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Risks and mitigation options for on-site storage of wastewater from shale gas and tight oil development

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ABSTRACT

We provide a critical review of existing research and information regarding the sources of risk associated with on-site shale gas and tight oil wastewater storage in the United States, the gaps that exist in knowledge regarding these risks, policy and technology options for addressing the risks, and the relative merits of those options. Specifically, we (a) identify the potential risks to human and ecological health associated with on-site storage of shale gas and tight oil wastewater via a literature survey and analysis of data on wastewater spills and regulatory violations, (b) provide a detailed description of government regulations or industry actions that may mitigate these risks to human and ecological health, and (c) provide a critical review of this information to help generate progress toward concrete action to make shale gas and tight oil development more sustainable and more acceptable to a skeptical public, while keeping costs down.

1. Introduction

Oil and gas production generates large volumes of wastewater that require management, especially when hydraulic fracturing is involved (Clark and Veil, 2009). Most of this wastewater must be temporarily stored at the well site in pits or tanks prior to recycling or disposal. However, on-site storage of wastewater from hydraulic fracturing can entail significant risks for human and ecological health. A range of stakeholder groups in shale gas development have identified on-site pit storage of flowback and produced water constituents and the potential for leakage into surface water and groundwater as priority risk pathways to be addressed by further government regulations or industry voluntary actions (Krupnick and Gordon, 2015). Furthermore, on-site storage of shale gas and tight oil wastewater has been an active area of focus for policymakers in the United States. In addition to rapidly-changing regulations at the state level, federal government agencies are seeking to influence industry practices surrounding wastewater pits and tanks.

Despite this academic and policy interest in on-site storage of wastewater from oil and gas production, existing literature on risks and mitigation options is scarce, and information on technologies and practices used specifically in shale gas and tight oil operations is even scarcer. The main contribution of this paper is to bring together this information into one comprehensive resource. We supplement this survey of the literature with information gained from a search of existing US state regulations and an analysis of four state databases on environmental incidents from oil and gas operations.

Different types of pits are used to store wastes from different stages of fossil fuel development. The classes of pits that most commonly appear in US state regulations are *reserve pits*, which are used to store fluids for use in drilling operations and/or to dispose of wastes generated by drilling operations and initial completion procedures; *produced water pits*, which are used for storage of produced water prior to injection for enhanced recovery or disposal, off-site transport, or surface-water discharge; and *workover pits*, which are used to contain liquids during remedial operations on a producing well in an effort to increase production (STRONGER, 2015). Distinguishing between these pit functions is important because states may impose different regulations or permitting requirements based on pit type. Because there is differing nomenclature across regulators and stakeholders for referring to each type of pit, we will rely on the pit classification employed by the State Review of Oil and Natural Gas Environmental Regulations (STRONGER), which is intended to serve as a guideline for regulatory programs.

Enclosed, portable tanks are a commonly used alternative to pits for the storage of wastewater. The use of tanks as a wastewater storage solution has been increasing in the oil and gas industry and has been a target for new regulations. Therefore, it is important to identify the risks associated with tanks and compare them with the risks associated with pits.

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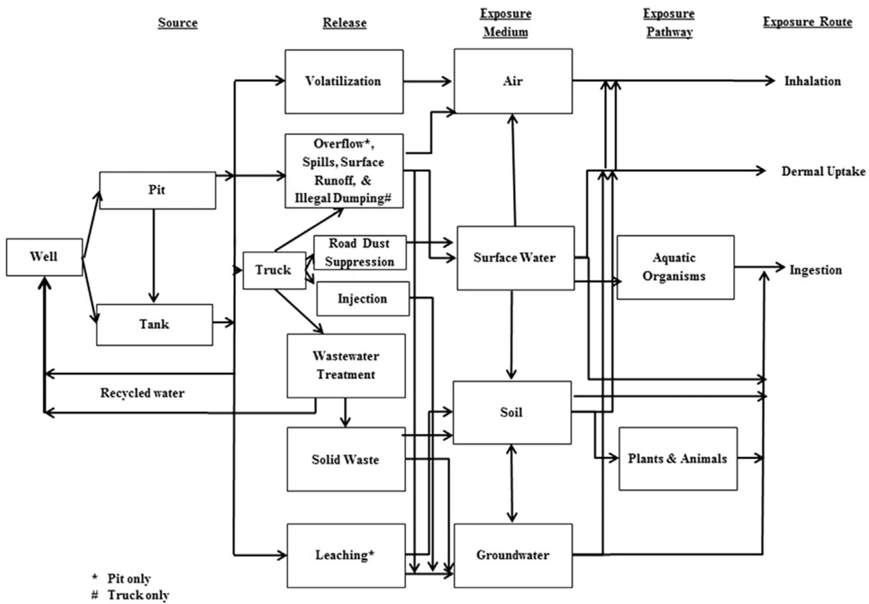

Fig. 1. Summary of contaminant release mechanisms and exposure pathways associated with pits (adapted from Johnson et al. (2003) to depict additional mechanisms and pathways identified in our literature survey).

2. Risks to human and ecological health: a review of the literature

Despite long-standing concerns that pits and tanks used to store oil and gas wastewater may allow the release of harmful substances and ultimately lead to human and ecological exposures, research in this area is sparse. In summarizing results from existing studies, we divide the processes by which humans and ecosystems may be exposed to contaminants contained in stored shale gas and tight oil wastewater into three parts: (1) the chemical composition of wastewater from hydraulic fracturing that is stored in pits and tanks; (2) the mechanisms by which the chemicals in wastewater stored in pits and tanks are released into the environment; and (3) the pathways through which humans and ecological systems are exposed to the chemicals that are released into the environment from pits and tanks. Fig. 1 illustrates how wastewater storage options, potential release mechanisms, and potential exposure pathways are related to the handling of fluids and wastewater in shale gas and tight oil production. Given the focus of our analysis on on-site wastewater storage, we will not address exposure processes that are associated with other parts of the wastewater handling process (such as off-site transportation, treatment, and disposal).

2.1. Chemical composition of wastewater from hydraulic fracturing

Existing studies have identified five major categories of substances commonly found in oil and natural gas waste pits and tanks that could result in negative human and ecological health effects at high enough doses: (1) volatile organic compounds (VOCs); (2) metals; (3) total dissolved solids (TDS); (4) naturally occurring radioactive material (NORM); and (5) oil. When possible, we provide information on the presence of these substances in shale gas and tight oil wastewater and compare their measured concentrations with levels that are known to generate adverse health risks and violate public health goals. For VOCs and metals, we refer to the Minimum Risk Levels (MRLs) List compiled by the Agency for Toxic Substances and Disease Registry (ATSDR).[1] We also provide the Maximum Contaminant Level Goals (MCLGs) for each substance as determined by the National Primary Drinking Water Regulations enforced by the US Environmental Protection Agency (EPA).

2.1.1. Volatile organic compounds (VOCs)

The VOCs commonly found in shale gas and tight oil wastewater are benzene, toluene, ethylbenzene, and xylenes, collectively referred to as BTEX (Havics and Wright, 2011). BTEX are present at low concentrations in crude oil and are also found in coal and gas deposits (Gross et al., 2013). During the drilling and hydraulic fracturing process, these chemicals can be brought to the surface with flowback and produced water and subsequently stored in pits and tanks. These chemicals can easily volatilize into the air and negatively affect air quality near pits. At sufficient doses, BTEX are known to have negative human health impacts (ATSDR, 2007).

Table 1 summarizes data from eight studies quantifying concentrations of VOCs present in oil and gas wastewater contained in pits and tanks and oil and gas wastewater more generally. The second-to-last column in Table 1 provides the MRLs for oral exposure to the VOCs measured in oil and gas wastewater by the eight studies. Based on some assumptions regarding the potential ingestion of wastewater,[2] these figures imply, for example, that an average adult ingesting 1 l of Pennsylvania oil and gas wastewater per day on a chronic basis could be at significant health risk based on benzene concentrations alone. However, such a characterization of health risk is only illustrative and is not linked to actual levels of exposure; it is highly unlikely that individuals will directly swim in or drink the wastewater.

2.1.2. Metals

Like VOCs, metals are distributed throughout geologic formations and are the most common class of chemicals found in industrial

[1] ATSDR's MRL List provides, for various substances, an estimate of daily human exposure that is "likely to be without appreciable risk" of adverse noncancer health effects over a specified duration of exposure (ATSDR, 2013). These MRLs are expressed in terms of milligrams per kilogram per day (mg/kg/day) and, depending on the substance, are

(*footnote continued*)
derived for acute 1–14 days), intermediate 15–364 days), and chronic (365 days and longer) exposure durations.

[2] In order to get a sense of whether direct ingestion of wastewater could lead to human health risks, the MRL needs to be multiplied by the weight of the individual (equal to 65kg for the average adult human) and divided by the volume of the wastewater ingested in a day. The Superfund Exposure Assessment Manual (SEAM) estimates that a human adult incidentally ingests 50 milliliters/hour of water while swimming and ingests 2l/day of drinking water in his or her daily life (EPA, 1989).