ERDC/TN DOTS-15-1
January 2015

Evaluation of Hydraulic Fracturing (Fracking) Plays for Potential Impact on USACE-Managed Waterways

by Victor F. Medina and Burton Suedel

PURPOSE: A recent study entitled "Impacts of Shale Gas Wastewater Disposal on Water Quality in Western Pennsylvania" by Warner et al. (2013) established that discharges of treated fluids from hydraulic fracturing operations (hydrofracturing or "fracking") to increase petrochemical (natural gas and petroleum) production resulted in elevated environmental contamination in the form of dissolved ions (chloride and bromide). The discharges also resulted in naturally occurring radioactive materials (NORM, primarily radium) in both water and sediments. This study, which was conducted in Pennsylvania in production areas associated with the Marcellus Shale, has raised concerns that fracking operations could impact waterways managed by the U.S. Army Corps of Engineers (USACE).

The purpose of this study was to investigate known areas of fracking to evaluate any areas where impacts could occur. The study was conducted on two scales: first, over the area of the contiguous lower 48 states, and second, on the Marcellus Shale region, which was a more focused evaluation.

BACKGROUND:

Hydrofracturing. Hydrofracturing is a process in which high pressure fluid injection is used to create fractures in a geological formation. In oil and gas production, these fractures allow for oil and gas to be recovered that normally cannot be produced with other methods. Hydrofracturing is a technology that dates back to the 1940s. However, new advances in hydrofracturing have resulted in very widespread applications to known geological formations previously thought to be too tight to allow commercial production.

Although hydrofracturing could be used for any kind of low permeable formation, it has been most extensively applied to shale plays (shale formations are typically referred to as plays). The energy production increase from hydrofracturing to date has been substantial (USEIA 2011). For example, shale oil has increased from less than 50 million barrels in 2007 to over 200 million in 2011 (GAO 2012).

Environmental Issues Associated with Hydrofracturing.

Environmental Issues Associated with Increased Activities in Areas with High Density of Hydrofracturing. Hydrofracturing can greatly increase human activities, such as

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
JAN 2015		**00-00-2015 to 00-00-2015**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Evaluation of Hydraulic Fracturing (Fracking) Plays for Potential Impact on USACE-Managed Waterways	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **U.S. Army Engineer Research and Development,Center,,Vicksburg,,MS,39180**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**11**	

truck traffic, road and other construction, water use, housing, etc., in a given area. This can result in increased air pollution due to vehicular traffic, increased runoff from associated construction activities, and other impacts from supporting higher population densities (GAO 2012, Rahm and Riha 2012).

Environmental Issues Similar to that of Conventional Oil/Gas Production. Hydrofracturing operations have similar environmental issues that are associated with conventional oil production. This includes potential contamination issues associated with spilled petroleum, methane gas leaks, drilling muds, well cuttings, and produced water (GAO 2012, Clark et al. 2012, Noreca 2013).

Environmental Issues Unique to Hydrofracturing. The key difference related to hydrofracturing in comparison to other oil and gas production methods is the fracking fluids. These fluids are injected at high pressure to create fracturing in the subsurface. The fluids consist of two parts: the solution, which is an aqueous-based liquid; and solid particulate material, which is called the proppant (sand, ceramic material, gels, etc). When the fluid is injected at high pressure, the proppant works its way into existing fractures, making them larger, and also can create new fractures by this action. The proppant tends to stay in the reservoir, helping to support the newly made or widened fissures. Much of the solution, on the other hand, returns to the surface, and this is called flowback.

Fracking solutions are primarily fresh water with various additives (GAO 2012), including:

- acids, such as hydrochloric acid (HCl), to remove any near well damage;
- biocides, such as glutaraldehyle, to control bacterial growth;
- breakers, such as ammonium persulfate, to delay breakdown of gelling agents;
- corrosion inhibitors, such as N,N-dimethyl formamide, to prevent pipe corrosion;
- friction reducers, such as polyacrylamide, to improve proppant placement;
- gelling agents, such as guar gum, to improve proppant placement;
- potassium chloride (KCl) to create a brine carrier fluid;
- oxygen scavengers, such as ammonium bisulfide, to prevent corrosion of well tubulars;
- pH adjusting agents, such as sodium bicarbonate, to adjust pH of fluid to maintain optimal properties of the various agents;
- scale inhibitor, such as ethylene glycol, to prevent scale deposits in the pipe;
- surfactants, such as isopropanal, which are used as winterizing agents to prevent freezing; and
- additives to promote microbially enhanced oil recovery (Bachmann et al. 2013).

These agents are usually used in very small amounts, making up 1% or less of the total solution. Still, they could be of environmental concern if improperly managed. In addition, dissolved and suspended constituents from the fractured shale play may be found in the flowback. These can include dissolved ions and naturally occurring radioactive materials (NORM) (GAO 2012, Rahm and Riha 2012, Rahm et al. 2013). Warner et al. (2013) conclusively demonstrated high concentrations of radium, barium, and salts (chloride and bromide), resulting from discharge of treated fracking fluids (flowback, production fluids, and produced water) into surface waters in western Pennsylvania.

It is common practice for both municipal and industrial wastewater to be intentionally treated to intermediate level, with reliance on natural processes (dilution, sedimentation, and biological degradation) in the receiving waters to complete the treatment process (Hammer 1986). The hydrofracturing discharges described in Warner et al. (2013) clearly have elevated concentrations of salts and radioisotopes that were not attenuated in the surface waters in which they were discharged. These salts and radioisotopes can also accumulate and contaminate sediments in stream channels, creating a long-term contamination issue (Vengosh et al. 2014). From a technical perspective, it is entirely possible to treat virtually any industrial water to background levels found in the natural environment. The key issue, of course, is that higher treatment quality adds to the total production costs.

Even when fracking solutions are properly managed, the intense needs for fresh water for the hydrofracturing processes can impact local ecosystems (Nicot and Scanlon 2012, Murray 2013, Vengosh et al. 2014). Water is typically taken from lakes, rivers, and streams, and these withdrawals can make these waterbodies more susceptible to temperature changes. Decreased flows can damage riparian ecosystems, which can have effects throughout entire ecosystems.

Assessing Environmental Risks Associated with Hydrofracturing. To assess environmental risks associated with hydrofracturing, it is useful to apply the chemical risk assessment process to assess the level of potential impacts. A conceptual model was developed by the USEPA (USEPA 2012) (Figure 1) to help promote a general understanding of the overall hydrofracturing process. The conceptual model identifies the components of the system, identifies relationships linking these components, and indicates potential pathways of environmental exposure.

There are five basic phases of the fracking process: water acquisition, chemical mixing, well injection, flowback and produced water, and wastewater treatment and waste disposal. Hydrofracturing operations require large quantities of supplies, equipment, water, and vehicles. Therefore, there are potential contamination issues common to all five phases, including spilled petroleum, drilling muds, well cuttings, produced water, and methane gas leaks. Each phase is briefly described below as it may affect USACE waterways.

The first stage is water acquisition. In this stage, large volumes of water are withdrawn from ground water, surface water, or from recycled wastewater from previous hydraulic fracturing activities, to be used in the hydraulic fracturing process. The primary impacts from the water acquisition phase are those that may affect water resources, including changes in the quantity of water available for drinking, changes in the quality of available drinking water, and decreases in the quantity of water available for other uses (navigation, wildlife). Hydrofracturing activities in this phase result in increases in truck traffic and road and other construction, increases in air pollution due to vehicular traffic, and increases in runoff from associated construction activities, thereby impacting surface water bodies.

In the chemical mixing phase, the source water, once delivered to the well site, is combined with chemical additives (see the section above) and proppant to create the fluid that is pumped into the well. Onsite storage, mixing, and pumping of hydrofracturing fluids may result in accidental releases, such as spills or leaks. Released fluids could then flow into nearby surface water bodies or infiltrate into the soil and near-surface ground water, potentially reaching waterways.

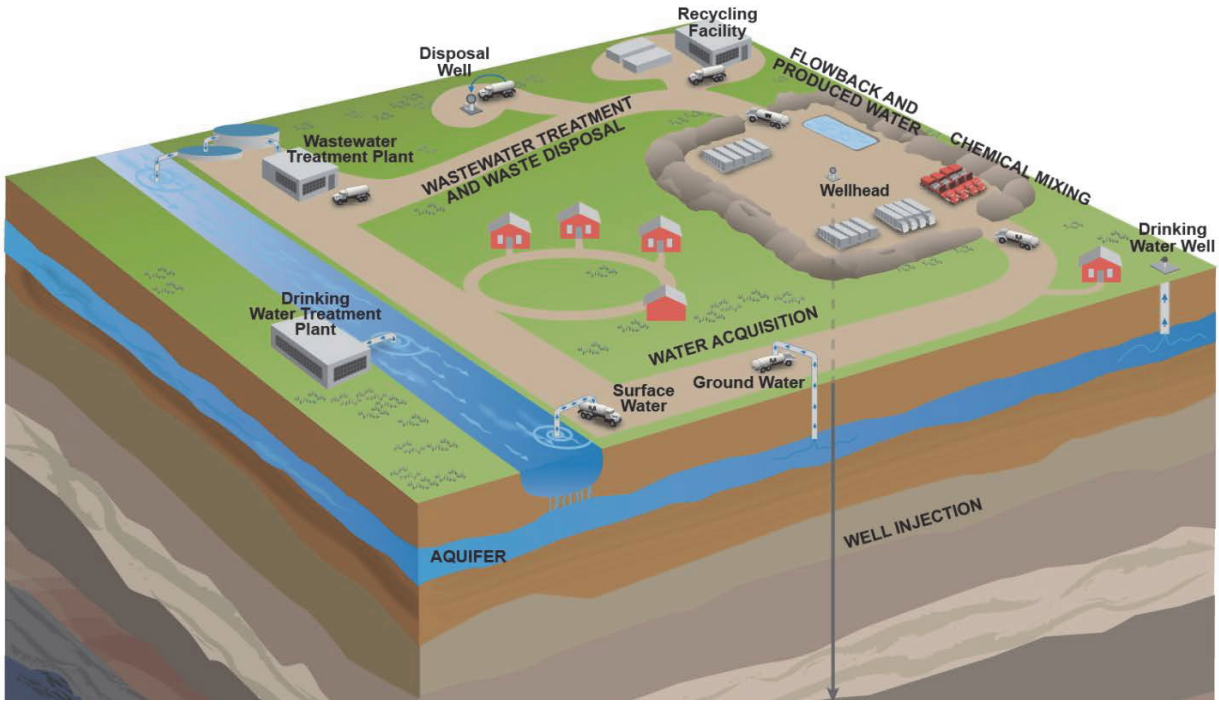

Figure 1. Generalized conceptual model of water cycling through the hydraulic fracturing process (from USEPA 2012).

During well injection, pressurized fluid created in the previous phase is injected into the well, creating cracks in the geological formation that allow oil or gas to escape through the well to be collected at the surface. Within this phase, well construction failure and induced fractures intersecting existing natural (e.g., faults or fractures) or man-made (e.g., abandoned wells) features may act as contaminant transport pathways. However, these are mostly potential threats to local groundwater drinking water resources and not surface water bodies.

When pressure in the well is reduced, hydraulic fracturing fluid, formation water, and natural gas begin to flow back up the well, necessitating their recovery. These wastewaters have different terms depending on the production status of the well. Flowback refers to fluid returning to the surface after hydraulic fracturing has occurred, but before the well is placed into production. After the well has been placed into production, the fluid returned to the surface is called produced water. Collectively, these fluids are termed hydraulic fracturing wastewater. These fluids, which may contain chemicals injected as part of the hydraulic fracturing fluid, are substances naturally occurring in the oil- or gas-producing formation, hydrocarbons, and potential reaction and degradation products, and must be stored on-site, typically in tanks or pits, before treatment, recycling, or disposal. Transfer and storage of hydrofracturing wastewater at the project site may result in accidental releases, such as spills or leaks, which may reach nearby surface waters. The potential impacts due to flowback and produced water releases are similar to the potential impacts identified in the chemical mixing phase except for the differing compositions of injected fluids and wastewater.

Once hydrofracturing fluids are returned to the surface, the wastewater must be managed. The wastewater is usually managed by disposing of it by underground injection; treating it and disposing of it to surface water bodies; or recycling it (with or without treatment) for use in

future hydraulic fracturing operations. The primary risk to waterways in this phase is the contaminants present in the wastewaters and their treatment at publicly owned treatment works, discharges from which may threaten downstream drinking water intakes. If the discharges are not adequately treated, they could pose a risk to aquatic resources. If hydrofracturing fluids are transported off-site for treatment or disposal, these activities may result in accidental releases, which could reach nearby surface waters.

The following sections provide a more detailed risk-based assessment of the chemicals used during the hydrofracturing process and the specific pathways by which hydrofracturing-related fluids can pose risks to USACE waterways: first, on a broader scale: covering the contiguous lower 48 states, with subsequent and more focused evaluations of the Great Lakes region in general; and finally, on a smaller scale, covering the Marcellus Shale region in particular.

APPROACH: This project involved a focused review of papers, reports, and other documents.

RESULTS:

Evaluation of Hydrofracturing in the United States and Its Potential Impact on USACE Waterways. Figure 2 shows current shale plays where hydrofracturing is being applied at commercial production levels (Adapted from GAO 2012), with USACE-managed waterways superimposed on the figure. Three plays significantly intersect USACE waterways. The first is the Marcellus Shale, which covers substantial areas of Pennsylvania and West Virginia. USACE waterways potentially impacted are the Allegheny, Monongahela, Kanawha, and the upper Ohio Rivers. The Fayetteville Shale is located in central Arkansas, and it could potentially impact the Arkansas and White Rivers. The Haynesville Shale intersects the USACE-managed portion of the Red River. The Woodford Shale is just south of the USACE-managed Arkansas River. The Marcellus, Fayetteville and Haynesville Shale plays are primarily gas production shales, while the Woodford Shale is both oil and gas. Oil-producing areas have potentially higher risks from a water contamination perspective than gas-producing areas have, due to the possibility of accidental oil spills.

In addition to areas where the shale production areas directly intersect, there are some shales in areas that would eventually drain into USACE waterways, albeit at some great distances. The Eagle Ford shale in Texas is in an area that would likely drain into the Gulf Intracoastal Waterway via rivers like the Trinity, Brazos, and Colorado. However, production practices in Texas are different than in the Marcellus Shale. Spent fracking fluids are typically disposed of by deep underground injection. Similarly, surface water discharges associated with exploration and production in the Bakken Shale in Montana and North Dakota would drain into the Missouri River, which eventually drains into USACE-managed portions of the Missouri River. Surface water associated with Woodford Shales in central Oklahoma that are not adjacent to the Arkansas (see previous paragraph) would eventually drain into the Mississippi River Watershed through the Red River. Surface water in the vicinity of Niobarra Shale appears to drain either into the Arkansas or Platte River watersheds, both of which would eventually lead to the Mississippi River Valley. In all of these cases, the distances from USACE waterways are on the order of hundreds of miles. It would be reasonable to expect that if problems surfaced regarding these areas, some mitigation would be implemented prior to impacts reaching USACE waterways.

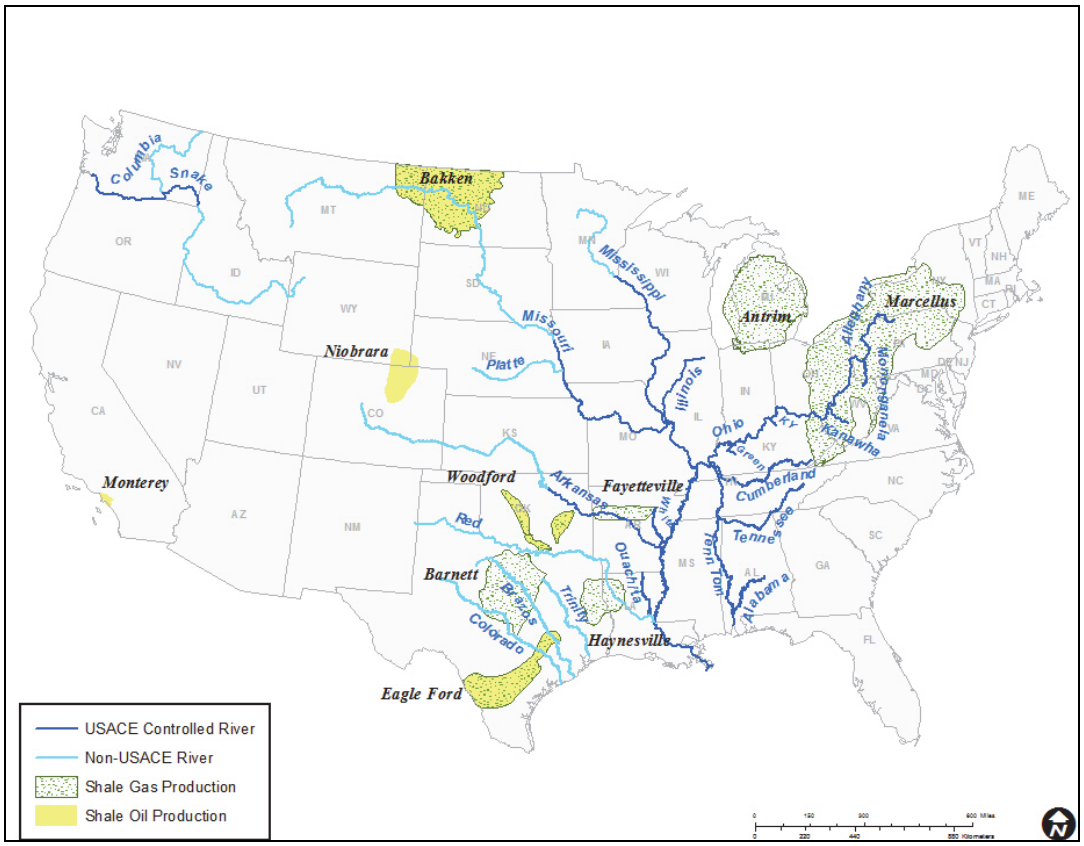

Figure 2. USACE-managed waterways and commercially productive shale plays that are primarily exploited using hydrofracturing (Prepared by Scott Bourne).

Evaluation of Fracking on the Great Lakes. Although they are massive water bodies, the Great Lakes have had significant water and sediment quality issues over the past 150 years. Part of the problem has been that the lakes are limited in their outflows, so any inputs of nutrients or contaminants tend to accumulate over time. Lake Erie, for example, had so much contamination from farming and industry that it was completely overrun with algae and was declared "dead" in the early 1970s (Jeanneret 1989). Fortunately, the Great Lakes are improving in water quality over time, due to better management practices of rivers and streams that discharge into the Lakes. Still, water and sediment quality issues persist. The U.S.-Canada Great Lakes Water Quality Agreement has defined an Areas of Concern (AOCs) as "geographic areas that fail to meet the general or specific objectives of the agreement where failure has caused or is likely to cause an impairment of beneficial use of the area's ability to support aquatic life." More simply put, an AOC is a location (generally a river or watershed discharge) that has experienced environmental degradation.

The senior author (VFM) reviewed the AOC documentation provided by the USEPA for sites located in Michigan, Ohio, Pennsylvania, and New York (states with significant fracking activities), and fracking activities were not mentioned as a reason for listing any of the AOCs (USEPA 2014).

The Antrium and Marcellus Shales either intersect or are immediately adjacent to the Great Lakes (Figure 3). Production along the Antrium Shale could result in discharges into Lake Michigan,

Lake Huron, and Lake Eire, and could affect 7 U.S. and 2 combined AOCs. Similarly, the Marcellus Shale could result in discharges to Lake Eire and Lake Ontario, and could affect 7 U.S., 1 combined, and two delisted AOCs.

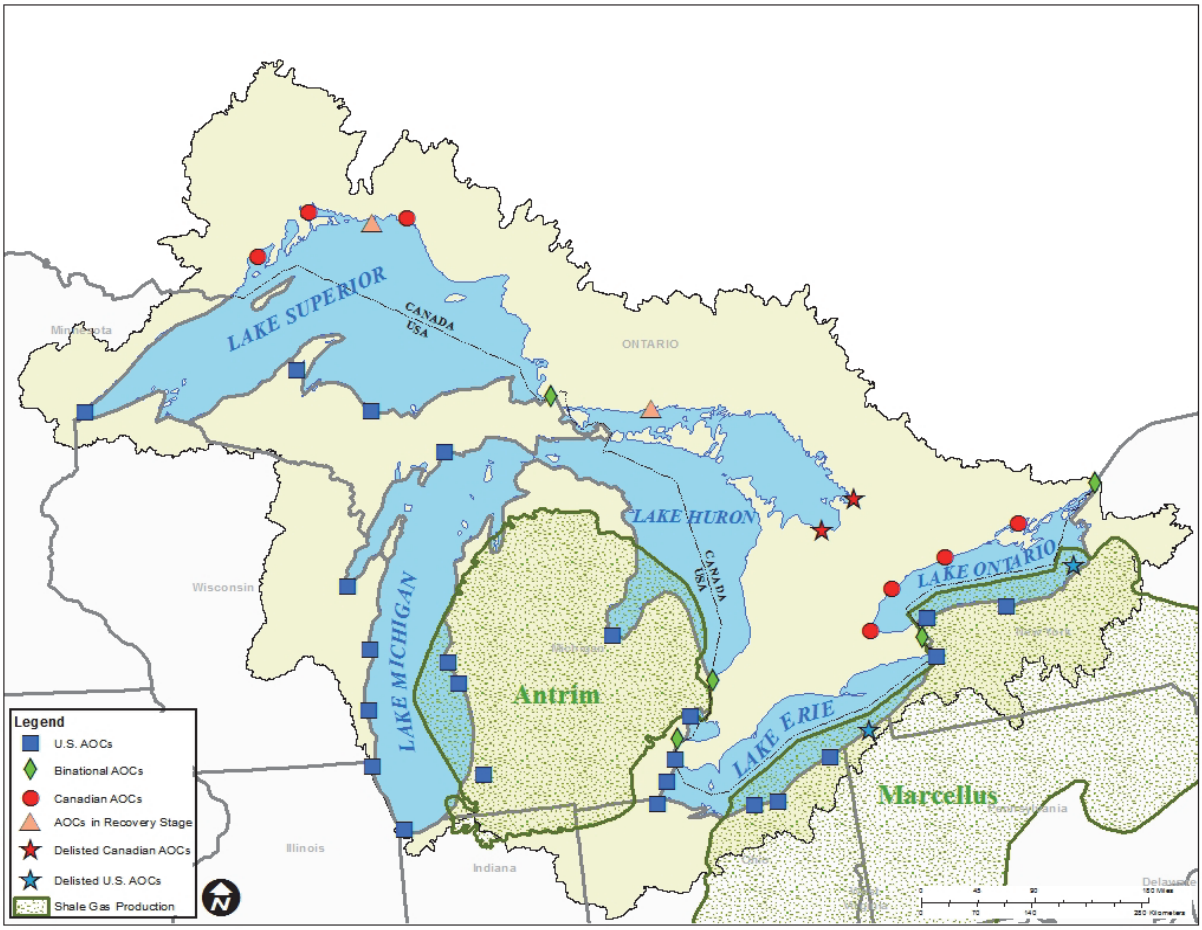

Figure 3. The Great Lakes, Atrium and Marcellus Shale Plays, and USEPA Areas of Concern (AOCs) (Prepared by Scott Bourne).

Gosman et al. (2012) reviewed fracking activities in the Great Lakes basin in Michigan and Ohio. The report did not specifically identify contamination from fracking activities to date, and suggested that existing laws were sufficient to protect the Lakes from contamination from historic production practices, which have involved shallow well fracking. Wastewater from fracking operations in Michigan and Ohio is largely disposed of by deep well injection, which also reduces potential for impacts (Gosman et al. 2012). However, the report documents a strong increase in deep well hydrofracking within the last five years or so. These systems have a much more complex network of well borings, and they use more water and chemicals than the shallow zone fracking. Deeper well systems also operate at greater pressures. Consequently, there has been a sharp increase of potential contamination, and existing laws may not be sufficient to protect the Great Lakes basin. Deep zone fracking is expected to continue to increase in the area (Gosman et al. 2012).

Marcellus Shale Evaluation. Figure 4 is adapted from Warner et al. (2013), the study that established presence of contamination in the discharges of partially treated frack flowback solutions, drilling fluids, and produced water. It shows frack water treatment plants (red squares) in Western Pennsylvania. All frack flowback water must be treated, and there are 74 plants in this area. In the middle left of the figure is Blacklick Creek, where the actual study was conducted. The light blue shaded area is the Ohio River watershed, which contains the Ohio, Allegheny, and Monongahela Rivers, all USACE waterways. The map reveals that 61 of the plants discharge directly into tributaries of these rivers. Additionally, in the upper portion of the map, 8 plants are shown discharging directly into the Allegheny River. The Marcellus Shale is therefore posing the greatest risk to USACE waterways of the known production areas investigated in this study, due to direct discharges into these water bodies. The area covered by this map is about a 10th of the total area of the Marcellus Shale (as estimated by visual interpolation).

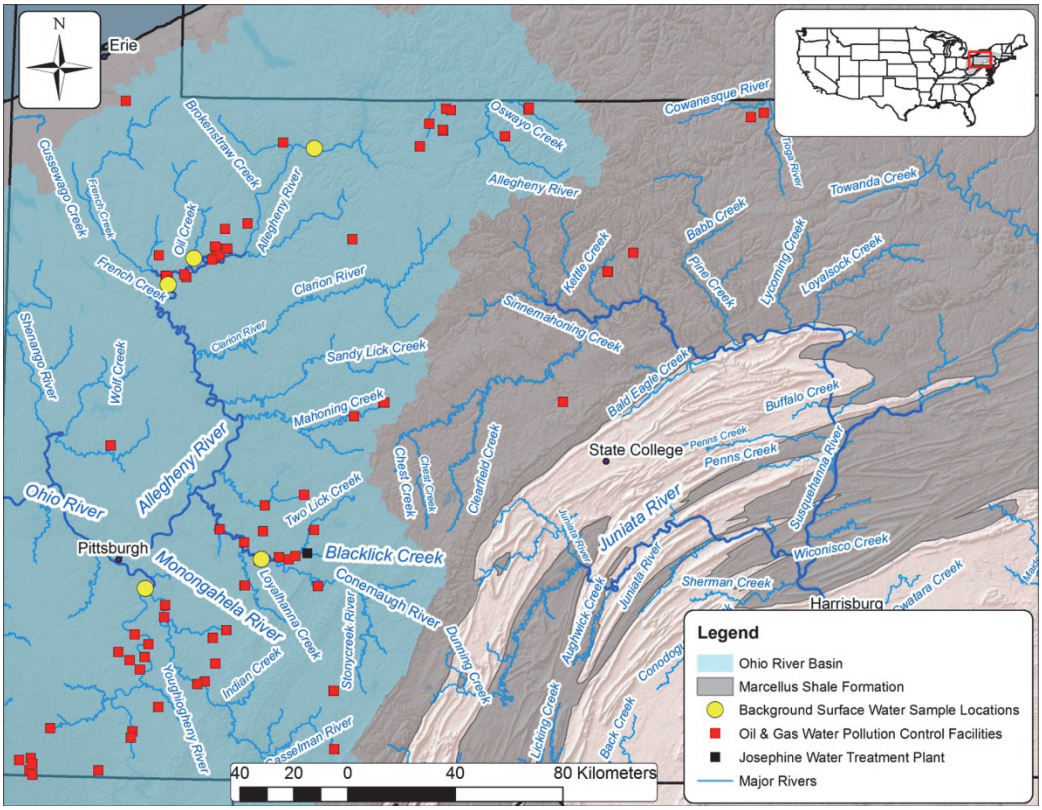

Figure 4. Frack water treatment plants/discharge sites in Western Pennsylvania (from Warner et al. 2013).

CONCLUSIONS/RECOMMENDATIONS: The following conclusions were drawn from this study:

- Three shale formations that are primarily exploited using hydrofracturing intersect USACE waterways: the Marcellus Shale in Pennsylvania and West Virginia, the Fayetteville Shale in central Arkansas, and the Haynesville Shale encompassing east Texas and west Louisiana.

- One oil- and gas-producing shale, the Woodford in Oklahoma, is just adjacent to one portion to the Arkansas River, which is managed as a USACE waterway.
- Shales in Texas (Eagle Ford and Barnett) are in areas that would drain into the Gulf Intracoastal Waterway. However, fracking fluid disposal in Texas is generally via deep well injection, which reduces surface water risks.
- The Woodford Shale in central Oklahoma, Niobarra Shale in northern Colorado, and the Bakken Shale in Northern Montana and North Dakota are in watersheds that would eventually drain into the USACE-managed portions of the Missouri or Mississippi Rivers. However, the distances involved are hundreds of miles. ***Overall, it appears that the greatest potential risk is from production shale plays that directly intersect USACE waterways.***
- The Antrium and Marcellus Shales border on the Great Lakes. Production in the area has not yet resulted in any documented releases into the Great Lakes. However, there is concern that new practices using deeper wells could result in accidental releases.
- A study (Warner et al. 2013) at the Marcellus Shale indicates that partially treated fracking fluids affect surface water quality.
- Fracking water treatment plants in eastern Pennsylvania discharge into tributaries that drain into the Allegheny, Monongahela, and Ohio Rivers - all USACE waterways. Several plants directly discharge into the Allegheny River. For these reasons, ***the Marcellus Shale appears to be the area of current greatest risk to USACE waterways.***

Based on the findings of this literature review, the following recommendations are proposed:

- Conduct a risk-based assessment of hydrofracturing practices at the Fayetteville, Haynesville, and Woodford Shales to determine potential risks for surface water contamination.
- Monitor activities at the Antrium and Marcellus Shales that may increase risk to discharges into the Great Lakes.
- Monitor new exploration and development activities at new shale locations to identify new risks to USACE waterways.
- Perform an enhanced record review study of the Marcellus Shale to identify other potential risk areas to surface water.
- Design and complete a field study of USACE waterways in the Marcellus Shale area to assess hydrofracturing-related contaminant risks to surface water bodies.
- Conduct a modeling study to assess potential long-term contaminant risks of Marcellus Shale discharges to USACE waterways.

To accomplish these goals, it is further recommended that USACE appoint a hydrofracturing expert, and this person should keep abreast of developments in the fracking industry.

ADDITIONAL INFORMATION: This technical note was prepared by Dr. Victor F. Medina, P.E., Research Engineer, and Dr. Burton Suedel, Research Biologists, Environmental Laboratory, U.S. Army Engineer Research and Development Center. The study was conducted as an activity of the Dredging Operations Technical Support (DOTS) program. For information on DOTS, please contact the Program Manager, Cynthia Banks, at *Cynthia.J.Banks@erdc.usace.army.mil*. This technical note should be cited as follows:

Medina, V.F., and B. Suedel. 2015. *Evaluation of Hydraulic Fracturing (Fracking) Plays for Potential Impact on USACE-Managed Waterways*. ERDC TN-DOTS-15-1. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

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