Project Acronym and Title:

**M4ShaleGas - Measuring, monitoring, mitigating and managing the environmental impact of shale gas**

# IMPROVING WATER MANAGEMENT AND TREATMENT IN SHALE GAS OPERATIONS


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## Public introduction

M4ShaleGas stands for *Measuring, monitoring, mitigating managing the environmental impact of shale gas* and is funded by the *European Union's Horizon 2020 Research and Innovation Programme*. The main goal of the M4ShaleGas project is to study and evaluate potential risks and impacts of shale gas exploration and exploitation. The focus lies on the four main areas of potential impact: the subsurface, the surface, the atmosphere & climate, and public perceptions.

The European Commission's Energy Roadmap 2050 identifies gas as a critical fuel for the transformation of the energy system in the direction of lower $CO_2$ emissions and more renewable energy. Shale gas may contribute to this transformation.

Shale gas is – by definition – a natural gas found trapped in shale, a fine grained sedimentary rock composed of mud. There are several concerns related to shale gas exploration and production, many of them being associated with hydraulic fracturing operations that are performed to stimulate gas flow in the shales. Potential risks and concerns include for example the fate of chemical compounds in the used hydraulic fracturing and drilling fluids and their potential impact on shallow ground water. The fracturing process may also induce small magnitude earthquakes which may raise public concern if felt at the surface. There is also an ongoing debate on greenhouse gas emissions of shale gas ($CO_2$ and methane) and its energy efficiency compared to other energy sources

There is a strong need of a better European knowledge base on shale gas operations and their environmental impact particularly, if shale gas shall play a role in Europe's energy mix in the coming decennia. M4ShaleGas' main goal is to build such a knowledge base, including an inventory of best practices that minimize risks and impacts of shale gas exploration and production in Europe.

The M4ShaleGas project is carried out by 18 European research institutions and is coordinated by TNO-Netherlands Organization for Applied Scientific Research.

## Executive Report Summary


Countries in Europe with known shale gas resources collectively accounted for almost 12% of the global shale gas resource potential at the end of 2012, but there is not any experience related to the flowback treatment, except for some explorations projects. All the information related to the water and wastewater management comes necessarily from the U.S. and Canada experiences.

The three key points identified in relation to the improvement of water management in shale gas operations have been 1) the prevention of spill and leakages, 2) the reduction of the water consumption and 3) the final destination of the liquid waste generated during the hydraulic fracturing operations.

The main measure to adopt in order to prevent the generation of spills and leakages consists in the reduction of the use of chemicals from the operators.

Reducing the amount of surface water and fresh groundwater in hydraulic fracturing is a priority for industry. There are several approaches to reducing fresh water use including:

- Using alternative, low quality or otherwise unusable sources of water such as saline groundwater
- Reusing produced and flowback water in subsequent hydraulic fracturing operations
- Sharing sources of water in multiple operations or with other operators
- Working with communities to use treated municipal wastewater
- Investing in research to develop hydraulic fracturing technologies that require less water or alternatives to water

There are a lot of techniques related to disposal and reuse of the wastewater which may be grouped in three basics categories: Water minimization techniques, Recycle/Reuse techniques and Disposal techniques (Veil, 2015):

- Water Minimization techniques:
    - Reduce the volume of water entering the wells
    - Reduce the volume of water managed at the surface by remote separation
- Recycle/Reuse techniques:
    - Underground injection for increasing recovery

  - Injection for hydrological purposes
  - Agricultural use
  - Industrial use
  - Treat to drinking water quality
- Disposal techniques:
  - Discharge
  - Underground injection (other than for enhanced recovery)
  - Evaporation
  - Offsite commercial disposal

The main proposed measures to reach an optimum water management approach are:

- Reduction of the use of chemicals from the operators.
- Disclosure of the chemicals used in hydraulic fracturing.
- Develop of meticulous equipment maintenance systems as well as employee comprehensive training.
- Reuse produced and flowback water in subsequent hydraulic fracturing operations whenever possible.
- Use alternative, low quality or otherwise unusable sources of water such as treated municipal wastewater or saline groundwater.
- Promote the investment in research to develop hydraulic fracturing technologies that require less water or alternatives to water.
- Reuse produced and flowback water in other close hydraulic fracturing facilities.
- Treatment of liquid wastes before recycling.

The main challenges to confront relies in the treatment of liquid wastes before recycling and the elaboration of a European database with information about the chemical compounds of the base fluid.

 

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# 1 INTRODUCTION

## 1.1 Context of M4ShaleGas

Shale gas source rocks are widely distributed around the world and many countries have now started to investigate their shale gas potential. Shale gas has already proved to be a game changer in the U.S. and Canadian energy markets (EIA 2015[1]). The European Commission's Energy Roadmap 2050 identifies gas as a critical energy source for the transformation of the energy system to a system with lower $CO_2$ emissions that combines gas with increasing contributions of renewable energy and increasing energy efficiency. It may be argued that in Europe, natural gas replacing coal and oil will contribute to emissions reduction on the short and medium terms.

There are, however, several concerns related to shale gas exploration and production, many of them being associated with hydraulic fracturing operations. There is also a debate on the greenhouse gas emissions of shale gas ($CO_2$ and methane) and its energy efficiency compared to other energy sources. Questions are raised about the specific environmental footprint of shale gas in Europe as a whole as well as in individual Member States. Shale gas basins are unevenly distributed among the European Member States and are not restricted within national borders which makes close cooperation between the involved Member States essential. There is relatively little knowledge on the footprint in regions with a variety of geological and geopolitical settings as are present in Europe. Concerns and risks are clustered in the following four areas: subsurface, surface, climate & atmosphere, and public perceptions. As the European continent is densely populated, it is most certainly of vital importance to include both technical risks and risks as perceived by the public.

Accordingly, Europe has a strong need for a comprehensive knowledge base on potential environmental, societal and economic consequences of shale gas exploration and exploitation. Knowledge needs to be science-based, needs to be developed by research institutes with a strong track record in shale gas studies, and needs to cover the different attitudes and approaches to shale gas exploration and exploitation in Europe. The M4ShaleGas project is seeking to provide such a scientific knowledge base, integrating the scientific outcome of 18 research institutes across Europe. It addresses the issues raised in the Horizon 2020 call LCE 16 – 2014 on *Understanding, preventing and mitigating the potential environmental risks and impacts of shale gas exploration and exploitation.*

[1] EIA (2015). Annual Energy Outlook 2015 with projections to 2040. U.S. Energy Information Administration (*www.eia.gov*).

 

## 1.2 Study objectives for this report

The main objectives of this report are 1) to identify the main key points to consider in order to reach as sustainable as possible water management for the shale gas industry 2) to show the trends in the activities of the shale gas sector in relation to the water and liquid waste management 3) to expose examples of best techniques available related to water management in the context of the hydraulic fracturing operations which are been currently used by the operators (European operators if possible) in order to advance to their sustainability objectives.

## 1.3 Aims of this report

The report aims to provide public information about the key aspects related to the water and wastewater management. Furthermore an explanation regarding the trends of the sector in water and wastewater management as well as several case stories found will be shown.

 

# 2 AVAILABLE DATA REGARDING WATER MANAGEMENT IN EUROPE

In an U.S. Energy Information Administration agency (EIA) report published in April 2011 (World Shale Gas Resources: an initial Assessment of 14 Regions outside the United States) technically recoverable shale gas resources in Europe were estimated at 17.1 $Bm^3$ (Billion cubic meter). This represented a little over 9% of the global shale gas resource potential. In 2013, the EIA published a revised assessment of world shale gas resources, which estimates potential resources greater (25.1 $Bm^3$). Countries in Europe with known shale gas resources collectively accounted for almost 12% of the global shale gas resource potential at the end of 2012. (http://www.ey.com/Publication/vwLUAssets/Shale_gas_in_Europe_revolution_or_evolution/$File/EY-Shale_gas_in_Europe-revolution_or_evolution.pdf).

Shale gas in Europe is currently in the phase of investigation and/or exploration. At this stage it is possible to assess the existing reserves in the different sedimentary basins. The only (incomplete) data available related to water cycle in hydraulic fracturing activities in Europe has been mainly originated in two research sites:

- UK: Bowland Hodder Shale (by Cuadrilla resources) over the Upper Carboniferous horizon (Andrews 2013),
- Poland: (by PGNiG) over the Upper Ordovician horizon (Konieczyńska et al. 2015).

Research expectations in the Basque-Cantabrian Basin (Spain) have been dissipated. BNK Petroleum has withdrawn its project due to the expiration of the research permit before the favorable Environmental Impact Declaration of its research project, called “Urraca”, which implies the perform of three exploration drillings, was issued.
In addition, there is not any experience related to the flowback treatment, except for some experimental project, in Europe (Michel et al. 2016).

 

# 3 KEY ASPECTS REGARDING THE WATER MANAGEMENT AND TREATMENT FOR SHALE GAS OPERATIONS

Three key points in the path of the improvement of water management for shale gas operations are 1) the prevention of spill and leakages, 2) the reduction in the water consumption and 3) the final destination of the liquid waste generated during the hydraulic fracturing operations.
This document will offer a general perspective of these three aspects of the water management and is used to expose several examples about what are the current hydraulic fracturing industries activities which are being developed in this regard.

## 3.1 Prevention of spills and leakages

There has not been much work on the frequency of spills of hydraulic fracturing fluids and additives. There is an estimated average of 2.6 reported spills for every 100 wells, with a range of 0.4 to 12.2. These values are uncertain because these rates used different criteria for including a spill and it is unknown whether these spill estimates are representative of national occurrences (U.S. EPA, 2016).
Spill causes included equipment failure, human error, failure of container integrity, and other causes. The most common cause was equipment failure. Equipment failure included blowout preventer failure, corrosion, and failed valves. More than 30% of the chemical or hydraulic fracturing fluid spills characterized by the EPA came from fluid storage units (U.S. EPA, 2016).

*New tendencies and reported cases*
An initial measure to adopt in order to prevent the generation of spills and leakages consists in the reduction of the use of chemicals from the operators. During the last decade a high number of the about 1200 chemicals and other components, that formerly were used in hydraulic fracturing, has been replaced or omitted as additives. Recent developments in fracking techniques have led to the current use of far fewer additives during the entire fracking procedure, which has resulted in an immediate reduction in the risk of groundwater and surface water contamination (e.g. some techniques based on UV radiation and some others non-chemicals techniques have been developed in order to avoid the use of biocides). Some of the remaining additives presently used, can cause environmental problems when they return to the surface in the flowback water. Consequently, special care must be taken in the disposal. The only option for temporarily storage in Europe is closed tank systems in the fracking operation.
In any case, the hydraulic fracturing operations inevitably produce the generation of flowback and produced water that, due to their composition, should be managed as pollutant. Reusing the liquid waste is a provisional solution and it involves a smart action because it implies not only to reduce the consumption of water as well as minimizing the generation of wastewater. Nevertheless, theoretically, this measure may not be applied indefinitely. Surface spills of produced water from oil and gas production have occurred across the U. S. country and, in some cases, have caused impacts on drinking water resources. Released fluids can flow into nearby surface waters, if not contained on-site, or infiltrate into groundwater via soil. Produced water spills and

 

releases can occur due to several causes, including events associated with pipelines, transportation, blowouts, and storage (U.S. EPA, 2016).

Representatives from oil and gas companies, chemical companies, and non-profits are working on strategies to reduce the number and the volume of chemicals used and to identify safer chemicals. Southwestern Energy Company, for example, is developing an internal chemical ranking tool and Baker Hughes is working on a hazard ranking system designed for wide-scale external use. Environmental groups, such as the Environmental Defense Fund, are also developing hazard rating systems. Typical criteria used to rank chemicals include mobility, persistence, biodegradation, bioaccumulation, toxicity, and hazard characteristics (U.S. EPA, 2016).

Given that human error is the cause of 25% of chemical mixing related spills and spill prevention can never be 100% effective, changes in the type of chemicals used could reduce the frequency or the severity of potential impacts. Using chemicals with specific physicochemical properties that affect the fate and transport of chemicals could reduce their potential impacts. Less mobile chemicals could make clean-up of spills easier. Using chemicals with lower persistence and higher biodegradability, if spill prevention and clean-up are not fully effective, would lessen the severity of potential impact.
On the other hand, in the sector there is a real concern in the assessment of the interaction between the hydraulic fracturing water (including the compounds used in the chemical mixture) and the geological media in order to explain the chemical features of the flowback and the long-term produced water.
Employee training and equipment maintenance are factors which have been recognized as effective spill prevention, containment, and mitigation measures (U.S. EPA, 2016).

*Proposed measures*

- Reducing the use of chemical compounds in hydraulic fracturing fluids. This measure leads to the minimisation of environmental impacts in the case of spill.
- Disclosing the chemicals used in hydraulic fracturing is essential to assess, mitigate and correct, risks linked directly to fracturing fluids and also to liquid waste.
- Developing meticulous equipment maintenance systems to ensure a proper state of all the facilities along all the project as well as employee comprehensive training to prevent failures due to an incompetent handling.
- Reusing produced and flowback water in subsequent hydraulic fracturing operations whenever possible otherwise the volume of liquid waste could tend to rise, increasing the risk of spills and leakages.

## 3.2 Reducing fresh water use

Fifty-six percent of hydraulically fractured wells in the United States are in regions experiencing short- to long-term drought conditions. Areas experiencing prolonged drought conditions include California and much of Texas, Colorado, Oklahoma, New Mexico, Arkansas and Louisiana. Operating in drought conditions makes it more difficult to physically source water. It can also lead to increasing groundwater depletion, competitive pressures over existing water resources and loss of social-license-to-operate. Groundwater depletion, a growing concern shale development in many regions, is highly reliant on groundwater resources, which are generally less regulated than surface waters, thus increasing risks of water resource depletion and water competition. Most water sourced for hydraulic fracturing in Texas, for example, comes from groundwater sources, yet there is no consistent requirement that groundwater used for hydraulic fracturing be reported, monitored or permitted. Overuse of groundwater is an increasingly serious problem that leads to land subsidence, reductions in surface water flows and ultimately unsustainable water supplies. Groundwater sources—from water in the soil to deep aquifers—are interconnected with one another and with surface water resources. Precipitation ultimately replenishes groundwater supplies, but in many cases this process can take decades, if not centuries or even longer. Surface and groundwater are in reality, a single resource although regulators and end-users often have historically viewed them separately (Freyman, 2014).

Agriculture and food production, drinking water supply, energy generation and different industrial sectors are among the areas where water resources are already or are rapidly becoming a limiting factor. On top of this, climate change intensifies the situation with increased variability in precipitation, changed run-off patterns and prolonged drought periods (Hoffman, Olsson & Lindström, 2014).

Large volumes of water extracted from ground or surface water sources for hydraulic fracturing affect public water resources and aquatic ecology, although increasingly, brackish and saline waters are injected. Freshwater availability is affected by local water budgets, populations, agricultural practices, and climate. Water supply concerns can be acute in areas that are susceptible to drought (Vengosh et al., 2014), such as areas of southern half of Spain, island of Sicily, Greek islands, northeast of Bulgaria and East of Rumania. The extraction of freshwater for hydraulic fracturing can also alter the hydrologic regime of rivers and streams and impact biological species through the loss of habitat, especially if the water withdrawal rate is high at a single location within a water body during a low-flow season or drought (Gallegos et al., 2015).
The first logical step towards the sustainable water management in shale gas operation consists of the optimization of the operational phase through an optimal exploitation design. An efficient design of operations and the implementation of best practices could reduce water consumption significantly (ter Heege, 2017). Optimization procedures that minimize drilling and well completions (with a corresponding reduction of water consumption) as well as the generation of flowback water can be implemented (ter Heege, 2016).

Nevertheless the exploitation design involves multiple factors headed by the gas recovery and the costs of the operations, and it could be unfeasible develop a project in which the water consumption will be the main approach. Anyway, provided that the water consumption is considered as another factor influencing the operational costs, the measures related to the operational design and procedures will have been taken into account somehow.

 

Reducing the amount of surface water and fresh groundwater in hydraulic fracturing is a priority for shale gas industry. There are several approaches to reducing fresh water use including:

- Using alternative, low quality or otherwise unusable sources of water such as saline groundwater,
- Reusing produced and flowback water in subsequent hydraulic fracturing operations,
- Sharing sources of water in multiple operations or with other operators,
- Working with communities to use treated municipal wastewater,
- Investing in research to develop hydraulic fracturing technologies that require less water or alternatives to water.

*New tendencies and reported cases*

According to the National Brackish Groundwater Assessment of the USGS, brackish aquifers are defined for purposes of that study as aquifers that have groundwater within 915 m (3000 ft) of land surface, contain dissolved-solids concentrations between 1,000 and 10,000 milligrams per liter, and can yield usable quantities of water. Recent advances in technology have reduced the cost and energy requirements of desalination, making treatment of brackish groundwater a more viable option for drinking-water supplies (National Research Council, 2008). Apache Corporation is the pioneer company in the use of brackish water. The company has closed-loop systems that use only brackish and recycled water at Bamhart project area in Iron County west of San Angelo. The non-potable water, from Santa Rosa aquifer, is treated to remove sulphates, magnesium, iron, bacteria, and large solids that can damage pipelines and pumping equipment. Then it is moved to large, lined retention ponds from which it can be pumped to the numerous pad drilling sites of the company in the Permian basin (http://www.ogj.com/articles/uogr/print/volume-2/issue-1/wolfcamp/apache-fracs-wolfcamp-wells-without-fresh-water-in-dry-barnhart-project-area.html).

Regards the water treatment, it should be noted the case of Antero Resources: a manufacturer of oil & natural gas in the Marcellus and Utica Shale plays which has selected Veolia, to design, build and operate an ultra-modern treatment complex in Appalachia. Planned to enter service at the end of 2017, the future plant will eventually treat and recycle around 9,500 $m^3$ of flowback and produced water a day. It will use exclusive `Veolia technology´, including AnoxKaldnes™ MBBR (Moving Bed Biofilm Reactor), Actiflo® clarification and the CoLD® Process, which are particularly innovative in the area of water treatment for reuse. Cold Process will completely desalinate high TDS produced water containing significant quantities of chloride salts. Substantial savings are achieved by eliminating the chemical softening step and discharging the final solid product as a wet cake, which does not require any further drying in order to transport it to a disposal site.

Fresh water (from both surface water and groundwater sources) currently supplies the vast majority of water used for hydraulic fracturing. However, the reuse of hydraulic fracturing wastewater for injection reduces the demand on fresh water sources.

 

Nationally, the proportion of water used in hydraulic fracturing that comes from reused hydraulic fracturing wastewater is generally low (U. S. EPA, 2016b). Alternatively, the use of treated municipal water has been commonly proposed as an alternative to fresh water.

The growing water shortages, combined with increases in the population, has forced to the government of Texas to design a use of water plan until 2070. Pioneer Natural Resources has been the first to try to source municipal effluent on a long term basis at industrial scale. The company reached a 10 year agreement with the city of Odessa in July 2014, under which it would purchase a baseline volume of treated municipal wastewater that it could then use to support hydraulic fracturing operations in the area. Initial water deliveries will cost Pioneer approximately \$1.71 / $m^3$, a significant discount given that procuring freshwater for hydraulic fracturing jobs in the Permian typically costs between \$3.16 / $m^3$ and \$9.47 / $m^3$. (https://www.bakerenergyblog.com/2015/07/23/toilet-to-frac-legal-and-practical-aspects-of-using-municipal-effluent-for-fracing-in-texas/).

Another example of use of treated municipal wastewater: in 2014, Apache Corporation worked with the city of College Station, Texas, and the Texas Commission on Environmental Quality approved to purchase about half of the treated municipal wastewater for it use in operations (water that would otherwise be a waste stream from the treatment plants). In 2015, approximately 650,000 $m^3$ of this treated municipal wastewater for fracking in Eagle Ford play were purchased. (http://www.apachecorp.com/Resources/Upload/file/sustainability/APACHE-Sustainability_Report_2016.pdf).

In a further example of industry best practice for effective water management is the effort of Shell Canada to reduce its overall fresh water footprint by using municipal wastewater as the first priority water in its operations. In late 2014, Shell entered into an agreement with the Town of Fox Creek to use treated wastewater in the completion operations. In return for the use of the water, Shell funded the engineering and design to upgrade the town's raw water facilities. This alternative source of water is a key component of Shell's overall water strategy in the Fox Creek area and replaces the use of about 400,000 $m^3$ of fresh water a year (http://www.capp.ca/~/media/capp/customer-portal/publications/307208.pdf).

The example of Fox Creek is not the only one: the Town of Edson is selling wastewater from the sewage lagoons to Shell Canada and other companies for the purposes of hydraulic fracturing. (http://www.edsonleader.com/2013/11/12/town-sells-treated-wastewater-for-hydraulic-fracking).

In addition, the improvement of the technology concerning the stimulation fluids provides more efficient and cost-effective treatments. Since the mid-90s, innovations have been extending the state of the art in four areas: 1) controlling fluid loss to increase fluid efficiency, 2) extending breaker to improve fracture conductivity, 3) reducing polymer concentrations to improve fracture conductivity and 4) eliminating proppant to stabilize fractures (Amstrong et al., 1995). Alternative fracture fluids are also under investigation. Some of the purposes of alternative fluids are to reduce water use and to reduce formation-damage effects sometimes caused by aqueous fracture fluids and by additives such as gels. These alternatives include supercritical $CO_2$ and supercritical $CO_2$ -nitrogen mixtures, $CO_2$ foam, nitrogen, liquid propane (LPG), and explosive propellant systems (EPS), but are not exempted from serious disadvantages (leakage of $CO_2$ into the atmosphere, risk of explosion with LPG, etc.) (Rogala et al., 2013).

*Proposed measures*

- Reuse produced and flowback water in subsequent hydraulic fracturing operations whenever possible. The more amount of wastewater is recycled, the less fresh water it would be necessary to consume.
- Use alternative, low quality or otherwise unusable sources of water such as treated municipal wastewater or saline groundwater. Alternative sources of water, if available, could help to reduce freshwater consumption.
- Promote the investment in research to develop hydraulic fracturing technologies that require less water or alternatives to water: some design factors of the hydraulic fracturing process (flow of the hydraulic fracturing fluids, clusters per stage, number of stages and stage length, etc.) could influence in the consumption of water. On the other hand the different chemical mixtures available for a specific project may require a variable quantity of water.

## 3.3 Final destination of the liquid waste generated

The final stage of the hydraulic fracturing water cycle encompasses disposal and reuse of hydraulic fracturing liquid waste. For the purposes of this assessment, the term liquid waste concerns both flowback and produced water coming from hydraulically fractured oil and gas wells that is being managed using practices that include, but are not limited to, reuse in subsequent hydraulic fracturing operations, treatment and discharge, and injection into disposal wells. The majority of the liquid waste generated from all oil and gas operations in the United States is managed via Class II injection wells (U.S. EPA, 2016).

There are a lot of techniques for the management of the wastewaters which may be grouped in three basic categories: Water minimization techniques, Recycle/Reuse techniques and Disposal techniques (Veil, 2015):

- Water minimization techniques:
  - Reduce the volume of water entering the wells
  - Reduce the volume of water managed at the surface by remote separation

- Recycle/Reuse techniques:
  - Underground injection for increasing recovery
  - Underground injection for future water use
  - Injection for hydrological purposes
  - Agricultural use

 

- o Industrial use
- o Treat to drinking water quality

- Disposal techniques:
  - o Discharge
  - o Underground injection (other than for enhanced recovery)
  - o Evaporation
  - o Offsite Commercial disposal

*New tendencies and reported cases*
As of 2015, available information suggests that Class II disposal wells are a primary wastewater management practice for operators in most of the major unconventional reservoirs in the United States, with the notable exception of the Marcellus Shale region in Pennsylvania. Operators producing from unconventional formations have managed their wastewater through the use of publicly owned treatment works (POTW), Centralized waste treatment plants (CWT), extensive reuse for hydraulic fracturing operations, and hauling to disposal wells (to a lesser degree). The history of the management of liquid wastes from shale gas operation in Pennsylvania provides an example of evolving strategies to manage the treatment, discharge, storage, and reuse of hydraulic fracturing liquid waste that are rich in constituents of concern. The reuse of liquid waste (mainly flowback) for subsequent hydraulic fracturing jobs is most prevalent in Pennsylvania (as high as 90%), with much of the reuse happening on-site. Reuse is practiced in other regions as well (e.g., Haynesville Shale, the Fayetteville Shale, the Barnett Shale, and the Eagle Ford Shale), but at much lower rates (about 5 - 20%). Other liquid waste management practices, such as evaporation and agricultural uses, represent a smaller fraction of liquid waste management nationally. These practices can, however, be locally significant. Although specific instances of contamination were not identified for this assessment, these practices could lead to impacts on drinking water resources if facilities are not properly constructed and maintained or if water quality is not adequately characterized to ensure that management is appropriate. Other management strategies such as irrigation, road spreading, and evaporation are less frequently employed for hydraulic fracturing wastewaters. The severity of impacts on surface waters from irrigation and road spreading will depend on the constituents in the wastewater (U.S. EPA, 2016).

Regardless of the wastewater management practices used, some type of temporary storage of fluids is generally required. Storage can be implemented in the form of tanks as well as pits and/or impoundments. Pits encompass a variety of structures, from on-site pits for storage at the well site to larger, centralized facilities (typically referred to as “impoundments” or “ponds”). Some states allow evaporation pit facilities or percolation pits as a means of wastewater disposal. The locations and number of pits are not well documented in most states (U.S. EPA, 2016).

In 2010, concerns arose over elevated TDS in the Monongahela River due to an increase in total wastewater generation in the Marcellus region around 570%. In response, Pennsylvania Department of Environmental Protection (PA DEP) amended Chapter 95

 

Wastewater Treatment Requirements under the Clean Streams Law for new discharges of TDS in wastewaters (regulation also informally known as the 2010 TDS regulation). The regulation disallowed any new direct discharges to streams as well as direct disposal at POTW of hydraulic fracturing wastewater and set limits on treated discharges. In April 2011, PA DEP announced a request that by May 19, 2011, gas drilling operators voluntarily stop transporting wastewater from shale gas extraction to the eight CWT and seven POTW that were exempt from the 2010 TDS regulation. In addition, there were letters from PA DEP to the owners of the wells, in which the concern about the role of bromides from Marcellus Shale wastewaters in the formation of total trihalomethanes (TTHM) due to the potential public health impacts was exposed. In response to the request, the oil and gas industry in Pennsylvania accelerated the switch of wastewater deliveries from POTW to CWT for better removal of metals and suspended solids. Between early and late 2011, although reported wastewater production more than doubled, Marcellus Shale drilling companies in Pennsylvania reduced their use of CWT that were exempt from the 2010 TDS regulation by 98%, and direct disposal of Marcellus Shale wastewater at POTW was “virtually eliminated”. Along with the decreased discharges from POTW, there has been increased reuse of wastewater in the Marcellus Shale region. From 2008-2011, the reuse of Marcellus wastewater for hydraulic fracturing increased, POTW treatment volumes decreased, tracking of wastewater improved, and wastewater transportation distances decreased. Maloney & Yoxtheimer (2012) analysed data from 2011 and found that reuse of flowback increased to 90% by volume. Eight percent of flowback was sent to CWT. Brine water, which was defined as formation water, was reused (58%), disposed via injection well (27%), or sent to CWT (14%). For all the fluid wastes in the analysis, brine water was most likely to be transported to other states (28%). Maloney & Yoxtheimer (2012) also concluded that wastewater disposal to municipal sewage treatment plants declined nearly 100% from about 7,500 $m^3$ in the first half of 2011 to 65 $m^3$ in the second half (U.S. EPA, 2016).

*Proposed measures*

- Reuse produced and flowback water in subsequent hydraulic fracturing operations whenever possible. Otherwise the amounts of liquid wastes would increase necessarily in the shale gas plays.
- Reuse produced and flowback water in other close hydraulic fracturing facilities. Sharing the fracking fluids with neighbouring operators is other possibility to reuse the wastewater.
- Treatment of liquid wastes before recycling. Due to the features of the wastewater, and because disposal on water courses/aquifers is prohibited in the EU territory under the current Water Framework Directive, it is necessary to apply treatment processes in order to give the recycled water an alternative use (agricultural, industrial or even as drinking water if necessary).

 

# 4 CONCLUSIONS

There is not any experience related to flowback treatment, except for some experimental project, in Europe. All the information related to the water management comes necessarily from the U.S. and Canada experiences.

Considering three main aspects to take into account in relation to the improvement of water management for shale gas operations (prevention of spill and leakages, reduction in the water consumption and final destination of the liquid waste generated during the hydraulic fracturing operations) as well as the current situation of the legal framework of the E.U., substantially different in several aspects from the U.S. status (scarcity of real data from European operators, insufficient common general framework to establish general or particular recommendations, issues and water management practices about the use of freshwater differ among State Members, etc.) some measures, in order to establishing an optimum water management approach, have been proposed:

- Reduction of the use of chemicals from the operators.
- Disclosure of the chemicals used in hydraulic fracturing.
- Develop of meticulous equipment maintenance systems as well as employee comprehensive training.
- Reuse produced and flowback water in subsequent hydraulic fracturing operations whenever possible.
- Use alternative, low quality or otherwise unusable sources of water such as treated municipal wastewater or saline groundwater.
- Promote the investment in research to develop hydraulic fracturing technologies that require less water or alternatives to water.
- Reuse produced and flowback water in other close hydraulic fracturing facilities.
- Treatment of liquid wastes before recycling.

Responsibility of most of these measures lies in the shale gas industry (in the potential future shale gas industry in the case of Europe). Furthermore, it will be necessary cooperative actions between the shale gas producers in order the share resources whenever possible.

For its part, authorities may adopt an alternative role (promoting the investment in research, managing the transfer of water resources between the municipal facilities and the shale gas industries, etc.). In addition, the approaches under the perspective of the Strategic Environmental Assessment, as well as the need of the evaluation on a case-by case basis are essential perspectives to take into account. Based on these considerations the establishment of prohibited/restricted areas or buffer zones regarding surface water and groundwater resources based on vulnerability criteria is the main measure to consider.

The areas of greatest current develop potential regarding the water management are:

- Reduction of the use of chemicals from the operators: The efforts made by the shale gas industry in the last decade have not gone unnoticed and have supposed real environmental improvements. Surface spills of chemicals and/or fracturing fluid may pose a greater contamination risk that hydraulic fracturing itself.

- Reuse produced and flowback water in subsequent hydraulic fracturing operations whenever possible, which implies the need to develop technologies that allow the use of brackish water with an increasing concentration of dissolved solids. The current upper limit for salinity for adjusting to friction reducers in hydraulic fracturing fluids is about 25000 to 30000 mg/L or even higher (Cuadrilla Resources has set, for Blackpol site TDS threshold of 250000 mg/L for its friction reducer). If TDS content would higher, the flowback fluid would be diluted with water to reduce this content. According to current researches, the flowback could be used with a primary and secondary treatment used in conjunction with the mixture with fresh water.

- Promote the investment in research to develop hydraulic fracturing technologies alternatives to water: Despite the disadvantages, the fracturing process employing $CO_2$ is becoming a real alternative to the classical hydraulic fracturing proceedings. In the same way, another option involves the substitution of water by other types of liquids (e.g., gel). This practice is gaining moment in U.S., but it presents some constrains: it would be necessary the existence of nearby wells prepared to be fractured and flowback probably will need some kind of treatment before it use.

On the other hand the main challenge identified relies in the treatment of liquid wastes before recycling: how to handle with the liquid wastes generated is one of the key points for the shale gas industry. Despite the use of chemical being dramatically reduced, the prohibition of discharge under the framework water Directive requires an alternative management ways of the wastewater, and all these ways go through recycling (or reuse in other shale gas play, but this procedure cannot be maintained indefinitely), and the recycling implies the treatment of this wastewater.

In addition it should be necessary the elaboration of a European database with information about the chemical compounds of the base fluid. Providing an initial description of the base fluid and each additive that the operator intends to use in the hydraulic fracturing fluid, including the trade name, supplier, purpose, ingredients, CAS Fact Sheet, maximum ingredient concentration in additive, and maximum ingredient concentration in hydraulic fracturing fluid is an essential question when risks are aimed to be measured, minimised or mitigated. Also, total volumes must be assessed. This measure is considered, by the European Commission, as a measure of high level of ambition to reduce likelihood and the reduction of damage of the risks linked to unconventional gas extraction.

 

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