Project Acronym and Title:

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

Integrated review of data and best practices of surface operations related to shale gas in the USA, Canada and Europe

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Disclaimer

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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 groundwater. 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

This report summarizes the work of six scientific teams engaged in studying the impact of surface operations related to shale gas exploration and exploitation on natural environment elements: groundwater, surface water, soil, waste management, well site infrastructure and transport.

As part of the performed work, individual teams conducted a review and performed an analysis of the literature data concerning the impact of surface operations connected with shale gas exploration and exploitation on groundwater, surface water, soil and generated waste. The teams also focused on the influence of well site infrastructure and transport on the environment. A review of the available data and information from the U.S., Canada and Europe was conducted. In the context of these reviews, knowledge gaps and the current best practices used in North America and particularly European countries, in the area of surface operations, were identified.

The reviews have shown that as far as the influence of surface operations on environmental compartments is concerned, there are many areas that require standardization and systematization, as well as further research. Thus, in the area of:

- *water and soil monitoring systems* - in the European countries, there are grounds for monitoring the environment and tendencies towards standardization and unification of the results in this respect, e.g. in the case of water monitoring by unification of reporting. It should be noted however, that currently the objectives, actions and results differ between European countries. In many countries environmental monitoring is operated at regional level. Therefore, it seems necessary to carry out further work, which will result in an integrated and unified system of monitoring the state of the environment at European level, taking into account also the monitoring conducted during exploration and exploitation of gas from shale formations. This system shall include i.a. the frequency of tests, its scope and method of data collecting and transmitting/

disclosing.

- *water management* - in spite of many available information concerning water resources management, there are still many areas that need to be unified and developed. Among these may be mentioned i.a. resolving knowledge gaps on the available water sources for shale gas operations in an European context, resolving knowledge gaps regarding the applicable legislation in each Member State in terms of water management. Proper monitoring of the impact on freshwater aquifers and surface water requires that the background conditions (baseline data) of those elements are properly documented in a scientific sound manner and by independent organizations before any drilling operation will be initiated. The baseline study should include, as a minimum, its flow properties and chemical composition.
- *the use of chemical substances and mixtures* - the review demonstrated that there are still many fields in the use of substances and chemicals during exploitation of gas from shale formations, improvement of which will contribute to minimizing the effects of chemicals on the environment and human health. In the case of the USA and Canada, there is no obligation, on the federal level, to disclose the composition of fluids used for hydraulic fracturing. Such an obligation exists in some states or provinces, but there are no uniform guidelines as to the scope of information that should be disclosed. In Europe, there is no obligation to disclose the composition of hydraulic fracturing fluids and amounts of the individual substances contained therein (at both EU level and individual Member States level). Tracing the fate of individual chemicals and chemical mixtures used in hydraulic fracturing operations is necessary from injection to production and water treatment. The full disclosure of the applied chemicals also is one of the main prerequisites for a knowledge-based decision about necessary water treatment and possible ways of disposal for the high amounts of flowback and produced waters.
- *waste management* - management of waste generated from exploration and exploitation of hydrocarbon deposits in the USA and Canada is regulated primarily at the level of individual states or provinces. There is a lack of guidelines in this respect at the federal level. Regulations at the level of states or provinces, however, differ in scope and detail, and do not always apply to the waste from exploitation of gas from shale formations. In Europe, waste generated during exploration and exploitation of gas from shale formations are bounded by the same legal regulations as waste generated during exploration and extraction of conventional hydrocarbons. Therefore, for the waste from exploitation of gas from shale formations there are no uniform requirements regarding the scope of research on quality of this type of waste, guidelines for their treatment, transportation, disposal and storage and need to disclose the results of research on their quality. In addition, there is no information concerning the comparison of harmfulness of waste generated during exploration and exploitation of conventional and unconventional hydrocarbons. In this respect, among the areas requiring further research, these should be mentioned:
  - identifying and resolving knowledge gaps about composition and evolution over time of flowback and produced water in European shale gas operations; currently available information is scarce and asymmetric,
  - identification and closing knowledge gaps regarding the applicable legislation in each Member State in terms of wastewater management.
- *influence of well site infrastructure and transport* - performed analyses have shown that the impact of well site infrastructure and transport is important but comparable to the impact of other industries. It can be minimized while maintaining the basic precautionary measures and applying the relevant provisions. Infrastructure measures could be expected to be increasingly effective as the industry matures, economies of scale come into effect or as technology changes.

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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. Some argue that shale gas has already proved to be a game changer in the U.S. energy market (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 the process of hydraulic fracturing. There is also a debate on the greenhouse gas emissions of shale gas (CO_2 and methane) and its energy return on investment 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, atmosphere and society. As the European continent is densely populated, it is most certainly of vital importance to understand public perceptions of shale gas and for European publics to be fully engaged in the debate about its potential development.

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.*

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[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

This report summarizes scientific literature and best practice reviews conducted by six scientific teams engaged in researching the impact of surface operations related to shale gas exploration and exploitation on natural environment elements: groundwater and surface water, and soil. Teams involved in the M4ShaleGas project were also interested in researching the influence of such actions on correct waste management and well site infrastructure and transport.

As part of the performed work, individual teams conducted reviews and performed analyses of available and accessible literature data concerning the impact of surface operations connected with shale gas exploration and exploitation on groundwater and surface water, soil and generated waste. A review of the available data and information from the USA, Canada and Europe was conducted. Best practices used in North America and European countries in the area of surface operations and existing gaps, were identified.

Detailed results obtained by different research groups were presented and discussed in six reports published on the M4Shalegas project website (http://www.m4shalegas.eu):

1. Joanna Fajfer, Monika Konieczyńska, Agnieszka Konon, Olga Lipińska, *Review of European soil and water monitoring systems for shale gas and best practices from USA and Canada*, Polish Geological Institute - National Research Institute (Report D7.1)
2. Ole Stig Jacobsen, Anders Risbjerg Johnsen, Peter Gravesen, Niels Hemmingsen Schovsbo, *Risk assessment of impacts on groundwater quantity and quality*, Geological Survey of Denmark and Greenland (Report D8.1)
3. Lucas Vadillo Fernández, Virginia Rodríguez Gómez, Julio López Gutiérrez, Francisco Javier Fernández Naranjo, *Review of water management related to shale gas activities in the U.S., Canada and Europe*, Instituto Geológico y Minero de España (Report D9.1)
4. Ewa Kukulska-Zając, Anna Król, Marta Dobrzańska, Monika Gajec, Jadwiga Holewa-Rataj, Justyna Mostowska, *Literature review concerning drilling materials and management of wastes*, Oil and Gas Institute - National Research Institute (Report D10.1)
5. Andrea Vieth-Hillebrand, Franziska E. Schmid, *Review on compositions of operational fluids and flowback in hydraulic fracturin*g, GFZ German Research Centre for Geosciences, Helmholtz Centre Potsdam (Report D11.1)
6. Sarah Antoinette Clancy, Fred Worrall, Paul Goodman, Neil Thorpe, *Review of impact of well site infrastructure*, Durham University, Newcastle University (Report D12.1)

Individual reports describe common practice in the proper management of groundwater and surface water in relation to the use of monitoring systems, pollution, quantity and quality of those waters in European countries. They also discuss proper management of waste, both solid and liquid, emerging during shale gas exploration and exploitation.

The reports include potential hydraulic fracturing and flowback fluids composition and the influence of well site infrastructure and transport. In addition, they focus on another important issue, related to the surface operations element, namely to the management and use of chemical substances and mixtures used during this type of work and drilling materials.

1.3 Aims of this report

The aim of this report is to integrate the obtained results of a number of review reports related to water, soil, waste, well site infrastructure and transport of shale gas operations. This report shows integrated data, existing best practices and knowledge gaps of surface operations from the USA, Canada and Europe. The results, conclusions and suggestions presented here are based on reports which are available on the M4ShaleGas project website (http://www.m4shalegas.eu).

2 RISKS AND BEST PRACTICES OF SURFACE OPERATIONS – REVIEW AND SYNTHESIS

2.1 Monitoring of groundwater, surface water and soil

The review and analysis of available information and data conducted in this area in the first phase within the work package "*Baseline and monitoring data assessment of surface, groundwater, and soils*", were aimed to answer the question of whether and how groundwater and surface water and soil monitoring is conducted in Europe (Report D 7.1). If so, to verify that in European countries where potentially exists the possibility of shale gas exploitation the operating systems are similar and sufficient to perform environmental monitoring in terms of resource assessment of surface water and groundwater. This review was supposed to demonstrate best existing practices from the USA and Canada.

Monitoring the status of individual environmental compartments is an important aspect connected with safety and determination of the impact of applied industrial technologies on the environment. Environmental data and knowledge on the state of the environment are widely used both for management and to make conscious decisions by parties involved, which is associated with the policy of sustainable development. The knowledge about performance level of the environmental monitoring, determining monitoring systems consistency and legal basis of their functioning is important in areas where are or can be carried out works related to shale gas exploration and exploitation. Environmental monitoring is performed in European countries. At this level, the basic principles of environmental monitoring are established in accordance with existing directives. With regard to water resources at European level, water quality monitoring is being harmonised and strengthened by the implementation of the Water Framework Directive (WFD) which gives basis for water monitoring (*Directive 2000/60/EC*).

The review of the current state-of-art in European soil and water monitoring systems, which was conducted in the first phase as part of work package “*Baseline and monitoring data assessment of surface, groundwater, and soils*”, showed that in European countries exists a desire for standardization and unification of the results in this respect, e.g. in the case of water monitoring by unification of reporting. It should be noted, however, that currently the objectives, actions and results differ from country to country. The report in relation to European countries focuses on selected aspects, related to the baseline environmental state assessment and applicability of existing systems for environmental changes due to unconventional hydrocarbons exploration. Whereas in the case of the United States and Canada, the report focuses on shale gas dedicated monitoring.

The results obtained for 20 European countries (Belgium, Bulgaria, Czech Republic, Denmark, Estonia, France, Germany, Hungary, Latvia, Lithuania, the Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Spain, Sweden, United Kingdom and Ukraine) have shown that information about water- body ecological status in any country is easily accessible, whereas data about the system, like a number of monitoring points, an exact list of tested parameters, or a sampling frequency, are less readily available. For these countries, a short summary of methods of performing the groundwater and surface water monitoring was made, taking into account such parameters as: responsible entity, network size, scope and frequency of observations. Additionally, other local or specific systems are mentioned, if they exist.

The responsible entity of surface water monitoring systems operation has been identified for Belgium, Bulgaria, Denmark, Estonia, France, Germany, Latvia, the Netherlands, Norway, Poland, Portugal, Slovakia, Spain, Sweden, United Kingdom and Ukraine, what represents 80% of the surveyed European countries. In the case of groundwater monitoring systems, the responsible entity were identified additionally for Hungary and Lithuania, which in total represents 90% of the surveyed countries with groundwater monitoring systems.

Information concerning network size of surface water monitoring systems are available for 65% of surveyed European countries, i.e. for Belgium, Czech Republic, Denmark, Estonia, France, Hungary, Latvia, Lithuania, Poland, Portugal, Romania, Slovakia and Spain. In turn, information on network size of groundwater monitoring systems are available, in percentage terms, for the same number of countries as in the case of surface water monitoring systems, except that data are available also for Germany and are not available for Estonia.

There is more information about parameters tested than about measurements and observations frequency. For surface water monitoring systems only in one case (Bulgaria) the scope of analysed parameters has not been revealed. Analysed parameters within the groundwater monitoring systems have not been defined in 10% of surveyed countries (Romania and Sweden). It should be noted, however, that in the case of other countries, information on the scope of observations are not always available for all identified measuring points. Information about observations frequency has been given in 55% of surveyed countries (Belgium, Czech Republic, Denmark, Estonia, Germany, Latvia, Lithuania, Norway, Poland, Slovakia and Spain) for surface water monitoring systems and in 50% of surveyed countries (Belgium, Czech Republic, Denmark, Germany, Latvia, Lithuania, the Netherlands, Poland, Slovakia and Spain) for groundwater monitoring systems. Table 1 summarizes the most commonly monitored physiochemical parameters during groundwater and surface water monitoring. The scope of tests differs depending on the country where monitoring is performed and the detailed ranges are available in the Report D7.1 (*M4ShaleGas - Measuring, monitoring, mitigating and managing the environmental impact of shale gas*). The recommended testing frequency, depending on the country and monitored water (surface, ground, lake or river) vary from once every two years to a few/several times a year.

Table 1. List of the most commonly monitored physiochemical parameters while performing surface water and groundwater monitoring in Europe.

Group	Parameter
Physical parameters	pH, conductivity, temperature, dissolved oxygen
Heavy metals	Zn, Cu, Cr, Pb, Ni, Hg, Cd, As
Organic compounds	phenols, pesticides, hydrocarbons (BTEX and PAH)
Inorganic compounds	chlorides, sulphates, carbonates, calcium, magnesium, nitrates, ammonia

For the part of the surveyed European countries, information about soil quality assessment is also available. Such data were identified for 70% of the surveyed countries, i.e. for Belgium, Bulgaria, Czech Republic, Estonia, France, Germany, Hungary, Latvia, Lithuania, the Netherlands, Norway and Poland. The available data and information refer to the scope of tests performed during assessing the quality of this environmental component and frequency, as well as the responsible entity. The most frequently examined physical parameters are granulometry, pH and electrical conductivity, whereas among the most commonly monitored chemical parameters are available nutrients (P, K, Mg), biogenic and hazardous trace elements (B, Be, Cu, Cr, Hg, Mn, Ni, Pb, Zn), organic carbon, free carbonates, cation exchange capacity CEC, exchangeable cations, and for some selected samples PAH, PCB, dioxins, herbicides. The frequency of performing research in the countries with monitoring varies from 1 year (e.g. in Latvia) to 5 years (e.g. in Poland).

Despite the fact that on the level of European countries there is a basis for environmental monitoring and tendencies towards unifying monitoring methods of various environmental compartments are visible, there are still big differences between the countries. In many countries, environmental monitoring is actually operated at regional level. At a country level aggregated results are provided. Therefore, it seems necessary to carry out further work, which will result in comprehensive information about existing monitoring systems in areas, where shale gas development is expected, including: network, range of parameters, and frequency. Based on this data assessment of possible use for shale gas monitoring will be made .

In the USA the Bureau of Land Management (BLM) may require water testing and monitoring, particularly if water quality impacts are significant concerns based on local conditions, and where testing could yield useful water quality information. Baseline water testing is the best management practice that BLM encourages (*Oil and Gas; Hydraulic Fracturing on Federal and Indian Lands, 2015*). Also the American Petroleum Institute (API) guidance document on hydraulic fracturing recommends baseline water quality monitoring of both surface water and groundwater prior to hydraulic fracturing (*Water Management Associated with Hydraulic Fracturing, 2010*).

In the USA the ongoing groundwater or surface water testing is generally not required by regulation. Groundwater tracing is a newer area of study but not required by regulation. In the case of a couple of States, regulations include pre-drilling testing of water to establish baseline conditions of the water sources that could potentially be impacted. These baseline studies are not broad in scope and specify simple water quality indicators such as alkalinity, pH, specific conductance, TDS, chloride, sulphate, cations (e.g. calcium, magnesium, potassium, sodium), and common metals.

Although not a regulatory requirement, drilling companies may perform their own baseline studies incorporating a much broader list of parameters to better define the baseline conditions prior to drilling. Private and public drinking water well owners, who consider collecting samples prior to oil and gas drilling near their properties, will find basic overview about documenting water quality at state authorities' websites. Moreover, mineral and surface owners may be able to negotiate water well testing, both pre- and post-drilling, as a part of their mineral lease or surface use agreement.

In the case of Canada, there are no legal requirements demanding groundwater characterization or monitoring at pads. In terms of surface water monitoring, monitoring networks that provide information on hydrological parameters at the local scale are few – only large rivers are monitored for flow and water quality monitoring is minimal (*Environmental Impacts of Shale Gas Extraction in Canada, 2014*). The challenges involved in shale gas development are considered to be different for the surface and shallow subsurface environments and for the deeper zone. More is known about surface waters and the fresh groundwater zone because these parts of the hydrological cycle have been well studied in terms of other types of environmental impacts.

2.2 Water management related to shale gas activities

A review of widely understood water management, conducted in the first stage within individual work packages, was aimed at identifying the environmental problems related to groundwater and surface water contamination (Report D 8.1). The research was also supposed to provide information on water consumptions, water sourcing, chemical substances and mixtures, relevant compounds in drilling and fracturing fluids and risk and best practices (Report D 8.1, D 9.1, D 10.1 and D 11.1).

2.2.1 Water resources management

Management of water and its resources during shale gas exploration and exploitation should be considered in two aspects, i.e. in terms of water usage during hydraulic fracturing and re-usage of water acquired from flowback fluids and disposal of wastewater from drilling and production.

Water consumption during hydraulic fracturing is large and variable, depending on the type of geological formation, the vertical depth of a well and the length of a horizontal well. Typical water consumption described in the literature is within the range of 10,000 and 16,000 cubic meters per well; in the case of some wells it can be even 30,000 cubic metres. Currently, water used in the process of hydraulic fracturing is obtained from various sources. EPA documents (*Assessment of the potential impacts of hydraulic fracturing for oil and gas on drinking water resources, 2015*) provide information for the USA on the percentage of water usage from different sources, as detailed in Table 2. It should be added that in the case of Europe there are no publicly accessible data on available water sources for shale gas operations in an European context (there is no single, reliable summary for Europe).

Table 2. Different water sources used in hydraulic fracturing technology (based on *Assessment of the potential impacts of hydraulic fracturing for oil and gas on drinking water resources, 2015*).

The use of each water source as a fracturing fluid by unconventional oil and gas operators in the United States	**%**
Surface water (rivers, lakes, etc.)	40
Groundwater	36
City/municipal water	16
Recycled UOG produced water	7
Industrial wastewater	1

Water used during shale gas exploration and exploitation must meet certain quality criteria. Fresh water was used in the first phase of shale gas exploration and exploitation. Due to the necessity of finding alternative sources of water required for a technological process, recently the resources of salt water from the sea, wastewater and flowback fluids have been used for this purpose. Usage of these types of water is possible thanks to the development of technology focused on treatment and purification of polluted water.

Several strategies have been implemented to solve water constraints, including reducing water demand, increasing water supplies (particularly non-freshwater supplies, including reuse/recycling of flowback and produced water, using municipal wastewater) and intersectoral transfers (primarily from irrigations or conventional gas and oil production).

In spite of many available information concerning water resources management, there are still many areas that need to be unified and developed. Among these may be mentioned:

- resolve knowledge gaps on the available water sources for shale gas operations in an European context,
- resolve knowledge gaps regarding the applicable legislation in each Member State in terms of water management.

2.2.2 The possible sources of groundwater and surface water contamination

Production of non-conventional gas includes many process steps, all of which involve the possibility of contaminating the environment. The land surrounding the well pad (the abstraction site) and groundwater and surface water (lake, rivers streams etc.) are the most obvious recipients.

In areas with tight gas or shale gas, fracture stimulation is typically done at a considerable depth of about 2,000 – 5,000 meters below the surface. In comparison, in such areas the groundwater aquifers are at depths from 0 – 500 meters below surface. In most basins there are at least 1,500 meters of vertical separation between the base of the freshwater aquifers. Most horizontal wells are drilled at depths of greater than 2,000 meters in order to place the horizontal well in reservoirs containing oil and gas.

Establishment of a drilling comprises the construction of a fenced areas of 2-5 ha size with all necessary technical equipment, including well pad, tanks and area for waste temporary storage for collecting drilling mud and cuttings, as well as water basins (tanks or open pits) for the flowback from the formations. The area must be hydraulically sealed off from the surroundings in order to contain any spills. Drilling muds contain different additives needed in the drilling process; they, in turn, contain substances which are not compatible with the natural environment and must be kept safe. The drilling muds contain water and a large range of chemical substances. Most of these are typical for drilling and do not used later in the process, for example bentonite and barium sulphate are used to control the density of the mud. It is possible that an emergency situation will happen, in which those substances will be released into the environment, which would lead to soil, groundwater and surface water contamination. Cuttings from drilling operations may also involve problems with leaching of various substances such as inorganic salts, trace metals and radioactive substances. The same is true for the suspended material in the produced water.

Individual elements of the environment may also get polluted during the next phase of work, i.e. during hydraulic fracturing. Fracturing may be performed with fracking fluids under high pressure and contain a proppant (sand or ceramic balls) together with auxiliary chemicals (1-2% on weight basis). The handling of fracking fluid, which volumetric can be quite large, may result in losses to the surrounding environment. When fracturing ends, the fluid is pumped back to the surface to clean up the well. Usually the flowback during the first 10 days amounts to 25- 50% of the total pumped volumes. The flowback water is usually stored in open pits or closed tanks. Flowback returning to the surface can contain substances like released metals, organic compounds and dissolved salts from the formation. It should be added that gas produced in the shale formation can under unfortunate circumstances escape to the overlying layers and may later diffuse upward to the groundwater bodies. Further, leaks caused by natural fractures or corrosion in production installations may cause gas contamination in the aquifers. It can thus be both methane as well as radon.

Baseline data and monitoring are essential for understanding when impacts on the water from shale plays may occur, and what they consist of. Both issues are essential to understand the root causes. Based on information available on the Marcellus Shale and other plays, water resource risks evolve and change over time, as stakeholders adapt and respond to economic, technological, social and political pressures. Therefore, it is difficult to say to what extent the risks and impacts experienced in the past will continue into future scenarios of an European context. In addition, the available information and data about this topic are based on the American experience, so it is difficult to determine new risks that are related with hitherto undeveloped shale plays and adapt them to other plays, regions, and countries. Research that has been carried out so far on other plays, within varying contexts and within different regulatory regimes, should help to create a clearer picture of national trends and to better predict future scenarios and thus to mitigate the risks.

Proper monitoring of the impact on freshwater aquifers and surface water requires that the background conditions (baseline data) of those elements are properly documented in a scientific sound manner and by independent organizations before any drilling operation will be initiated. The baseline study should include, as a minimum, its flow properties and chemical composition. The EU minimum principles define that a baseline study of the quality and flow characteristics for surface water and groundwater shall be determined (*Commission Recommendation of 22 January 2014, 2014*).

Substances that can be released into the environment during shale gas exploration and exploitation and cause pollution, are described in detail in Reports D 8.1, D 9.1, D 10.1 and D11.1 (*M4ShaleGas - Measuring, monitoring, mitigating and managing the environmental impact of shale gas*), and are summarized later in this chapter.

2.2.3 Used chemical substances and mixtures

During the exploration and exploitation of gas from shale formations a large number of chemical substances and compounds with different harmfulness for the environment and human health are used. These substances are used for preparing drilling fluid materials, drilling fluids and fluids for hydraulic fracturing. Information on harmfulness of substances and chemicals is included in safety data sheets. They are the primary source of information about the properties of hazardous chemical substances and mixtures, the type and size of risks they present for humans and the environment and recommendations and principles of their safe handling during production, transport, use and storage. The use of substances and chemicals is regulated all over the world by many laws. In the United States the primary legal act that established requirements for federal, state and local governments, tribes, and industry regarding emergency planning and "community right-to-know" reporting on hazardous and toxic chemicals, is the Emergency Planning and Community Right to Know Act - EPCRA (*United States Code, 2011 Edition Title 42*). The community right-to-know provisions of EPCRA are the most significant parts of law for companies involved in gas exploration and extraction from shale formations. All chemical substances produced or used in Canada, together with substances used in hydraulic fracturing fluids, have been regulated since 1999 by the federal government under the Canadian Environmental Protection Act - CEPA (*Canadian Environmental Protection Act, 1999*). The management of chemicals, including those used during shale gas exploitation, is regulated at EU level by two regulations i.e. REACH (*Regulation (EC) No 1907/2006*) and CLP (*Regulation (EC) No 1272/2008*).

2.2.3.1 Drilling muds and fluids used for fracturing

In order to undertake a full review of materials and chemicals used when carrying out exploitation of gas from shale formations, it must be remembered that during first phase of this kind of work, i.e. before the hydraulic fracturing operation, drilling fluids/muds are used. Often during drilling of a single hole, several types of drilling fluids/muds are being used, depending on the drilled formation. Currently, a wide range of drilling fluid materials produced by different companies is available. However, the workflow for the production and regulation of drilling fluid/mud properties, seems to be the same. Among the drilling fluid materials commonly known and used in the drilling technology, there should be listed such materials as bentonite, barite, starch and cellulose formulations, lignites, lignosulfonates, tannins, polymers, lubricants, surfactants and others (*Raczkowski and Półchłopek, 1998; TDEX: The Endocrine Disruption Exchange*).

It should be emphasized that among the basic materials used for preparation and adjustment of the characteristics of water drilling fluids, it is difficult to find substances that appear on the list of hazardous substances and mixtures. Hazardous substances may only be included in the materials classified as other components of the drilling fluid, which represent not more than 1%. There exists much greater probability that hazardous substances will appear in the non-aqueous drilling fluids, in particular those based on oil. The possibility of occurrence of hazardous substances exists in about 60% of used materials (*Environmental Aspects of the use and disposal drilling fluids associated with offshore oil and gas operation, 2003; Jamrozik, 2009*).

In the case of fracturing fluids those water-based are the most common but other types also can be used. Foams or emulsions are composed of material that is not miscible with water, like nitrogen, carbon dioxide or hydrocarbons (*Montgomery, 2013; Assessment of the potential impacts of hydraulic fracturing for oil and gas on drinking water resources, 2015*). The most common water-based fluid systems are slickwater formulations, which are typically used in very low permeability reservoirs and gelled fracturing fluids, which can be used in reservoirs with higher permeability (*Barati and Liang, 2014*).

The largest constituent of a typical fracturing fluid is water (>90%), followed by proppants (<10%) and additives (0.5 – 2%). Each additive is a mixture of various chemicals with the main ingredient serving a specific purpose during hydraulic fracturing (e.g. friction reducer, gelling agent, crosslinker, breaker, biocide, stabilizer), which is presented in Figure 1 and in Table 3 (*Spellman, 2012; Carter et al., 2013; FracFocus: Introduction to Chemical Use*).

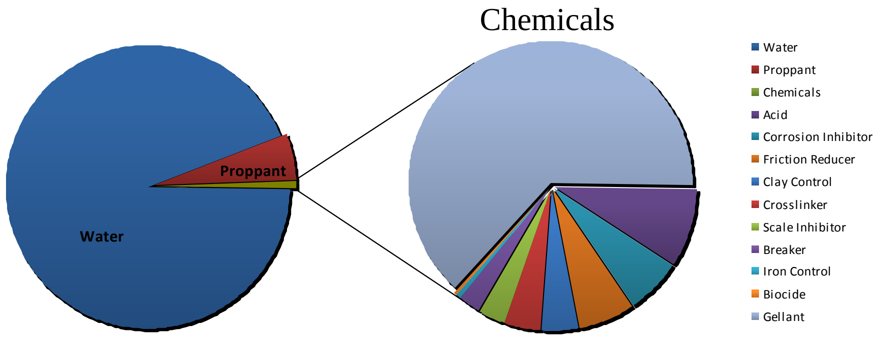

Figure 1. Illustrative composition of a fracturing fluid (based on *FracFocus: Introduction to Chemical Use*).

Table 3. Examples of common additives and their functions (based on *Economides and Nolte, 2000; FracFocus: Why Chemicals Are Used?; McCurdy, 2011; Modern Shale Gas Development in the United States: A Primer, 2009; Otwór badawczy Markowola 1 jako przykład działań prowadzonych z troską o środowiska [Markowola-1 exploratory borehole as an example of activities carried out with care for the environment], 2011; Petroleum information sheet, 2015; Stringfellow et al., 2014; Supplemental Generic Environmental Impact Statement On The Oil, Gas and Solution Mining Regulatory Program, 2011; URS Corporation, 2011; United States Environmental Protection Agency, 2004*).

Fluid component	**Role**	**Concentrations range in fracturing fluid**	**Exemplary substance**
Acid	Helps dissolve minerals and initiate cracks in the rock	70 - 150 mg/l	Hydrochloric Acid
Biocide	Eliminates bacteria in the water that produces corrosive by-products; Controls bacteria that degrades fracturing chemicals and contributes to corrosion of well tubing, casings, and equipment	10 – 800 mg/l	Glutaraldehyde, Ammonium Chloride, Quaternary Ammonium Chloride, Tetrakis Hydroxymethyl Phosphonium Sulphate
Breaker	Allows a delayed break down of the gel; Reverses crosslinking, which reduces viscosity of gelled fluids and allows removal of residual polymers from newly created fractures, which would otherwise impede flow of gas and reduce well productivity	1.0 - 400 mg/l	Ammonium Persulphate, Sodium Chloride, Magnesium Peroxide, Magnesium Oxide
Clay Stabilizer	Prevents the swelling of clays found in gas shale layers, particularly smectite	500 – 2,000 mg/l	Choline Chloride, Tetramethyl Ammonium Chloride, Sodium Chloride, Isopropanol
Corrosion Inhibitor	Forms a protective layer on metal well components, preventing corrosion by acids, salts, and corrosive gases	10 – 7,000 mg/l	Isopropanol, Methanol, Formic Acid, Acetaldehyde
Crosslinker	Chemically binds individual gel polymer molecules together to form larger molecules, resulting in higher viscosity, more elasticity, and better proppant transport compared with linear gels that are not crosslinked	0.5 – 250 mg/l	Triethanolamine, Sodium Tetraborate, Boric Acid, Zirconium Complex, Borate Salts, Ethylene Glycol
Friction Reducer	"Slicks" the water to minimize friction; Carrier fluid for polyacrylamide friction reducer; Product stabilizer and / or winterizing agent	30 – 1,200 mg/l	Polyacrylamide, Hydrotreated Light Petroleum Distillate, Methanol, Ethylene Glycol
Gelling Agent	Thickens the water in order to suspend the sand; Increases fracturing fluid viscosity, allowing for better proppant suspension and transport into	10 – 1,000 mg/l	Guar Gum, Polysaccharide Blend, Ethylene Glycol, Cellulosic compounds

Fluid component	Role	Concentrations range in fracturing fluid	Exemplary substance
	developed fractures		
Iron Control	Prevents precipitation of metal oxides (in pipe); Controls iron precipitates that block flow paths within the formation, reducing reservoir rock permeability, well productivity and fluid recovery	50 – 200 mg/l	Citric Acid, Acetic Acid, Thioglycolic Acid, Sodium Erythorbate
pH Adjusters	Adjusts the pH of fluid to maintain the effectiveness of other components, such as crosslinkers	100 – 300 mg/l	Sodium Hydroxide, Potassium Hydroxide, Acetic Acid, Sodium Carbonate, Potassium Carbonate
Scale Inhibitor	Prevents scale deposits downhole and in surface equipment	75 – 400 mg/l	Copolymer of Acrylamide and Sodium Acrylate, Sodium Polycarboxylate, Phosphonic Acid Salt
Surfactant	Reduces surface tension of the treatment fluid in the formation and helps improve fluid recovery from the well after the fracking is completed	500 – 1,800 mg/l	Lauryl Sulphate, Ethanol, Isopropyl Alkohol, 2-Butoxyethanol
Proppant	Proppant or tiny solids (e.g. sand) are used to physically hold open tiny rock fractures or cracks and to allow fluids and gas to move around them	35 - 100 g/l	Crystalline silica (quartz), Crystalline silica (cristobalite), Ceramic

It is worth mentioning that not all substances listed in Table 3 are always used to prepare fracturing fluid. The particular composition of the fracturing fluid is selected by a design engineer and based on empirical experience, geological setting, reservoir geochemistry, economics, availability of chemicals and preference of the service company or operator. In addition, it is sometimes necessary to use other additives than those commonly used. A typical fracture treatment will use very low concentrations of between 3 and 12 additive chemicals, depending on the characteristics of the water and the rock formation being fractured. Each component serves a specific, engineered purpose.

It should be emphasized that it is difficult to find detailed information on the exact composition of fluids used in hydraulic fracturing treatments, because the companies designing and executing these treatments usually do not reveal such data for commercial reasons. Such approach and lack of information about the properties of components that are used to create fracturing fluids, have become a cause of concern among the general public about possible risks to the environment and human health due to the use of these substances.

2.2.3.2 The availability of information on chemical substances and mixtures and shale gas activities

Information on substances and materials used during exploration and exploitation of unconventional hydrocarbons is partly accessible to the public, both for the work carried out in the USA and Canada, as well as in Europe.

In the United States in 2011, FracFocus, a web-based database, was launched to provide public access to reported chemicals used for hydraulic fracturing. It serves as the national hydraulic fracturing chemical registry. FracFocus is managed by the Ground Water Protection Council and Interstate Oil and Gas Compact Commission and currently is in use in 23 states as a mean of chemical disclosure. FracFocus database contains 106,132 registered well sites and disclosures of the applied chemicals used for hydraulic fracturing. The database contains 692 unique chemical ingredients for additives, base fluids and proppants. Per gas disclosure, the median number of additive ingredients was 12. One or more ingredients were claimed confidential in more than 70% of the evaluated disclosures and operators designated 11% of all ingredient records as confidential business information. The most commonly reported additive ingredients for gas disclosures were hydrochloric acid, methanol and hydrotreated light petroleum distillates (*FracFocus: Introduction to Chemical Use*).

FracFocus Chemical Disclosure Registry website was also created in Canada (http://fracfocus.ca/). The purpose of this website is to provide Canadians with objective information on hydraulic fracturing, what legislation and regulations are in place to protect the environment including groundwater, and transparency of the ingredients that make up hydraulic fracturing fluids (*FracFocus*).

Both in the USA and Canada there is a lack of uniform public disclosure requirements between the federal government and the respective state or provincial laws. None of the countries have uniform public disclosure laws among the constituent states or provinces that are in the process of developing shale oil and gas regulatory regimes. In the United States and Canada there have been created (at the federal level) legislative requirements concerning issues of health and safety during the use of chemical substances and compounds in general. Although some of these substances include chemicals that may be added to hydraulic fracturing fluids, the studies are not specifically concerned with such chemicals. Whether the contents of the fracking fluids need to be disclosed before the fracturing operations or after the fracturing operations (or both) varies among different states, as does the extent to which the fluid developer or owner may limit disclosure of the chemical contents of the fluid (*Ingelson and Hunter, 2014*).

Information about works carried out in Europe and related to the exploration and exploitation of gas from shale formations, can be found on the Natural Gas from Shale website (NGS FACTS http://www.ngsfacts.org/) (*Natural Gas from Shale Hydraulic Fracturing Fluid and Additive Component Transparency Service*). The primary purpose of this site is to provide information concerning hydraulic fracturing of natural gas from shale wells and other issues including voluntary disclosure of chemical additives on a well-by-well basis in the European Economic Area. On the website it could be found what substances were used to prepare the hydraulic fracturing fluid. The site includes natural gas from shale directed hydraulically fractured wells drilled after 1 January 2011 by participating operators in the Energy Community. Currently, the only available information on the site is on wells located on Polish territory. For each disclosed well drilling a Disclosure Sheet is available. It contains following information: well location and description, hydraulic fracturing fluid products, data and constituents.

On the basis of data collected on the NGS FACTS website and on The Polish Exploration and Production Industry Organization (OPPPW) website (*Organizacja Polskiego Przemysłu Poszukiwawczo-Wydobywczego [The Polish Exploration and Production Industry Organization]*) concerning hydraulic fracturing, which have been carried out in Poland since 1 January 2011 (22 boreholes), a detailed analysis of chemical substances and compounds used during such operations for preparing the fracturing fluids was carried out.

Based on the available literature on chemical composition of fluid in hydraulic fracturing operations, the most prominent knowledge gap is the missing full disclosure of all chemicals and their used amounts. Tracing the fate of individual chemicals and chemical mixtures used in hydraulic fracturing operations is necessary from injection to production and water treatment. The full disclosure of the applied chemicals is also a prerequisite for a knowledge-based decision about necessary water treatment and possible ways of disposal for the high amounts of flowback and produced waters. On the other hand, if spills or leakages or other accidents happen where fracturing fluids or flowback and produced waters are released to the environment (e.g. soil, surface water and groundwater), information on the chemical composition is necessary for proper treatment and remediation. With full disclosure of chemicals it will be possible to elucidate suitable chemical tracers of the applied fracturing fluids for contamination issues.

It is worth adding that in Europe there is no obligation to disclose the composition of hydraulic fracturing fluids and amounts of the individual substances contained therein (at both EU level and individual Member States level).

2.3 Management of waste produced during shale gas activities

Exploration and exploitation of unconventional hydrocarbon deposits generate various types of waste. Part of this generated waste is a typical drilling waste, i.e. drill cuttings and used drilling mud, which are well known and characterized. Such waste typically have a semi-solid or solid consistency. A new kind of waste is associated with hydraulic fracturing (flowback and produced water). This type of waste is not, however, well characterized in terms of quality.

The aim of this part of the research was to collect and systematize available information from the USA, Canada and Europe, concerning the applicable legal requirements regarding drilling waste management, including waste generated during exploration and exploitation of unconventional hydrocarbons (Report D 10.1). A review of data and information about the wastewater and waste management in relation with shale gas exploration and exploitation operations was also conducted as a part of the work (Report D 9.1 and D 11.1).

2.3.1 Legal requirements

Currently in the United States wastes generated from crude oil and natural gas exploration and production (E&P wastes) are generally subject to non-hazardous waste regulation under Subtitle D of the Resource Conservation and Recovery Act (RCRA), state regulations or other federal regulations. In addition, many state governments have specific regulations and guidance for E&P wastes. In 2002 EPA issued the publication "Exemption of Oil and Gas Exploration and Production Wastes from Federal Hazardous Waste Regulations" (*Exemption of Oil and Gas Exploration and Production Wastes from Federal Hazardous Waste Regulations, 2002*). According to this document, produced water, drilling fluids, drill cuttings and well completion, treatment and stimulation fluids are on E&P list of wastes which are excluded from federal hazardous waste regulations. The exemption does not mean these wastes could not present a hazard to human health and the environment if improperly managed. Proper waste management is crucial in order to ensure protection of human health and environmental safety.

As previously mentioned, E&P wastes are also subject to state regulation. These regulations, however, differ as to the scope and level of detail. Regulatory programs can include regulatory parameters such as liner requirements, clear definitions of waste fluids and characterization requirements, operational controls, maintenance, closure and financial assurance requirements. Unfortunately, there are still areas that do not have specific requirements, like groundwater monitoring requirements for solid waste management facilities, leachate collection requirements, air monitoring of solid waste management facilities and waste characterization requirements. In addition to the legal requirements in respective states, there is a variety of voluntary management practice guidances for operators to evaluate and use in the development of site-specific E&P waste management plans.

Similar to the United States, the federal-provincial structure in Canada allocates primary authority to ten provinces and three territories over the relevant areas of regulation with regard to shale gas. Although Canada has strong provincial and federal regulations concerning operational practices to protect the environment, these regulations are not specific to the shale gas industry.

In Canada, the National Energy Board (NEB) regulates oil and gas exploration and production activities under the Canada Oil and Gas Operations Act (*Canada Oil and Gas Operations Act*). In all cases where a proposed work or activity requiring an Operations Authorization involves hydraulic fracturing (i.e. on federal lands), the NEB assesses future applications for drilling that involve hydraulic fracturing. With regard to unconventional gas production, the NEB recently issued Filing Requirements for Onshore Drilling Operations Involving Hydraulic Fracturing. The requirements detail numerous steps that an operator must undertake before drilling a well which will be subject to hydraulic fracturing. This includes the requirement that the operator will conduct an environmental assessment for any proposed activity. After performing this evaluation, but before obtaining the Operating License, the operator must provide, among others, a waste management plan (*Popp, 2014*).

At the European Union level the extractive waste management is regulated by Directive 2006/21/EC of the European Parliament and of the Council of 15 March 2006 on the management of waste from extractive industries and amending Directive 2004/35/EC (*Directive 2006/21/EC*), which entered into force on 1 May 2006. Currently, the majority of Member States of the European Union rely mainly on the general mining and environmental legislation transposing the EU legislation and related permitting procedures to regulate such activities, as they do for conventional gas extraction. None of the countries assessed provide specific requirements for the management of waste derived from hydraulic fracturing. They rely mainly on the national legislation transposing the EU waste legislation. However, the selected Member States do not have a common view on the applicability of the Mining Waste Directive to this type of waste. There are major differences between Member States and uncertainties as to the legislation and requirements applicable to the management of wastewater resulting from hydraulic fracturing.

2.3.2 Waste and wastewater management

Proper management of waste generated during exploration and exploitation activities of conventional and unconventional hydrocarbon deposits, requires a reliable data on the quantity and quality of this waste. Waste generated during the initial drilling of the well typically maintains the characteristics of the drilling fluid but also contains additional solids related to the geological formations. Flowback is produced when the hydraulic fracturing procedure is completed and pressure is released. Composition of flowback is related to the composition of the initial fracturing fluid, the composition of the natural formation water of the shale and the possible interactions between fracturing fluid and shale system over time at the in-situ conditions. Initially this water, called flowback, is mostly fracturing fluid, but with time it becomes more similar to the natural formation water, e.g. there is an increase in salinity, and decrease in DOC (*Cluff et al., 2014*). This later stage water is also called a produced water. With regard to the composition of flowback and produced water, inorganic constituents (metals, salts), organic compounds (hydrocarbons, organic acids) and naturally occurring radioactive material (NORM) have to be considered.

Volume and composition of flowback and produced water varies over the lifetime of the well. This is an important issue when making treatment decisions. Constituents of concern in flowback and produced water include total dissolved solids (TDS), total suspended solids (TSS), organics, hardness, metals, biological load and naturally occurring radioactive material (NORM).

Having information about quality and quantity of generated waste it is possible to select one of the possible options of their further management. In the USA the decisions about wastewater treatment for reuse/recycle purposes are primarily influenced by TDS and NORM content in wastewater. There are several options for wastewater management:

- disposal via surface discharge, underground injection or land application,
- reuse/recycle wastewater in subsequent fracturing works,

- transfer wastewater to a Centralized Waste Treatment (CWT) facility,
- transfer wastewater to a Publicly Owned Treatment Works (POTW) facility,
- re-use produced water for beneficial purposes,
- in selected areas, operators also use evaporation ponds (impoundments) for disposal of produced water.

Disposal via underground injection is the most widespread method in the U.S., but operators increasingly try to implement reuse/recycle options for wastewater management. CWTs are becoming more common since larger volumes of produced water can be treated at lower costs. Produced water transfer to POTW facilities is in decline due to high requirements of wastewater quality. Beneficial use of treated produced water can only be applied when the treatment is sufficient to produce a high quality water.

Reuse/recycle options are increasingly developed as the regulatory frameworks for wastewater disposal and treatments recently developed.

Wastewater treatment can be done in two ways: basic treatment, which is ineffective for reducing total dissolved solids (TDS) and typically is not labour intensive, and advanced treatment which can remove TDS but is energy and labour intensive. In general, basic treatment technologies would be those designed for clarification and softening purposes, and advanced treatment technologies would be designed for desalination purposes.

In spite of many available information concerning management of this type of waste, there are still many areas that need to be unified and developed. Among these may be mentioned:

- identify and resolve knowledge gaps about composition and evolution over time of flowback and produced water in European shale gas operations,
- resolve knowledge gaps regarding the applicable legislation in each Member State in terms of waste management.

2.4 Impact of well site infrastructure and transport

The aim of the work package “Review of impact of well site infrastructure and transport” was to answer some of the public concerns with regard to the physical implication of developing well pads and their associated infrastructure on the land. In addition to the above, this report will aim to review the impact of traffic generated by shale gas activities on general traffic networks (Report D 12.1).

When assessing the impact of infrastructure, following things have been taken into consideration: the well pad, pipelines, access roads and boreholes. The study has considered issues for public safety (including: spills and leaks) and site safety and concludes that mitigation strategies from existing industries could be readily-translated to any shale gas industry. Due to the small amount of available information in this respect from Europe, the majority of the review is derived from literature based on the more exploited U.S. shale plays, such as the Marcellus and Barnett Shales.

Because of the fact that exploration and exploitation of gas from shale formations require a broad spectrum of chemical substances and mixtures, which are present both in materials used in the work and in generated waste, it is clear that the storage and transportation for long distances on public roads involve a risk to public safety. In addition to public risks associated with transport, as with other outdoor activities, well pad sites are exposed to extreme weather and environmental conditions (e.g. heavy rainstorms, severe windstorms, floods and freezing conditions) which makes working on those sites difficult and also elevate the risk of accidents, spills or leakages. Unless these spills and accidents are prevented and/or quickly and carefully contained, contamination of land, surface water and groundwater may result, which, if severe, may lead to potentially highly toxic chemicals being exposed to humans and natural ecosystems (*Eshleman and Elmore, 2013*).

Well site infrastructure such as pipelines and boreholes need to be well constructed, monitored and maintained to avoid leakage into surface water and groundwater, for there are some references about the American experiences of migration of hydrocarbons into the water. Within the U.S. the frequency of spillage events related to shale gas developments is not well known, there have been a number of media reports citing spills but there is a lack of robust data on the frequency, cause and impact on public safety of such events (*Broomfield, 2012*). Typically, spills and leaks tend to occur near the drilling location, with occurrence and frequency linked to the density of the shale gas drilling developments (*Vengosh et al., 2014; Gross, et al., 2013*). Spills and leaks of hydraulic fracturing and flowback water (often containing organics, salts, metals, and other constituents) can pollute soil, surface water, and shallow groundwater (*Vengosh et al., 2014*).

The presence and operation of heavy equipment and the large quantities of hazardous chemicals used on shale gas sites present similar risks to other industrial facilities, thus making the site secure is extremely important to ensure public safety. Well sites and their associated infrastructure should be treated like any other industrial site and made to adhere to securing these facilities so they can operate in a safe manner (*Eshleman and Elmore, 2013*).

With the development of shale gas landscape, disturbance is inevitable as numerous wells from many well pads are required to intersect the gas bearing formation(s) in order to be economic. The amount of land disturbed will vary depending on, amongst other considerations, the well pad size, number of wells per pad, well pad density and specifics of the shale play that is being developed (*Baranzelli et al., 2015*). However, even with technological advancements the footprint from well site infrastructure is still significant, it causes a relatively big change in a natural landscape and has a substantial impact on agricultural and forested land. There exist four exceptions that investigate the impact of land use and land cover change and the accompanying ecological, physical and aesthetic changes that can result from well site development and associated infrastructure.

As it was mentioned before, aside from the impacts that can directly be associated with the spatial footprint of a well pad site and associated access to that site, the impact of traffic generated by shale gas activities on general traffic networks (primarily roads but also possibly rail or other modes) needs to be considered. In general these impacts fall into the following categories: direct road and traffic management concerns (e.g. additional disruption, congestion and delay to other road users, damage to pavement surfaces), pollution concerns (e.g. Greenhouse Gas Emissions, noise and vibration) and additional concerns (e.g. changes to the employment opportunities, culture or heritage of a region). Reducing this impact may be achieved through e.g. the utilisation of either existing water supply networks or construction of new pipeline facilities or the use of on-site lined ponds to store wastewater and may also be used to ‘buffer’ transportation requirements, to spread the temporal intensity of demand for waste removal over a longer period.

In the report a number of potential mitigation measures have been highlighted to reduce the impact of shale gas traffic – including infrastructure changes at well sites and supporting infrastructure changes. Infrastructure measures could be expected to be increasingly effective as the industry matures, economies of scale come into effect or as technology changes.

3 CONCLUSIONS

Surface operations related to shale gas exploration and exploitation affect environmental elements such as groundwater and surface water and soil. Generated waste and the entire infrastructure associated with shale gas operations also have an influence on the environment and public safety.

To assess whether hydraulic fracturing can be conducted in an environmentally safe manner, proposed procedures should be first checked against local geological conditions in each individual case and accompanied by appropriate monitoring measures. For this an environmental impact assessment based on the corresponding mining regulations should be carried out. Furthermore, it should be ensured to involve the environmental administration, in particular the water authorities, in the process.

At the level of European countries, there are grounds for monitoring the environment and are visible tendencies towards unifying the methods of monitoring different elements of the environment. However, it should be noted that there are still many significant differences between the countries. In many of them, the environmental monitoring is actually operated at regional level. Therefore, it seems necessary to carry out further work, which shall result in an integrated, unified and effective system of monitoring the state of the environment at European level, including also the monitoring of exploration and exploitation activities of shale gas. This monitoring system shall include guidelines concerning i.a. the frequency of research, its scope and method of data collecting and transmitting/disclosing.

In spite of many available information concerning water resources management, there are still many areas that need to be unified and developed. Among these may be mentioned:

- resolve knowledge gaps on the available water sources for shale gas operations in an European context,
- resolve knowledge gaps regarding the applicable legislation in each Member State in terms of water management.

Proper monitoring of the impact on freshwater aquifers and surface water requires that the background conditions (baseline data) of those elements are properly documented in a scientific sound manner and by independent organizations before any drilling operation will be initiated. The baseline study should include, as a minimum, its flow properties and chemical composition.

The review of literature and available data has demonstrated that there are still many fields in the use of substances and chemicals during exploitation of gas from shale formations, improvement of which will contribute to minimizing the effects of chemicals on the environment and human health. In the case of the USA and Canada, there is no obligation, on the federal level, to disclose the composition of fluids used for hydraulic fracturing. Such an obligation exists in some states or provinces, but there are no uniform guidelines as to the scope of information that should be disclosed. In Europe, there is no obligation to disclose the composition of hydraulic fracturing fluids and amounts of the individual substances contained therein (at both EU level and individual Member States level). Tracing the fate of individual chemicals and chemical mixtures used in hydraulic fracturing operations is necessary from injection to production and during water treatment. The full disclosure of the applied chemicals is also a prerequisite for a knowledge-based decision about necessary water treatment and possible ways of disposal for the high amounts of flowback and produced waters.

Management of waste generated from exploration and exploitation of hydrocarbon deposits in the USA and Canada is regulated primarily at the level of individual states or provinces. There is a lack of guidelines in this respect at the federal level. Regulations at the level of states or provinces, however, differ in scope and detail, and do not always apply to the waste from exploitation of gas from shale formations. It should be added that many states and provinces are developing legislation and regulations in response to the increase in the use of hydraulic fracturing, including requirements related to waste management. In Europe wastes generated during exploration and exploitation of gas from shale formations are bounded by the same legal regulations as waste generated during exploration and extraction of conventional hydrocarbon deposits. Therefore, for the waste from exploitation of gas from shale formations there are no uniform requirements regarding the scope of research on quality of this type of waste, guidelines for their treatment, transportation, disposal and storage and need to disclose the results of research on their quality. In addition, there is no information concerning the comparison of harmfulness of waste generated during exploration and exploitation of conventional and unconventional hydrocarbon deposits.

Treatment of wastewater for beneficial uses is increasing due to the extensive costs in handling and management of produced water that operators have to conduct. Some of these beneficial uses include livestock watering, irrigation, farmland restoration and industrial and domestic uses.

In spite of many available information concerning management of wastewater and waste from shale gas activities, there are still many issues that need to be unified and developed. Among these may be mentioned:

- identify and resolve knowledge gaps about composition and evolution over time of flowback and produced water in European shale gas operations,
- resolve knowledge gaps regarding the applicable legislation in each Member State in terms of wastewater management.

The impact of well site infrastructure and transport is important but comparable to the impact of other industries. It can be minimized while maintaining the basic precautionary measures and applying the relevant provisions. Infrastructure measures could be expected to be increasingly effective as the industry matures, economies of scale come into effect or as technology changes.

4 REFERENCES

Assessment of the potential impacts of hydraulic fracturing for oil and gas on drinking water resources, 2015, External Review Draft, EPA/600/R-15/047a, United States Environmental Protection Agency, Washington, DC. Website: https://cfpub.epa.gov/ncea/hfstudy/recordisplay.cfm?deid=244651, accessed in March 2016.

Baranzelli, C., Vandecasteele, I., Barranco, R.R., Rivero, I.M., Pelletier, N., Bateaan, O., Lavalle, C. (2015) Scenarios for shale gas development and their related land use impacts in the Naltic Basin, Northern Poland, Energy Policy, 84, p. 80-95.

Barati, R., Liang, J.T. (2014) A review of fracturing fluid systems used for hydraulic fracturing of oil and gas wells, Journal of Applied Polymer Science, 131, n/a-n/a.

Broomfield, M. (2012) Support to the identification of potential risks for the environment and human health arising from hydrocarbons operations involving hydraulic fracturing in Europe, AEA:ED57281:17.

Canada Oil and Gas Operations Act, R.S.C., 1985, c. O-7. Website: http://laws-lois.justice.gc.ca/eng/acts/o-7/page-1.html#h-1, accessed in March 2016.

Canadian Environmental Protection Act, 1999. Website: http://laws-lois.justice.gc.ca/eng/acts/C-15.31/page-1.html#h-1, accessed in March 2016.

Carter, K.E., Hakala, A.J., Hammack, R.W. (2013) Hydraulic fracturing and organic compounds – uses, disposal and challenges, Society of Petroleum Engineers, SPE 165692.

Cluff, M.A., Hartsock, A., MacRae, J.D., Carter, K., Mouser, P.J. (2014) Temporal Changes in Microbial Ecology and Geochemistry in Produced Water from Hydraulically Fractured Marcellus Shale Gas Wells, Environmental Science & Technology, 48, p. 6508-6517.

Commission Recommendation of 22 January 2014 on minimum principles for the exploration and production of hydrocarbons (such as shale gas) using high-volume hydraulic fracturing (2014/70/EU) (Official Journal of the European Union L 39/72).

Environmental Impacts of Shale Gas Extraction in Canada, 2014, The Expert Panel on Harnessing Science and Technology to Understand the Environmental Impacts of Shale Gas Extraction, Council of Canadian Academies, Ottawa. Website: http://www.scienceadvice.ca/en/assessments/completed/shale-gas.aspx, accessed in March 2016.

Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy (Official Journal L 327, 22/12/2000 P. 0001 – 0073).

Directive 2006/21/EC of the European Parliament and of the Council of 15 March 2006 on the management of waste from extractive industries and amending Directive 2004/35/EC (Official Journal 11.04.2006 UE L 102 with later amendments).

Economides, M.J., Nolte, K.G. (2000) Reservoir Stimulation, Third Edition, John Wiley &Sons, p. 7-10 – 7-19. Website: http://pl.scribd.com/doc/129519407/Economides-M-J-and-Nolte-K-G-Reservoir-Stimulation-3rd-Edition#scribd, accessed in March 2016.

Environmental Aspects of the use and disposal drilling fluids associated with offshore oil and gas operation, 2003, International Association of Oil and Gas Producers, Report no. 342. Website: http://www.ogp.org.uk, accessed in November 2015.

Eshleman, K.N., Elmore, A. (2013) Recommended Best Management Practices for Marcellus Shale Gas Development in Maryland. Final Report submitted to: Maryland Department of the Environment Baltimore, MD. Website: http://www.slideshare.net/MarcellusDN/recommended-best-management-practices-for-marcellus-shale-gas-development-in-maryland, accessed in March 2016.

Exemption of Oil and Gas Exploration and Production Wastes from Federal Hazardous Waste Regulations, 2002, United States Environmental Protection Agency. Website: http://www3.epa.gov, accessed in March 2016.

FracFocus Chemical Disclosure Registry (http://fracfocus.ca/), visited on March 2016.

FracFocus Chemical Disclosure Registry (https://fracfocus.org/), sub-page “Introduction to Chemical Use” (https://fracfocus.org/water-protection/drilling-usage), visited on March 2016.

FracFocus Chemical Disclosure Registry (https://fracfocus.org/), sub-page “Why Chemicals Are Used?” (https://fracfocus.org/chemical-use/why-chemicals-are-used), visited on March 2016.

Gross, S.A., Avens, H.J., Banducci, A.M., Sahmel, J., Panko, J.M., Tvermoes, B.E. (2013) Analysis of BTEX groundwater concentrations from surface spills associated with hydraulic fracturing operations, Journal of the Air and Water Management Association, 63, 4, p. 424-432.

Oil and Gas; Hydraulic Fracturing on Federal and Indian Lands, 2015, Federal Register, Bureau of Land Management, Vol. 80, No. 58, Part III Department of the Interior. Website: https://www.govinfo.gov/, accessed in March 2016.

Ingelson, A., Hunter, T. (2014) A Regulatory Comparison of Hydraulic Fracturing Fluid Disclosure Regimes in the United States, Canada, and Australia, Natural Resources Journal, No. 2, 54, p. 217-255.

Jamrozik, A. (2009) Wpływ wybranych czynników chemicznych i fizycznych na właściwość płuczek wiertniczych [Influence of selected chemical and physical factors on drilling fluids properties], AGH University of Science and Technology, Krakow. Website: http://winntbg.bg.agh.edu.pl, accessed in November 2015.

M4ShaleGas - Measuring, monitoring, mitigating and managing the environmental impact of shale gas (http://www.m4shalegas.eu), visited on March 2016.

McCurdy, R. (2011) High rate hydraulic fracturing additives in non-Marcellus unconventional shale, in: Proceedings of the Technical Workshops for the Hydraulic Fracturing Study: Chemical & Analytical Methods, United States Environmental Protection Agency, Washington, p. 17–21. Website: http://water.epa.gov, accessed in November 2015.

Modern Shale Gas Development in the United States: A Primer, 2009, U.S. Department of Energy, Office of Fossil Energy, National Energy Technology Laboratory. Website: http://energy.gov, accessed in March 2016.

Montgomery, C. (2013) Fracturing Fluids, in: Effective and Sustainable Hydraulic Fracturing, Bunger, A.P., McLennan, J., Jeffrey, R. (Eds), InTech (http://www.intechopen.com/books/effective-and-sustainable-hydraulic-fracturing/fracturing-fluids), visited on March 2016.

Montgomery, C. (2013) Fracturing Fluids Components, in: Effective and Sustainable Hydraulic Fracturing, Bunger, A.P., McLennan, J., Jeffrey, R. (Eds), InTech (http://www.intechopen.com/books/effective-and-sustainable-hydraulic-fracturing/fracturing-fluid-components), visited on March 2016.

Natural Gas from Shale hydrauling fracturing Fluid and Additive Component Transparency Service (NGS FACTS) (http://www.ngsfacts.org/), visited on March 2016.

Organizacja Polskiego Przemysłu Poszukiwawczo-Wydobywczego [The Polish Exploration and Production Industry Organization] (http://www.opppw.pl/), visited on March 2016.

Otwór badawczy Markowola 1 jako przykład działań prowadzonych z troską o środowiska [Markowola-1 exploratory borehole as an example of activities carried out with care for the environment], 2011, Polish Oil and Gas Company (PGNiG SA), Rzeszow. Website: http://www.wios.rzeszow.pl, accessed in November 2015.

Petroleum information sheet, Chemicals used in hydraulic fracture stimulation, 2015, Government of Western Australia, Department of Mines and Petroleum. Website: http://www.dmp.wa.gov.au, accessed in November 2015.

Popp, S.M. (2014) Unconventional Gas Regulation in Canada, Oil, Gas & Energy Law Intelligence, Vol. 12 - issue 3.

Raczkowski, J., Półchłopek, T. (1998) Materiały i środki do chemicznego sporządzania płuczek wiertniczych [Materials and measures for chemical preparation of drilling fluids], works of Oil and Gas Institute, No 95.

Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), establishing a European Chemicals Agency, amending Directive 1999/45/EC and repealing Council Regulation (EEC) No 793/93 and Commission Regulation (EC) No 1488/94 as well as Council Directive 76/769/EEC and Commission Directives 91/155/EEC, 93/67/EEC, 93/105/EC and 2000/21/EC and its subsequent amendments (Official Journal of the European Union, L 396/1).

Regulation (EC) No 1272/2008 of the European Parliament and of the Council of 16 December 2008 on classification, labeling and packaging of substances and mixtures, amending and repealing Directives 67/548/EEC and 1999/45/EC, and amending Regulation (EC) No 1907/2006 and its subsequent amendments (Official Journal of the European Union, L 353/1).

Spellman, F.R. (2012) Environmental impacts of hydraulic fracturing, in: Environmental impacts of hydraulic fracturing, Boca Raton, Florida, CRC Press.

Stringfellow, W.T., Domen, J.K., Camarillo, M.K., Sandelin, W.L., Borglin, S. (2014) Physical, chemical, and biological characteristics of compounds used in hydraulic fracturing, Journal of Hazardous Materials, 275, p. 37–54.

Supplemental Generic Environmental Impact Statement on the Oil, Gas and Solution Mining Regulatory Program, 2011, Revised Draft, Well Permit Issuance for Horizontal Drilling and High-Volume Hydraulic Fracturing in the Marcellus Shale and Other Low-Permeability Gas Reservoirs, New York State Department of Environmental Conservation (NYS DEC). Website: http://www.dec.ny.gov, accessed in November 2015.

TDEX: The Endocrine Disruption Exchange (http://www.endocrinedisruption.org/chemicals-in-natural-gas-operations/chemicals), visited on March 2016.

United States Code, 2011, Title 42 - The Public Health and Welfare, Chapter 116 - Emergency Planning and Community Right to Know Act. Website: https://www.epa.gov/epcra/what-epcra, accessed in March 2016.

United States Environmental Protection Agency (2004) Chapter 4: Hydraulic Fracturing Fluids, in: Evaluation of Impacts to Underground Sources of Drinking Water by Hydraulic Fracturing of Coalbed Methane Reservoirs, EPA 816-R-04-003, Washington, p. 4-1 – 4-29. Website: https://fracfocus.org, accessed in November 2015.

United States Environmental Protection Agency (http://www3.epa.gov/), sub-page “Wastes - Non-Hazardous Waste - Industrial Waste” (http://www3.epa.gov/epawaste/nonhaz/industrial/special/oil/hydrofrac.htm#regs), visited on March 2016.

URS Corporation (2011) Water-related Issues Associated with Gas Production in the Marcellus Shale: Additives use, flowback quality and quantities, regulations, on-site treatment, green technologies, alternate water sources, water well-testing, Contract PO No. 10666, Fort Washington, p. 2-1 – 2-15.

Technical Development Document for Proposed Effluent Limitations Guidelines and Standards for Oil and Gas Extraction, 2015, EPA-821-R-15-003. U.S. Environmental Protection Agency, Office of Water, Washington DC. Website: https://www.epa.gov/eg/unconventional-oil-and-gas-extraction-effluent-guidelines-documents, accessed in March 2016.

Vengosh, A., Jackson, R.B., Warner, N., Darrah, T.H., Kondash, A. (2014) A critical review of the risks to water resources from unconventional shale gas development and hydraulic fracturing in the United States, Environmental Science and Technology, 48, p. 8334-8348.

Water Management Associated with Hydraulic Fracturing, 2010, API Guidance Document HF2, American Petroleum Institute. Website: http://www.api.org, accessed in March 2016.