Appendix E:

Groundwater and Surface Water Contamination Risks during Transport of Fracturing Additives and Fluids

Scope

Hydraulic fracturing is a method for extracting hydrocarbons from shale formations. Briefly, the method entails pumping large volumes of fracturing fluid under high pressure through shale formations. The movement and pressure of the fluid creates fractures in the shale allowing hydrocarbons to be accessed. Horizontal directional drilling combined with hydraulic fracturing techniques has allowed energy companies to access to larger areas of hydrocarbons using comparatively less surface area.

Fracturing fluid is composed of water and hydraulic fracturing fluid additives. By weight, hydraulic fracturing fluid additives account for only 1 to 3% of the total weight, approximately 10% is proppant, and the remaining volume is water (NYSDEC, 2011). The NYSDEC(2011) cites 10 classes of additives (including proppant) that have been used in the natural gas in the Marcellus shale formation:

- Acid
- Breaker
- Bactericide/Biocide
- Corrosion inhibitor
- Friction reducer
- Gelling Agent
- Iron Control
- Scale Inhibitor
- Surfactant
- Proppant

Although fracturing fluid additives comprise a relatively small fraction of the total volume of fracturing fluid, the volume of fracturing fluid needed for a single fracturing fluid operation is substantial, which makes the total volume of additives needed significant. (Ernstoff & Ellis, 2013; Rozell & Reaven, 2011). Furthermore, there is not a linear relationship between concentration and toxicity that can be applied to all chemical compounds. Regardless, there are large volumes of fracturing fluid additives stored on site at the drill pad during fracturing operations.

Each class of additive may be composed of one or more chemical compounds. These compounds, and their potential for release into the environment, form the basis for quantifying the environmental and public health risk caused by hydraulic fracturing. As noted in Appendix H, the following chemicals that are human health hazards have been used in the fracturing process: methanol, ethylene glycol, diesel fuel, napthalene, etc. (Waxman, 2011)

Chronological Overview of Hydraulic Fracturing Steps

Transportation of Hydraulic Fracturing Additives to Well Pad

Activity Description

The hydraulic fracturing process requires large volumes of water and hydraulic fracturing additives. The revised draft Supplemental Generic Environmental Impact Statement prepared by the New York State Department of Environmental Conservation (here referenced as New York DEC 2011) states that fracturing additives are transported in United States Department of Transportation approved trucks or containers. Fracturing fluid additives are often transported in plastic totes that are loaded onto flat-bed trucks (Figure 1). These totes are referred to as intermediate bulk containers (IBC). Other liquid additives that are used in smaller quantities can be transported in one-gallon sealed jugs carried in the side boxes of the flat-bed truck. Other bulk liquids, such as hydrochloric acid, are transported in tank trucks. Dry additives, such as proppants, can be transported on flat-beds in bags set on pallets or in plastic buckets or sand transport trucks (NYSDEC, 2011).

Figure 1: Hydraulic fracturing totes

Activity Duration and Scope

The duration and scope of this activity would be a function of distance traveled and number of wells. For the purpose of this risk assessment, it will be assumed that all fracturing fluid additives will be imported from out of state. NYSDEC (2011) provides estimates for total one way truck trips per drilling well for fracturing chemicals to be 20 (NYSDEC, 2011). Therefore, under Scenario 1:

150 wells * 20 chemical trucks/well = 3,000 loaded chemical truck trips

And under Scenario 2:

450 wells * 20 chemical trucks/well = 9,000 loaded chemical truck trips

If we assume that each truck will travel 100 miles within the state of Maryland and will travel an average of 50 miles per hour, we can deduce that each loaded chemical truck will be traveling on roads in Maryland for 2 hours.

Literature Review of Associated Risks to Surface Water and Ground Water

Chemicals being transported can be released into the environment as a result of accidents, container failure, or other mishaps. Rozell and Reaven (2011) attempted to quantify the relative risk of chemical spills associated with trucks carrying hydraulic fracturing fluid additives and flowback water by using data from United States hazmat trucking accidents as a proxy. However, these data may be underreported. Elsewhere in this risk assessment, using information from the Pipeline and Hazardous Materials Safety Administration, we estimate that the probability that any single shipment of hazardous materials would result in a release of hazardous materials to the environment is 0.005 percent.

Risk Mitigation: Current Regulations and Proposed BMPs

Federal regulations (49 CFR Part 178) set minimum standards and integrity testing requirements for IBCs to ensure that they can withstand normal conditions of transportation. Each IBC must be manufactured and assembled so as to be capable of successfully passing the prescribed tests. This testing includes qualifying in the performance of drop, leak-proofness, hydrostatic pressure, stacking, bottom-lift or top-lift, tear, topple, righting and vibration tests. The specific conditions of the tests (e.g., drop height) are determined by the physical characteristics of the substance intended to be transported.

Maryland proposes the following BMPs that are relevant to reducing the risk of accidental fracturing fluid additives release from trucks:

- Identification of travel routes in the Comprehensive Gas Development Plan

- Encourage local jurisdictions to develop adequate transportation plans, which will be considered in the CGDP process and the review of the transportation plan for the individual permit.
- The applicant for a well drilling permit must submit a plan that addresses, among other things, road construction and maintenance; and transportation planning, including the identification of routes to be traveled in Maryland by heavy duty trucks and tractor trailers coming to or leaving the pad site
- Routes and times of travel shall be established to minimize use conflicts, including school bus transport of children, public events and festivals, and periods of heavy public use of State lands.
- Applicants shall be required to enter into agreements with the county and/or municipality to restore the roads which it makes use of to the same or better condition the roadways had prior to the commencement of the applicant’s operations, and to maintain the roadways in a good state of repair during the applicant’s operations. The agreement may mandate that the applicant post bond.

Risk Assessment

The level of risk associated with transporting fracturing fluid additives would also be a function of the toxicity of the fracturing fluid additives themselves, the volume of fluids being transported, the distance each truck travels in the state of Maryland, the probability of accidental release in relation to the distance traveled, and the number of trucks. The predicted distance traveled by each truck has already been described above.

Quantifying the risk associated with transporting fracturing fluid is difficult. Because the chemical mixture that composes fracturing fluid is proprietary, there are very few peer reviewed studies that establish relationships between fracturing fluid concentrations and effects to ecological or human health. However, Bamberger and Oswald (2012) reported several incidences of live stock health problems and mortality caused by fracturing fluid release. Furthermore, in a written testimony before the House Committee on Oversight and Government Reform, Dr. Theo Colborn (2007) testified that certain chemicals associated with fracturing fluid could cause health problems to people and wildlife if exposed. Dr. Colborn’s testimony also included an analysis of certain chemicals used in natural gas development and delivery in Colorado. The report stated that many chemicals were classified as respiratory toxicants, immunotoxicants, and carcinogens. However, a specific risk associated with these chemicals cannot be properly quantified because the concentrations of fracturing fluid chemicals are unknown. If an incident resulted in the release or spill of drilling fluid additives transporting directly into a stream the contaminated surface water could significantly impair water quality and adversely affect the health of aquatic life.

The Departments will require the disclosure of all chemicals that the applicant expects to use on the site. 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. MDE will retain the list or lists in the permit file. Each permittee must prepare a site-specific emergency response plan and the permittee must provide a list of chemicals and corresponding Safety Data Sheets to first responders before beginning operations. MDE must approve the use of any chemical, and will encourage the use of less dangerous chemicals.

Lacking information regarding the specific fracturing fluid additives that will be used in Maryland, for purposes of this risk assessment, we will utilize the precautionary principle. For the purposes of this risk assessment, it will be assumed that fracturing fluid additives are harmful to people and environmental receptors.

The total amount of additives being transported for a single well can be estimated if we assume that volume of water needed for hydraulic fracturing is 5,000,000 gallons (41.7 million pounds) and 2% by weight of the fracturing fluid is fracturing fluid additive. This would equate to approximately 800,000 pounds of additives for each well to be fractured, an amount that could be accommodated by 20 trucks without violating the limits on gross vehicle weight for multi-axel vehicles. Under scenario 1, there will be approximately 3,000 truck trips associated with transporting fracturing fluid additives; under scenario 2, there will be approximately 9,000 truck trips. If the probability of a release from any one shipment of additives is 0.005 percent, this would equate to less than one incident under either scenario. The probability of fracturing fluid additive truck accidents is therefore classified as low.

Soil contamination is likely to be localized and contaminated soil could be removed. This consequence will be classified as moderate for human impact because it could have an adverse impact in the immediate vicinity, causing localized or temporary damage. Contaminated ground water could impair water quality in public and private wells at levels that adversely affect human health through water consumption.

If an incident resulted in the release or spill of fracturing additives directly into a stream the contaminated surface water could significantly impair water quality and adversely affect the health of aquatic life. Damages would be extensive if direct discharges occurred in the headwaters of streams, particularly in Tier II and Use III streams that support pollution intolerant aquatic life and native Brook trout populations. The consequences associated with surface water or ground water contamination from accidental releases or spills of fracturing fluid additives during transport will therefore be classified as severe for ecological effects. For both risk assessment scenarios 1 (150 wells) and 2 (450 wells) the consequences will be classified as moderate for soil contamination, ground water and surface water contamination for humans, and moderate for ecological effects. Figure 5 presents a flow diagram of the risk pathway for soil, surface water and ground water contamination associated with the transport of drilling fluid additives to the well pad.

Figure 2 describes the risk associated with the transportation of fracturing fluid additives. As shown in the flow chart, a risk to soil, surface water or ground water would occur if a truck transporting fracturing fluid additives released the material.

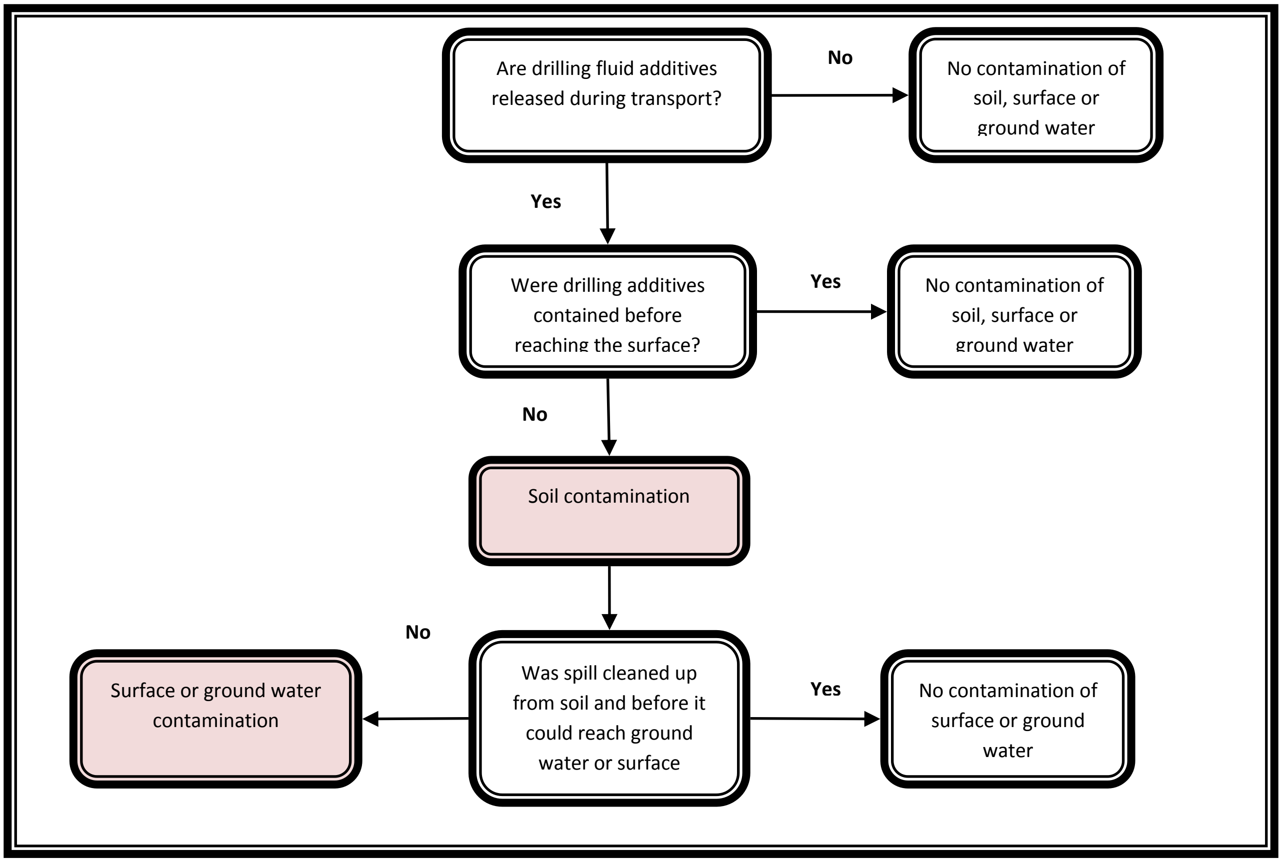

Figure 2: Risk flow chart for truck transportation of fracturing fluid additives

Storage and Handling of Hydraulic Fracturing Additives and Fluid

Activity Description

When fracturing fluid additives arrive at the drill pad, they remain in the totes, containers, and trucks in which they were transported. When the hydraulic fracturing process begins, the additives are transferred to a mixing apparatus (NYDDEC, 2011; King, 2012).

Activity Duration and Scope

Fracturing fluid additives are not delivered to the well pad until fracturing operations are set to proceed for logistical and economic factors. Therefore, on-site storage time is on average less than a week and only the amount of additives needed for scheduled hydraulic fracturing operations is delivered at any one time (NYSDEC, 2011).

The volume of additives on site depends on the amount needed for one well's fracturing operation, because it will be assumed that only one fracturing operation will take place at any given time on the well pad. Therefore, the volume of additives required will be assumed to be 100,000 gallons.

Literature Review of Associated Risks to Surface Water and Ground Water

Accidental releases of fracturing fluid additives may occur as a result of failure to maintain stormwater controls, ineffective surface and subsurface additive fluid containment practices, or accidental spills. Bamberger and Oswald (2012) reported two cases of hydraulic fracturing fluid additive spills from storage containers and three incidences of storm water run-off from the drilling pads.

Chemical components of hydraulic fracturing fluid additives may also be protected by proprietary licenses. The disclosure of these chemical components to public agencies has therefore been contentious. A lack of full disclosure to first responders may hinder mitigation and remediation actions in the event of accidental spills. As noted above, Maryland's proposed best practices address this issue.

Risk Mitigation: Current Regulations and Proposed BMPs

Maryland proposes the following BMPs that are relevant to reducing the risk associated with accidental release of fracturing fluid additives during storage and handling at the well pad:

- Storage of chemicals in tanks or containers on the well pad with secondary containment
- Avoidance of siting well pads on land with greater than 15 percent slope
- 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
- The term "well pad" is defined to include the areas where drill rigs, pumps, engines, generators, mixers and similar equipment, fuel, pipes and chemicals are located. No discharge of potentially contaminated stormwater or pollutants from the pad shall be allowed. Drill pads must be underlain with a synthetic liner with a maximum hydraulic conductivity of 10-7 centimeters per second and the liner must be protected by decking material. Spills on the pad must be cleaned up as soon as practicable and the waste material properly disposed of in accordance with law. The well pad must be surrounded by an impermeable berm such that the pad can contain at least the volume of 4.0 inches of rainfall within a 24 hour period. The design must allow for the transfer of stormwater and other

liquids that collect on the pad to storage tanks on the pad or to trucks that can safely transport the liquid for proper disposal.

- Tanks shall be above ground, constructed of metal or other material compatible with the contents, and lined if necessary to protect the metal from corrosion from the contents. Tanks and containers shall be surrounded with a continuous dike or wall capable of effectively holding the total volume of the largest storage container or tank located within the area enclosed by the dike or wall. The construction and composition of this emergency holding area shall prevent movement of any liquid from this area into the waters of the State
- Each permittee must prepare a site-specific emergency response plan and the permittee must provide a list of chemicals and corresponding Safety Data Sheets to first responders before beginning operations. Facilities must develop plans for preventing the spills of oil and hazardous substances, using drip pans and secondary containment structures to contain spills, conducting periodic inspections, using signs and labels, having appropriate personal protective equipment and appropriate spill response equipment at the facility, training employees and contractors, and establishing a communications plan. In addition, the operator shall identify specially trained and equipped personnel who could respond to a well blowout, fire, or other incident that personnel at the site cannot manage. These specially trained and equipped personnel must be capable of arriving at the site within 24 hours of the incident.
- Setbacks from the edge of drill pad disturbance
    - 450 feet from aquatic habitat
    - 600 feet from special conservation areas
    - 750 ft setback from downdip side of limestone outcrops to borehole
    - 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

Risk Assessment

Because of the requirements for stormwater controls, spill cleanup and secondary containment, it is judged unlikely that fracturing fluid additives would escape the pad. This risk is therefore considered to be low. Surface water contamination on-site and off may occur from major and cumulative minor spills and accidents involving chemicals use for fracturing; Resulting impacts to water quality could adversely affect aquatic species and recreational activities.

The consequence of soil, surface water or ground water contamination is considered moderate because although it could cause considerable impact on people or the environment and could affect the health of persons in the immediate vicinity, the impact would be local.

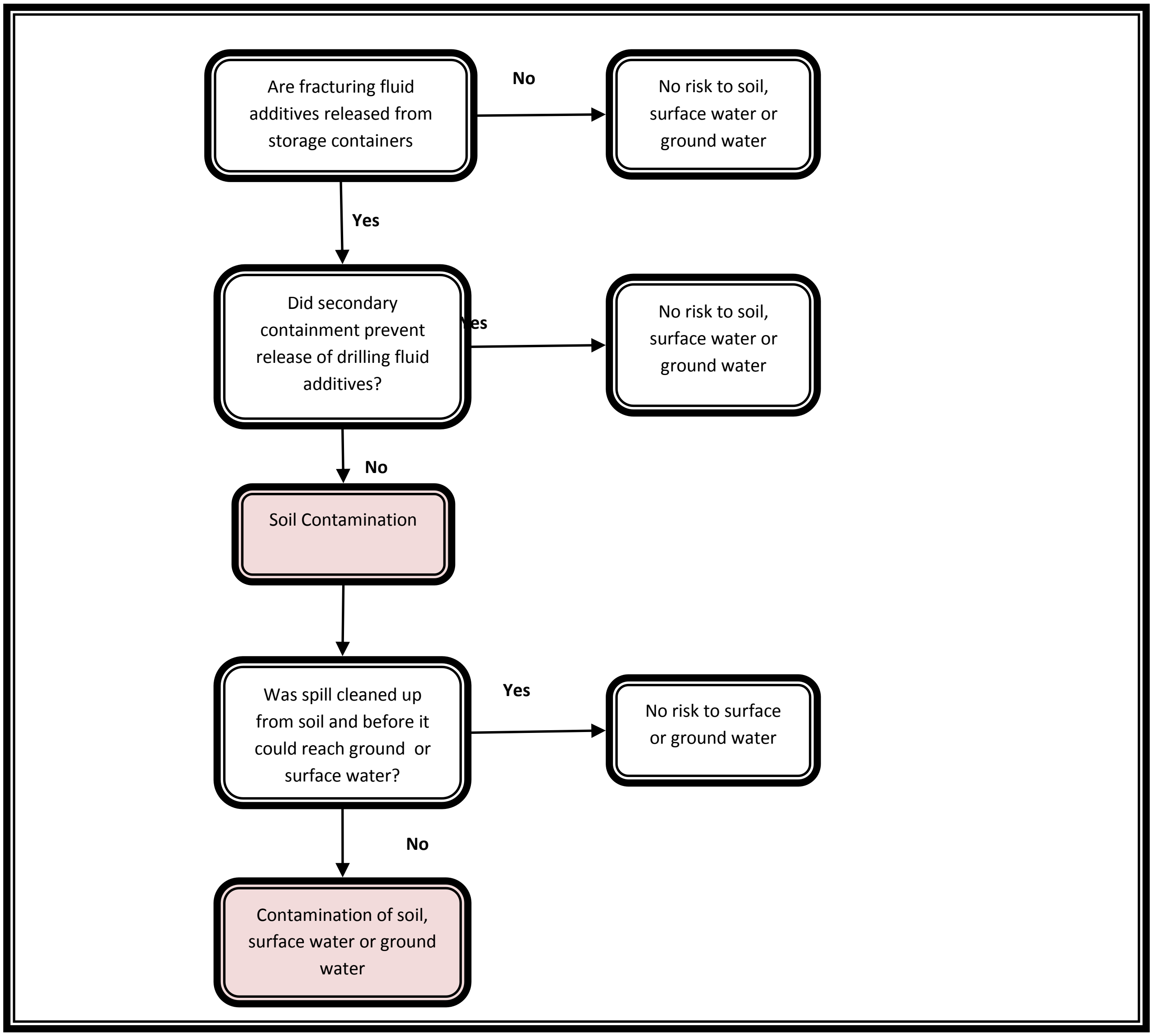

Figure 3: Risk flow chart associated with storing and handling fracturing fluid additives on drill pad

Mixing of Hydraulic Fracturing Additives and Fluid

Activity Description

When hydraulic fracturing procedure begins, pumps and hoses are used to transfer liquid fracturing additives from holding tanks to a chemical blending unit. Dry fracturing additives are added by hand into the blending unit. Materials are blended with proppants to form the hydraulic fracturing fluid, which is immediately pumped into the well bore (King, 2012).

Activity Duration and Scope

The mixing process takes less than one day. As stated above, the weight of fracturing fluid additives involved is about 800,000 pounds if additives make up 2 percent of the fracturing fluid and 5 million gallons of fracturing fluid are needed per well.

Literature Review of Associated Risks to surface water and ground water

There is potential for the accidental discharge of fracturing fluid additives or mixed fluids to the environment during the mixing process. The primary risk is associated with improper connections that would allow leaks.

Mixing and pumping of the fluid increases the risk of leaks and spills. Stored fluid is pumped first to the chemical addition trailer, then to the blender where proppant is added, before going to the high pressure pumps and down the bore hole. Bamberger and Oswald (2012) surveyed 25 gas wells that reported accidental releases (e.g. stormwater, wastewater) to ground and/or surface water and found two cases were fracturing fluid additives were discharged into the environment. In one case an operational error allowed a chemical blender to discharge fracturing fluid into a cow pasture and the other involved a defective valve leaking into a goat pasture. King (2012), however, states that the impacts of spill and leak events are generally low.

Risk Mitigation: Current Regulations and Proposed BMPs

The proposed BMPs for reducing the risk of accidental release of fracturing fluid during mixing and handling are the same as those noted above in connection with reducing the risk associated with accidental release of fracturing fluid additives during storage and handling at the well pad.

Risk Assessment

The risks associated with mixing fracturing fluid additives primarily relate to the possibility of releasing fracturing fluid additives while transferring the additives to the mixing apparatus and the mixing process itself. There is insufficient information to quantify the frequency of improper installation or failure of hoses and fittings while transferring hydraulic fracturing additives.

Because of the requirements for stormwater controls, spill cleanup and secondary containment, it is judged unlikely that fracturing fluid would escape the pad. This risk is therefore considered to be low.

The consequence of soil, surface water or ground water contamination is considered moderate because although it could cause considerable impact on people or the environment and could affect the health of persons in the immediate vicinity, the impact would be local.

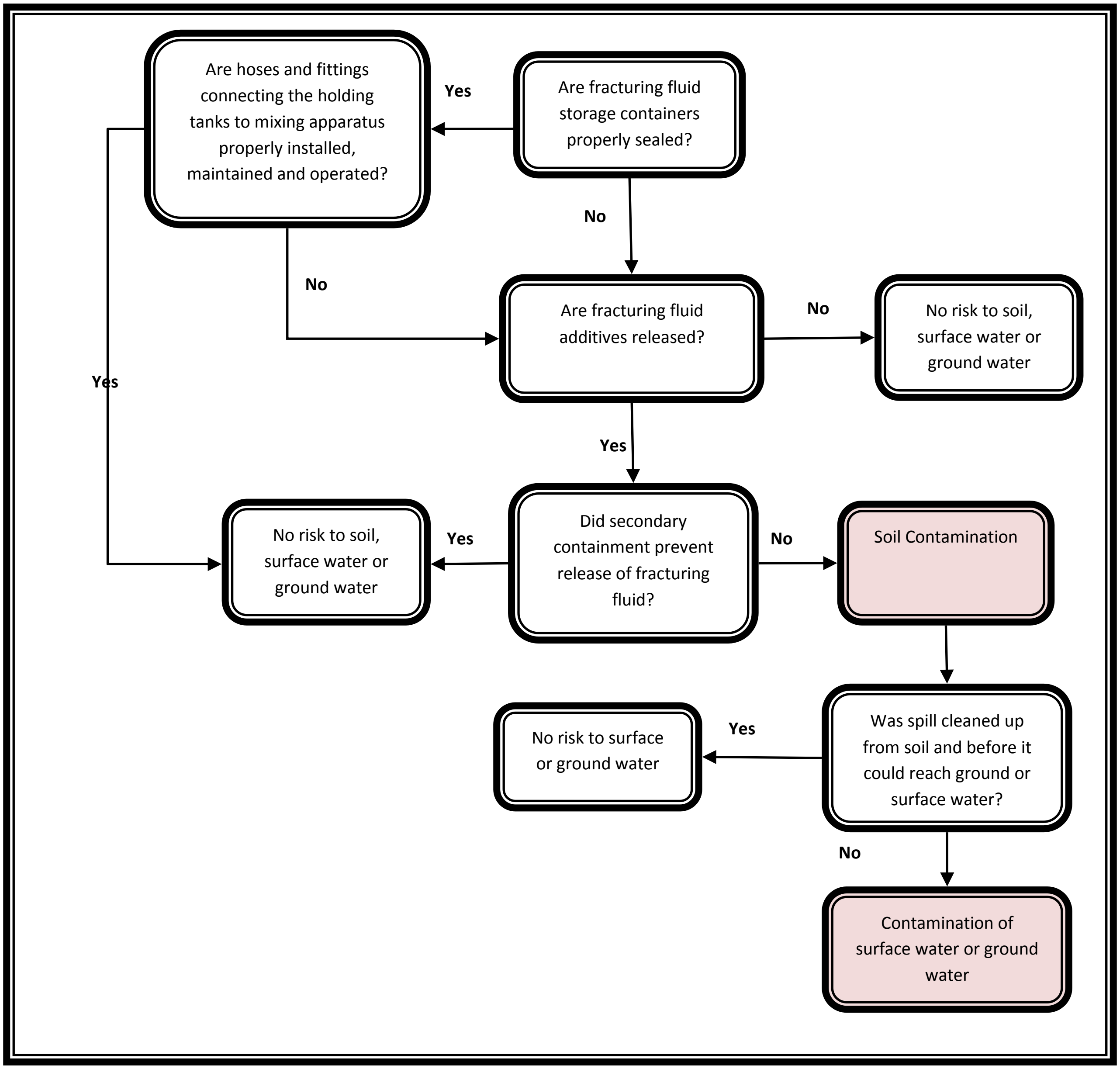

Figure 4: Risk flow chart associated with mixing fracturing fluid additives on drill pad

Fluid Return and Treatment, Recycling and Reuse

Activity Description

When the hydraulic fracturing process is completed, the fracturing fluid begins to flow back to the borehole. The return water is also referred to as flowback water. New York DEC (2011) states that the flowback water components that are of greatest environmental concern are gelling agents, surfactants, and chlorides. Olmstead et al. (2013) states that the peak flowback water transport occurs during well fracturing and completion. After the initial discharge of flowback water is diminished, the discharge begins to transition to produced water. Produced water is a term referring to water found in the shale that can flow to the surface throughout the lifespan of the gas well. Produced water us often characterized as having high TDS, dissolved hydrocarbons, and naturally occurring radioactive materials (NORM).

The NY EIS states that the reported amount of flowback water recovered in the northern tier of Pennsylvania ranges from 9 to 35 percent of the total fracturing fluid pumped in. Based on these percentages, flowback water volume could range from 216,000 gallons to 2.7 million gallons per well, based on the pumped fluid estimate of 2.4 million to 7.8 million gallons (NYSDEC, 2011). For the purposes of this risk assessment, 30% flowback will be assumed. This would equate to 1.5-million gallons of flowback.

Flowback and produced water is generally recovered in two to eight weeks, after which the flowback rate rapidly declines to about a few barrels a day for the remainder of its production life. In some states, flowback and produced water can be stored in lined pits or in tanks.

Spills or releases result from tank ruptures, piping failures, equipment or surface impoundment failures, overfills, vandalism, automobile accidents, fires, drilling and production equipment defects, or improper operations (NYSDEC, 2011).

There may be an economic incentive to reuse flowback water for subsequent hydraulic fracturing operations, either for the same well pad that produced the flowback water or at a different well pad (Ernstoff& Ellis, 2013; NYSDEC, 2011; ALL Consulting, 2010). Reuse avoids the need for extensive treatment or disposal of produced water, helps to lessen demand on freshwater resources, and lessens the amount of liquid and solid waste. According to the Industry response to information requests from the New York EIS, companies target 100% recycling of produced water. However, Rozell and Reaven (2012) found that many operators do not use recycled water due to the cost of separation and filtration (Arthur & Coughlin, 2008 ; Rozell & Reaven, 2011). David Vando has stated that approximately 88% of flowback water is being recycled in Hydraulic Fracturing operations in Pennsylvania.

In reality, the chemical components of produced water prevent 100% recycling, but recycling methods and efficiency are evolving. Operators in the past had used polymers and flocculants to remove metals but more recently filtration technologies have been implemented. The ability to place a centralized water processing facility for returned water on site can be limited by local conditions. Steel tanks may be used to store produced water that does not need to be treated and used for re-use. According to ALL Consulting (2010), current fracturing treatments use between 10% and 20% recycled fluids, but additives are still required.

Activity Duration and Scope

The NYSDEC (2011) estimates that the total number of truck trips associated with produced water disposal to be 100 (NYSDEC, 2011).

A well may continue to produce flowback water for 2 to 8 weeks. There is a wide range of reported volumes of flowback water, ranging from 30% to 70% of the total injection volume (Ernstoff & Ellis, 2013). King (2012) states that approximately 50% flowback is associated with the Marcellus formation. Reuse involves either simple dilution or more sophisticated treatment. This treatment reduces the number of truck trips for hauling waste fluids. But it may also increase the probability of accidental release or leaks (NYSDEC, 2011).

Literature Review of Associated Risks to Surface Water and Ground Water

Potential releases from hoses or pipes used to convey flowback water tanks or a tanker truck and tank leakage are potential pathways for contamination (NYSDEC, 2011).

Flowback is composed of the fracturing fluids pumped into the well which return up the well to the surface and produced water, which is water trapped in underground formations that is brought to the surface during oil and gas exploration and production. The fracturing fluid flowback consists of water and additives; any new compounds that may have formed due to reactions between additives; and substances mobilized from within the shale formation due to the fracturing operation. Produced water from the Marcellus Shale is characterized by its high salinity and total dissolved solids and may contain a variety of elements such as potassium, calcium, silicon, sodium, magnesium, tin, sulfur, strontium, zinc, rubidium, arsenic, chromium, and several naturally occurring radioactive materials (NORMs) such as radium. Produced water can also contain organic compounds, including volatile organic compounds (VOCs). A recent analysis of Marcellus shale produced water found that the organic molecules were principally saturated hydrocarbons, with relatively lower levels of aromatic, resin and asphaltene compounds (Maguire-Boyle & Barron, 2014).. According to ALL Consulting (2010), the maximum TDS expected in the flowback water ranges from 300,000 to 360,000 mg/L.

Flowback waters are commonly stored in specialized above-ground holding tanks or ponds, depending on state regulations. A literature review has shown that unintentional discharges from these storage tanks and ponds have polluted surface waters; however, rates of occurrence have proven difficult to obtain. Ernstoff and Ellis (2013) state that the greatest risk of freshwater contamination from the process is associated with the storage and handling of return water.

NYSDEC (2011) makes the point that any chemicals that are spilled, including fracturing fluid additives and fuel, are exposed to rainfall, so that contaminants may be conveyed off-site during rain events if the site is not properly contained.

When flowback waters are treated at wastewater treatment plants, the treated effluent may contain high levels of salts and other contaminants, because the treatment processes at many wastewater treatment plants are not designed to remove them. Olmstead et al. (2013) analyzed over 8,000 observations to examine relationships among elevated chloride and total suspended solids (TSS) concentrations in streams, upstream gas wells pads, and upstream treatment plants that received flowback wastewaters. The authors found that elevated chloride concentrations were significantly associated with upstream treatment facilities but not with upstream well pads. Upstream well pads were significantly associated with elevated TSS but not with elevated chloride concentrations. These results do not seem to support the idea that spills from upstream wellpad facilities increase chloride concentrations, but rather contribute to TSS from storm water runoff or during site prep.

Surface water leaks and spills of produced water are associated with shale gas operations (Vengosh et al., 2014). Analysis has shown that the number of violations is positively correlated with gas drilling density. Vengosh et al. (2014) deduce that growth and intensity could lead to a higher probability of surface spill leaks.

In other states, hydraulic fracturing fluid and flowback water have been stored in open pits. Under normal circumstances, the pit is lined with impervious material that prevents the stored fluid from migrating to the environment. Bamberger and Oswald (2012) described an incident where the lining of a storage pond ripped, allowing flowback water to migrate to a livestock drinking water source. They also cited an incident that involved the dumping of flow back water in a stream that was being used as a drinking water source for cattle, allegedly causing health problems in the exposed cattle.

Risk Mitigation: Current Regulations and Proposed BMPs

In New York, drilling and fracturing fluids and flowback water and production brine are classified as non-hazardous industrial-commercial waste. This waste classification does not require tracking or verification (NYSDEC, 2011). Pennsylvania classifies non-hazardous industrial waste, including gas non-hazardous wastes from drilling as "residual waste" and issues permits to waste handlers and requires transporters to develop contingency plans and submit reports and analyses (PADEP 2014). Maryland classifies wastes as hazardous or non-hazardous, with no intermediate category.

Maryland proposed the following BMPs that are relevant to the treatment, recycling and reuse of produced water:

- The application for a well permit must include a plan that addresses waste handling, treatment and disposal.
- Flowback and produced water shall be handled in a closed loop system of tanks and containers at the pad site. Flowback and produced water may not be stored in surface impoundments or ponds.
- Tanks shall be above ground, constructed of metal or other material compatible with the contents, and lined if necessary to protect the metal from corrosion from the contents. Except for tanks used in a closed loop system for managing drilling fluid and cuttings, which may be open to the atmosphere, tanks shall be closed and equipped with pollution control equipment specified in other sections of this report. Tanks and containers shall be surrounded with a continuous dike or wall capable of effectively holding the total volume of the largest storage container or tank located within the area enclosed by the dike or wall. The construction and composition of this emergency holding area shall prevent movement of any liquid from this area into the waters of the State.
- The term "well pad" is defined to include the areas where drill rigs, pumps, engines, generators, mixers and similar equipment, fuel, pipes and chemicals are located. No discharge of potentially contaminated stormwater or pollutants from the pad shall be allowed. Drill pads must be underlain with a synthetic liner with a maximum hydraulic conductivity of 10-7 centimeters per second and the liner must be protected by decking material. Spills on the pad must be cleaned up as soon as practicable and the waste material properly disposed of in accordance with law. The well pad must be surrounded by an impermeable berm such that the pad can contain at least the volume of 4.0 inches of rainfall within a 24 hour period. The design must allow for the transfer of stormwater and other liquids that collect on the pad to storage tanks on the pad or to trucks that can safely transport the liquid for proper disposal.
- Flowback and produced water shall be recycled to the maximum extent practicable. Unless the applicant can demonstrate that it is not practicable, the permit shall require that not less than 90 percent of the flowback and produced water be recycled, and that the recycling be performed on the pad site of generation.
- The permittees must keep a record of the volumes of wastes and wastewater generated on-site, the amount treated or recycled on-site, and a record of each shipment off-site, including confirmation that the full shipment arrived at the facility. The records may take the form of a log, invoice, manifest, bill of lading or other shipping documents
- EPA has committed to develop standards to ensure that wastewaters from gas extraction receive proper treatment and can be properly handled by POTWs. EPA plans to propose a rule for shale gas wastewater in 2014. Until these regulations are in place, MDE has requested that POTWs not accept these wastewaters without prior consultation with MDE. MDE does not intend to authorize any POTW facility that discharges to fresh water to accept these wastewaters.

Risk Assessment

The probability that flowback water would be released during treatment, recycling and reuse is not known. There is a high probability, however, that released flowback water would be contained on the well pad and not reach the environment. The probability of a release to the environment of return water is therefore low.

The release of flowback water from the drill pad could cause considerable adverse impact on people and the environment, but the damage would be localized. For this reason, the consequence is considered moderate. Figure 4 illustrates the course of events that would need to occur to create a risk to ground water associated with treatment, recycling and reuse of flowback water.

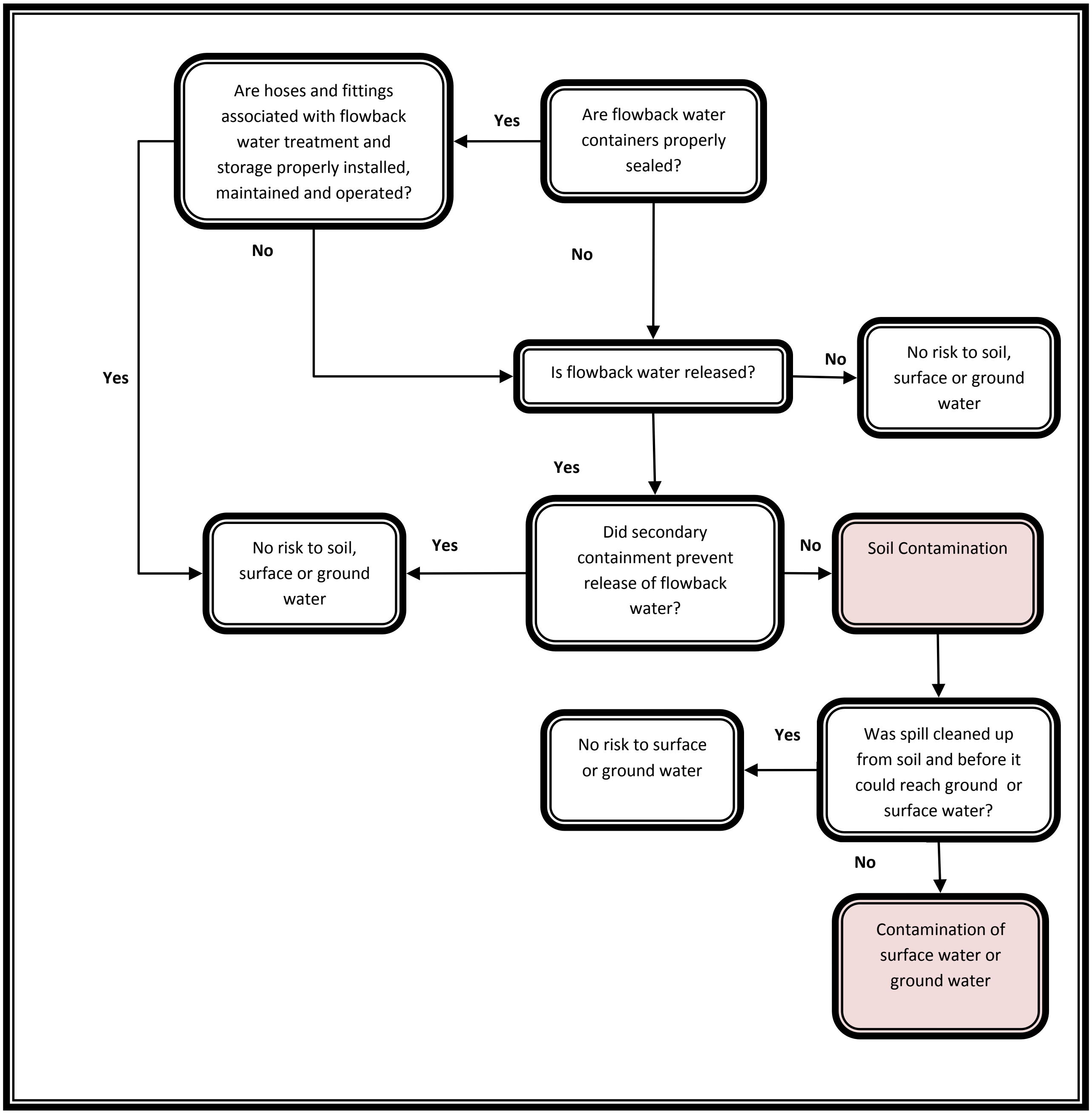

Figure 5: Risk flow chart associated with fluid treatment, recycling and reuse

Transportation of Wastewater off Site

Activity Description

Flowback water that is not recycled or treated on site needs to be transported to a treatment or disposal facility. Flowback water is transported in chemical trucks or via pipelines. For the purposes of this risk assessment, it will be assumed that flowback water will be transported via trucks.

Activity Duration and Scope

Based on the assumption that each well would produce 30% flowback by volume and none would be recycled, the total number of truck trips needed to transport waste water would be 300 loaded trips per well. Based on scenario 1 (150 wells drilled) the total number of truck trips would equate to 45,000. Based on scenario 2 (450 wells drilled) the total number of truck trips would equate to 135,000. Assuming that all these trucks would be transported out of state, the average distance traveled for each truck would equate to 100 miles.

Risk Mitigation: Current Regulations and Proposed BMPs

Maryland has adopted federal Department of Transportation regulations regarding the transport of hazardous material.

Proposed BMPs Associated with Risk Mitigation

- The proposed BMPs that would address releases of flowback during transportation are similar to those listed above, with the addition of the following recommendations associated with reducing the risk of accidental return water release via trucks:
- Identification of travel routes in the Comprehensive Gas Development Plan
- Routes and times of travel shall be established to minimize use conflicts, including school bus transport of children, public events and festivals, and periods of heavy public use of State lands
- The permittees must keep a record of the volumes of wastes and wastewater generated on-site, the amount treated or recycled on-site, and a record of each shipment off-site, including confirmation that the full shipment arrived at the facility. The records may take the form of a log, invoice, manifest, bill of lading or other shipping documents
- All trucks, tankers and dump trucks transporting liquid or solid wastes must be fitted with GPS tracking systems to help adjust transportation plans and identify responsible parties in the case of accidents/spills

Risk Assessment

The likelihood of release of hazardous material from any one shipment has been estimated above as 0.005%. Under scenario 1, if none of the return flow were recycled, this would equate to fewer than 3 incidents in which flowback would be released from a truck. Under scenario 2, if none of the return flow were recycled, this would equate to approximately 7 such incidents. With the requirement for recycling return flow on site, the number of truck trips and thus the number of incidents predicted would be reduced by about 90 percent. If a release or spill did occur during a vehicular accident, the probability of soil, surface water or ground water contamination would be reduced if the spill were properly identified, contained and cleaned up. These steps are considered likely to occur because wastes will be tracked by records and by GPS. The probability that materials would be released during transport is considered low, and the existence of emergency response plans further lowers the risk that the released material would contaminate soil, surface water or ground water.

The consequence of the release of flowback/return water is classified as moderate because, although it could cause considerable adverse impact on people or the environment, the damage would be localized.

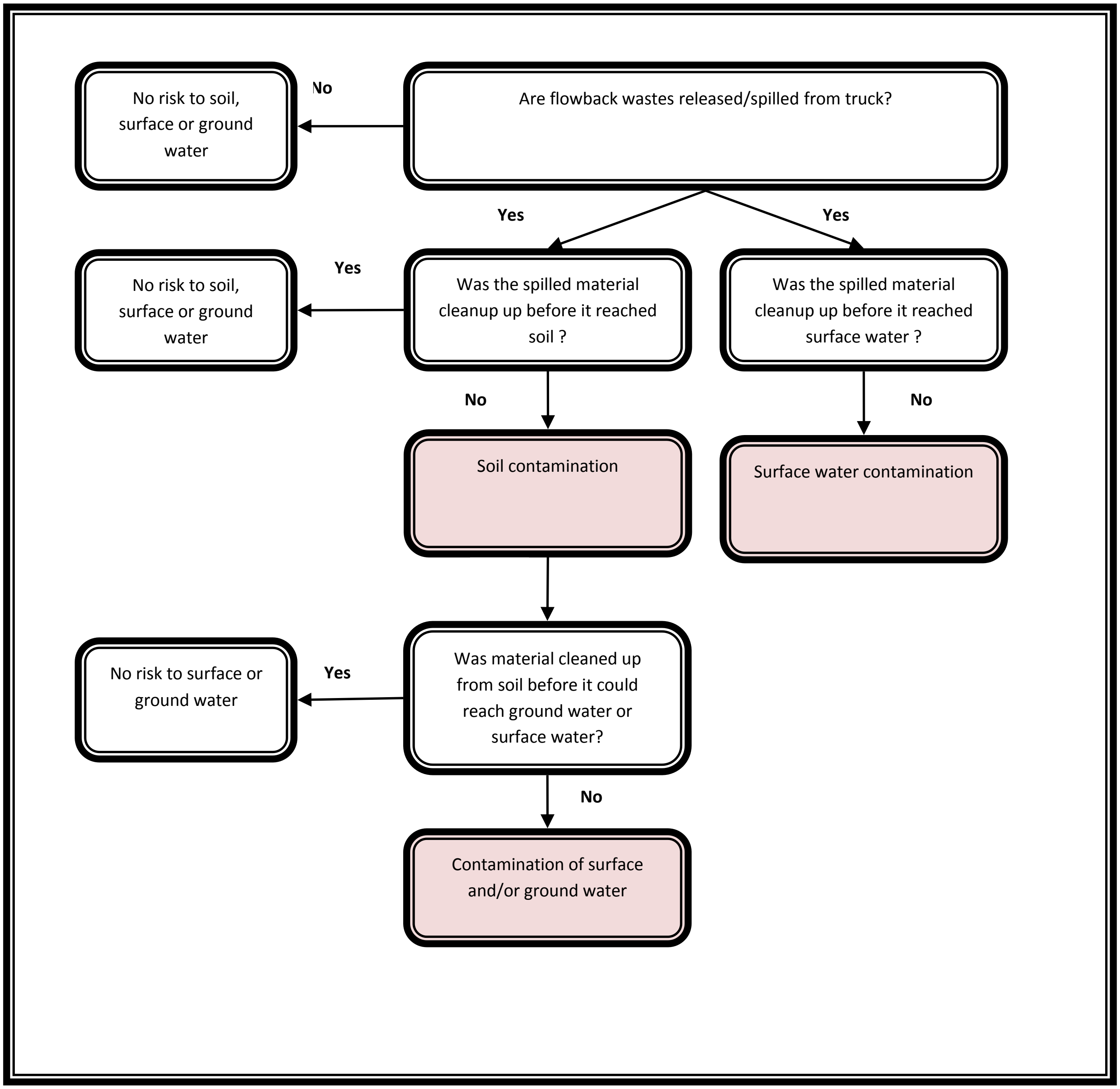

Figure 6: Risk flow chart associated with transporting flowback fluids

Summary Assessment of Impacts from Fracturing Additives

Activities associated with hydraulic fracturing have the potential to pose and environmental risk to ground and surface water via accidental release of fracturing fluid additives themselves or flowback water. These releases can occur during transportation operations, storage or during the hydraulic fracturing fluid operation. The risks analyzed in this section have a low probability of occurring because of regulations that are currently in place and recommended practices that are described in the BMP document. The consequences of all risks in this process were classified as moderate because, although they could cause considerable adverse impact on people or the environment, the damage would be localized. Adverse impacts from direct spills and inappropriate disposal of hydraulic fracturing additives and flowback water would have more extensive impacts on aquatic life should they occur in the area of Tier II and Use III waters. Extensive and perhaps permanent damage would be exacerbated if contamination events occurred in the headwaters of such streams and in areas where complexes of wetlands and streams provide significant habitat and support to sensitive aquatic resources (e.g., native Brook trout). In these cases, the potential downstream impacts and adverse effects to macroinvertebrates and other sensitive aquatic species could pose problems beyond the localized area of the spills or inappropriate disposals. The risks are summarized in Table 1.

Table 1: Probability, consequence and risk ranking

Operation	Occurrence	Environmental Impact	Risk		Risk Ranking
			Probability	Consequence	
Transportation of Hydraulic Fracturing Additives to Well Pad	Vehicular accidents causing release of fracturing fluid additives	Soil, surface water and ground water (Human)	Low	Moderate	Low
		Soil, surface water and ground water (Ecological)	Low	Moderate	Low
Storage and Handling of Hydraulic	Accidental spill of additives	Soil, surface water and	Low	Moderate	Low

Fracturing Additives and Fluid	from well pad	ground water			
Mixing of Hydraulic Fracturing Additives and Fluid	Accidental release or spill of fracturing fluid from well pad additives during fluid preparation	Soil, surface water and ground water	Low	Moderate	Low
Fluid Return and Treatment	Accidental release or spill of fracturing fluid from well pad additives during treatment	Soil, surface water and ground water	Low	Moderate	Low
Transportation of Flowback Water offsite	Vehicular accidents causing release of fracturing fluid additives	Soil, surface water and ground water	Low	Moderate	Low

Suggestions for Additional Mitigation

For purposes of this risk assessment, we have assumed that best practices are followed; for example, that spills are always promptly and completely cleaned up and that accumulated stormwater is removed from the pad and placed in storage tanks before the pad overflows. If this does not occur, however, intense and/or sequential storm events could overwhelm stormwater capacity at the well pad resulting in stormwater runoff and chemicals from prior spills being discharged into streams and thereby impacting aquatic species and recreational activities. Because accidents and employee errors occur, we recommend two additional measures. First, the containment capacity of the pad should be increased to contain the precipitation from a 25-year storm. Initial estimates indicate that this would require increasing the berm height from 4 inches to 5 inches. Second, vacuum trucks should be on standby at the site during drilling, fracturing, and flowback so that any spills during those stages, which could be of significant volume, could be promptly removed from the pad.

The use of “green” fracturing fluid (fracturing fluid that is composed of less toxic or non-toxic ingredients) would further reduce the risk associated with accidental spills while transporting and storing fluids. For this reason, we recommend that further research be conducted to identify fracturing fluid additive alternatives that result in reduced risk to the environment and human health.

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