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Monitoring and modeling wetland chloride concentrations in relationship to oil and gas development

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ABSTRACT

Extraction of oil and gas via unconventional methods is becoming an important aspect of energy production worldwide. Studying the effects of this development in countries where these technologies are being widely used may provide other countries, where development may be proposed, with some insight in terms of concerns associated with development. A fairly recent expansion of unconventional oil and gas development in North America provides such an opportunity. Rapid increases in energy development in North America have caught the attention of managers and scientists as a potential stressor for wildlife and their habitats. Of particular concern in the Northern Great Plains of the U.S. is the potential for chloride-rich produced water associated with unconventional oil and gas development to alter the water chemistry of wetlands. We describe a landscape scale modeling approach designed to examine the relationship between potential chloride contamination in wetlands and patterns of oil and gas development. We used a spatial Bayesian hierarchical modeling approach to assess multiple models explaining chloride concentrations in wetlands. These models included effects related to oil and gas wells (e.g. age of wells, number of wells) and surficial geology (e.g. glacial till, outwash). We found that the model containing the number of wells and the surficial geology surrounding a wetland best explained variation in chloride concentrations. Our spatial predictions showed regions of localized high chloride concentrations. Given the spatiotemporal variability of regional wetland water chemistry, we do not regard our results as predictions of contamination, but rather as a way to identify locations that may require more intensive sampling or further investigation. We suggest that an approach like the one outlined here could easily be extended to more of an adaptive monitoring approach to answer questions about chloride contamination risk that are of interest to managers.

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1. Introduction

Extraction of oil and gas via unconventional methods (e.g. hydraulic fracturing) is becoming an important aspect of energy production worldwide (U.S. Energy Information Administration, 2013). Studying the effects of this development in countries where these technologies are being widely used may provide other countries, where development may be proposed, with some insight in terms of concerns associated with development (e.g. Uliasz-Misiak et al., 2014). A fairly recent expansion of unconventional oil and gas development in North America provides such an opportunity. Rapid increases in energy development in North America have caught the attention of managers and scientists as a potential stressor for wildlife and their habitats (e.g. Ramirez, 2005; Gilbert and Chalfoun, 2011; Naugle, 2011). This is especially true for the Northern Great Plains of the U.S., where oil and gas development has undergone a revival. In particular, the Williston Basin, which includes the U.S. states of Montana, North Dakota, and South Dakota, and the Canadian provinces of Manitoba and Saskatchewan, has undergone a recent resurgence of development. The bulk of conventional petroleum drilling and recovery began in the Basin during the 1950s. Peak drilling levels were reached around 1980 in response to high oil prices, followed by a decrease in drilling (Peterson, 1995; Tangen et al., 2014a). Since about 2007, there has been renewed interested in the Williston Basin, which has led to the rapid expansion of drilling and production activities (Tangen et al., 2014a). As of the summer of 2014, the North Dakota Department of Mineral Resources reported over 10,000 producing

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wells within the state, which was up from just over 3000 at the beginning of the year 2000 (NDIC Oil and Gas Division, 2014). This current upsurge in petroleum-field activity is associated with advances in horizontal drilling and hydraulic fracturing technologies (Gaswirth et al., 2013). Currently, estimates suggest that this upward trend will continue for 20–50 years (Mason, 2012).

One of the major wildlife-related concerns within the Basin involves the Prairie Pothole Region (PPR), which happens to overlay areas with intense oil and gas development. The PPR is recognized for its high densities of depressional wetlands, called "potholes." Wetlands, in general, have been recognized as important features of landscapes around the world because of the valuable ecosystem services they provide (de Groot et al., 2012). Prairie pothole wetlands, in particular, have been recognized for providing ecosystem services related to atmospheric carbon sequestration, water retention, outdoor recreation and important habitat for migratory birds (Knutsen and Euliss, 2001; Gleason et al., 2008, 2011). The ecological value of pothole wetlands is related to their diverse plant and invertebrate communities, as well as their hydrologic diversity, which spans a continuum from ephemeral to permanent water. A major source of concern with regard to oil and gas development in this region is related to produced water entering these wetland systems. Produced water is a by-product of drilling and production and constitutes the single largest waste stream for the oil and gas industry (Ahmadun et al., 2009; Sirivedhin and Dallbauman, 2004). Unconventional development has raised concerns in numerous countries about how to best dispose of produced water to avoid problems with contamination (e.g. Gordalla et al., 2013). Produced water, sometimes called "brine" because of its high salt concentrations, is suggested to be one of the main causes of surface water, groundwater, and soil contamination in oil-producing states in the U.S. (Kharaka and Otton, 2003; Gleason and Tangen, 2014).

Because of their temporal and spatial diversity (e.g. hydroperiod, relation to groundwater, background water chemistry), pothole wetlands display a wide range of salt concentrations and salinities (Swanson et al., 1988; LaBaugh, 1989; Gleason et al., 2009; Tangen et al., 2013). However, because of the differences in ionic composition and salinity between brines and natural surface water in pothole wetlands (e.g. Gleason and Tangen, 2014), there is potential for introduced brine to alter wetland water chemistry, and consequently biotic communities. Elevated chloride levels could result in a shift from relatively diverse freshwater plant and invertebrate communities to less diverse, salt-tolerant communities (Gleason et al., 2009; Gleason and Tangen, 2014). Such a shift could reduce habitat quality for wetland-dependent wildlife. Additionally, altered water chemistry or elevated salinity could make wetlands unsuitable as a water source for domestic livestock and other wildlife.

Recent work in the Williston Basin suggests that produced water has migrated from well sites into wetlands and shallow groundwater (Murphy, 1983; Murphy and Kehew, 1984; Beal et al., 1987; Murphy et al., 1988; Reiten and Tischmak, 1993; Thamke and Craigg, 1997; Peterman et al., 2010, 2012; Preston et al., 2014b). Much of this research has focused on subsurface migration of brine from historical reserve pits, which were once used to store and dispose of drilling fluids and to evaporate brine. There are legal requirements in many states that preclude the use of reserve pits for contemporary wells and call for brine storage and offsite disposal. Despite these new requirements, it is possible that produced water may still affect wetlands through sources such as unregulated discharges or leaks during truck or pipeline transport or leakage from well casings or storage tanks (Reiten and Tischmak, 1993; Thamke and Craigg, 1997). In fact, some estimates suggest that up to five percent of all the brine produced in the U.S. could be released as surface discharges (Sirivedhin and Dallbauman, 2004). While some research has demonstrated considerable potential for chloride-rich brines to alter wetland water chemistry (Reiten and Tischmak, 1993; Preston et al., 2014b; Tangen et al., 2014b), we know of no landscape-scale models or monitoring programs that have been designed to examine the relationship between potential chloride contamination and patterns of oil and gas development.

Preston et al. (2014a) developed a vulnerability assessment model that computed the weighted sum of a set of scores assigned to variables such as surficial geology and the age wells in an area. While their work was a useful first start, it was not developed for making landscape scale predictions or developing an understanding of the potential cumulative and widespread effects of oil and gas development. This is important because future well placement and management decisions hinge on understanding the landscape context of development and any accumulated impacts. While not a panacea, we contend that a predictive statistical approach could potentially help in guiding wetland monitoring across the landscape.

Here we present an approach and a potential framework for landscape scale monitoring of chloride contamination in wetlands. Our main goal with this paper was to develop a model relating chloride concentrations to patterns of oil and gas development, as well as surficial geological factors, based on a statistical sample of wetlands. We then discuss how such a modeling approach could be expanded or updated as more data are collected. Lastly, we discuss our modeling and sampling approach with implications for future monitoring and risk assessments associated with cumulative effects of oil and gas development.

2. Methods

2.1. Study area

Our study was focused on wetlands in the PPR that overlapped the Bakken Formation within Williston Basin (Fig. 1); the Bakken Formation is the primary target of recent production activity. Our total study area was approximately 40,000 km^2 and included only wetlands in North Dakota and Montana. Our study area included the following counties in North Dakota: Bottineau, Burke, Divide, McHenry, Mountrail, Renville, Sheridan, Ward and Williams; and the following counties in Montana: Daniels, Sheridan and Roosevelt.

2.2. Wetland selection

We only considered wetlands that we could classify as seasonal or semipermanent (Stewart and Kantrud, 1971; Cowardin et al., 1979) using data from a modified National Wetlands Inventory (NWI) database described by Tangen et al. (2014a). Based on this database we computed that there were over 315,000 of these wetlands in our study area. Based on previous research pertaining to brine contamination in wetlands (Reiten and Tischmak, 1993; Preston et al., 2014b), we decided to focus on wetlands nearest to production wells to increase the probability that the sample population would include brine-affected wetlands. We combined well data, described in Tangen et al. (2014a), with the NWI data in a geographic information system (GIS), and computed the distances between all of the wetlands in our study area and the nearest oil and gas-related well. We then eliminated all wetlands with well distances greater than the 25th percentile to ensure that some of our sample was relatively close to oil and gas developments. We assigned the remaining wetlands to a broad land ownership category (private or public) using the U.S. Geological Survey Protected Areas Database (U.S. Geological Survey Gap Analysis Program, 2010). For publicly-owned wetlands, we considered those located