Appendix H

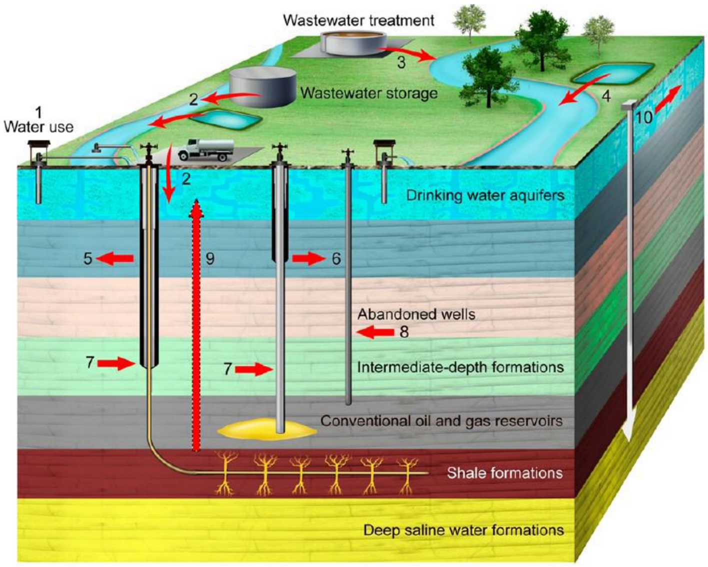
Water Contamination Risks from Well Construction and Formations

Introduction

This appendix evaluates risks associated with contamination of groundwater during the drilling of a well, due to casing and cementing failures, interactions with other formations (e.g. natural voids, faults) and historic gas wells, and deep well waste injection. Specifically, the following seven risks were identified by the Advisory Commission and were grouped as being associated with wells and formations. An additional risk was added in order to evaluate a contamination from methane due to migration through faults and old wells (#6 below).

1. Impact to groundwater from saline intrusion during drilling of vertical and lateral wellbore
2. Impact to groundwater from methane due to drilling through coalbed or other methane containing formations
3. Impact to groundwater from saline intrusion due to casing and cementing failure
4. Impact to groundwater from methane due to casing and cement failure
5. Impact to groundwater from fracturing fluids and mobilized substances via migration through faults and old wells
6. Impact to groundwater from methane due to migration through faults and old wells
7. Impact to community from seismic vibrations caused by deep underground injection
8. Impact to groundwater from deep well injection of flowback and produced water

Figure 1: Pathways of Groundwater Contamination



(1) overuse of water that could lead to depletion and water quality degradation particularly in water-scarce areas; (2) surface water and shallow groundwater contamination from spills and leaks of wastewater storage and open pits near drilling; (3) disposal of inadequately treated wastewater to local streams and accumulation of contaminant residues in disposal sites; (4) leaks of storage ponds that are used for deep-well injection; (5) shallow aquifer contamination by stray gas that originated from the target shale gas formation through leaking well casing. The stray gas contamination can potentially be followed by salt and chemical contamination from hydraulic fracturing fluids and/or formational waters; (6) shallow aquifer contamination by stray gas through leaking of conventional oil and gas wells casing; (7) shallow aquifer contamination by stray gas that originated from intermediate geological formations through annulus leaking of either shale gas or conventional oil and gas wells; (8) shallow aquifer contamination through abandoned oil and gas wells; (9) flow of gas and saline water directly from deep formation waters to shallow aquifers; and (10) shallow aquifer contamination through leaking of injection wells. (Vengosh 2014)

Impact of Groundwater Contamination

As described above, this appendix evaluates eight individual contamination pathway combinations. These can be simplified into two broad categories – contamination of groundwater from methane or contamination from other liquids (saline, fracturing fluids, and other formation liquids). Contamination of groundwater from any of these substances would have a negative impact on human health and aquatic life. The main BMPs to prevent contamination of groundwater are effective cementing and casing and monitoring for leaks.

Based on the literature reviewed, evidence has shown contamination from methane gas to be a more likely occurrence than contamination from liquids. A likely reason for this is that methane is buoyant and moves upwards, whereas liquids generally move only in response to pressure gradients. The strongest evidence of methane contamination of groundwater has been presented by Osborn et al. (2013), showing statistically higher levels of methane within 1 km of active drilling areas. The pathway of contamination (e.g. cement/casing failure, migration through faults) is not identified.

Methane is a colorless, odorless gas that does not affect the taste or appearance of drinking water, except that it can cause the water to appear cloudy or produce effervescent gas bubbles. There is no evidence that ingestion of methane in drinking water affects human health. (NIOSH 2009). Methane is extremely flammable and can form an explosive mixture with air at concentrations between 5% (lower explosive limit) and 15% (upper explosive limit). The US Department of the Interior, Office of Surface Mining, suggests that when the level of methane gas in the water is less than 10 mg/L it is safe, but monitoring is required at 10 to 28 mg/L, and immediate action is needed above 28 mg/L. **(**Eltschlager, 2001). Methane in its gas form is a simple asphyxiant, which in high concentrations may displace the oxygen supply needed for breathing, especially in confined spaces. Decreased oxygen can cause suffocation and loss of consciousness. It can also cause headache, dizziness, weakness, nausea, vomiting, and loss of coordination. Skin contact with liquid methane (which is very cold) can cause frostbite (NIH, 2014).

The impact of contamination of groundwater from the various liquids is somewhat harder to evaluate because of the number of chemicals present in drilling fluids and fracturing fluids, as well as deep underground formations of saline water and naturally occurring radioactive material (NORM). The precise composition of these liquids is often unknown and therefore there is insufficient data to determine to what extent it will impact human health or aquatic life. The following chemicals that are human health hazards have been used in the fracturing process: methanol, ethylene glycol, diesel fuel, napthalene, etc. (Waxman, 2011). Saline contamination would render groundwater unusable for drinking water and could also impact aquatic life that need freshwater. Overall, more research is needed to evaluate the impact of these liquids on groundwater.

Risk Mitigation (Current Regulations & Proposed BMPs)

Many of the risks associated with contamination to groundwater can, in some part, be reduced by current State regulations, as well as by the recommendations found in *Marcellus Shale Safe Drilling Initiative Study, Part II: Interim Final Best Practices* (MDE & DNR, 2014). The following is a summary of regulations and BMPs that can be expected to help prevent or mitigate groundwater contamination. This list will be used throughout the appendix to refer back to the detailed information given here.

Existing Regulations

The Code of Maryland Regulations (COMAR) Chapter 26.19.01 establishes regulations regarding Oil and Gas Resources in the State. The following requirements regarding setbacks, isolation of fresh water, and plugging of abandoned wells will help mitigate contamination of groundwater. If the recommended best practices are more stringent than the existing regulations, the existing regulations are not mentioned.

COMAR 26.19.01.10

- Determination of the depth of fresh water zones
- Run and permanently cement surface casing in the hole to a depth which is at least 100 feet below the deepest known strata bearing fresh water, or the deepest known workable coal, whichever is deeper
- If other strings of casing, in addition to surface casing, are run in the hole, they shall be cemented with sufficient cement circulated in the annular space to provide an effective seal above any producing zone;
- Within 30 days after the drilling, stimulating, and testing of a well are completed, a completion report of the well shall be submitted to the Department.

COMAR 26.19.01.12

- Upon the abandonment or ending of operation of any dry hole, gas or oil well, storage well, pressure maintenance well, or stratigraphic well, the permittee shall plug the hole.

Proposed Best Practices

In addition to the regulations, *Marcellus Shale Safe Drilling Initiative Study, Part II: Best Practices* includes many practices that will help mitigate groundwater contamination. These include:

- Preparation of a Comprehensive Gas Development Plan (CGDP) that, to the maximum extent practicable, avoids impacts to natural, social, cultural, recreational and other resources, minimizes unavoidable impacts, and mitigates remaining impacts
- The CGDP must include a geological investigation by the applicant of the area covered by the CGDP. At a minimum, the geological survey will include location of all gas wells (abandoned and existing), current water supply wells and springs, fracture-trace mapping, orientation on the location of all joints and fractures and other additional geologic information as required by the State. The applicant will be required to submit the survey data to the State; however, if the applicant asserts that the geological information is confidential business information, the State will not release the information to the public for a period of three years
- Setbacks from edge of disturbance for well pad
    - 1,000 feet from the boundary of the property on which the well will be drilled (a waiver can be granted if this is infeasible)
    - 450 feet from aquatic habitat
    - 600 feet from special conservation areas
    - 750 ft setback from downdip side of limestone outcrops to borehole

  - 1,000 feet from a school, church, or other occupied building (Unless written permission of the owners is submitted with the application and approved by the Department)
  - 1,320 ft setback from historic gas wells to borehole, including laterals
  - 2,000 foot setback from a private drinking water well
  - 1,000 foot setback from the perimeter of a wellhead protection area or source water assessment area for a public water system for which a Source Water protection Area has been delineated
  - No well pads on land at an elevation equal to or greater than the discharge elevation of a spring that is used as the source of domestic drinking water by the residents of the property on which the spring is located, but not to exceed 2,500 feet unless a delineation of the recharge area prepared by a registered geologist, and approved by the Department
- Site evaluation, pilot hole investigation and geologic investigation to develop site specific drilling, casing and cementing techniques in the event well drilling will encounter coal mines.
- No well pads within the watersheds of public drinking water reservoirs
- All surface disturbance for pads, roads, pipelines, ponds and other ancillary infrastructure will be prohibited on State owned land, unless DNR grants permission
- State agencies will develop standard protocols for baseline and environmental assessment monitoring, recordkeeping and reporting. In addition, the State agencies will develop standards for monitoring during operations at the site, including drilling, hydraulic fracturing, and production
- The monitoring, recordkeeping and reporting requirements will assist with identification of impacts from hazardous material releases so that remediation can be appropriate.
- Pre-development environmental assessment of site to identify all on-site drilling hazards such as underground mine workings, orphaned gas or oil wells, caves, caverns, Karst features, etc.
- Diesel fuel shall not be used in hydraulic fracturing fluids
- The permittee will be required to provide a complete list (Complete List) of chemical names, CAS numbers, and concentrations of every chemical constituent of every commercial chemical product brought to the site. If a claim is made that the composition of a product is a trade secret, the permittee must provide an alternative list (Alternative List), in any order, of the chemical constituents, including CAS numbers, without linking the constituent to a specific product. If no claim of trade secret is made, the Complete List will be considered public information; if a claim is made, the Alternative List will be considered public information.
- Following well completion, the operator shall provide MDE with a list of all chemicals used in fracturing, the weight of each used, and the concentration of the chemical in the fracturing fluid. If a claim is made that the weight of each chemical used or the concentration of each chemical in the fracturing fluid is a trade secret, the operator may attest to that fact and provide a second list that omits the weight and concentration to the extent necessary to protect the trade secret. If no claim of trade secret is made, the full list shall be public information; if a claim of trade secret is made, the list without the trade secret weight and concentration shall be public information.
- The applicant for an individual well permit must submit a plan for construction and operation that meets or exceeds the standards and/or individual planning requirements for engineering, design and environmental controls. In preparing the plan, the applicant shall consider all relevant API Standards and Guidance Documents, including normative references, and, if the plan fails to follow a minimum requirement of a relevant API standard, the plan must explain why and demonstrate that the plan is at least as protective as the minimum requirement. Elements of the plan include:
  - Evaluation of potential flow zones. Identification and evaluation of shallow and deep hazards
  - Monitoring and maintaining wellbore stability
  - Addressing lost circulation
  - Casing
  - Cementing
  - Wellbore hydraulics
  - Integrity and pressure testing
- Performance of well logging and submission of results to the State
  - Open hole logging

  - Cased hole logging using segmented radial cement bond logging, supplemented by other methods including omnidirectional cement bond logging and observations and measurements during cementing.
- Requirements for casing and cement
  - Steel alloy casing that meets standards for construction and pressure
  - Coupling threads that meet API standards
  - Use of centralizers
  - The cement shall be allowed to set at static balance or under pressure for a minimum of 12 hours and must have reached a compressive strength of at least 500 psi before drilling the plug, or initiating any integrity testing
  - Reconditioned casing may be permanently set in a well only after it has passed a hydrostatic pressure test with an applied pressure at least 1.2 times the maximum internal pressure to which the casing may be subjected, based upon known or anticipated subsurface pressure, or pressure that may be applied during stimulation, whichever is greater, and assuming no external pressure. The casing shall be marked to verify the test status.
  - All hydrostatic pressure tests shall be conducted pursuant to API "5 CT Specification for Casing and Tubing" or other method(s) approved by the Department. The owner shall provide a copy of the test results to MDE before the casing is installed in the well
  - Surface casing shall be run and permanently cemented from the surface to a depth at least 100 feet below the deepest known stratum bearing fresh water, or the deepest known workable coal, whichever is deeper. Intermediate casing, if used, must isolate all fluid bearing zones through which it passes. Production casing must be cemented along the horizontal portion of the well bore and to at least 500 feet above the highest formation where hydraulic fracturing will be performed, or 500 feet above the uppermost fluid bearing formation not already isolated by surface casing or intermediate casing, whichever is shallower.
  - If there is evidence of inadequate casing integrity or cement integrity, the Department must be notified and remedial action proposed.

Risk Assessments

Saline or methane intrusion during drilling

The section evaluates the impact to groundwater from saline intrusion during drilling of vertical and lateral wellbore or from methane due to drilling through coalbed or other methane containing formations.

Literature Review

No literature sources were found specifically related to contamination of groundwater by methane or saline water during the drilling of the wellbore. Most literature sources are concerned with fluid and gas migration to groundwater through cement/casing failure or other subsurface formations, which will be evaluated later in this appendix. Contamination during drilling is more likely due to drilling muds and cuttings, which will be evaluated in another section of this report.

Risk Analysis

Regarding saline contamination, in order for saline intrusion to occur during the drilling of the wellbore, both the fresh water and saline formations would need to be exposed simultaneously. As noted above, the surface casing must be installed and cemented to at least 100 feet below the deepest known strata bearing fresh water, or the deepest known workable coal, whichever is deeper, and the cement must be allowed to set before drilling the plug, which must be done before drilling deeper. The deepest stata bearing fresh water will ordinarily be established during drilling of the pilot hole. Also, as depicted in Figure 1 above, there is often great distance between the groundwater and saline formations, which would reduce the chance that they are exposed simultaneously.

Regarding methane contamination, the first priority should be to isolate fresh water strata as efficiently as possible, and secondly, to isolate other fluid-bearing zones. Intermediate casing, if used, must isolate all fluid bearing (liquid or gas) zones through which it passes. Production casing must be cemented along the horizontal portion of the well bore and to at least 500 feet above the highest formation where hydraulic fracturing will be performed, or 500 feet above the uppermost fluid bearing formation not already isolated by surface casing or intermediate casing, whichever is shallower. In this way, casing and cement will isolate all fluid-bearing (gas and liquid) formations through which the borehole passes before reaching the target formation.

Probability:

The probability of saline or methane contamination during drilling is rated as low based on the absence of reported cases, the best practices that require isolation of all fluid-bearing strata, and the relatively large separation between fresh water and salt water formations.

Consequence:

Impacts to groundwater could cause considerable adverse impact on people or the environment in the vicinity and is therefore rated as a moderate consequence.

Saline intrusion due to casing or cement failure

This section evaluates the impact to groundwater from saline intrusion due to casing and/or cementing failure.

Literature Review

Few literature sources were found related to groundwater contamination by saline due to casing/cement failure. Based on literature review, it is more likely that gas will be released in the event of casing/cement failure. However, it is notable that casing/cement failure is one of the most likely causes of environmental contamination in the hydraulic fracturing process.

Several literature sources state that no evidence of contamination of drinking water from deep saline brines was found. (Osborn et al., 2011 & Jackson, 2013) In a recent report investigating the mechanisms by which human activity could cause methane gas contamination to occur in drinking water wells, the authors noted that samples with significantly higher levels of thermogenic gas did not correlate with chloride levels, indicating that the thermogenic hydrocarbon gas had separated from the brine and migrated in the gas phase. For other samples where gas and brine levels did correlate, they concluded that the presence of gas and Cl^- was indicative of natural in situ presence or tectonically driven migration over geological time of gas-rich brine from an underlying source formation or gas-bearing formation of intermediate depth. (Darrah et al., 2014) This would indicate that saline intrusion was not caused by casing/cementing failure or any other step in the hydraulic fracturing process. Additionally, due to the density of saline brine, it is not likely to move upward through casing/cementing failures without significant induced pressure.

Risk Analysis

The best practices for casing and cement will reduce the risk of casing and cement failures.

Probability:

The probability of saline or methane contamination during drilling is rated as low based on the absence of reported cases and the best practices for casing and cement.

Consequence:

Impacts to groundwater could cause considerable adverse impact on people or the environment in the vicinity and is therefore rated as a moderate consequence.

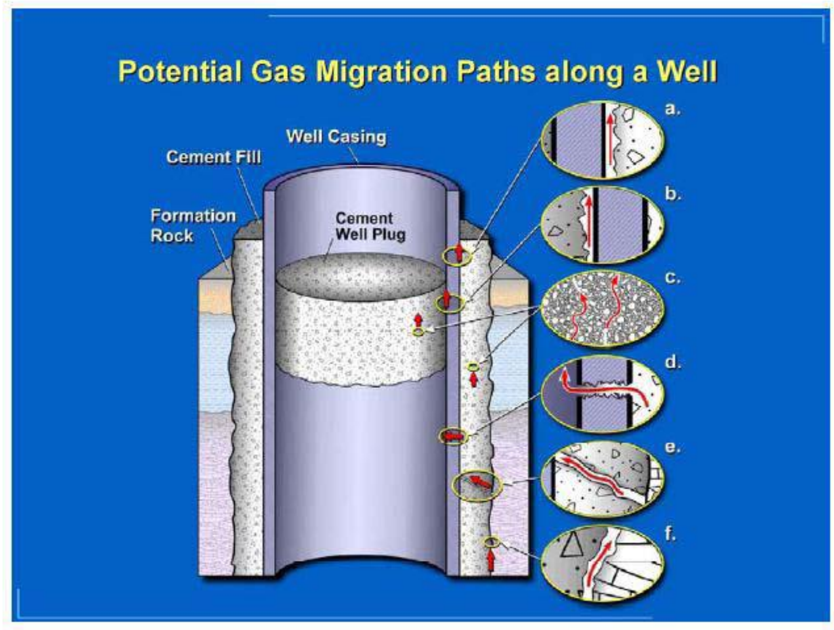
Methane intrusion from casing and/or cementing failure

This section evaluates the impact to groundwater from methane intrusion due to casing and/or cementing failure.

Literature Review

It is widely believed that casing/cement failure is one of the most likely causes of environmental contamination in the hydraulic fracturing process. (Darrah et al., 2014; Ingraffea et al., 2014, Vengosh, 2014; Rozell & Reaven, 2012). One source notes that gas migration through faulty casing is a “common occurrence” in the gas industry (Muehlenbachs, 2011).

There are several pathways for gas migration in a faulty well, as shown in Figure 2 below (Ingraffea, 2012). Ingraffea cites an approximate 6-7% failure rate in Pennsylvania wells (Ingraffea, 2012), while Vengosh presents findings from various sources estimating from 3 – 50% failure rates (Vengosh, 2014). It should be noted that there can be a wide range of issues which could constitute “failure” and that not all lead to contamination.



Source: Alberta Energy Utilities Board

Figure 2: Potential Gas Migration Paths along a Well

Zoback assesses the risk of groundwater contamination from casing or cement failure as great. A 2007 example is given of groundwater contamination in Ohio from a well that was almost 4,000 feet deep in tight sands, via cement failure.

In a report to the US Department of Energy, the Secretary of the Energy Advisory Board (SEAB) states that contamination from methane is widely believed to be due to poor well completion. The recommend multiple engineered barriers to prevent groundwater contamination from methane and that properly cemented and cased wells do not allow contamination (SEAB, 2011).

A study in Pennsylvania documented elevated levels of methane in groundwater wells within 1 km of natural gas wells compared to groundwater wells farther away and the authors identified several possible mechanisms. (Jackson, 2013) A subsequent investigation tested the likelihood of seven different scenarios that, alone or together, could account for the elevated methane levels in shallow aquifers. The authors concluded that of the eight clusters of groundwater wells that showed fugitive gas contamination, four were consistent with the release of intermediate-depth hydrocarbon gas along the well annulus, probably as a result of poor cementation. Three of the remaining four were consistent with migration of deep shale gas, "presumably" through improper, faulty or failing production casing. The eighth cluster was located near a natural gas well that had documented an underground well failure (a casing well packer failure at depth). (Darrah, 2014) In contrast, an investigation in the Fayetteville shale in north-central Arkansas found no direct evidence for stray gas contamination in wells located near shale gas sites. (Warner, 2013) One of the authors wrote that "The authors hypothesized the potential for stray gas contamination likely depends on both well integrity and local geology, including the extent of local fracture systems that provide flow paths for potential gas migration" (Vengosh, 2014).

Risk Analysis

The best practices for casing and cement reduce the risk of casing and cement failures. Integrity testing may identify problems that can be remedied. Setbacks from source water protection areas and private drinking water wells also reduce the likelihood that stray methane will reach wells. The geological survey of the area covered by the Comprehensive Gas Development Plan will provide information about the locations of existing joints and fractures.

Probability:

Failures of casing and cement are common and, although the best practices should greatly reduce them, they probably will not be eliminated. The probability of groundwater contamination via casing/cement failure is being evaluated for two scenarios, based on MDE's Best Practices recommendations. The first scenario is if a gas well is set back 2,000 feet from a drinking water well and the probability for this is moderate. The second scenario is if a gas well is set back 1 km (3,280ft) from a drinking water well, and the probability for this is low.

Consequence:

Impacts to groundwater could cause considerable adverse impact on people or the environment in the vicinity and is therefore rated as a moderate consequence.

Contaminant migration through faults and old wells

This section evaluates the impact to groundwater from fracturing fluid, flowback and methane via migration through faults and old wells.

Literature Review

Most literature sources indicate that groundwater contamination via migration through faults or old wells would be a rare and site specific occurrence.

Zoback (2014) states that the risk of migration from methane or fluids from Marcellus Shale, which is 4,000 to 8500 feet below the surface, to groundwater which is approximately 850 feet below the surface is very low. He does state that there are shallower shales, such as Antrim or New Albany, which migration could be significant.

Rozell and Reaven (2012) used probability bounds analysis (PBA) to evaluate risk of five pathways for water contamination. The lack of consensus on the likelihood that hydraulic fracturing fluids would migrate through fractures resulted in a probability range of 1 in 10 to 1 in a million.

Vengosh (2014) reports that methane and fluid migration to groundwater is highly debated. An investigation of mechanisms for stray gas migration found no unequivocal evidence that stray gas contamination of shallow groundwater was caused by direct migration of gases upward through intervening strata following drilling or hydraulic fracturing; the cluster that was consistent with migration of gas from depth through water-saturated strata in the crust to the shallow aquifer was more likely caused by the documented underground well failure (Darrah 2014).

The SEAB reports that regulators and geophysical experts agree that the likelihood of properly injected fracturing liquid or naturally occurring contaminants reaching underground sources of drinking water through fractures is remote where there is a large depth separation between drinking water sources and the producing zone (SEAB, 2011).

Vidic (2013) indicates that fluid migration through natural faults is possible when brines are present at relatively shallow depths, such as in much of the northeastern and southwestern United States and Michigan.

Risk Analysis

The best practices for casing and cement reduce the risk of casing and cement failures. Integrity testing may identify problems that can be remedied. Setbacks from source water protection areas and private drinking water wells also reduce the likelihood that stray methane will reach wells. The geological survey of the area covered by the Comprehensive Gas Development Plan will provide information about the locations of existing joints and fractures as well as old wells.

Probability:

Based on the literature review and BMPs available, the risk is classified as low.

Consequence:

Impacts to groundwater could cause considerable adverse impact on people or the environment in the vicinity and is as a moderate consequence for people and a serious consequence for the environment. Aquatic organisms are highly sensitive to dissolved toxins and the uncertainty regarding the specific chemical composition of fluids and the specific sensitivity of the exposed organisms warrents are greater consequence. Cave systems and their unique biological communities are also particularly sensitive to groundwater toxins.

Seismic vibrations from underground injection

This section evaluates the impact to communities from seismic vibrations caused by deep well injection of wastewaters.

Literature Review

While many industries dispose of waste to deep wells, the high volume of wastes associated with hydraulic fracturing that will need to be disposed of to deep disposal wells is a concern. There is significant consensus that waste disposal to deep wells has caused an increase in seismic activities.

In early 2014, USGS published an article on their website, *Man-made Earthquakes Update*. It reported that the number of earthquakes has increased recently, especially in the central and eastern United States. In some locations, they were able to directly connect the increase in seismicity with the injection of wastewater in deep disposal wells. Deep injection disposal in often used by the oil and gas industry into wells specifically designed for such purpose. (USGS 2014)

Ellsworth (2013) reports a growing realization that the principal seismic hazard from injection-induced earthquakes comes from those associated with disposal of wastewater into deep strata.

King (2012) cites established connections between earthquakes and deep well disposal of some produced water from the oil and gas industry, as well as injection of other fluids such as military wastes and wastes from geothermal energy production.

Zoback (2010) details a number of the small-to-moderate earthquakes that occurred in the U.S. interior in 2011 appear to be associated with the disposal of wastewaters, in part from natural gas production. These include locations in Arkansas, Colorado/New Mexico, and Ohio.

Risk Analysis

With regard to disposal in Class II injection wells, the UMCES-AL report noted that locations in Maryland suitable for siting injection wells may be very limited. MDE and DNR agree that it is not likely that Class II wells will be located in Maryland and therefore defers any consideration of the matter.

In response to the increase in the frequency of seismic events associated with underground injection, Governor Mary Fallin established a working group, the Coordinating Council on Seismic Activity, to investigate the issues. (Oklahoma, 2014) In Texas, the regulatory agency has proposed regulations that would require applicants for injection well permits to provide information regarding historic seismic events and monitor injection pressure and injection rates as required by the commission. (Railroad Commission of Texas, 2014)

Probability

Based on the literature review, risk of seismic activity due to deep underground injection is moderate because it occurs occasionally or could potentially occur under foreseeable circumstances if management or regulatory controls fall below best practice standards. However, because it is not likely that Class II wells will be located in Maryland, this risk is assumed to have a low probability.

Consequence

The consequence of an earthquake induced by deep well injection would be serious because it would have a major adverse impact on people or the environment.

Impact to groundwater from deep well injection of wastewater

This section evaluates the impact to groundwater of deep well injection of wastewaters.

Literature Review

The consensus from literature sources indicates that it is possible that fluids disposed of via deep well injection could contaminate groundwater, but that it is rare.

McLin (1986) reports that no systematic survey has been completed to determine the extent of groundwater contamination from deep well injection.

Vidic (2013)states that between 1982 and 1984, Texas reported at most approximately 100 cases of confirmed contamination of groundwater from oilfield injection wells, despite more than 50,000 injection wells associated with the oil and gas industry.

An American Petroleum Institute reports estimated the risk of contaminating groundwater from a Class II injection well at 2 in 100,000 well-years to 2 in 100,000,000 well-years (Rozell & Reaven, 2012).

Risk Analysis

With regard to disposal in Class II injection wells, the UMCES-AL report noted that locations in Maryland suitable for siting injection wells may be very limited. MDE and DNR agree that it is not likely that Class II wells will be located in Maryland and therefore defers any consideration of the matter.

Probability

Based on the literature review, contamination of groundwater due to deep underground injection rarely happens and therefore the probability is low. However, because it is not likely that Class II wells will be located in Maryland, this risk is assumed to have a low probability in Maryland.

Consequence

Impacts to groundwater could cause considerable adverse impact on people or the environment in the vicinity and is therefore rated as a moderate consequence.

Risk Assessment Table

Risk	Environmental Impact	Probability	Consequence	Risk Ranking
Impact to groundwater from saline intrusion during drilling of vertical and lateral wellbore	Human and Ecological	Low	Moderate	Low
Impact to groundwater from methane due to drilling through coalbed or other methane containing formations	Human and Ecological	Low	Moderate	Low
Impact to groundwater from saline intrusion due to casing and cementing failure	Human and Ecological	Low	Moderate	Low
Impact to groundwater from methane due to casing and cement failure if well is within 2,000 feet	Human	Moderate	Moderate	Moderate
Impact to groundwater from methane due to casing and cement failure if well is greater than 3280 feet away	Human	Low	Moderate	Low
Impact to groundwater from fracturing fluids and mobilized substances via migration through faults and old wells	Human	Low	Moderate	Low

Impact to groundwater from fracturing fluids and mobilized substances via migration through faults and old wells	Ecological	Low	Serious	Moderate
Impact to groundwater from methane due to migration through faults and old wells	Human	Low	Moderate	Low
Impact to community from seismic vibrations caused by deep underground injection	Community	Low – MD	Serious	Moderate
Impact to community from seismic vibrations caused by deep underground injection	Community	Moderate – States with Class II wells	Serious	High
Impact to groundwater from deep well injection of flowback and produced water	Human	Low – MD	Moderate	Low
Impact to groundwater from deep well injection of flowback and produced water	Human	Moderate – States with Class II wells	Moderate	Moderate

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