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A multiple lines of evidence approach for the ecological risk assessment of an accidental bitumen release from a steam assisted gravity drainage (SAGD) well in the Athabasca oil sands region

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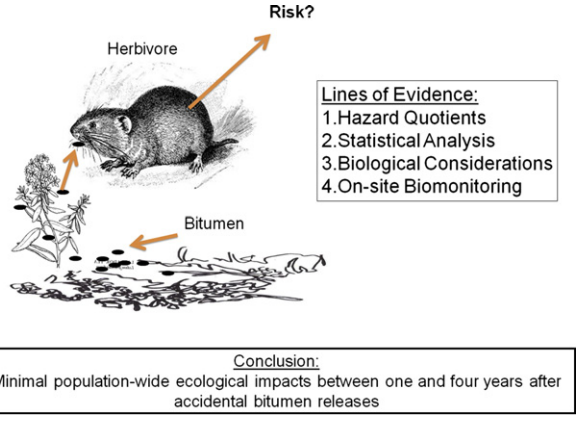
HIGHLIGHTS

- A Multiple LOE ERA characterized risk at two SAGD accidental bitumen release sites
- ERA predicted negligible likelihood of adverse outcomes
- Small mammal collection conducted to substantiate the conclusions of the ERA
- An increase in EROD activity observed in voles, but no other adverse outcomes
- Biological sampling program supported the conclusion of the initial ERA

GRAPHICAL ABSTRACT



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ABSTRACT

To assess the ecological impacts of two independent accidental bitumen releases from two steam assisted gravity drainage (SAGD) wells in the Athabasca oil sands region, a multiple lines of evidence (LOE) approach was developed. Following the release in 2010, action was taken to minimize environmental impact, including the selective removal of the most highly impacted vegetation and the use of oil socks to minimize possible runoff. An ecological risk assessment (ERA) was then conducted based on reported concentrations of bitumen related contaminants in soil, vegetation, and water. Results of biological assessments conducted at the site were also included in the risk characterization. Overall, the conclusion of the ERA was that the likelihood of long-term adverse health effects to ecological receptors in the area was negligible. To provide evidence for this conclusion, a small mammal sampling plan targeting Southern red-back voles (*Myodes gapperi*) was carried out at two sites and two relevant reference areas. Voles were readily collected at all locations and no statistically significant differences in morphometric measurements (i.e., body mass, length, foot length, and adjusted liver weight) were found between

Abbreviations: AhR, Aryl hydrocarbon receptor; BTEX, benzene, toluene, ethylbenzene and xylenes; CYP1A1, Cytochrome P450 1A1; COPC, Contaminants of potential concern; EPC, Exposure point concentrations; ERA, Ecological risk assessment; EROD, Ethoxyresorufin O-deethylase; HI, Hazard index; HQ, Hazard quotient; LOE, Line of evidence; PAH, polycyclic aromatic hydrocarbons; PHC, Petroleum hydrocarbon; SAGD, Steam assisted gravity drainage; TDI, Total daily intake; TRV, Toxicity reference values.

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Red-backed voles
Steam assisted gravity drainage

animals collected from impact zones of varying levels of coverage. Additionally, no trends corresponding with bitumen coverage were observed with respect to metal body burden in voles for metals that were previously identified in the source bitumen. Hepatic ethoxyresorufin-O-deethylase (EROD) activity was statistically significantly elevated in voles collected from the high impact zones of sites compared to those collected from the reference areas, a finding that is indicative of continued exposure to contaminants. However, this increase in EROD was not correlated with any observable adverse population-wide biological outcomes. Therefore the biological sampling program supported the conclusion of the initial ERA and supported the hypothesis of no significant long-term population-wide ecological impact of the accidental bitumen releases.

1. Introduction

In the Athabasca oil sands region of Alberta, Canada, the majority of bitumen and heavy crude oil deposits are not recoverable using surface mining. These heavy oil deposits are a mixture of sand (~83–85%), water (~4–5%), and bitumen (~10–12%). To help recover these highly viscous and almost immobile oils underground, in situ methods of extraction, such as steam assisted gravity drainage (SAGD), have been developed (Butler and Mokrys, 1989). This thermal oil production method uses two parallel horizontal well pairs, one approximately 5 m above the other. Steam injected by the upper well creates a chamber that expands vertically and horizontally and as this steam chamber expands, it heats the bitumen, which results in decreased viscosity and increased flow. The bitumen subsequently drains via gravity to the lower well head, at which point it is pumped to the surface for processing.

Today surface mining accounts for approximately 20% of oil sands production and SAGD accounts for the remaining 80% (GOA 2015). Though protective measures are continually developed, failure points along the extraction pipeline may develop (Yu et al., 2013). Environmental concerns from SAGD operations primarily relate to air emissions, water use and land disturbance but occasionally an accidental release of bitumen occurs and the number of failures on crude oil pipelines is quite small (AER 2013).

In July 2010, an accidental release from a Devon Energy SAGD well in the Athabasca oil sands region occurred, resulting in the deposition of crude bitumen and water to a surrounding area of approximately 636 ha (herein referred to as Site 1). The majority of Site 1 (623 ha) was categorized as 'low impact' (i.e., cover of bitumen on the leaf surface of understory plants <25%); 13.6 ha was considered the 'moderate impact zone' (25–75% coverage); and 3.4 ha classified as 'high impact' (>75% coverage). Following the release at Site 1, action was immediately taken to minimize environmental impact, including the removal of highly covered vegetation and ground lichen, hand clearing of vegetation surrounding a nearby creek, and the use of oil socks to minimize the impact of runoff. Chemical concentrations in surface water, sediment, soil, moss and herbaceous plants and shrubs were assessed and extensive surveys of wildlife utilization of the area conducted.

In 2012, an ecological risk assessment (ERA) was carried out for Site 1 to evaluate the potential that ecological receptors living in or frequenting Site 1 might experience toxicologically induced changes in health. To characterize risk, three lines of evidence (LOE) were developed: a hazard quotient (HQ) approach using reported bitumen-related contaminant concentrations from environmental media at Site 1 to inform estimates of exposure/dose, a review and evaluation of the statistical representation of the data, and a review of the biological assessment conducted at the site. This ERA concluded that the likelihood of long-term adverse health effects to receptors in Site 1 was negligible. The possibility of acute effects in wildlife exposed to bitumen prior to the extensive remediation was not assessed in the ERA. It is well documented that acute exposure to petroleum oil can have adverse health effects, including alterations of thermal regulation and respiratory and gastrointestinal distress (Davis et al., 1988; Rebar et al., 1995).

The conclusion of the ERA for Site 1was revisited in 2013 following the occurrence of a second accidental release at a separate and independent Devon Energy SAGD well. The 2013 release affected a considerably smaller area (63 ha) (Site 2), and resulted in lower overall coverage. Cover of bitumen on the leaf surface of understory plants was 20–50% in the highest impact zone and <0.5–10% and <0.5–3% coverage in the moderate and low impact zones, respectively. Given the smaller scale of the incident at Site 2 and the results of the ERA for Site 1, it was expected the likelihood of long-term adverse health effects to receptors in Site 2 would also be negligible. As a fourth LOE to corroborate this hypothesis, a small mammal sampling program was undertaken targeting Southern red-back voles (*Myodes gapperi*) in the low, moderate, and high impact zones of Site 1 and 2, as well as in two relevant reference areas. The use of small mammals as biological indicators of environmental contaminant exposure has been widely tested and used (e.g., Milton and Johnson, 1999; Gonzalez et al., 2008; Wren, 1986; Johnson et al., 1996; Shore, 1995; Saunders et al., 2009; Knopper and Mineau, 2004). For this study, Southern red-backed voles were determined to be ideal bioindicators as they are herbivorous and thus likely to consume bitumen coated plant material more than other animals in the vicinity of Site 1 and 2. Furthermore, Southern red-backed voles are known to be present within the affected area, have a relatively confined home range, and are generally abundant and zoonotic disease free. The captured voles were used to investigate the effect of the bitumen release on general morphometric characteristics (i.e. body mass, length, foot length, and adjusted liver weight) as well as on metal body burden and hepatic ethoxyresorufin O-deethylase (EROD) induction; both of which are markers of exposure to bitumen. In this paper, the methods and results of the initial ERA of Site 1 are described, as well the supporting results provided by the sampling and analysis of voles collected from both Site 1 and Site 2.

2. Methods

2.1. Ecological risk assessment (ERA) of site 1

The ERA was conducted according to a widely recognized framework that progressed from a qualitative initial phase (Problem Formulation), through Exposure and Toxicity Assessments, and culminated in a quantitative/qualitative Risk Characterization and discussion of the assumptions and uncertainties inherent to ERA. The ERA was informed by site-specific data collected in the vicinity of Site 1.

2.1.1. Problem formulation

Contaminants of potential concern (COPC) selected for this risk assessment were identified based on the composition of the released bitumen from Site 1 in 2010 and subsequent comparisons of the maximum levels of these COPC in soil, moss, herbaceous plants, and shrubs at Site 1 to local reference locations that were not affected by the accidental release. Bitumen was primarily composed (> 95% by mass) of petroleum hydrocarbons (PHC) in F3 (C_{16}–C_{34}), F4 (C_{34}–C_{50}), and F5 (C_{50}–C_{100+}) fractions. To a lesser extent, bitumen also contained detectable levels of F1 (C_6–C_{10}) and F2 (C_{10}–C_{16}) fractions, and a number of metals (barium, copper, beryllium, calcium, chromium, cobalt, iron, lead, magnesium, manganese, molybdenum, nickel, phosphorus, potassium, sodium, strontium, sulfur, vanadium, zinc, and zirconium). No detectable