources completely ignores the role of natural fractures. This is a major oversight! It needs to be fixed so the public can appreciate and understand the entire potential migration process.

11. ES-16, paragraph 1, lines 3-13: The reader needs to know which of the studies described are based on direct observations (measurements), which are conceptual, and which are based on interpretive models. Statements qualifying the results presented in this paragraph need to be added.

12. Page ES-16, Flowback and Produced Water: The material in this section largely ignores the presence, chemical composition, and chemical characteristics of the natural groundwaters contained in the rocks surrounding the fracked well. At depths greater than 3000 to 4000 feet, most of these waters will be brines having TDS concentrations ranging from 100,000 to more than 300,000 mg/L. The role and impact of these naturally-occurring fluids needs to be added to this section and to the Chemical Mixing section of the report. Many brines naturally contain high concentrations of benzene, toluene, and xylene (Bair and Digel, 1990; Breen et al., 1984), which are suspected carcinogens. The potential impact of these natural solutes and others needs to be described, especially since brines are legally used to de-ice roads and control dust in several states.

13. Page ES-17, line 4: For greater clarity, insert the underlined word into the sentence so that it reads "…and the characteristics of the surrounding geologic environment."

14. Page ES-17, line 24: Insert the underlined phrase at the end of the sentence "…of the fractured formation and its natural formation water."

15. Page ES-17, line 29: It needs to be clarified that neither produced water or natural brines contain "metals" per se; meaning solids with zero valences (i.e. native metals). Rather, these fluids contain dissolved ions.

16. Page ES-18, line 26: For greater clarity, insert the underlined word in the sentence as follows "… tend to be less mobile in the subsurface environment."

17. There are several more pages and many more lines that can use additional clarification for the reader.

Comments from Dr. Elizabeth W. Boyer

The EPA's conclusion that the EPA did not find evidence of widespread, systemic impacts on drinking water resources has been widely quoted and interpreted in many different ways. The executive summary and press materials should be carefully reworded, to be clearer on their meaning and interpretation.

Comments from Dr. James V. Bruckner

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

Both are clearly written and cover key aspects of hydraulic fracturing and its potential impacts on drinking water supplies in a logical manner.

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 coverage in the Executive Summary is definitely consistent with information in the body of the report. I felt I was reading Chapter 10 again when I read the Executive Summary for the first time. The Executive Summary would be more appropriate for a broad audience, if it were somewhat shorter and much less detailed. The level at which it is written should be lowered, so it can be understood by a general readership. The meaning of terms such as oral reference value, oral slope factor, conductivity, integrity

failure, physicochemical, sorbed, proppant, etc. should be explained. The use of abbreviations should be avoided when possible.

c. In Chapter 10, have interrelationships and major findings for the major stages of the hydraulic fracturing water cycle been adequately explored and identified? Are there major findings that have not been brought forward?

A major finding of the assessment in lines 26-30 of page 10 – 1 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 was small compared to the number of hydraulicly fractured wells." It is pointed out in the next paragraph that there is insufficient data, a paucity of long-term systemic studies, and other mitigating factors. Nevertheless, I do not think that the document's authors have gone far enough to emphasize how preliminary these key conclusions are and how limited the factual bases are for their judgments. Estimates of the frequency of on-site spills were based upon information from just 2 states. How much confidence is there in these 2 estimates? Was reporting of spills mandatory? Data on the presence/identity of chemicals in flowback and produced water appears to be minimal. Only 3 references are cited for all of the chemicals listed in table A-4. I have not located any information on concentrations that were measured, so it has not been possible to estimate human exposures or begin to assess the potential risks to health. I would have liked to have some idea, at least in orders of magnitude, of how far exposure levels are from adverse effect doses for a few of the most potent chemicals.

It would have been useful at the end of Chapter 10 to have included a subsection that listed and perhaps prioritized major research needs. Nevertheless, some data needs, particularly with respect to identification and quantification of chemicals, are clearly addressed on pages 10-18. Commonly used/occurring chemicals for which toxicology data are lacking could be recommended for toxicity testing. Perhaps, at some point in the future, drilling/fracturing firms could be required to monitor a limited number of chemicals used in their own operations. Selection criteria for monitoring might include toxic potency, mutagenicity/carcinogenicity, occurrence and concentrations in flowback and waste water, mobility in water, persistence, etc.

Comments from Dr. Joseph J. DeGeorge

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

In general, the ES and Chapter 10 are clearly written and logically organized. There are, however, a number of improvements to these sections that should be made. Critically, the major findings are in need of substantial elaboration as to how the conclusions are derived, including a brief description of the specific information drawn upon in support of the conclusion.

- To state that "that there are above and below ground… inadequate treatment and discharge of waste water." without providing any insight as to which have the greatest likelihood of potential impact and which are unique or specifically enhanced by HF activity is of minimal utility for the stated purposes of the report. Both in the individual section of the ES and Chapter 10 and in the specific topic Chapters, some assessment of likelihood of impact, actions that have been observed that can mitigate the potential impacts (Best Practices), and those specifically linked to HF activity should be defined. The "Best Practices" can be derived from State, regional, or specific well data which are noted in the assessment (e.g., open pit regulations, or specific secondary containment activities) and could be further developed in the report.

- With regard to "We did not find evidence…. in the United States." EPA should state what is specifically meant by "widespread, systemic", and to what extent the methodology used in the assessment was capable of detection of such impacts had they occurred. This is clearly a concern based on many of the comments to the docket and warrants being more comprehensively addressed.

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?

A major gap in the assessment, which is carried through to the ES and Chapter 10, is the failure to dissect impacts by general gas and oil development from those associated with HF gas and oil development. While it is important to understand the potential impacts to DW resources in circumstances where HF has been used as part of the energy extraction process, it needs to be clearly, concisely and accurately delineated as to what the specific potential impacts are that differentiate in either extent or likelihood of impact by application of HF in oil and gas development as opposed to conventional development. Unfortunately, this conflation of impacts is consistent throughout the report. This would not appear to enable a broad audience to understand the assessment with regard to its intended objective as related to HF. A specific illistration of this in the ES, Chapter 10 and throughout much of the text is in the reporting of spill rates. It is unclear whether the rates and range of rates reported are unique to HF oil and gas activities, HF materials, or a common rate for all oil and gas development. This can only be partially discerned if the spills discussed were of specifically of HF fluids.

c. In Chapter 10, have interrelationships and major findings for the major stages of the hydraulic fracturing water cycle been adequately explored and identified?

While the interrelationships appear to have been adequately explored, it is not clear why some aspects of HF gas and oil development have been included and others excluded. For example, potential impacts from drilling are excluded, possibly as they do not differ between conventional and non-conventional development, while transport and treatment of wastewater (particular for PW), which would also seem to be similar between the two development methods, are included. Specific rationales for inclusion and exclusion of

the various stages should be addressed in the assessment. Moreover, one way to improve the delineation and explorations of the interrelationships is to specifically speak to the unique aspects of HF activity that influence the potential impacts at each stage investigated.

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

There is not an integrated assessment of the relative contributions of potential impacts by stage in the summaries. In some of the chapters there is information that suggests either the most likely or concerning potential impacts, although firm conclusions are not made. Bringing these observations forward, along with practices that have been observed to reduce the impact would greatly increase the utility of the report for the broad audience and for policy makers in particular.

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

The impact on the report by the imposed stringent data requirements for the chemical hazard information should be better elaborated. Discussion of what the reduction in unknown chemical hazards would have been had broader inclusion criteria, beyond ACToR, been allowed, as well as whether this would likely change the identity of compounds of most concern. Further, how use of exposure information, some of which can be derived from data available in the assessment, could further alter concerns for given chemicals.

Other aspects that need to be brought forward in Chapter 10 and ES:

The impact and reasons that the prospective case studies that were planned were not conducted or were not reported. The data from these case studies could have dramatically reduced the uncertainties carried forward in many aspects of the assessment and the absence of these studies is a significant loss for the assessment.

The impact and rationale for the very broad, non-traditional definition of DW resources needs discussion. This definition does not appear consistent with definitions used by EPA or other regulatory bodies. It would appear to include in some cases a DW resource that would require reclamation actions that may also mitigate any HF activity impacts. This is also not addressed.

Comments from Dr. Elaine M. Faustman

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.

Are the Executive Summary and Chapter 10 clearly written and logically organized?

> Yes, this reviewer thought the Executive summary was especially well done and did not suffer as did some of the chapters in "glossing over the significance of the findings". Please note the request for additional analysis to be a part of Chapter 9 as this will affect these document.

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?

> This reviewer felt that in many places the impacts that were found in the chapters were "downplayed" or covered in a context of uncertainty. For example, Industry's own database FracFocus (non-peer reviewed) found "annual hydraulic fracturing water use was 10% or more compared to 2010 total annual water use in 6.5% of counties with FracFocus disclosures analyzed by the EPA, 30% or more in 2.2% of counties, and 50% or more in 1.0% of counties." Yet the document does not acknowledge these impacts and continues to discuss this as potential impacts.
>
> Example wording of sections such as page ES-23 lines 16 to 17 in the Conclusions needs to be rewritten: "Through this national-level assessment we have identified potential mechanisms by which hydraulic fracturing could affect drinking water resources." The word "could" needs to be replaced with the word "has" and the summary needs to provide a clear path to address both the data inadequacies as well as better address what is already known. Lack of information in many cases in this report is not treated as what it is "lack of study" and replacement of statements in the body of the report that says no impacts have been seen under these conditions be replaced.
>
> In other section of the report reports on number of counties requiring desalination operations to meet water needs stand in strong contrast to these assessments. Nowhere did I see a statement that says "EPA is concerned about this level of water use"! We have to be honest about the significant levels of potential impact and not hide this behind a veil of unknown or potential concern. Such numbers are of concern, what we do about it and how we handle these challenges is another question.
>
> The Executive Summary did not suffer from such "soft-peddling" however thus was inconsistent with some of the specific chapters. This reviewer would suggest an additional read through of the document to ensure that the "bottom-line" statements with the chapters is reflective of what has been determined in the analysis.

a. ~~Overall in the assessment, and especially~~ In Chapter 10, ~~are the~~ have interrelationships and major findings ~~integrated between~~for the major stages of the hydraulic fracturing water cycle ~~to the extent allowed by available data~~been adequately explored and ~~literature?~~ identified? Are there other major findings that have not been brought forward?

See this reviewer's comments above regarding the assessment in Chapter 9 of chemicals across the water cycle which this reviewer thought was inadequate as written and analyzed.

b. Are there sections in Chapter 10 that should be expanded? Or additional information added?

The last section of the ES page ES-4 starting line 6 to 16 is very open. As a reviewer I am not certain that .."the findings in this assessment can be used by federal, state, tribal and local officials; industry; and the public to better understand and address any vulnerabilities of drinking water resources to hydraulic fracturing activities". Shouldn't this report more clearly help to identify critical missing information versus "interesting to know" information? Each chapter should stop with not only conclusions but some idea of potential level of impact of missing versus known information. That missing part would indeed allow the assessment to be used by the stakeholders. It is very evident from the stakeholder comments we have received, compiled in the Appendix. Our board members have prepared a very detailed and useful assessment of these comments. Shouldn't this feed into our comments on this last concluding paragraph?

General comments:

Please note that there is inconsistency within the chapters on how they are formatted. Some of the chapters end with a set of "boxed" conclusions (see Text Box 3-1 in Chapter 3 page 3-12) and some end with a series of Questions and Answers (see Text Box 9-1 in Chapter 9, page 9-40). This reviewer would suggest that there is a need for consistency and that actually both types of information is needed. The conclusions are needed to help the stakeholder audience anticipated for these reports and in this reviewer's opinion would have a conclusion and then key action points that would provide reader with what might be "next steps" in the EPA's assessment. In addition, the questions and answers seemed to be useful and directed to perhaps a more communication purpose.

A large component of impacts could be in ecological impacts and this reviewer felt it was important to state this lack of information and discussion and to ensure that our comments are so noted.

Inconsistent application of peered and non-peered review data between chapters

This reviewer applauds the report and the approach to be inclusive of data sources. The quote below from the review document is excellent and represents a monumental approach to compiling relevant data from many sources some of which have been extremely difficult to

obtain and locate in one place. This is a great success of this document. The EPA has met its intent as stated below:

"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 EPA. The assessment also included citation of relevant literature developed as part of the Study Plan. "

However given this statement and approach this reviewer feels that the EPA assessment is not a consistent "synthesis of the science." For example in Chapter 5, there is extensive use of all data sources and many non-peer reviewed documents are listed –see page 5-70, lines 4 to 13 and discussion of strategies for reducing toxic chemical use across these documents.
Yet in Chapter 9 a very strict criteria for data use and access in provided (see pages 9-16 through 9-18). In fact for this chapter's assessment, the lack of formal risk evaluation numbers such as oral RfV,or lack of available data on frequency of use negated the review of those chemicals and resulted in a dramatic drop in the number of the chemicals to be assessed from 1,076 and 134 representing chemicals used in hydraulic fracturing fluid and flowback and produced water respectively to only 37 and 23 respectively for further health impact. This only represented 3 percent of the total chemicals of interest and found present in these fluids under review to be assessed as few chemicals met this criteria not that the other chemicals were without hazard. This reviewer feels strongly that other health impact assessment approaches should have been presented perhaps in parallel. (some of these comments are also included in the discussion of Chapter 9).

Comments from Dr. Abby A. Li

8a. Are the Executive Summary and Chapter 10 clearly written and logically organized?

> The Executive Summary and Chapter 10 are clearly written and logically organized. EPA organized the full report by each stage of the hydraulic fracturing water cycle and summarized key conclusions in each chapter. EPA faithfully repeats what was summarized in each chapter for the benefit of those who are not likely to read each chapter carefully. However, I was looking for additional synthesis to support EPA's major finding: "We did not find evidence that these mechanisms have led to widespread, systemic impacts on drinking water resources in the United States." EPA does qualify this statement in the next paragraph by stating that this finding could reflect a rarity of effects or be due to a number of limiting factors. At present, the public comments focused primarily on chemical and other constituent contamination of surface and ground water suggest that there is a disconnect between all the uncertainties listed and the lack of data described in Chapters 5, 7, and 9 with this main conclusion. This indicates Chapter 10 and supporting Chapters 5, 7 and 9 may need to add perspective on what's unique or

not unique to HF, how spill volumes compare with other industries, the concentrations of different constituents in produced water (missing in Chapter 10), and how common the worse-case scenarios might be taking into consideration regulations that might enforce some level of "best practice". Comments on Chapter 10 necessarily require discussion of the earlier chapters upon which they are based.

Chapters 5, 7 and 9 identify a large number of uncertainties that lead the reader to assume possible findings rather than absence of finding. This is understandable because EPA needs to protect against worse case scenarios. However, I don't always get a sense of what's a realistic worse case scenario taking into consideration depth, distance, geology, volume and concentration of HF fluids, volume and concentration of flowback and produce water and "best practices" that might be driven by regulations in most states (e.g. for spills). For example, in Chapter 5, EPA tends to assume absence of findings is "unknown" rather than not detected, suggesting to the reader that there is possible contamination. Figures 5-15 highlights "unknown" in red histogram bars, leading me to presume that this might be possible impacts that were never measured but closer read of the text suggests it's possible that measures were taken but there were no detects. An understanding of "best practices" based on regulations might be helpful. Figure 5-14 adds all the volumes of fluids spilled across all spills for each spill source, rather than the median volume of spills based on different spill source. This gave me an impression that the volumes of gallons spilled are much greater than they actually are per spill. Similarly, Chapter 9 tends to lead the reader to assume absence of toxicology value is absence of any toxicology data, which is not correct (see my comments on Question 7 on what needs to be added in both Chapter 9 and 10).

What I find to be missing in this chapter, as well as Chapters 5, 7, and 9 is a greater understanding of the relative likelihood of the many uncertainties noted or possibilities for contamination based on realistic worst-case scenarios by shale type (or other appropriate sub-category rather than merge all uncertainties together for a national analysis of all types of HF operations). At present, some of these uncertainties are discussed in some of the chapters as if they are equally probable, and tend to be compounded in the final summaries of each chapter because of the need to be concise. Modeling worse-case scenarios using data available on volumes and concentrations with appropriate geological assumptions may be very helpful to include, or is an important research need.

8b. 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?

Yes, the Executive Summary clearly describes the major findings for a broad audience. Based on public comments, EPA may not have adequately supported the major findings. See comments above.

8c and 8d. In Chapter 10, have interrelationships and major findings for the major stages of the hydraulic fracturing water cycle been adequately explored and identified? Are there other major

findings that have not been brought forward? Are there sections in Chapter 10 that should be expanded? Or additional information added?

> I expected to find more context and synthesis in Chapter 10 because they weren't in previous chapters (e.g., Chapter 9), especially given that Chapter 10 is titled, "synthesis." Here, EPA could impart an understanding of the regulatory requirements for CBI and for a spill, comparison with other, similar industries (and what can be learned from this), differences in environmental fate characteristics in mixtures and single chemicals at high vs. low concentrations, and existence of quality toxicology data that didn't meet their initial criteria that could address both shorter term and longer term toxicity.

Comments from Dr. Laura J. Pyrak-Nolte

A potential source of confusion in the Executive Summary and Chapter 10 on Synthesis is the use of the word systemic. While the reports documents localized impacts to drinking water from hydraulic fracturing, the report concludes that the identified mechanisms for potential impacts are not widespread or systemic. Spills may appear to be systemic but fracturing into an adjacent well may be limited to sites with a high density of wells. A clear definition or explanation of what is meant by this term and how it is used in this report is required. Is the system all hydraulic fracturing sites in the US or a few local wells in a community/county/state.

A definition is key for understanding the local versus global behavior and what impacts will apply to specific regions. This is not clearly stated until lines 11-13 on page 10-5:

> "*These location-specific examples emphasize the need to focus on regional and local dynamics when considering potential impacts of hydraulic fracturing water acquisition on drinking water resources.*"

While that sentence is specific to the water acquisition portion of the report, the general concept should be part of the major findings as it applies to all steps in the water cycle for hydraulic fracturing (e.g. lines 15-20 on page 10-8). The major finding is that the potential impact is site-specific (local) depending on all of the factors/mechanisms identified in the various steps of the water cycle for hydraulic fracturing. This is a different concept than not being systemic.

The report in general lacks information on "geologic features" and does not clearly state specific examples. For example, pre-existing fractures and fracture networks are not adequately identified nor are their impact induced fractures and flow through geologic formations addressed. While the report mentions induced fractures intersecting the fracture network from another hydraulic fracturing well, it never adequately assesses natural or pre-existing fracture networks or other zones of weakness.

A major gap in the synthesis, and the report is general, is the assessment of the impact of the unrecovered or unproduced water after injection/flowback. The amount of unproduced water is site specific and no verified theory exists to ascertain where the water goes in the system (i.e.

formations, trapped on clay particles/minerals, induced fractures, existing porosity/fractures, etc.). If 50-80% of the water is unrecovered, where does that volume reside.

What is the impact of UIC (disposal wells) on the local groundwater? This is not in the summary. All of the issues of related to well integrity and flow through "geologic features" or "pathways in subsurface rock formations" are applicable to disposal wells.

Comments from Dr. James E. Saiers

The organization of the Executive Summary and Chapter 10 (Synthesis) mirrors the overall structure of the report, and these sections effectively distill the key findings from the extensive analyses documented within Chapters 2 – 9 of the Assessment Report. I anticipate that the the summary and synthesis sections will be illuminating to scientists and engineers and understandable to reasonably well informed government officials and members of the general public.

The Executive Summary and Chapter 10 are faithful to the content of the report, and I did not identify any serious problems in either section with respect to Charge Question 8 of the SAB Review. In the comments below, I've made several suggestions for clarifying the description of major findings. With the exception of opening background sections, the Executive Summary shares much of the same content as Chapter 10. Hence, the following suggestions for revision to Chapter 10 also apply to the Executive Summary.

Page 10-1, lines 29 to 30: The report reads: "The number of cases is small compared to the number of hydraulically fractured wells." The descriptor "small" is vague (and subjective). Can this be quantified (based on the available data) or a more precise description provided?

Page 10-6, lines 3-23: The report indicates that the frequency of on-site spills can be estimated for only two states. Doesn't this small sample suggest that current reporting is inadequate? If so, I believe this scarcity of information constitutes an important finding that should be stated.

Page 10-9 to 10-10: The research question posed is "how effective are well construction practices at containing liquids and gases before, during, and after hydraulic fracturing?" The Synthesis does not address this question definitively. Two cases of well-integrity loss are cited; however, the reader cannot determine whether these are two illustrative examples drawn from a larger pool of incidences or if Bainbridge and Mamm Creek are the sole proven cases of groundwater contamination arising from inadequate well construction. How many cases of faulty well construction practices were identified as a part of the EPA analysis?

Page 10-11, line 1: The report reads: "The overall frequency of occurrence [of fracking geologic units that also serve as a drinking water source] is low." "Low" is ambiguous. Please be precise as possible.

Pages 10-12 to 10-13: Recently published work by Shih et al. (2015) provides a comprehensive description of the chemical composition of flowback and produced waters generated from the Marcellus Shale.

> Shih, J-S., J.E. Saiers, S.C. Anisfeld, Z. Chua, L. A. Muehlenbachs, and S.M Olmstead. 2015. Characterization of liquid waste from Marcellus Shale gas development. Environmental Science and Technology, DOI 10.1021/acs.est.5b01780.

Page 10-14, lines 22-26: What is the frequency of produced-water releases from pits and impoundments? Where (what states or plays) have these been found to occur? Has the frequency decreased over time with changes in the regulatory landscape?

Pages 10-20 to 10-21: The synthesis chapter identifies several limitations and uncertainties that hinder evaluation of the effects of hydraulic fracturing on water resources. In my view, the usefulness and overall impact of the report could be increased through recommendations of steps that could be taken to mitigate the limitations and reduce the uncertainties. Building from report's content, these recommendations could address monitoring programs, data reporting and accessibility, and areas of high-priority research.

Comments from Dr. Thomas M. Young

I would like to add the following to preliminary comments related to the executive summary/chapter 10.

As it stands, the document seems to be seeking to draw a global (and permanent) conclusion about the safety/impacts of HF at the national level. I believe that is what motivated the statement about no "widespread and systemic" impacts. I suggest that the blanket overview statement be replaced by a series of statements such as:

1. Water quality impacts associated with hydraulic fracturing have occurred in a number of locations. Occasionally, these have been severe.

2. Many of the impacts have been associated with failures to follow industry best practices and might be preventable.

3. Quantifying the frequency and severity of water quality impacts is difficult to do accurately because of data limitations including: reporting of incidents is often voluntary, uneven follow-up regarding impacts, lack of systematic study of these impacts, sealed information in litigation, lack of knowledge about or monitoring methods for compounds in hydraulic fracturing fluids.

4. With the available information, the number of documented cases of impacts is small relative to the number of wells developed using HF.

General Comments, Editorial Suggestions, and Comments Not Related to Charge Questions on EPA's Draft Assessment Report

Comments from Dr. Joseph J. DeGeorge

Text edits:

Text Box 3-1 first 3 bullets are repeated in next 3 bullets

6-35 ln 20- 6-26 ln4 there is repeated text

Appendix C table C.1 it appears that either the last column or some of the values used are incorrect. Values >60% by mass would suggest that for some HF fluids most of, and in some cases the entire, HF fluid is composed of that specific chemical. Are the mass percentages provided in some (or all) cases pre-HF mixture concentrations?

Comments from Dr. Katherine Bennett Ensor

The EPA scientists bring forward a comprehensive document outlining the process and potential impact of hydraulic fracturing to water quantity and quality in the United States. The effort is commendable and represents a valuable contribution to the critical hydraulic fracturing conversation in the United States.

Comments from Dr. Dawn S. Kaback

Overall, I believe the document is well written and comprehensive. It is also generally written at a level that could be understood by the stakeholder audience. However, in a few sections, I believe the terminology needs to be revised to be more scientifically accurate. I also bring up an issue related to use of the term "chemicals," which I think may be too broadly applied and perhaps in some instances the word "compounds" or "constituents" would be better used. I also bring up the issue of the term "soil" that is inaccurately used in one section. Some of the historical explanation of hydraulic fracturing and horizontal wells is inaccurate and needs to be revised. I also question the use of the words "ground water" as two words, while I believe the USGS and the National Groundwater Association have all adopted the use of "groundwater" as a single word.

Comments from Dr. Stephen J. Randtke

Editorial Notes and Suggestions

p. 3-7: It might be helpful to add a note to clarify that some PWSs utilize more than one water source, so it is clearer to readers who are not aware of this why the number of water sources exceeds systems the number of systems.

p. 3-12: The last three findings are duplicates of the first three.

p. 4-25: Part "a" of the caption for Figure 4-6 ("Estimated annual surface water runoff from the USGS"). It would be better to say "Annual surface water runoff estimated by the USGS."

APPENDIX A:
LIST OF MEMBERS ON SAB HYDRAULIC FRACTURING RESEARCH ADVISORY PANEL

CHAIR

Dr. David A. Dzombak, Hamerschlag University Professor of Environmental Engineering and Head of the Department of Civil and Environmental Engineering, College of Engineering, Carnegie Mellon University, Pittsburgh, PA

MEMBERS

Dr. Stephen W. Almond, Director of Research & Development, Fritz Industries, Inc, Houston, TX

Dr. E. Scott Bair, Emeritus Professor, School of Earth Sciences, Ohio State University, Columbus, OH

Dr. Peter Bloomfield, Professor, Statistics Department, North Carolina State University, Raleigh, NC

Dr. Steven R. Bohlen, State Oil and Gas Supervisor, and Head of the Division of Oil, Gas and Geothermal Resources (DOGGR), State of California Department of Conservation, Sacramento, CA

Dr. Elizabeth W. Boyer, Associate Professor, Department of Ecosystem Science & Management, Pennsylvania State University, University Park, PA

Dr. Susan L. Brantley, Distinguished Professor of Geosciences and Director, Earth and Environmental Systems Institute, Pennsylvania State University, University Park, PA

Dr. James V. Bruckner, Professor of Pharmacology and Toxicology, Department of Pharmaceutical and Biomedical Sciences, College of Pharmacy, University of Georgia, Athens, GA

Dr. Thomas L. Davis, Professor, Department of Geophysics, Colorado School of Mines, Golden, CO

Dr. Joseph J. DeGeorge, Global Head of Safety Assessment and Laboratory Animal Resources, Merck Research Laboratories, Lansdale, PA

Dr. Joel Ducoste, Professor, Civil, Construction, and Environmental Engineering Department, North Carolina State University, Raleigh, NC

Dr. Shari Dunn-Norman, Professor, Geosciences and Geological and Petroleum Engineering Department, Missouri University of Science and Technology, Rolla, MO

Dr. Katherine Bennett Ensor, Professor and Chair, Department of Statistics, Rice University, Houston, TX

Dr. Elaine M. Faustman, Professor, Department of Environmental Health, and Director, Institute for Risk Analysis and Risk Communication, School of Public Health, University of Washington, Seattle, WA

Mr. John V. Fontana, Professional Geologist and President, Vista GeoScience LLC, Golden, CO

Dr. Daniel J. Goode, Research Hydrologist, U.S. Geological Survey, Pennsylvania Water Science Center, Exton, PA

Dr. Bruce D. Honeyman, Associate Vice President for Research and Emeritus Professor of Environmental Science and Engineering, Colorado School of Mines, Golden, CO

Mr. Walter R. Hufford, Director of Government and Regulatory Affairs, Talisman Energy USA Inc. - REPSOL, Warrendale, PA

Dr. Richard F. Jack, Director, Vertical Marketing for Environmental and Industrial Markets, Thermo Fisher Scientific Inc., San Jose, CA

Dr. Dawn S. Kaback, Principal Geochemist, Amec Foster Wheeler, Denver, CO

Dr. Abby A. Li, Senior Managing Scientist, Exponent Health Sciences, Exponent, Inc., San Francisco, CA

Mr. Dean N. Malouta, White Mountain Energy Consulting, LLC, Houston, TX

Dr. Cass T. Miller, Daniel A. Okun Distinguished Professor of Environmental Engineering, Department of Environmental Sciences and Engineering, University of North Carolina, Chapel Hill, NC

Dr. Laura J. Pyrak-Nolte, Professor, Department of Physics, College of Science, Purdue University, West Lafayette, IN

Dr. Stephen Randtke, Professor, Department of Civil, Environmental, and Architectural Engineering, University of Kansas, Lawrence, KS

Dr. Joseph N. Ryan, Professor of Environmental Engineering and Bennett-Lindstedt Faculty Fellow, Department of Civil, Environmental, and Architectural Engineering, University of Colorado-Boulder, Boulder CO

Dr. James E. Saiers, Clifton R. Musser Professor of Hydrology and Associate Dean of Academic Affairs, School of Forestry and Environmental Studies, Yale University, New Haven, CT

Dr. Azra N. Tutuncu, Professor and Harry D. Campbell Chair, Petroleum Engineering Department, and Director, Unconventional Natural Gas and Oil Institute, Colorado School of Mines, Golden, CO

Dr. Paul K. Westerhoff, Professor, School of Sustainable Engineering and The Built Environment, Ira A. Fulton Schools of Engineering, Arizona State University, Tempe, AZ

Dr. Thomas M. Young, Professor of Civil and Environmental Engineering, University of California – Davis, Davis, CA

APPENDIX B:
AGENDA FOR OCTOBER 28-30, 2015 MEETING OF THE SAB HYDRAULIC FRACTURING RESEARCH ADVISORY PANEL

U.S. Environmental Protection Agency

Science Advisory Board Hydraulic Fracturing Research Advisory Panel
Public Meeting, October 28-30, 2015
Washington Plaza Hotel
10 Thomas Circle, NW
Washington, DC 20005

As of October 13, 2015

Purpose: To conduct a peer review of the EPA draft report, *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)*

Wednesday, October 28, 2015

9:00 - 9:20 a.m.	**Convene Meeting**	Mr. Edward Hanlon *Designated Federal Officer*
	Welcoming Remarks	Mr. Thomas H. Brennan *Deputy Director* *EPA Science Advisory Board Staff Office*
	Purpose of Meeting and Review of Agenda	Dr. David A. Dzombak *Chair*
9:20 - 10:05 a.m.	**Remarks from EPA's National Center for Environmental Assessment**	Dr. Jeffrey Frithsen National Center for Environmental Assessment, EPA Office of Research and Development
10:05 - 10:15 a.m.	**Review of Charge Questions**	Dr. Dzombak and Panel Members

Wednesday, October 28, 2015 (continued)

10:15 - 10:30 a.m.	**Break**	
10:30 - Noon	**Public Comments**	Registered Speakers
Noon – 1:15 p.m.	**Lunch**	
1:15 - 1:45 p.m.	**Public Comments (continued)**	Registered Speakers
	Discussion of Panel's Responses to EPA Charge Questions	
1:45 - 3:30 p.m.	**Charge Question 1 – Goals, Background and History of the Assessment**	Lead Discussants: Drs. Bloomfield, Bohlen, Boyer, Ensor, and Faustman
	Charge Question 2 – Water Acquisition Step in the Hydraulic Fracturing Water Cycle	Lead Discussants: Dr. Boyer; Mr. Fontana; and Drs. Goode, Randtke and Saiers
3:30 - 3:45 p.m.	**Break**	
3:45 - 5:30 p.m.	**Charge Question 3 – Chemical Mixing Step in the Hydraulic Fracturing Water Cycle**	Lead Discussants: Drs. Almond, Bohlen, Dunn-Norman, Ensor, Faustman, Goode, Honeyman, and Jack; Mr. Malouta; and Drs. Miller, Tutuncu and Young

Wednesday, October 28, 2015 (continued)

3:45 - 5:30 p.m.	**Charge Question 4 – Well Injection Step in the Hydraulic Fracturing Water Cycle**	Lead Discussants: Drs. Bair, Davis, Dunn-Norman, and Ensor; Mr. Fontana; Drs. Goode and Honeyman; Messrs. Hufford and Malouta; and Drs. Miller, Pyrak-Nolte, Ryan, Tutuncu, Westerhoff and Young
5:30 p.m.	**Recess for the Day**	

Thursday, October 29, 2015

8:30 a.m.	**Reconvene**	
	Discussion of Panel's Responses to EPA Charge Questions (continued)	
8:30 - 10:15 a.m.	**Charge Question 4 (continued) – Well Injection Step in the Hydraulic Fracturing Water Cycle**	
	Charge Question 5 – Flowback and Produced Water Step in the Hydraulic Fracturing Water Cycle	Lead Discussants: Drs. Almond, Bohlen, Brantley, Ducoste, and Dunn-Norman; Messrs. Fontana, Hufford and Malouta; and Drs. Miller, Tutuncu, Westerhoff and Young
10:15 - 10:30 a.m.	**Break**	

Thursday, October 29, 2015 (continued)

10:30 - 12:15 p.m.	**Charge Question 5 (continued) – Flowback and Produced Water Step in the Hydraulic Fracturing Water Cycle**	
	Charge Question 6 – Wastewater Treatment and Waste Disposal Step in the Hydraulic Fracturing Water Cycle	Lead Discussants: Drs. Ducoste, Randtke and Westerhoff
12:15 - 1:30 p.m.	**Lunch**	
1:30 - 3:30 p.m.	**Charge Question 7 – Chemicals Used or Present in Hydraulic Fracturing Fluids**	Lead Discussants: Drs. Almond, Bloomfield, Bruckner, DeGeorge, Faustman, Jack and Li
	Charge Question 8 – Synthesis of Science on Potential Impacts of Hydraulic Fracturing on Drinking Water Resources, and Executive Summary	Lead Discussants: Drs. Bair, Bruckner, Davis, DeGeorge, Li, Pyrak-Nolte, Ryan and Saiers
3:30 - 3:50 p.m.	**Brief Clarifying Comments from Members of the Public**	
3:50 - 4:00 p.m.	**Recap and Preparation for Writing Session**	Dr. Dzombak

Thursday, October 29, 2015 (continued)

4:00 - 5:30 p.m.	**Writing Session by Panel Subgroups**	Dr. Dzombak and Panel
	Charge Question 1 – Goals, Background and History of the Assessment	Drs. Bloomfield, Bohlen*
	Charge Question 2 – Water Acquisition Step in the Hydraulic Fracturing Water Cycle	Dr. Boyer*[7], Mr. Fontana, Dr. Goode
	Charge Question 3 – Chemical Mixing Step in the Hydraulic Fracturing Water Cycle	Drs. Honeyman*, Miller, Young
	Charge Question 4 – Well Injection Step in the Hydraulic Fracturing Water Cycle	Drs. Davis, Dunn-Norman, Ensor, Mr. Malouta*, Drs. Pyrak-Nolte, Tutuncu
	Charge Question 5 – Flowback and Produced Water Step in the Hydraulic Fracturing Water Cycle	Drs. Almond, Brantley*, Mr. Hufford
	Charge Question 6 – Wastewater Treatment and Waste Disposal Step in the Hydraulic Fracturing Water Cycle	Drs. Ducoste, Randtke, Westerhoff*
	Charge Question 7 – Chemicals Used or Present in Hydraulic Fracturing Fluids	Drs. Bruckner, DeGeorge, Faustman, Jack, Li*, Ryan
	Charge Question 8 – Synthesis of Science on Potential Impacts of Hydraulic Fracturing on Drinking Water Resources, and Executive Summary	Drs. Bair, Dzombak, Saiers*
5:30 p.m.	**Recess for the Day**	

[7] * = Lead Writer

Friday, October 30, 2015

8:30 a.m.	**Reconvene**	
8:30 - 10:30 a.m	**Discussion of Key Points in Responses to Charge Questions**	Dr. Dzombak and Panel Members
	Charge Question 1	Dr. Bohlen
	Charge Question 2	Dr. Boyer
	Charge Question 3	Dr. Honeyman
	Charge Question 4	Mr. Malouta
	Charge Question 5	Dr. Brantley
	Charge Question 6	Dr. Westerhoff
	Charge Question 7	Dr. Li
	Charge Question 8	Dr. Saiers
10:15 - 10:30 a.m.	**Break**	
10:30 a.m.-12:30 p.m	**Discussion of Key Points in Responses to Charge Questions (continued)**	Dr. Dzombak and Panel Members
12:30 - 12:45 p.m.	**Summary and Next Steps**	Dr. Dzombak
12:45 p.m.	**Adjourn**	Mr. Hanlon