Appendix D:

Groundwater and Surface Water Contamination Risks from Drilling during UGWD

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Introduction

This section evaluates the environmental risks associated with drilling during unconventional gas well development (UGWD). The drilling process requires the use of air or drilling fluids to cool and lubricate the drill bit. These fluids also aid in the removal and transport of cuttings from the borehole to the surface for containment. The cuttings are removed from the drilling fluids using separation equipment (e.g., mud shakers). The drilling fluids are then re-circulated to the well for reuse. The cuttings may contain naturally occurring radioactive materials (NORM) as well as heavy metals and other chemical contaminants present within the rock formations that have been drilled. Drilling fluids may also contain chemical additives as well as oil or polymer compounds depending on the fluid type selected for the drilling process. In addition the fluids may contain the same compounds found in the cuttings once they have come into contact (NYSDEC, 2011). Accidental releases or spills of drilling fluids or cuttings could potentially contaminate soil, surface water and ground water. These accidents may occur on the well pad or off-site during the transport of drilling fluid chemical additives and waste materials. This chapter will provide an overview of the drilling process, identify the risks associated with the various stages in the drilling process, present existing regulations or proposed BMPs which may reduce or mitigate these risks, and provide an overall risk assessment. Risks associated with ground water contamination due to methane migration from within the well, methane releases to the air from drilling muds, and the disposal of waste drilling fluids and cuttings will be addressed in another section.

Drilling Process Overview

Unconventional gas wells are generally drilled to a depth of 500 feet above the target shale formation before directional drilling is initiated to drill the horizontal portion of the well (NYSDEC, 2011). Previous applications for gas well development in Maryland by Chief Oil and Gas LLC indicated wells would be drilled to a total vertical and total measure depth of around 9,000 feet and 12,000 feet, respectively (Chief Oil & Gas LLC 2010, 2011). Directional drilling requires that a down-hole motor be connected behind the drill bit at the end of the drill pipe (NYSDEC, 2011)

Figure 1: Triple rotary rig

Multiple rotary rigs may be required to complete the drilling operation for a horizontal well. A smaller rig would drill the vertical portion while a larger rig would drill the horizontal portion. Multi-well sites may have two rigs on a well pad at one time. Rotary rigs are generally classified by height where a single is 40-45 feet high, a double is 70 -80 feet high, and a triple is over 100 feet high. Triple rotary rigs are commonly used for drilling wells for Marcellus Shale natural gas extraction (See Figure 1). Auxiliary drilling equipment includes tanks for water and drilling fluids, generators, compressors, solids control equipment, choke manifold (device used to lower the pressure from the well head), accumulator (device used to store energy for blowout preventer operation), pipe racks and office space. It may take up to five weeks to complete the drilling operation including cementing and casing (NYSDEC 2011). A horizontal well will include conductor, surface, intermediate, and production casing. The surface casing extends below all freshwater aquifers and is cemented in place within the borehole to ensure that fluids and gases within the well do not escape into the ground water.

Figure 2: Blowout prevention system

A blowout prevention (BOP) system is installed in all gas well operations to prevent a release of drilling mud, formation fluids, or equipment in the event unexpected pressure is encountered in the wellbore during drilling operations. (See Figure 2). A blow out may cause significant damage to the equipment, injury or death to the workers, and environmental contamination.

The drilling process requires the use of drilling fluids to cool and lubricate the drill bit, provide stability to the borehole, and prevent formation fluids from entering the wellbore. These fluids also aid in the removal and transport of cuttings from the borehole to the surface for containment. The vertical portion of the well passing through the freshwater aquifer zone can only be drilled using compressed air or freshwater based drilling fluids. The horizontal portion of the well is generally drilled using fluids that are water, polymer or oil based (NYSDEC, 2011). Various chemical additives are also incorporated in order to improve the performance of the drilling fluid.

Drilling fluids are contained in a closed-loop system (See Figure 3). The drilling fluids are pumped from storage tanks down the well through the drill string and out the drill bit. The fluids then return to the surface containing the drill cuttings and flow to the separation equipment where the fluids are separated from the cuttings and re-circulated back to the storage tanks for reuse. Separation equipment is dependent on fluid type and may consist of shale shakers, de-sanders, and de-silters. Additional equipment such as drying shakers, rotary cuttings dryers, squeeze presses or centrifuges may be required to further separate liquids from cuttings for reuse (NYSDEC, 2011). A diagram of the closed-loop drilling fluid system depicting the steps in the recirculation and separation process is displayed in Figure 4.

Following completion of the drilling process, including casing and cementing, the well will be prepared for hydraulic fracturing. The drilling rig and auxiliary equipment will be removed from the site and waste drilling fluids and cuttings will be transported for disposal.

Figure 3: Closed-loop drilling

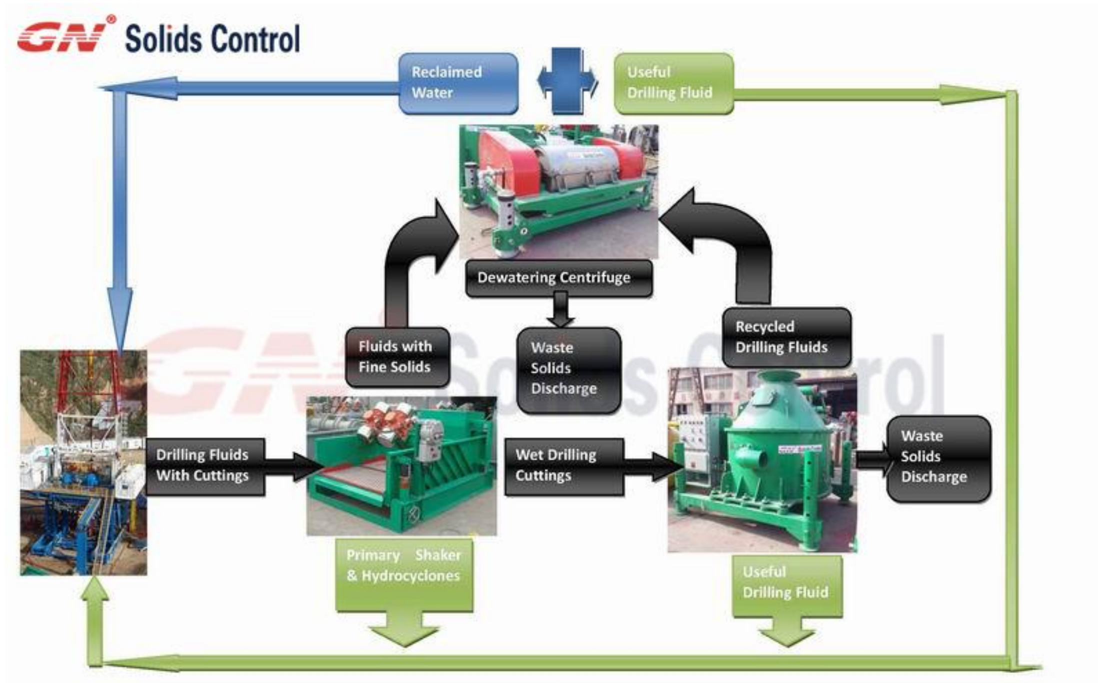

Figure 4: Diagram of a closed-loop drilling fluid system

Activity, Risk Identification and Risk Assessment : Transport of Drilling Fluid Additives to the Well Pad

Risk Identification

Drilling fluids used in UGWD may be aqueous (i.e., water-based) or non-aqueous (i.e. oil-based). Chemical additives may also be required to improve the performance of these fluids. An aqueous drilling fluid would generally be composed of the following chemicals by weight: brine/water (76%), barite (14%), clay/polymer (6%) and other chemical additives (4%). A non-aqueous drilling fluid would generally be composed of the following chemicals by weight: non-aqueous fluid (46%), barite (33%), brine (18%), emulsifiers (2%), and gellants/other chemical additives (1%) (IPIECA 2009). The transportation of chemical additives that are classified as hazardous materials is regulated by federal law. Among the requirements are proper containers, shipping papers, marking, labeling, placarding, emergency response information and an emergency response telephone number.

Vehicular accidents involving trucks transporting these chemical additives may result in the release of vehicle fluids (fuel, antifreeze, etc.) or the cargo if the tank trucks or containers are compromised or rupture. The released material could potentially contaminate soil, ground water or surface water if clean up does not occur in a timely manner prior to infiltration or run off to surface water. In recent years, large trucks have accounted for approximately 6 percent of all highway crashes, accidents and incidents. (US DOT, 2013). Of the 15,433 hazardous materials transportation incidents in 2012, 13, 241 were on the highway or in truck terminals, of which 362 (2.3 percent) were accident-related. Most of the other incidents involved human error or package failure, and were likely to occur during loading or unloading. (US DOT, 2013). There are more than 800,000 shipments of hazardous materials per day in the United States (Craft, 2004). The most recent tabulation of incidents (2004-2013) by the Pipeline and Hazardous Materials Safety Administration reported that the annual average number of incidents involving hazardous materials and highway transportation was 14,074. (PHMSA 10 year Incident Summary Report). Based on 800,000 shipments per day over a year and 14,074 incidents per year, not all of which resulted in a release of hazardous materials to the environment, the probability that a shipment of hazardous materials would result in a release would be less than 0.005% [14,074 incidents per year / (800,000 shipments per day x 365 days per year)]. No information on incidents related specifically to drilling fluid additive spills was found following an extensive literature search.

A single unconventional gas well requires 45 heavy truck trips for delivery of chemical additives. Another 140 light truck trips are also required for rig mobilization, drilling fluids, and non rig drilling equipment (NYSDEC, 2011). The liquid chemical additives for drilling fluids are typically transported in bulk totes referred to as intermediate bulk containers (IBCs). The dry chemical additives are transported on flat-beds in bags set on pallets or in plastic buckets (NYSDEC, 2011). Under risk assessment scenarios 1 (150 total wells) and 2 (450 total wells), a total of 6,750 (45 truck trips x 150 wells) and 20,250 (45 truck trips x 450 wells) one-way heavy truck trips, respectively, would be required for transport of chemical additives. Assuming an incident probability of 0.005% under risk assessment scenarios 1 and 2, 0.3 and 1 incidents involving the release of drilling fluid additives during transport would occur, respectively, during the delivery of chemical additives to all the well pads.

Risk Mitigation: Current Regulations and Proposed BMPs

Current Federal regulations and best management practices (BMPs) proposed by Maryland will reduce the risk of soil, surface water or ground water contamination from accidental releases or spills of drilling fluid additives that are hazardous materials during transport. 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 protection of the soil, surface water and ground water from releases of drilling additives during transportation or off-loading:

- Identification of travel routes in the Comprehensive Gas Development Plan
- 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.
- 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
- 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.

Risk Assessment

The probability of a hazardous material cargo release for a single shipment has been estimated above as 0.005%. This would indicate 0.3 incidents (0.005% probability x 6,750 truck trips) and 1 incident (0.005% probability x 20,250 truck trips) incidents for all truck trips under risk assessment scenarios 1 and 2, respectively. If a release or spill did occur during a vehicular accident, the probability of soil, surface water or ground water contamination by hazardous materials would be reduced if the spill were properly identified, contained and cleaned up. These steps are considered likely to occur because of the federal requirements for marking, labeling, placarding, emergency response information and an emergency response telephone number. There is the potential that chemicals could infiltrate the ground prior to emergency response team arrival on site or be conveyed by surface runoff if the accident occurs during a rain event. Spills associated with dry chemical additives are less likely to contaminate surface or ground water since infiltration or transport within surface runoff will only occur due to dissolution during a rain event. The probability that hazardous 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. If the release were to occur during off-loading the requirements for clean up of spills on the pad and secondary containment would reduce the likelihood that the material would reach soil, surface water or ground water. The frequency of surface water or ground water contamination from accidental releases or spills of drilling fluid additives during transport is also considered low on a cumulative basis.

Soil contamination is likely to be localized and contaminated soil could be removed. This consequence will be classified as moderate because it could have an adverse impact in the immediate vicinity, causing localized or temporary environmental 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 drilling fluid additives directly into a stream the contaminated surface water could significantly impair water quality and adversely affect the health of aquatic life. The consequences associated with surface water or ground water contamination from accidental releases or spills of drilling fluid additives during transport will be classified as moderate because these could have a considerable adverse impact on people and the environment causing localized damage. For both risk assessment scenarios 1 (150 wells) and 2 (450 wells) the consequences will be classified as moderate for soil contamination and moderate for ground water and surface water contamination. 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.

Impact Assessment: Release during transport of drilling fluids and additives to well pad

Impact	Probability	Consequence	Risk Ranking
Human	Low	Moderate	Low
Ecological	Low	Moderate	Low

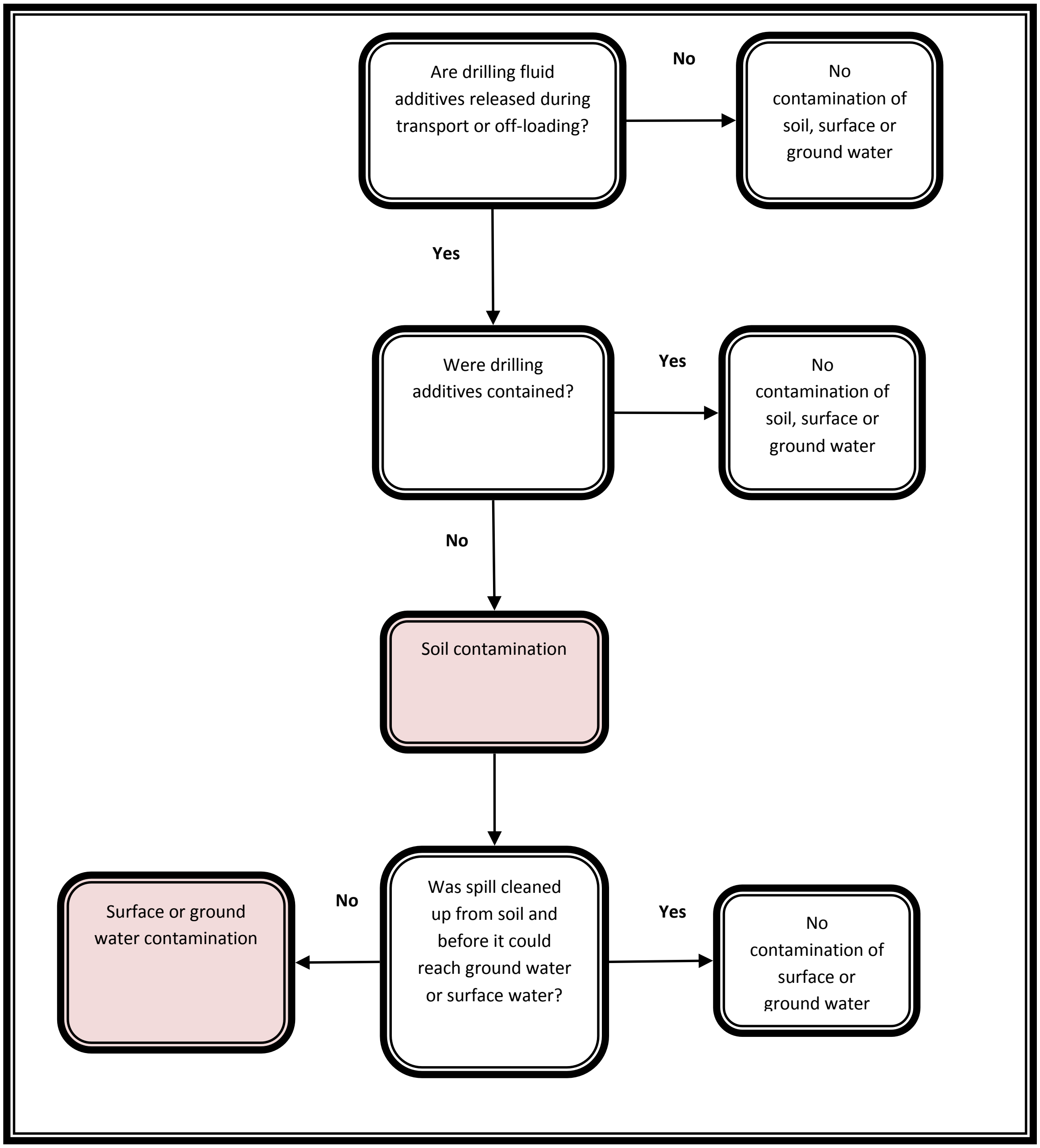

Figure 5: Risk flowchart for the transport of drilling fluid additives to the well pad

Drilling Fluid Preparation

Risk Identification

Before a drilling operation can proceed, the drilling fluids are prepared in storage tanks within a closed loop system. Chemical additives used in the preparation of drilling fluids may either be liquid or dry. Liquid additives will be contained in storage tanks while dry additives will most likely be contained in bags on palettes or in plastic containers. In a closed loop system the liquid chemical additives will be transferred to the drilling fluid storage tanks for mixing through hoses while dry additives would be poured directly into the tanks which are open at the top. The potential exists for liquid chemical additives to be released accidentally due to line ruptures, leaks, or operational error. Dry chemical additives could also be accidentally spilled on the ground from operational error. These releases or spills have the potential to contaminate soil, surface water and ground water if they are not properly contained. A study conducted by the New York State Water Resources Institute (NYSWRI) identified that 8% of wells drilled in Bradford County, PA in 2010 had violations handed out to gas well operators for spills/leaks on the well pad (NYSWRI, 2012). This study did not distinguish in which stage of UGWD these spills or leaks occurred or whether it resulted in the transport of contaminants off the well pad. This statistic only applies to spills or leaks for which the State of Pennsylvania issued a citation and therefore the incidence rate would likely be greater. On the other hand, because the spills or leaks could have occurred at any stage of UGWD, it is likely that fewer spills or leaks occurred during any individual stage. For the purposes of this risk assessment, it will be assumed that there is an 8% likelihood of a spill or leak at every stage of UGWD. Assuming an 8% probability of a spill or release occurring on-site, under risk assessment scenarios 1 (150 wells) and 2 (450 wells), 12 (8% probability x 150 wells) and 36 (8% probability x 450 wells) incidents would occur, respectively for all UGWD in Maryland. No additional information on incidents related specifically to releases or spills of drilling fluid additives was found following an extensive literature search. Drilling fluid preparation is a short-term process (on the order of a few days) therefore any spills or releases that occur would most likely only account for a small percentage of the total spills or leaks that occur on the well pad during the entire gas well development process.

Risk Mitigation: Current Regulations and Proposed BMPs

Maryland proposes the following BMPs that are relevant to protection of the soil, surface water and ground water from releases during mixing of the drilling additives:

- 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

As noted above, it will be assumed that there is an 8% likelihood of a spill or leak at every stage of UGWD. This results in 12 (8% probability x 150 wells) or 36 (8% probability x 450 wells) incidents for UGWD in Maryland for risk assessment scenarios 1 and 2, respectively. If a release or spill does occur on the well pad the BMPs proposed by Maryland requiring “zero discharge,” a synthetic liner over the well pad with decking for protection, an impermeable berm surrounding the well pad capable of containing 4 inches of rain in a 24 hour period, and transfer of all stormwater collected on the well pad to storage tanks or trucks as well as the implementation of spill cleanup and emergency response plans will significantly reduce the potential for these releases or spills to leave the well pad and contaminate soil, surface water or ground water.

In the event that a storm event over 4 inches in 24 hours overwhelms stormwater capacity, or the impermeable berm surrounding the well pad fails, any releases or spills that had occurred and not been cleaned up could result in the transport of drilling fluid additives off the well pad. Maryland’s Stormwater Design Manual indicates that a rainfall depth of 4 inches for a storm event over 24 hours is just below the threshold for a 10-year storm in Allegany (4.5 inches) and Garrett County (4.3 inches) where UGWD in Maryland will be focused (MDE, 2000). The stormwater overflow would probably cause some soil contamination, but the solution would be significantly diluted by the stormwater, possibly reducing the impact to soil, surface water and ground water. If stormwater flow carried spilled chemicals, the setbacks for well pads from private/public water supply and aquatic habitat and requirement that well pads be constructed on land with a slope less than 15% would reduce the potential for surface water and ground water contamination. The probability that drilling fluids would be released to the environment during the mixing of the drilling fluid is considered low.

Several BMPs have been proposed to minimize the potential impacts from spills. Surface water contamination on-site and off may occur from major and cumulative minor spills and accidents involving chemicals use for drilling. Resulting impacts to water quality could adversely affect aquatic species and recreational activities. 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. The consequences associated with soil, surface water or ground water contamination from accidental releases or spills of drilling fluid additives during drilling fluid preparation will be classified as moderate as these incidents could have a considerable adverse impact on the environment causing localized environmental damage. Contaminated surface water could impair water quality at levels that adversely affect the health of aquatic life and contaminated ground water could impair water quality in public and private wells at levels that adversely affect human health through water consumption. For both risk assessment scenarios 1 (150 wells) and 2 (450 wells) the consequences will be classified as moderate because there could be a considerable adverse impact on people or the environment in the immediate vicinity and localized or temporary environmental damage.

Impact Assessment: Release during drilling fluid preparation

Impact	Probability	Consequence	Risk Ranking
Human	Low	Moderate	Low
Ecological	Low	Moderate	Low

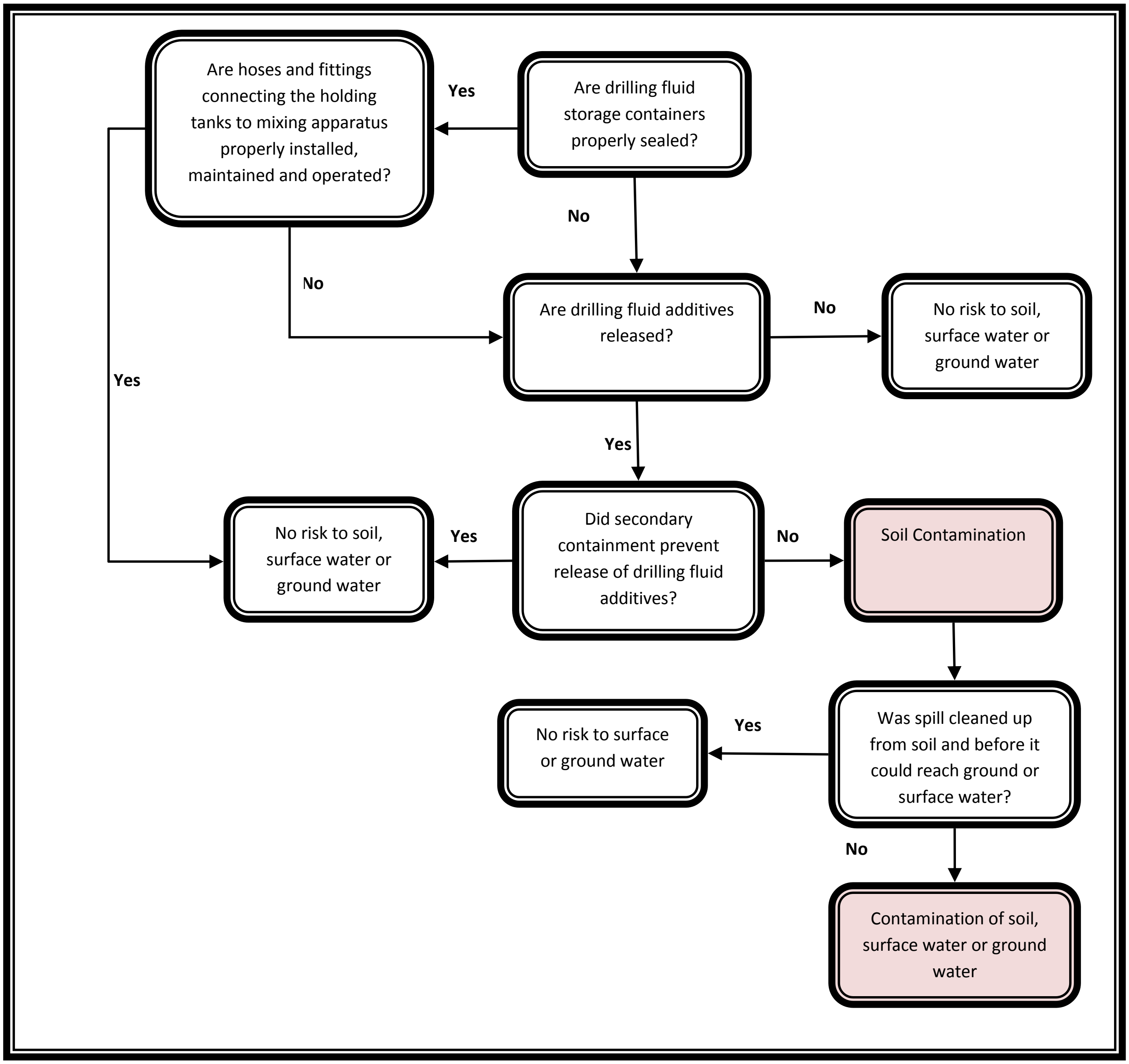

Figure 6: Risk flow chart for drilling operations

Drilling Operations

Risk Identification

Following site preparation, the drilling operation begins and drilling fluids are pumped from the storage tanks down the well through the drill string and out the drill bit. The fluids then return to the surface carrying the drill cuttings and flow to the separation equipment. Following separation, the drilling fluids are re-circulated back to the storage tanks for reuse. These fluids throughout the entire drilling operation could potentially be released to the surface due to accidental releases from line ruptures, leaks, equipment failure, and operational error. These releases have the potential to contaminate soil, surface water and ground water if they are not properly contained. Drilling fluids initially entering the well will only contain the chemical additives while the return fluids containing the cuttings may be contaminated with materials present in the formations through which the borehole passes. After the drilling fluids are recycled within the closed loop system, the injected fluids from this point on in the process will also contain these contaminants. The drilling process takes up to five weeks to complete, including two weeks for drilling the vertical portion and two weeks for drilling the lateral portion of the well (NYSDEC, 2011).

Drilling occurs in stages in order for casing to be installed and cemented. The drilling fluids that remain within the borehole are forced to the surface by the cement being injected into the well to fill the space between the formation and the casing. These fluids return to the surface and are also recycled within the closed loop system. These fluids could also potentially be released to the surface due to accidental releases from line ruptures, leaks, equipment failure, and operational error. These releases also have the potential to contaminate soil, surface water and ground water if they are not properly contained. In a previous section (Drilling Fluid Preparation) it was explained that, for the purposes of this risk assessment, it will be assumed that there is an 8% likelihood of a spill or leak at every stage of UGWD. No additional statistical information specific to accidental releases during drilling operations was found following an extensive literature search. Based on this probability, 12 and 36 incidents would occur under risk assessment scenarios 1 and 2, respectively for all UGWD in Maryland.

Risk Mitigation: Current Regulations and Proposed BMPs

Maryland proposes the following BMPs that are relevant to protection of the soil, surface water and ground water from releases during drilling operations:

- 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.

- Drilling fluids and cuttings must occur in a closed loop system.
- 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
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    - 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

The probability that a leak or spill during drilling would occur is the same as the probability during drilling fluid preparation. The probability is considered low.

The drilling fluid that could be released during drilling would differ from the unused drilling fluid in that it may be contaminated with materials present in the formations through which the borehole passes. These could include metals and naturally occurring radioactive material (NORM). The consequence of the release of drilling fluid is classified as moderate because, although it could cause considerable adverse impact on people or the environment, the damage would be localized. Figure 7 presents a flow diagram for the risk associated with drilling fluid during drilling operations.

Impact Assessment: Release from line ruptures, leaks, equipment failure, and operational error

Impact	Probability	Consequence	Risk Ranking
Human	Low	Moderate	Low
Ecological	Low	Moderate	Low

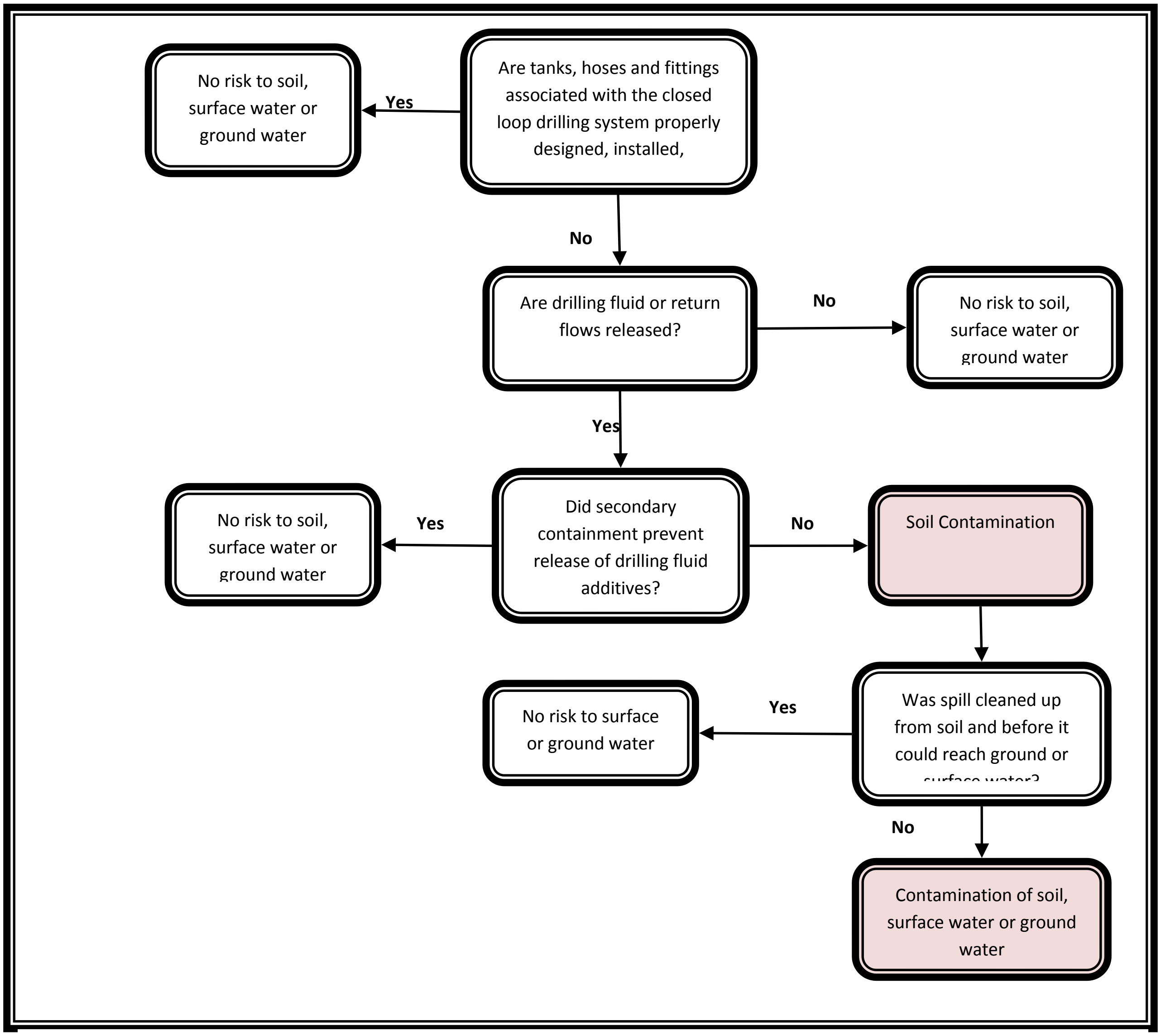

Figure 7: Risk flow chart for drilling operations

Well blowout during drilling

Risk Identification

A blowout is an uncontrolled flow of gas or other well fluids from the top of the borehole; it occurs when formation pressure exceeds the pressure applied to it by the column of drilling fluid. Blowout prevention equipment are devices attached to the top of the well casing that can be closed and shut off to control pressure at the wellhead. If a blowout occurs it can release formation fluids and eject casing, tools, and equipment (NYSDEC, 2011). This could cause injury or death to workers on-site and serious damage to rotary rig equipment. In addition, the formation fluids that are released under pressure from the well including the cuttings and drilling fluids present in the wellbore would be ejected, potentially causing contamination of soil, surface water and ground water if not properly contained. Well blowouts occur very rarely as approximately only 1.2 wells will blowout per 1,000 wells. This well blowout rate was calculated based on an average of well blowout frequency data for shallow and deep gas reservoir exploratory and developmental drilling documented by the International Association of Oil and Gas Producers. Offshore well data was applied as onshore unconvential gas well data was limited. Please refer to the Phase 3: Drilling Section in Appendix B for further explanation.

Risk Mitigation: Current Regulations and Proposed BMPs

Current Maryland regulations require that blowout prevention equipment shall be installed at an early stage of drilling, i.e., before drilling the plug on the surface casing. It must be tested weekly (COMAR 26.19.01.10Q). These requirements are being retained. In addition, Maryland proposes the following BMPs that are relevant to protection of the soil, surface water and ground water from releases during a blowout:

Blowout prevention equipment must have two or more redundant mechanisms

BOPs be tested at a pressure at least 1.2 times the highest pressure normally experienced during the life of the blow out preventer

Risk Assessment

The probability of a well blowout is low as they rarely occur (approximately 1.2 well blowouts per 1,000 wells). Implementation of the best practices, especially redundant mechanisms and frequent testing, should further reduce the potential for a well blowout to occur. The likelihood of a blowout is considered low.

When a blowout occurs, material may be ejected high into the air and it may or may not fall directly on the pad. A well pad with a four inch berm can contain hundreds of thousands of gallons; it is likely that the well pad could contain material that falls on it. Material that falls away from the pad would have to be cleaned up. Setbacks will reduce the chance that material that falls off the pad will impact surface water or ground water before spill cleanup and emergency response.

The material that could be released from a blowout would be similar to the materials that could be released during drilling. These could include metals and naturally occurring radioactive material (NORM). The consequences associated with soil, surface water or ground water contamination from accidental releases of material during a blowout is classified as moderate because, although it could cause considerable adverse impact on people or the environment, the damage would be localized. Figure 8 illustrates the pathway for releases of material during a well blowout.

Impact Assessment: Release of material during well blowout

Impact	Probability	Consequence	Risk Ranking
Human	Low	Moderate	Low
Ecological	Low	Moderate	Low

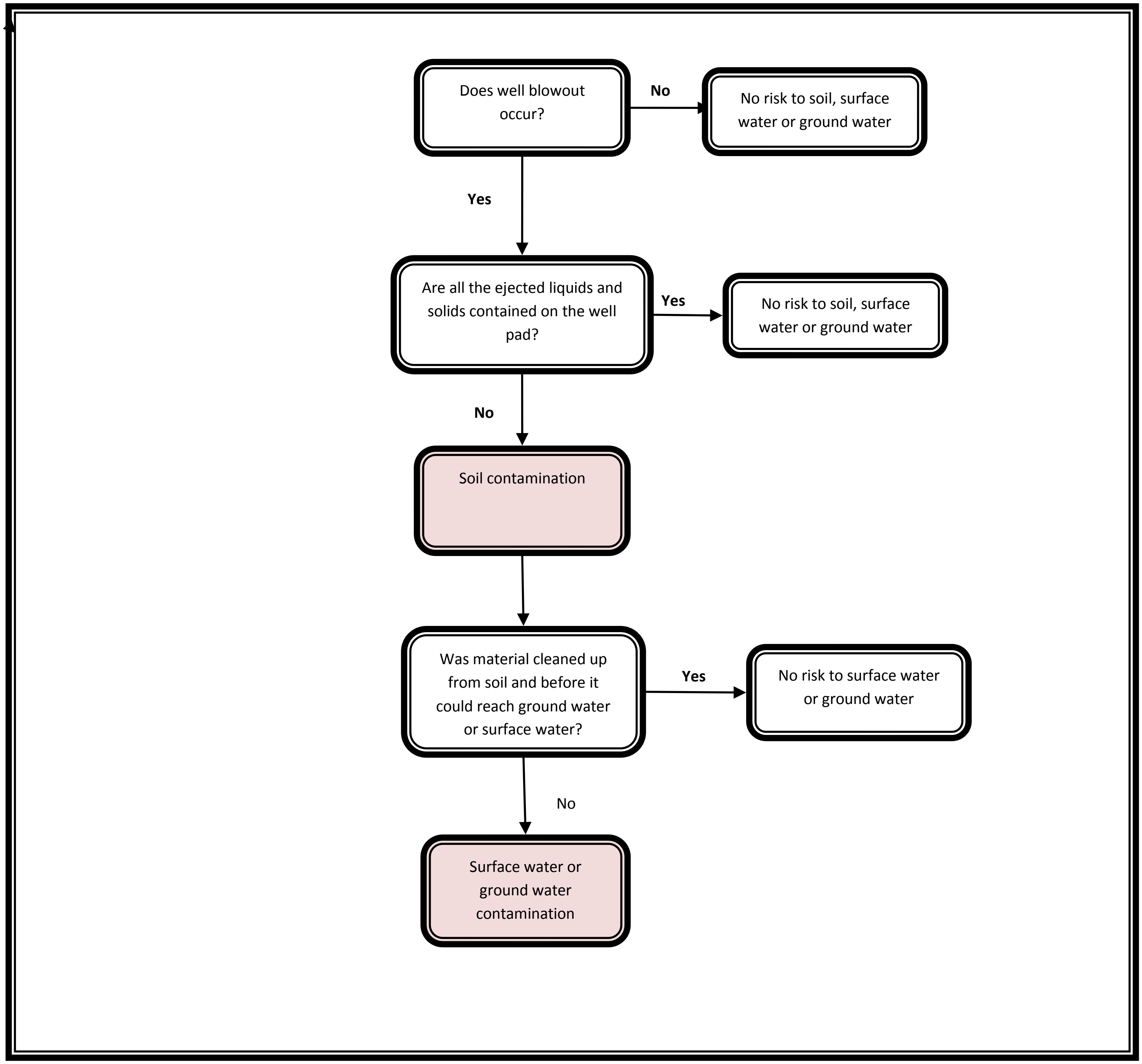

Figure 8: Risk flow chart for well blowout

Drilling Cuttings Separation, Storage and Transfer for Disposal

Risk Identification

Drilling fluids that return from the well flow to separation equipment in order to remove cuttings from the fluid for storage and disposal and re-circulate the fluids back to the storage tanks for reuse in drilling. Separation equipment may consist of shale shakers, de-sanders, and de-silters (NYSDEC, 2011). Additional equipment such as drying shakers, rotary cuttings dryers, squeeze presses or centrifuges may be required to further separate liquids from cuttings for reuse. The cuttings are transferred to storage containers and may contain NORM as well as heavy metals and other chemical contaminants associated with the formation that was drilled. Vertical wells with a total depth of 7,000 feet will produce approximately 154 cubic yards of cuttings while a horizontal well with the same target depth and 4,000 foot lateral section will produce 217 cubic yards of cuttings (40% more) (NYSDEC, 2011). The total volume of cuttings for risk assessment scenario 1 (150 wells) and 2 (450 wells) would amount to 32,550 cubic yards (217 cubic yards x 150 wells) and 97,650 cubic yards (217 cubic yards x 450 wells) cubic yards. Because space on a well pad is valuable, it is likely that cuttings will be disposed of off-site periodically. Cuttings could spill or be released as a result of failure tanks or containers in the closed loop or during transfer to storage containers.

In a previous section (Drilling Fluid Preparation) it was explained that, for the purposes of this risk assessment, it will be assumed that there is an 8% likelihood of a spill or leak at every stage of UGWD. No additional statistical information specific to accidental spills or releases of cuttings on site during separation and storage was found following an extensive literature search. Based on this probability, 12 and 36 incidents would occur under risk assessment scenarios 1 and 2, respectively for all UGWD in Maryland.

Risk Mitigation: Current Regulations and Proposed BMPs

Maryland proposes the following BMPs that are relevant to protection of the soil, surface water and ground water from releases of cuttings from the well pad:

- Drilling fluid, the returned drilling fluid and the cuttings must be managed in a closed loop system with secondary containment on the well pad.
- 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

In a previous section (Drilling Fluid Preparation) it was explained that, for the purposes of this risk assessment, it will be assumed that there is an 8% likelihood of a spill or leak at every stage of UGWD. This results in 12 or 36 incidents for UGWD in Maryland for risk assessment scenarios 1 and 2, respectively. A well pad with a four inch berm can contain more than 1,500 cubic yards; it is therefore likely that the pad could contain any cuttings accumulated on a drill pad. The probability will therefore be classified as low.

The consequences associated with soil, surface water or ground water contamination from accidental releases or spills of drilling cuttings during separation and storage will be classified as moderate as these incidents could have a considerable adverse impact on people or the environment causing localized damage. For both risk assessment scenarios 1 (150 wells) and 2 (450 wells) the consequences will be classified as moderate. Figure 9 presents a flow diagram of the risk associated with drilling cuttings separation, storage and transfer for disposal.

Impact Assessment: Release of drilling cuttings during separation, storage and transfer for disposal

Impact	Probability	Consequence	Risk Ranking
Human	Low	Moderate	Low
Ecological	Low	Moderate	Low

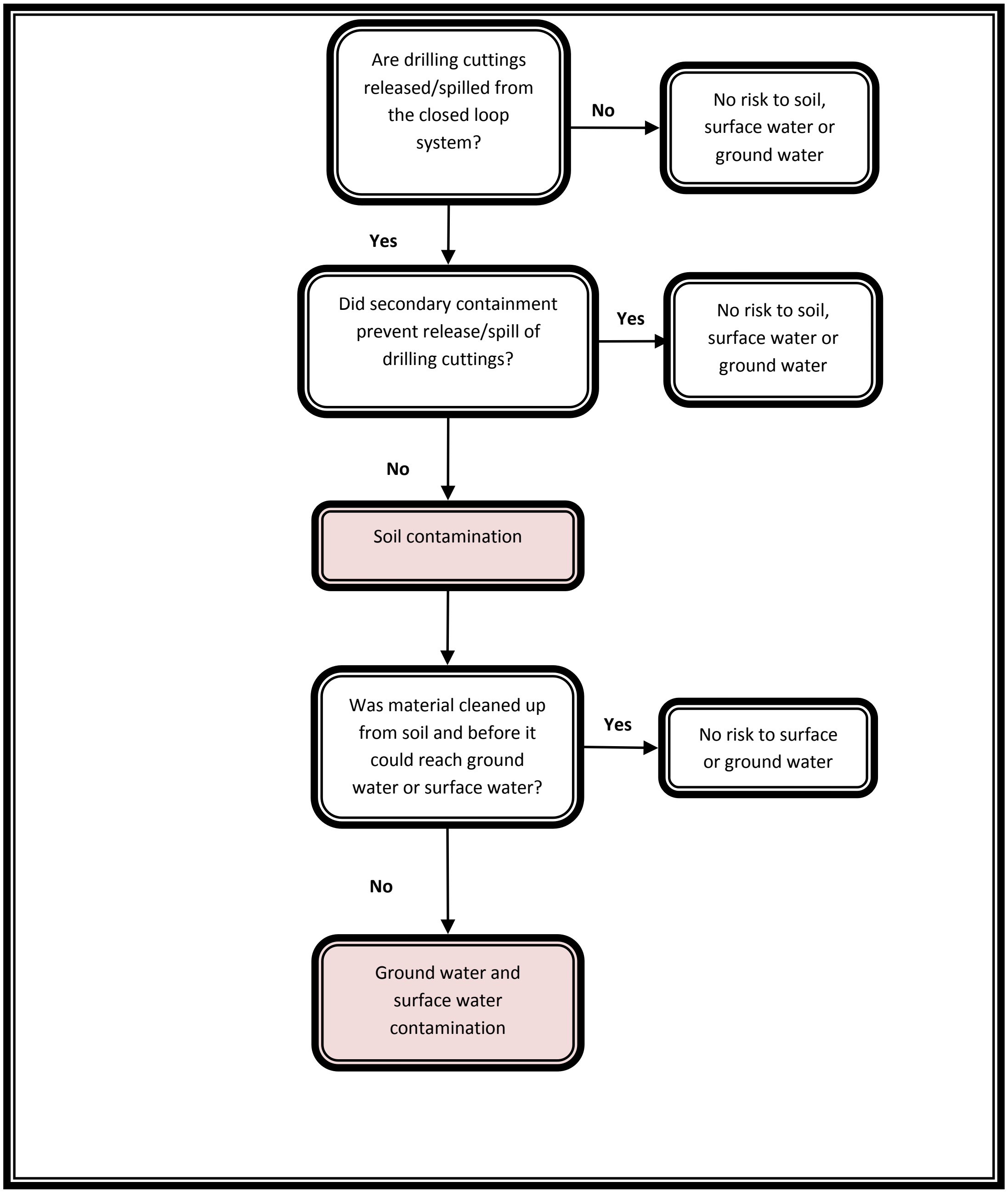

Figure 9: Risk Flow chart for drilling cuttings separation, storage and transfer for disposal

Waste Drilling Fluids Storage

Risk Identification

Used drilling mud is usually not discarded, but rather reconditioned for reuse at a subsequent well that may be located at the same well pad or a different well pad (NYSDEC, 2011). Following completion of the drilling operation the waste drilling fluids will likely remain in storage tanks until it is reconditioned for reuse or shipped off-site for reuse, reconditioning or disposal. While on the pad, these fluids could potentially be released to the surface due to accidental releases from line ruptures, leaks, equipment failure, and operational error during the storage period. These releases have the potential to contaminate surface water and ground water if they are not properly contained. Marcellus Shale gas wells on average generate 175,000 gallons of waste drilling fluids per well (Lewis, 2012). The total volume of waste drilling fluids for risk assessment scenario 1 (150 wells) and 2 (450 wells) would amount to 26,250,000 (175,000 gallons x 150 wells) and 78,750,000 gallons (175,000 gallons x 450 wells) for the entire state of Maryland. In a previous section (Drilling Fluid Preparation) it was explained that, for the purposes of this risk assessment, it will be assumed that there is an 8% likelihood of a spill or leak at every stage of UGWD. Based on this probability, 12 and 36 incidents would occur under risk assessment scenarios 1 and 2, respectively for all UGWD in Maryland.

Risk Mitigation: Current Regulations and Proposed BMPs

Maryland proposes the following BMPs that are relevant to protection of the soil, surface water and ground water from releases of waste drilling fluid during storage:

- 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
- 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.
- 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
- 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

Ina previous section (Drilling Fluid Preparation) it was explained that, for the purposes of this risk assessment, it will be assumed that there is an 8% likelihood of a spill or leak at every stage of UGWD. This results in 12 or 36 incidents for UGWD in Maryland for risk assessment scenarios 1 and 2, respectively. If a release does occur on the well pad , the pad can contain significantly more than the 175,000 gallons of waste drilling fluids estimated to be produced per well. Setbacks will reduce the chance that material that escapes the pad will impact surface water or ground water before spill cleanup and emergency response

This information indicates that soil, surface water or ground water contamination from accidental releases of waste drilling fluids during storage will rarely occur if best practices are implemented; therefore, the probability will be classified as low.

The consequences associated with soil, surface water or ground water contamination from accidental releases of stored waste drilling fluid are classified as moderate because, although it could cause considerable adverse impact on people or the environment, the damage would be localized. Figure 10 presents a flow diagram of the risk associated with waste drilling fluid storage.

Impact Assessment: Waste Drilling Fluids Storage

Impact	Probability	Consequence	Risk Ranking
Human	Low	Moderate	Low
Ecological	Low	Moderate	Low

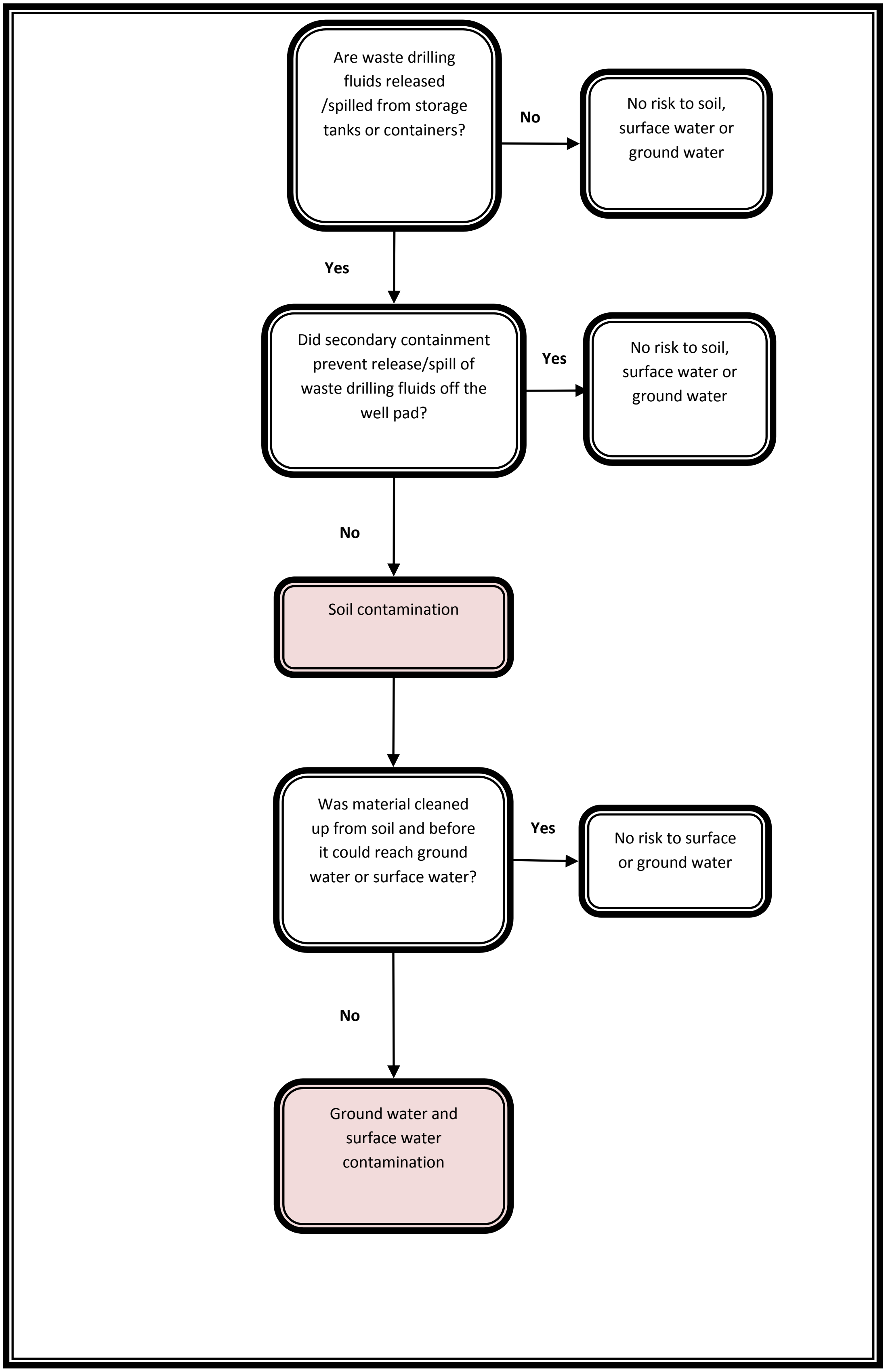

Figure 10: Risk flow chart for waste drilling fluid storage

Transport of Used Drilling Fluids from the Well Pad

Risk Identification

Used drilling mud is usually not discarded, but rather reconditioned for reuse at a subsequent well that may be located at the same well pad or a different well pad (NYSDEC, 2011). Waste cuttings will be transported off site for disposal at an appropriate facility (e.g., industrial waste landfill). Onsite disposal of cuttings will be prohibited in Maryland if testing shows elevated levels of radioactivity, sulfates, salinity and other criteria. Vehicular accidents involving trucks transporting these waste materials may result in their release if the storage tanks containing waste fluids are compromised or rupture, or containers holding cuttings overturn spilling their contents. These materials could potentially contaminate ground water or surface water if clean up does not occur in a timely manner prior to infiltration or leaching into ground water or surface transport during rain events. In addition, if NORM is present at elevated levels the accidental spill of cuttings could lead to radioactive contamination of ground water or surface water potentially impacting private or public water supply or aquatic systems.

As previously stated in another section the total volume of waste drilling fluids for risk assessment scenario 1 (150 wells) and 2 (450 wells) would amount to 26,250,000 and 78,750,000 gallons for the entire state of Maryland. High-volume capacity options for water hauling trucks vary from about 4,000 to 6,000 gallons (The Gasaway Co. 2002, J&J Truck Bodies & Trailers 2008, Ledwell 2014, Oilmen's Truck Tanks 2012). Applying a volume of 5,000 gallons per truck, the total number of truck trips for transporting waste drilling fluids under risk assessment scenarios 1 and 2, will be 5,250 (26,250,000 gallons / 5,000 gallon truck capacity) and 15,750 (78,750,000 gallons / 5,000 gallon truck capacity), respectively. As previously stated in the section on Drilling Cuttings Separation & Storage, the total volume of drilling cuttings for risk assessment scenario 1 and 2 would amount to 32,550 cubic yards and 97,650 cubic yards for the entire State of Maryland. Dump trucks (10-wheel) with a capacity of 10-12 cubic yards can be used to transport drilling cuttings for disposal (B.L. Hayes 2014, Desert Trucking 2014). Applying a volume of 11 cubic yards per truck, the total number of truck trips for transporting drilling cuttings under risk assessment scenarios 1 and 2, will be 2,960 (32,550 cubic yards / 11 cubic yard truck capacity) and 8,877 (97,650 cubic yards / 11 cubic yard truck capacity), respectively.

As stated previously in another section of this report there is a 0.005% probability of a hazardous material cargo spill incident occurring in the U.S. based on information provided by PHSMA. No information on incidents related specifically to the accidental releases or spills of drilling waste fluids and cuttings was found following an extensive literature search. While this incidence probability applies to hazardous material and not hazardous waste transport it will still be applied in determining incident rates for risk assessment scenario 1 and 2 as no other information was available. Based on an incident probability of 0.005% under risk assessment scenarios 1 and 2, 0.3 and 0.8 incidents involving the release of waste drilling fluids during transport would occur, respectively and 0.2 and 0.4 incidents involving the spill of drilling cuttings during transport would occur, respectively.

Risk Mitigation: Current Regulations and Proposed BMPs

Maryland proposes the following BMPs that are relevant to protection of the soil, surface water and ground water from releases of waste drilling fluids and cuttings during transportation:

- 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 probability of a hazardous material cargo release for a single shipment has been estimated above as 0.005%. This results in 0.3 and 0.8 incidents for all truck trips under risk assessment scenarios 1 and 2 involving the release of waste drilling fluids during transport, respectively and 0.2 and 0.4 incidents involving the spill of drilling cuttings during transport, respectively. 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 frequency of surface water or ground water contamination from accidental releases or spills of drilling fluid additives during transport is also considered low on a cumulative basis.

The consequences associated with soil, surface water or ground water contamination from accidental releases or spills of drilling cuttings during transportation will be classified as moderate as these incidents could have a considerable adverse impact on the environment causing localized environmental damage. The consequences associated with soil, surface water or ground water contamination from accidental releases of waste drilling fluid during transport are classified as moderate because, although it could cause considerable adverse impact on people or the environment, the damage would be localized. Figure 11 presents a flow diagram of the risk associated with the transport off-site of waste drilling fluids and cuttings for disposal.

Impact Assessment:

Impact	Probability	Consequence	Risk Ranking
Human	Low	Moderate	Low
Ecological	Low	Moderate	Low

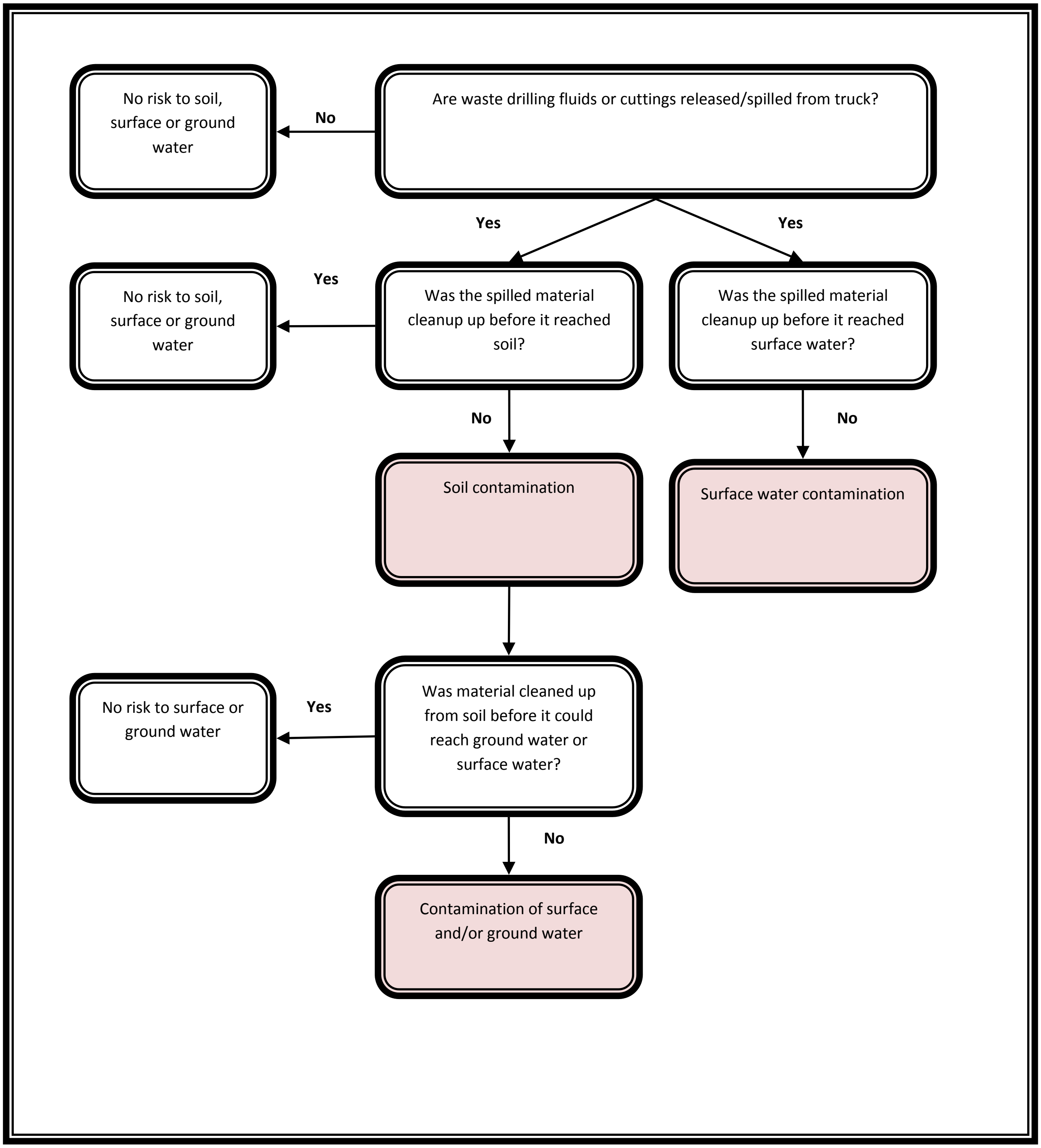

Figure 11: Risk flow chart for transport off-site of waste drilling fluids and cuttings for disposal

Summary Assessment of Impacts from Drilling Additives, Fluids and Cuttings

Drilling operations for UGWD pose an environment risk due to the potential for accidental releases or spills of drilling fluids and cuttings during operations on the well pad or off-site during the transport of drilling fluid additives or waste drilling fluids and cuttings. These accidental releases or spills have the potential to contaminate soil, surface water and ground water if they are not properly contained and may occur during the following stages in the drilling process: 1) transport of drilling fluid additives to the well pad, 2) drilling fluid preparation, 3) drilling operations, 4) well blowout during drilling, 5) drilling cuttings separation and storage, 6) waste drilling fluid storage, and 7) transport off-site of waste drilling fluids and cuttings for disposal. This risk assessment has determined that there is low probability for surface water or ground water contamination from accidental releases or spills in all stages of the drilling process including the transport of drilling fluid additives and waste drilling fluids and cuttings. The consequences associated with surface water or ground water contamination from accidental releases or spills was classified as moderate for all stages of the drilling process except for transport of drilling additives on aquatic life. Human health could be adversely affected if contaminated ground water impairs the water supply. Aquatic life could be adversely affected if contaminated surface water or ground water impairs the waterways. Adverse impacts from direct spills and inappropriate disposal of drillings and cuttings 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 overall risk assessment is summarized in Table 1.

Table 1: Risk Assessment table

Operation	Occurrence	Environmental Impact	Probability	Consequence	Risk Ranking
Transport of Drilling Fluid Additives to the Well Pad	Release of drilling fluid additives	Soil, Surface water, Ground water (Human)	Low	Moderate	Low
		Soil, Surface water, Ground water (Ecological	Low	Moderate	Low
Drilling Fluid Preparation	Release or spill of drilling fluid additives during fluid preparation	Soil, Surface water, Ground water	Low	Moderate	Low
Drilling Operations	Release of drilling fluids during drilling operation: fluid	Soil, Surface water, Ground water	Low	Moderate	Low

	storage, fluid injection, fluid return, fluid/cuttings separation, & fluid reuse				
Well Blowout during Drilling	Release of formation fluids, drilling fluids and cuttings during well blowout	Soil, Surface water, Ground water	Low	Moderate	Low
Cuttings Separation & Storage	Spill of cuttings during separation and storage	Soil, Surface water, Ground water	Low	Moderate	Low
Waste Drilling Fluid Storage	Release of waste drilling fluids during storage	Soil, Surface water, Ground water	Low	Moderate	Low
Transport Off-site of Cuttings for Disposal	Vehicular accidents causing spill or release of drilling waste fluids and cuttings	Soil, Surface water, Ground water	Low	Moderate	Low
Transport Off-site of Waste Fluids for Disposal	Vehicular accidents causing spill or release of drilling waste fluids and cuttings	Soil, Surface water, 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. 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.

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Figure 2: <http://www.mesawellservicing.com/

Figure 3: <http://www.gn-desander-desilter.com/closed-loop-mud-system/

Figure 4: <http://www.gn-desander-desilter.com/closed-loop-system-for-oil-drilling/

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