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Research article

A safe, efficient and cost effective process for removing petroleum hydrocarbons from a highly heterogeneous and relatively inaccessible shoreline

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ABSTRACT

A rocky, intractable and highly heterogeneous, intertidal zone, was contaminated from a diesel fuel spill that occurred during refuelling of a grader used in road construction, on an operational mine's shiploading facility. A practical, cost-effective, and safer (to personnel by avoiding drilling and earthworks), and non-invasive sampling and remediation strategy was designed and implemented since the location and nature of the impacted geology (rock fill) and sediment, precluded conventional ex-situ and any in-situ treatment where drilling would be required. Enhanced biostimulation with surfactant, available N & P (which were highly constrained), and increased aeration, increased the degradation rate from no discernable change for 2 years post-spill, to 170 mg/kg/day; the maximum degradation rate after intervention. While natural attenuation was ineffective in this application, the low-cost, biostimulation intervention proved successful, allowing the site owner to meet their regulatory obligations. Petroleum hydrocarbons (aliphatic fraction) decreased from ~20,000 mg/kg to <200 mg/kg at the completion of 180 weeks of treatment.

1. Introduction

Resource construction, as well as operational mine sites, for both new and expansion of existing projects, has been a major contributor to the growth of Australia's economy in the past two decades, deploying large numbers of plant and equipment, and necessitating the transfer and use of large volumes of chemicals including fuels and lubricants. Despite the effort made by resource companies to comply with the standards governing the safe handling of hazardous and dangerous goods, loss of containment of chemicals still occurs on mining and resource construction operations (Guerin, 2014), in some cases with potentially significant impacts on aquatic and marine ecosystems, or even human health (Al-Mansouri and Alam, 2008; Ausma et al., 2002; Guerin, 2001; Hewstone, 1994; Ismail and Karim, 2013). Habitat loss and its effects on biodiversity are a growing global concern and is a major cause of the decline of coastal species. Changes in habitat as a result of petroleum spills is of particular concern (Margesin and Schinner, 2001; Olagbende et al., 1999), and the region where the current spill occurred is an important marine conservation area and is under consideration by regulatory authorities for further increasing the conservation value of the region. Heavy vehicles and equipment at remote construction and operational sites must be maintained and operated in ways that ensure their serviceability, and good and proper condition, such that any fluids are contained and leaks are minimized and prevented (Guerin, 2009). In addition, training of machine operators is required to ensure refuelling and fluids handling are conducted in such a way so as to minimize loss of these fluid products to the environment. Loss of fluids from large plant items used in mining can present hazards to the environment (Guerin, 2002), particularly where they are operating under harsh environmental conditions over continuous shifts, and are working close to waterways and marine environments. A recent study by the author (Guerin, 2014) showed that the majority of fluid spills from plant commonly used in resources construction projects are hydraulic fluids. In the same study, where fuel spills are reported, these are typically from refuelling activities and usually a result of operator or procedural error.

Mining operations and resource construction with activities adjoining marine waters, present a particularly high potential risk to marine pollution, and mine owners and plant operators must be vigilant to ensure integrity of chemical (fuel, lubricant, hydraulic fluid) storage tanks, lines, pumps, secondary containment and wash down facilities (Guerin, 2002, 2009). Problems associated

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with working close to marine waters are the risks from loss of containment from such facilities and the resulting loss of aquatic life and negative impacts on marine ecosystems. Operational personnel must also be trained in the risks and the specific controls to prevent fluid releases and emergency procedures where preventative measures fail. While biodegradable refined products are increasingly gaining popularity in marine and related applications (Mercurio et al., 2004), spills into marine waters (regardless of purported biodegradability), attract heavy fines and pose unacceptable risks to operator (owner) companies. Diesel on the other hand, is a "light oil" and small spills of 2–20 kL will usually evaporate and disperse within a day or less in ocean environments. For larger spills, a residue of up to one-third of the amount spilled will usually remain after a few days. Diesel will not sink or accumulate on the seafloor, except as a result of adsorption to sediment, but is considered to be one of the most toxic oils to water-column organisms and fish kills are possible if large spills occur in non-readily mixing water. Light oils contain moderate concentrations of soluble toxic compounds, and can leave a film or layer in the intertidal zone with the potential to cause long-term contamination (Anonymous, 2011). A very effective clean-up is possible for spills of light oil such as diesel. In Australian states, there are stringent reporting guidelines for handling and managing spills onto marine waters.

The site on which the current spill study is focused is a small island off the coast of North West Western Australia which has been joined by a causeway to another island, which in turn is also connected to the mainland (Fig. 1). One of the most common habitats on the coast of this region is the widespread array of rocky shores, developed along wave exposed portions of islands such as the impacted site on the small island in the current study. Significant Aboriginal rock art sites occur on many of the nearby rock-pile islands, and the peninsula (Jones, 2004). Several of the beaches on nearby islands are also important marine turtle nesting sites and migrating shore birds utilize the salt marshes, extensive mud flats and intertidal reefs. The fauna of the upper shores is sparse, dominated by littorinid snails and grapsid crabs. The intertidal region has a diverse fauna dominated by silt-size sediment consists of 30% carbonate and 70% siliciclastic sediment. Benthic skeletal fragments include mostly bivalves, gastropods, sponge spicules, foraminifers, and bryozoans (Jones, 2004). The climate of the peninsula is tropical semi-desert and pseudo-monsoonal tropical and arid or tropical arid. The climate is severe, temperatures may be high, rainfall is erratic and low, and evaporation exceeds it throughout the year. Rainfall is seasonal but very unreliable. The region is unique within Australia in that it is the only marine environment adjacent to an arid tropical terrestrial environment. Rocky shores are the most common habitat in the region. The coastline is largely Precambrian igneous rock, but in some areas there is an overlay of Pleistocene limestone (Jones, 2004).

2. Purpose

The purpose of the current study was to design, construct and operate a process to remove spilt diesel entrapped in a rock fill and, to eliminate this source of the diesel, so as to avoid ongoing pollution of the marine environment. The implemented treatment strategy was required to eliminate the ongoing release and subsequent formation of a petroleum hydrocarbon sheen on the water, and in so doing, meet the critical regulatory criteria.

3. Materials and methods

3.1. Review of geographic information

Key information on the region in which the mining operation had its jurisdiction and where the spill occurred was identified from the literature, from site visits that were held to collect geographic information prior to and throughout the treatment period, and during a corporate audit. This was assessed in the context of designing and planning a full scale, practical and low-cost treatment option.

3.2. Site location and assessment

The site was located on a small island connected via a causeway to the mainland, on a rocky outcrop on the North West Western Australian coastline, used for loading mined product onto ships (Fig. 1). The principal product being mined was salt (sodium chloride) and the operation was undergoing earthworks to expand the evaporation area of the mine, and to improve roads across the mine and port loading facilities (Table 1 refer to Supplementary Material – e-component) at the time of the spill. The spill location was on the top of a rock fill area approximately 8 m above the low tide mark. The coastline was exposed to a large daily tidal movement of approximately 5–6 m. During king tide events (1–2 per year) the tidal variation increased to approximately 7–8 m.

3.3. Plant, equipment and spill source

A refuelling bay (within concrete secondary containment) was located on the eastern edge of the island, on top of the rock fill area (Fig. 1). An above ground diesel storage tank (30 kL) was located in the refuelling area. During the peak of the construction expansion works, the diesel tank was refilled from a land-based tanker fortnightly. A grader and excavators (for road construction), and bulldozers (for stockpile movement) were being refuelled from the same refuelling bay. Table 2 (refer to Supplementary Material – e-component) describes the types of activities across the entire operation that are potential sources of contamination.

3.4. Root cause analysis of spill

Internal investigations (by the site owner) identified that the cause of the spill was the release of 7000 L of diesel during the refuelling operation of a grader undertaking road construction activity near the stockpile. Only limited information was made available on the cause of the spill. The author became aware of the spill when advised by the site owner, in addition to the requirements for analytical and remedial works (as specified by the government environmental regulator), approximately 24 months after the spill event.

3.5. Shoreline sediment and rock fill sampling

After a consideration of the intractability of the shoreline and above lying rock fill, a purposive sampling plan was developed. This plan required collection of samples from the area immediately below the spill location (or spill zone), a 40 m^2 area including representative samples from the upper, middle and lower intertidal zones (Fig. 2). Samples were collected in a directed (purposive) manner so as to represent the size fraction of −50 mm, and to ensure the most visibly contaminated material was collected, reflecting the practical objectives of this study (to ensure cost-effective remediation of the diesel spill). This sampling (in the depth range of 0–15 cm) included small rocks, stones, sand, fines and the residual liquor. Sediment and rock fill samples were collected from the intertidal area up to a distance of 200 m away from the center of the spill zone. Fig. s2b (refer to Supplementary Material – e-component) sets out the locations from where samples were taken.