Project Acronym and Title:

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

# The impacts of fracking fluids on drinking water resources and quality


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## Public introduction

M4ShaleGas stands for *Measuring, monitoring, mitigating and 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 four main areas of potential impact: the subsurface, the surface, the atmosphere, and social impacts.

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. 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 for a better European knowledge base on shale gas operations and their environmental impacts 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 minimise risks and impacts of shale gas exploration and production in Europe, as well as best practices for public engagement.

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

In the four reports M4ShaleGas D8.1 to D8.4, we reviewed and synthesized scientific literature, including the publications resulting from the research and information provided from North America, to assess knowledge and experience of the potential for hydraulic fracturing to change the quality or quantity of surface and groundwater resources.

In this report we have gathered the available knowledge from North America about the potential for hydraulic fracture for shale gas to change the quality or amount of drinking water resources and surface water and further identified factors that affect the frequency or severity of potential effects. Potential for drinking water is broadly defined in this report as any groundwater or surface water that may serve as a source of drinking water for public or private use. The report compiles these reviews based on the four reports that have already been published.

In this final report, emphasis is placed on the problems and solutions that can be attributed to hydraulic fracking and only minor attention to general pollution risks of on shore drilling.

At the end is included all references, which have been cited in the four reports M4ShaleGas D8.1 to D8.4.

 

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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 make 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 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.*

## 1.2 Study objectives for this report

The main objective of this report is to summarize the impacts on groundwater and surface waters quantity and quality with regards hydraulic fracking procedures. This work package will address the environmental problems related to groundwater and

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

 

surface water contamination and methodologies, including geological models, and impacts on groundwater quality and finally the toxic potential contaminants. The research activities intend to summarize the knowledge gap useable for a possible European assessment for application in on-shore hydraulic fracking.

## 1.3 Aims of this report

Review of data and existing best practices from U.S.A. and Canada of the environmental problems related to groundwater and surface water contamination. This report gives summary of the present knowledge on the environmental impact of shale exploration and production with special emphasis on groundwater and surface water quality and resources.

 

## 2 BACKGROUND

The increasing on-shore gas exploration and production is a direct result of the expanded use of hydraulic fracturing. However, this has raised public and scientific concerns about its potential for impacts to the environment. Special emphasize have been directed towards the effects of hydraulic fracturing on surface water and the quality and quantity of drinking water aquifers. Several residents areas close to well sites has reported changes in the quality of groundwater resources used for drinking water, which might origin from hydraulic fracturing activities. In other areas there have been pronounced competition for water between hydraulic fracturing operations and other water users, e.g. domestic users, agricultural and industrial users. Problems have been most pronounced in areas of minor net precipitation with risk for drought. Other concerns have been appointed to the disposal of wastewater generated from hydraulic fracturing.

In the four reports M4ShaleGas D8.1 to D8.4, we reviewed and synthesized scientific literature, including the publications resulting from the research and information provided from North America, to assess knowledge and experience of the potential for hydraulic fracturing to change the quality or quantity of surface and groundwater resources. In the final report, emphasis is placed on the problems and solutions that can be attributed to hydraulic fracking and only minor attention to general pollution risks of on shore drilling.

By the fracking process, hydraulic fracking liquids are used, which contain a large numbers of additives that will penetrate into the shale formation. There are in USA reported more than 1000 different substances, which have been used for fracking additives over time. From the Polish wells are a corresponding list in form of factsheets, NGS-factsheets, which, however is somewhat reduced relative to the USA list. Fracking fluid is squeezed into the shale formation in the subsurface with high pressure; where after the return pumping only recovers about 4-8 % of the water in the flowback stream immediately after fracking. Part of the remaining volume will be held in the shale formation and will return slowly during the production of shale-gas from the formation. The water produced throughout the production period must consequently be treated to a level of emission requirement.

Throughout the fracking development there will be processes where there will be potential danger to or impact on both surface water and groundwater quantity and quality. First, the amount of water used for fracking might be a resource problem in certain areas. Next, chemicals to the hydraulic fracking must be handled at the well site, which allows for spillage. Afterwards, hydraulic fracking is carried out at great depths but under high pressure and high temperatures, which in case of defects or insufficient materials could give a discharge to the environment. After fracking, part of the fracking liquid will return to the surface as flowback, which may contain environmentally polluting or contaminating elements, with potential for spillage or discharge. Lastly, during the production of gas, larger or smaller amounts of produced water will be separated from the gas. Produced water generally consists of brines with varying amounts of contaminants. This must be handled and cleaned before disposal of this to the environment, which in turn allows for spill or accident.

 

# 3 WATER ACQUISITION

## 3.1 Process

Hydraulic fracturing is the process used to stimulate gas production from unconventional gas reservoirs. At each well fracturing may need a volume of 10 – $20\times10^3$ $m^3$ of fluid as each fracking stage uses between 1000 and 2000 $m^3$. The fracturing fluid consists of at about 98% water and about 2% of sand or ceramics besides a number of chemicals having specific functions, Report D8.4. Formerly, more than hundred chemicals have been used as additives, but recently no more than 10 -15 chemicals are used in the fracking process. After stimulation, about 4% to 8% of the fluid may flow back to the surface.

Water consumption for unconventional gas production may increase the pressure on freshwater resources, especially in areas where water abstraction is already intense. Within a shale gas production, it is therefore important to analyse the extent to which production will affect water resources. As shale gas production has been widely used, primarily in North America, several estimates of water consumption has been published calculated per well. In September 2015 the most comprehensive inventory was published, based on about 45,000 wells in seven different formations and showed average consumption from 13,000 to 24,000 $m^3$ / well (Kondash and Vengosh, 2015 & 2017) but showed a considerable variation from 2000 to 100,000 $m^3$ / well.

Total water use for shale gas operation in the European countries is not expected to stress the available groundwater resource beyond sustainability even though groundwater is used as the primary water source for drilling and hydraulic fracturing. The British Geological Survey (BGS) state that water uses for shale gas operation in United Kingdom will be less than 1 % of total groundwater abstraction. In Denmark the estimated water use for the prospected available shale gas resource with exploitation during a 20 year period, will consume less than 0.5 % of the total annual groundwater abstraction, Hansen et al. 2016. In Poland show calculation of different scenarios that between 0.03 and 0.86 % of the total water withdrawals for portable water could be attributed to shale gas exploitation within the study area, López-Comino et al. 2017.

## 3.2 Problem or Impact

The large amount of water needed for hydraulic fracturing may limit gas exploration in areas of scarcity of water and may induce restrictions. In connection with the over-exploitation of groundwater resource, both traditional and unconventional solutions have to be used. Not at all sites are groundwater resource sufficient to cover both domestic and industrial needs while hydraulic fracturing requires large amounts of water. The local groundwater resource can be overexploited by shale gas operation in several ways. One is a basic resource availability issue regarding either the size of the local resource compared with demand from shale gas uses, or simply withdrawing from an already exhausted or overexploited groundwater resource.

EPA began to research the potential impacts of hydraulic fracturing on drinking water resources, if any, and to identify the driving factors that could affect the severity and frequency of any such impacts, (US-EPA, 2012). Local impacts on drinking water quantity have occurred in areas with increased hydraulic fracturing activity. In 2011, for example, drinking water wells in an area overlying the Haynesville Shale ran out of water due to higher than normal groundwater withdrawals and drought. Water withdrawals for hydraulic fracturing contributed to these conditions, along with other water users and the lack of precipitation. Groundwater impacts have also been reported elsewhere. In a detailed case study, Scanlon et al. (2014) estimated that groundwater levels in approximately 6% of the area studied dropped more than 30 m (locally up to more than 60 m) after hydraulic fracturing activity increased. Because the same water resource can be used to support hydraulic fracturing and to provide drinking water, withdrawals for hydraulic fracturing may directly impact drinking water resources by changing the quantity or quality of the remaining water.

As all water withdrawal affects water quantity, the water withdrawals that have the significantly potential to impact drinking water resources, may also influence its quality. Therefore, if multiple gas wells are established within such an area, the total volume of water needed to hydraulically fracture of all the wells using a significant portion of the water available, an impact on drinking water resources will be a consequence.

## 3.3 Solution or Gaps

Proper monitoring of the impact on freshwater aquifers and surface water requires that the baseline data of those elements are properly documented in a scientific sound manner and by independent organizations before any drilling operation initiates. The baseline study should as a minimum include groundwater flow properties and its chemical composition. Analysis on these issues considers, for instance, yearly water availability versus total water demand from all users, including expected demand to shale gas plays. Based on such analyses, sustainable aquifer management plans may be formulated, and water rights to public and private consumers, irrigation and industry may be calculated. A sustainable aquifer abstraction plan is defined in order to keep the resource renewing itself, without degrading the water quality besides the water quantity over time. Basically, this involves keeping the groundwater head steady at a specified level, in affected aquifers. Establishment of background quality conditions must be organized so that both the impact of the current aquifer from which the abstractions are made, and the impact of the near-surface aquifers are examined. A correlation of the influence of deeper water aquifers and surface aquifers is not always possible, and therefore the impact is assessed independently. Existing abstraction of water from the area must be included in the overall analysis of the impact of water extraction by shale gas production.

Monitoring design must be based on a prior local characterization of the hydrological and hydrogeological conditions. Characterization and monitoring must be organized according to: 1) Improve knowledge and understanding of the local area. 2) Documenting this understanding by observations. 3) Be able to conduct remediation of inappropriate influences.

For most small streams there exist no historical time series of water flow, and it will in most cases be necessary to include water transfer data from the national surveillance network. Thus, baseline monitoring of the individual streams is carried out for a sufficient period of time. Then, a good correlation between the historical data from the national monitoring network and the new monitoring stations can be provided.

 

However, American experience has shown that much of the uncertainty regarding the environmental impacts of shale gas production is a consequence of ill-defined baseline conditions both in terms of hydrogeological and geochemical conditions (Vengosh et al., 2014).
Extensive recycling of flowback and produced water to the further hydraulic frackings will reduce the need for water. Furthermore, the use of groundwater that was not suitable for drinking water could also reduce the pressure on this resource.
With very few exceptions, hydraulic fracturing has used relatively small percentage of water when compared to total water used and availability at large geographic scales. However, hydraulic fracturing water withdrawals may affect the quantity and quality of drinking water resources by changing the balance between the demand on local water resources and the availability of those resources. It is however without any doubt that water management strategies will reduce the frequency or severity of impacts on drinking water resources from hydraulic fracturing water withdrawals. Despite many studies in the United States and Canada, we must acknowledge that background values for groundwater quality are generally lacking in the period prior to gas extraction.

 

# 4 CHEMICALS USED

## 4.1 Process

The chemicals used in hydraulic fracturing and drilling are usually transported to the well pad in tankers, stored and mixed on site. Although the fracking liquid additives seldom exceeding 2% of the fracturing fluid, of which proppant makes up the majority, the total amount of chemicals may be significant. Accidents and possible loss to the surface and groundwater may occur if traffic accident creates chemical spills. Chemical additives in the fracking fluids may include friction reducers, scale inhibitors, and biocides. Formerly many chemicals were applied in North America, but several local authorities currently require that all chemicals must be published online, and many companies are disclosing this information (FracFocus). Due to different operators and different geological settings the variability of additives, both in their purpose and chemical composition, means that a large number of different chemicals have been used for hydraulic fracturing. Hydraulic fracturing fluids are composted to facilitate introduction of fractures in the formation and to inject proppant into the newly created fractures. Hydraulic fracturing fluids are typically made up of freshwater, proppant, and additives. Sand, ceramic materials or sintered bauxite are the most commonly used proppant.

However, 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. 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 of these. Four commonly used options for temporarily storage in open air pits or in closed tank systems until the use in the fracking operation.

## 4.2 Problem or Impact

Fracking fluid may have harmful effects to soils, surface waters and groundwater, and this is important to be addressed. In spite of impacts on surface water and groundwater resources have been documented, studies on site-specific factors, that could describe the frequency or severity of impacts, are not available. Knowledge of these factors affects how wasted liquids can reach groundwater and surface water resources and how local conditions affect the frequency and severity of pollution of drinking water resources has not yet been achieved. It is clear that spillage during the chemical mixing step for the production of the hydraulic fracturing fluid must be critical due to relatively high concentrations.

It has to be emphasized that the proper management of injecting, hauling and disposing of these fluids is maintained and that the most serious of chemical in the fluid is always designed to be kept from contaminating groundwater. Although additives make up the smallest proportion of the overall composition of hydraulic fracturing fluids, they have the greatest potential to affect the quality of drinking water resources compared to proppant and base fluids.

 

Hydraulic fracturing fluids and additives have reached surface water in some cases during the chemical mixing stage and have the potential by infiltration to reach groundwater resources. Small spills of various volumes have reached surface water, whereas large volume spills may travel longer distances to groundwater or surface waters, which increase the frequency of impacts on drinking water resources. In addition, concentrated additives may result in more severe contamination of drinking water resources than small volume spills. Impacts on groundwater resources must be classified as more severe than impacts on surface water resources because of the much longer renewal time of groundwater and the difficulties to remediate.

In many phases of the hydraulic fracturing process will spill or leakage induce impact on the aqueous environment and may contaminate drinking water resources. This depends in part on the composition and amount of the chemicals that enters the environment as well as the properties of the chemical substances and the effect on the surroundings. Finally, the effect of the spill depends, further, on how the contaminants move and may convert in the environment. Consequently, some chemicals in hydraulic fracturing liquids are of more concern than others are, because they are more likely to move with the water by spills into the drinking water, and may proceed in the environment for long periods if they are not degraded.
A spill might contaminate the aquifer below and by this the drinking water resources by many pathways. The reported data from USA showed that it was a minority directly related to the hydraulic fracturing process whereas a majority was related to spill from logistics reloading, handling and similar processes Report D8.4. Among these are overland flow to adjacent surface waters, soil contamination and eventual transport to surface water by ditches or drain, or by infiltration through the unsaturated zone to underlying groundwater. However, infiltration may take several years depending of geology, and therefore, it may not be immediately apparent whether a spill has reached groundwater or not.

## 4.3 Solution or Gaps

The potential for spilled fluids to impact groundwater or surface water depends on the characteristics of the spill, the environmental fate and transport path of the spilled fluid. Although impacts on surface water have been well documented, site-specific studies that could be used to determine factors that affect the frequency or severity of impacts are not available. In the absence of such studies, we relied on fundamental scientific know-how to identify factors that affect how hydraulic fracturing fluids and chemicals can move through the environment to drinking water resources. As these factors influence whether spilled fluids reach groundwater and surface water resources, they affect the frequency and severity of impacts on drinking water aquifers from spills during the chemical mixing stage of the hydraulic fracturing water cycle.
Consequently, spill prevention and immediate response activities has to be designed as a standby to prevent spilled fluids from reaching groundwater or surface water resources and minimize contamination from spilled fluids or chemicals. Generally, highly permeable soils or fractured rocks can allow spilled liquids to move quickly through the subsurface, which will reduce the opportunity for spilled liquids to move over land to

 

surface water resources. In low permeability soils, spilled liquids are less able to move into the subsurface and are more likely to move over the land surface. However, very water-soluble contaminants may be infiltrated due to preferential flow down to the subsoils. In either case, the volume spilled and the distance between the location of the spill and nearby water resources affects whether spilled liquids reach drinking water. Although the available data indicate that spills of various minor volumes can reach surface water resources, large volume spills are more likely to travel longer distances to adjacent groundwater aquifers or surface waters, which imply that large volume spills increase the frequency of impacts on drinking water resources. Large volume spills, particularly of concentrated additives, may also result in more severe impacts on groundwater than small volume spills because they can deliver a large quantity of potentially hazardous chemicals to groundwater or surface water.

Spill prevention and response activities are designed to prevent spilled fluids from reaching groundwater or surface water resources and minimize impacts from spilled fluids.

The lack of information of the composition of chemicals in fracturing fluids, and the fate and transport of spilled fluids greatly limits our ability to evaluate the potential impacts to surface water and groundwater resources. However, to improve our knowledge we need more information on the chemical composition of fracturing fluid and a full disclosure of additives. In order to predict impact from spills or accidents we need baseline monitoring data and field studies of hydrogeological properties of the areas in question.

 

# 5 WELL FRACKING

## 5.1 Process

Hydraulic fracturing is used to enhance gas production from low permeable reservoirs such as tight sand or shale formations. During hydraulic fracturing, the fracturing fluid is injected down a gas producing rock formation under high pressures, great enough to fracture the gas bearing formation. The hydraulic fracturing fluid usually carries proppant into the newly opened fractures in order to keep the fractures open for extraction of gas. After hydraulic fracturing, gas and other fluids flow through the fractures and up the production well to the surface, where they are separated and managed.

## 5.2 Problem or Impact

During hydraulic fracturing, a well is subjected to greater pressure and temperature changes than during any other activity in the life of the well. As hydraulic fracturing fluid is injected into the well, the pressure applied to the well increases until the targeted rock formation fractures; then pressure decreases. Maximum pressures applied to wells during hydraulic fracturing have been reported to range from less than 14 MPa to over 80 MPa. A well can also be exposed to temperature changes as cool hydraulic fracturing fluid is injected into the hot well. In some cases, the temperature in casing has dropped from 100 °C to 15 °C, which can induce leakage along the casing. Casing, cement, steel and other well components need to be able to withstand these changes in pressure and temperature, so that hydraulic fracturing fluids can flow to the formation without leaking.

The fracture system induced by hydraulic fracturing is the pathways along which hydraulic fracturing fluids move and depends on the characteristics of the shale formation. Besides, the natural stresses, which put on the formation due to the weight of the overburden, affect how the fractures will be formed, vertically as well as horizontally. Because hydraulic fracturing fluids are used to form fractures, fracture growth during hydraulic fracturing can be controlled by limiting the rate and volume of hydraulic fracturing fluid injected into the well.

The possibility for fracturing fluids to reach subsurface drinking water aquifers is depending on the pathways along which fracturing fluids primarily move during the fracturing. As the well itself can be a pathway for fluid movement, the physical integrity of the well is an important factor that affects the impacts from the well injection stage of the hydraulic fracturing. A well with insufficient physical integrity could allow unintended fluid movement, either from the inside to the outside as well as vertically along the outside of the well. Contamination of drinking water aquifers might also occur if gases or liquids released from the formation facilitate movement along these pathways to groundwater. Despite of the vertical separation between the shale formation and the subsurface drinking water aquifer, the presence of other wells near hydraulic fracturing operations can increase the potential for hydraulic fracturing fluids or other subsurface fluids to move to drinking water resources. It is known that this most commonly occur when multiple wells are drilled from the same well site and when wells are spaced less than 300 meter apart. However, short cuts have also been observed at wells at greater distance.

## 5.3 Solution or Gaps

The available data on fracture development during hydraulic fracturing are currently limited. But what has been measured onto now shows that about 99 % of the fractures had a length less than 350 m, and the maximum identified 588 m, Davis et al. 2012. The fracture lengths indicate that some fractures can exceed the gas bearing formation and into an overlying formations. As the shales and mudstones are situated in depths below 1500 m and down to 5000 m, normally, it is not likely that contamination may occur directly from these fractures.

Concerns about well integrity and a better understanding of methane gas migration associated with shale gas hydraulic fracking on aquifers are most important. As the uncertainty and data gaps of contaminant flow pathways, focus on identifying the most likely pathways is essential for an appropriate risk management practices.

Although the minor possible for hydraulic fracturing to create subsurface pathways that could permit contamination of shallower aquifers from injected chemicals and dissolved compounds from the shales from depth, we believe that migration via leaks in old or abandoned wells is the much more likely pathway. Consequently, the physical integrity of the well and the vertical separation distance between the shale formation and subsurface drinking water resources are important factors that affect the frequency and severity of impacts on drinking water resources. The presence of multiple layers of cemented casing and more than thousand meters between hydraulically fractured shale formations and subsurface drinking water aquifer can reduce the frequency of impacts on drinking water resources during the well hydraulic fracturing.

Hydraulic fracturing operations have to use casing that are designed with sufficient strength to withstand the stresses there will evolve after installation, during fracturing, and later in production phases. Further, the casing must be resistant to corrosion from contact with any liquids that will be transported through the casing, e.g. hydraulic fracturing fluids, brines, and gas.

 

# 6 FLOWBACK AND PRODUCED WATER

## 6.1 Process

As the hydraulic fracturing is done under high pressure, a part of the injected fracking fluid will return to the surface mixed with the connate formation brine. After end of the fracturing the fluid is pumped back to the surface to clean up the well. Usually the flowback during the first 2 weeks amounts to 20 – 50 % of the total pumped volume. The flowback might be stored temporarily in open impoundments or in closed tanks until further management depending on volume or regulations. Since fracking takes place in great depth the temperature will correspondingly be high and at the same time under a high pressure that overcome the lithostatic pressure. This means that substances such as released metals or dissolved salts from the formation together with the remaining fracking chemicals may be bought up with the flowback water. Flowback contains high concentrations of total dissolved solids (TDS), heavy metals, suspended solids, sand and in some areas dissolved radioactive substances.

During gas production period, which might be 10 – 20 years, variating amount of produced water will be separated at the well site. Produced water may besides elevated chloride concentrations contain toxic materials, including barium, cadmium, chromium, lead, mercury, nitrates, selenium, and BTEX. If the shales or the mud stones have an elevated content of uranium or thorium, the flowback and produced water normally will contain dissolved radium and radon, sometimes small amounts of the normally immobile uranium if there are applied oxidizing chemicals.

## 6.2 Problem or Impact

Contamination risks to surface water or aquifers during development of shale gas plays have led to increased regulations in North America. The potential pathways for contamination include surface spills, leakage from impoundments and incidental disposal. Study of the shale gas development showed several documented increase in chloride downstream of shale gas wells and also elevated total suspended solids. Several case studies found potential impacts from produced water impoundments with elevated chloride concentrations. Similar to this impacts on water wells were attributed to brine, but the data were not in all cases sufficient to distinguish among possible sources, one of which was leaks from reserve pits and/or impoundments. Over the past decades the major causes of gas well induced groundwater pollution was caused by surface spills of flowback or produced water. Reports on leaks of flowback and produced water from on-site pits and impoundments have shown releases of more than 200 $m^3$, which had caused surface and groundwater contamination.

In some cases the flowback water that contains heavy metals and radioactive substances which have been leached from the formation. In addition to this radioactive gases (radon) may be dissolved in the flowback water. Studies have shown that the content of radium may be close to 0 Bq / $m^3$, but may be considerably larger. Content in the flowback / produced water has been measured up to 176 Bq / $m^3$. Radon, which follows with flowback to the surface, is likely to disappear into the atmosphere and has a half-life time less than 4 days.

 

Leakage from surface storage has been a significant cause of groundwater contamination in the past, including saline contamination of freshwater aquifers nearby well site brine-holding impoundments and water wells. The storage and management of flowback water may also present risks from heavy metals, radioactive materials and fracturing chemicals.
The impoundments for storage are typically constructed of clayey material and often liners and membranes to yield an expected impermeable condition. These liners may in some situation get damaged making a saturated flow possible through the unsaturated zone below, due to clay shrinkage and fissuring in the underlying clay till. The impoundments are also susceptible to overflow due to extreme precipitation events or to the management failure to empty the impoundment over periods of several years. But in recent decades is the growth in drilling activity has increased and the number of such storage facilities also increased, which has led to increased concerns about the risk of groundwater contamination that could be caused by leaking or overflowing pits and impoundments. At present known sources for flowback and produced water spills include storage containers (e.g. pits, impoundments, or tanks), wells or wellheads, hoses or lines, and equipment. Storage containers accounted for more than half of flowback and produced water spills. The fewest spills occurred from wells and wellheads, but these spills had the greatest spill volumes compared to all other sources.

## 6.3 Solution or Gaps

For many decades, well operators have used open pits or impoundments to store flowback / produced water at well sites until further treatment or disposal. However, with the growth of shale gas recovery in North America, many operators have changed to raised impoundments to store both large amount of freshwater needed for hydraulic fracturing, as well as the flowback/produced water. As a consequence of these problems, storage tanks are increasingly required by regulatory agencies to replace such storage impoundments and reduce the potential for overflow due to extreme precipitation events, to minimize the risk for liner leakage or to the failure to empty the impoundment over periods of several years. The major causes identified for these spills are container and equipment leakage, human incorrect handling, pipeline leaks, or illegal dumping. Spills due to transport accidents are possible, but is estimated to a small number.
Spills of produced water during the handling stage have reached groundwater and surface water resources in some cases. And in absence of direct rescue plan, larger volume spills are more likely to travel further from the site of the spill, potentially to groundwater or surface water. Spill prevention plans and response activities might prevent spilled fluids from reaching groundwater or surface water and minimize impacts from spilled fluids.

 

# 7 WASTEWATER MANAGEMENT AND WASTE DISPOSAL

## 7.1 Process

The wastewaters are managed in North America in a variety of ways including treatment and reuse for new well completions, disposal through publicly owned or commercial wastewater treatment plants, or disposal by injection wells. Wastewater is principal all flowback and produced water, which cannot be reused at the well pad or nearby. However, before the management the wastewater is normally stored in pits, impoundments or tanks. The composition of wastewater changes with time as the flowback and produced water change in composition after contacts with the formation and mixes with the formation brine. At the same time, reactions occur between the constituents of the fracturing fluid and the formation. Although flowback and produced water varying within and between formations and by this also the wastewater, the wastewater typically contains high levels of TDS and salinity and also ionic constituents as bromides, calcium, chlorides, iron, potassium, manganese, and sodium.
As the gas-bearing shales lies in between 1.7 and 7 km depth, substantial amounts of drill cuttings will be produced during the deep drilling. The drilling will pass through different geological materials depending on the geology. The drill cuttings can be very different in composition but will always include shale material. The volume of cuttings may be estimated from known drill diameter and depth of the well. The total amount of cuttings for an approximately 4 km long well is estimated to 1900 tons at a rate of 1.3 tons / drill meter in the upper strata and for some 100 kg / meters at the bottom. Cuttings are transported to the surface by the drilling mud during the drilling process and are separated. Cuttings are removed from the drill mud and transported to the landfill. A part of the additives for the drill mud will be retained in the pore water of the wet cuttings or bound to the sediments by sorption or ion exchange processes. The generated waste will thus - besides the actual cuttings - contain additives from the drilling mud why a pre-treatment may be necessary before final disposal. However, special focus is required on drill cuttings from the older shales, as the shale may have relatively high content of inorganic trace elements, many of them bound to reduced sulphur compounds - particularly for uranium (U), vanadium (V), molybdenum (Mo) and nickel (Ni). The shales may also contain radioactive materials that could mean the waste will not be received on ordinary landfills, but will be characterized as low-radioactive materials requiring special management (NORM).

## 7.2 Problem or Impact

The wastewaters can be managed in many ways as treatment and reuse for new well completions, disposal through publicly owned or commercial wastewater treatment plants, or disposal after treatment to surface waters. However, before the management the wastewater is normally stored in pits, impoundments or tanks. Impacts on environmental health from accidental or intentional releases during handling, disposal, treatment, or reuse are poorly documented, with few reports in the literature. Potential pathways for wastewater to enter surface water or groundwater include leaks from pipelines or tanker trucks transporting fluids, leakage from wastewater storage ponds through compromised liners and overflows from the ponds. Although few reported

impacts on the environment, more knowledge is needed to examine the potential impacts from wastewater releases, which are likely to accelerate with the increased exploitation of shale gas. Potential pathways for wastewater to enter surface water or groundwater include leaks from pipelines or tanker trucks transporting fluids, leakage from wastewater storage ponds through compromised liners and overflows from the ponds. Reports on leaks of wastewater from on-site pits and impoundments have shown discharges of more than 200 $m^3$, which had caused surface and groundwater contamination, Patterson et al 2017.
The most problematic substances in wastewater have a negative impact on the topsoil quality. This is mainly due to the content of salts, organic pollutants and metal ions, which is expected to be high, as well as a possible content of radioactive substances. Potential impacts on drinking water aquifers from technologically enhanced naturally occurring radioactive material (TENORM) associated with wastewater may arise from a number of sources. This may be treated wastewater that does not have adequately reduced radionuclide concentrations.
Most substances that negatively affect groundwater and surface water will also have a negative effect on the terrestrial environment. The focus should therefore be on the wastewater handling, transport and storage in lined sedimentation pits. As the entire drilling process is carried out in a ‘closed’ system, a wastewater disposal to the surrounding land will only take place by accident.
At the well sites, pits are situated to store solid waste from the drilling or precipitate from the production. They are either dug into the ground or placed above with embankments. The temporary storage is used for solid waste, drill cuttings, drilling mud and fracturing sand. The construction of these pits is regulated according to guidelines and restrictions. However, liners might be broken and untighten by accident with a following leakage of fluid into springs, ponds, and streams or infiltration to groundwater by saturated flow. After the temporary storage in a pit on the well site, solid waste will be transported to repositories that are more permanent. Both drilling mud and cuttings contain large amounts of salts, metals and may contain radioactive materials, which under certain conditions may leach into either surface water or infiltrate through the unsaturated zone to the groundwater. Depending on soil and sediment types the different substances will move at various velocities towards the recipients.

## 7.3 Solution or Gaps

Shale gas operators may have several strategies for management of wastewaters, with the most common choice being disposal via wells. If possible, reuse in a subsequent hydraulic fracturing operation could be an option after adequate treatment. Also treatment at a centralized waste treatment facility is practiced or in other cases various other wastewater management strategies as treatment of unconventional wastewaters at publicly owned treatment works. Unpermitted discharges of wastes related to hydraulic fracturing have been described in a number of instances.
Recycling parts of the wastewater with a reduced treatment will help to reduce chemical consumption and water requirement. There will be need for removing particles of respect to equipment damage and risk of blockages in the well. However, it is often necessary to reduce the amount of dissolved salts. This may be done by precipitation,

 

which will produce a limited amount of solid waste, or by using membrane filtration, that will make a concentrated salt fraction to be disposed, or by reversed osmosis. Documented cases of groundwater and surface water impacts from wastewater spills provide insights into the types of impacts that can occur. In most of the cases, the documented impacts showed elevated levels of salinity in groundwater and/or surface water. These unauthorized discharges represent both documented and potential impacts on groundwater resources. However, there are gaps in the information as data do not exist to evaluate whether such episodes are uncommon or whether they happen on a more frequent basis and remain largely undetected.
Injection of the wastewater from the shale gas in an abandoned well is preferred method for disposal of wastewater in some states in USA. It happens in dedicated wells for disposal. In EU this is not expected to be approved, so all wastewater must be handled and treated for discharge to the environment.
In the absence of direct pathways to groundwater resources (e.g., fractured rock), large volume spills are more likely to travel further from the site of the spill, potentially to groundwater or surface water resources. Additionally, saline produced water can migrate downward through soil and into groundwater resources, leading to longer-term groundwater contamination. Spill prevention and response activities can prevent spilled fluids from reaching groundwater or surface water resources and minimize impacts from spilled fluids. Wastewater management is dynamic, and recent changes in regulations and practices have been made to limit impacts on groundwater and surface water from the aboveground disposal of hydraulic fracturing wastewater

With regard to solid waste, the available data are limited, which makes it difficult to fully assess or verify the type, volumes, and final destination of field waste. This reflects the status solid waste management that poses current and future risks to the environment, as the amounts grows with as drilling continues. It is likely that at least some of the waste generated would be classified as hazardous due to the composition, reactivity, and toxicity. However, we still have gaps in the knowledge of solid waste impact on groundwater and surface water. Radioactive materials of this level instead should be properly disposed of by shipping the waste to licensed low-level radioactive waste landfills. These have also implemented increased levels of monitoring of these areas and the leachate from these areas. Concern about the radon gas emissions from these landfills must be taken seriously.

 

# 8 CONCLUSIONS

Over the last decades, the development of drilling techniques with horizontal wells and multi-stage hydraulic fracture has made it possible to extract more shale gas from the same well pad. This has given increase of unconventional gas extraction in North America. However, the rapid expansion has also induced broad public awareness of the environmental effects and its impact on drinking water resources and quality.

In this light, a total understanding of the amount groundwater or freshwater is used for hydraulic fracturing is largely hindered lack by of data, where the information is either missing or difficult to record and compile. Regulation has not kept up to date with shale gas development, which has resulted in insufficient or lacking data reporting regarding the source of water used in hydraulic fracturing. In general, baseline-monitoring data is missing in the majority of regions and the data, which are available, are often difficult to interpret.

A lack of good scientific hydrogeological field observations and a scarcity of published peer-reviewed articles on the effects of unconventional gas activities on shallow groundwater make it difficult to address these issues. On the other hand, numerous reports from governmental institutes, from universities, or from operators are available. However, the framework of data and statements can be threshold for quality verification and interpretation.

The potential role of the hydrogeology and geochemistry in identifying, characterizing, and monitoring drinking water aquifers vulnerability to contamination by chemicals, wastewater and spill are mandatory for a safe development of shale gas. These topics will require a tight collaboration of engineers and geoscientists from both industry and research community.

If hydraulic fracking was just a new-and simple method of extracting shale gas sources, it would be welcomed by most of the public as a less $CO_2$-contaminating alternative to oil and coal. The problems are the method of extraction. As hydraulic fracking require a number of chemicals for the fracking, the flowback and produced water brings back the great deal of these chemicals and their transformation products in a mixture with the deep brine. Consequently, due to the fracking process large amounts of liquid has to be handled on the well site. In addition, all handling contains risks for spill and accidents.

The major gaps in our knowledge should be incorporated in future research programs to support both sustainable development of unconventional gas and protection of groundwater resources. These are about the environmental impact are a draw back to the safe development of natural gas resources and the protection of groundwater as drinking water resource and not least to the social perception of shale gas industry. Further, the authorities could oblige the operators to always perform analyses at independent laboratories of wastewater and waste before discharge or disposal to ensure a minimized environmental impact. It will also be adequate to require operators to hold a basic monitoring around the potential drilling sites.

For a safe development, a numbers of environmental projects have to be initiated. Among these could one project be a review of analysis of existing cases of unconventional gas development and the environmental problems with waste handling. Another could be a potential classification of both liquid and solid wastes as industrial or hazardous, thereby subjecting them to additional testing and disposal requirements.

 

And further, testing of solid waste and clear risk-based numerical standards indicating which levels of NORM in waste would prompt more stringent waste management practices. Last but not least a number of controlled experiments to understand processes that are believed to be responsible for or may result in groundwater contamination from surface spills.
A large number of parameters must be considered to have an overall assessment of the landscape's vulnerability and to gain knowledge about the security of supply of water resources for drinking water and possibly for irrigation in agriculture. There may be uncertainty about the location of drinking water aquifers, and especially deep groundwater resources, which in the future could be potentially drinking water resources.
Because of the significant gaps and uncertainties of the available data, it is rarely possible to access the groundwater risks of a particular production activity. Thus, it may not be possible for local decision to calculate or estimate the impact on the level of resources of drinking water due to activities in unconventional gas production based on hydraulic fracturing. Hence, there is a need for procedure and legislation in order to collect all the data necessary for a holistic assessment of the impact on the water cycle, both quantitatively and qualitatively. In general, comprehensive information on the location of activities in the hydraulic fracturing water cycle is lacking, either because it is not collected, not public available, or prohibitive difficult to achieve. Hence, not all information might practically be addressed that will be useful information for technical decisions, which imply that a priority must be setup to ensure the most important issues and gaps receive appropriate attention. In view of the importance of decisions that are challenging, trust in the sources of data is fundamental. Specific geological factors, such as the depth of the gas, drinking water interests and the surrounding nature are crucial to the decisions.
An overall view for decision-makers could be that their attention on hydraulic fracturing activities and local conditions could be focused on more obvious or more severe impacts. This may include:

- Water acquisitions for hydraulic fracturing over time and also in areas of low water availability.
- Spills during hydraulic fracturing liquids and additives is managed
- Management of flowback and produced water that result in large volumes wastewater with high concentrations of chemicals that might reach groundwater.
- Injection of hydraulic fracturing fluids, which could leak directly into groundwater aquifers.
- Discharge of inadequately treated hydraulic fracturing wastewater to surface water.
- Disposal or storage of hydraulic fracturing wastewater in unlined pits, resulting in contamination of groundwater.
- The large amounts of solid waste and cuttings present a particular risk due to the content of environmentally harmful substances and, in some cases, radioactive substances. Depositing this must be carried out with great control.

 

By direct attention on the possibility described above, impacts on drinking water quantity and quality from hydraulic fracturing activities might be prevented or minimized. Whether hydraulic fracturing for unconventional gas is a practice that will continue to evolve or alternative sources will come in future is not clear. Nevertheless, potentials for activities in the hydraulic fracturing to impact drinking water and surface water resources will need to keep up to date with new technologies and new scientific studies.

 

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