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Factors influencing recovery and restoration following a chemical incident

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ABSTRACT

Chemicals are an important part of our society. A wide range of chemicals are discharged into the environment every day from residential, commercial and industrial sources. Many of these discharges do not pose a threat to public health or the environment. However, global events have shown that chemical incidents or accidents can have severe consequences on human health, the environment and society. It is important that appropriate tools and technical guidance are available to ensure that a robust and efficient approach to developing a remediation strategy is adopted. The purpose of remediation is to protect human health from future exposure and to return the affected area back to normal as soon as possible. There are a range of recovery options (techniques or methods for remediation) that are applicable to a broad range of chemicals and incidents. Recovery options should be evaluated according to their appropriateness and efficacy for removing contaminants from the environment; however economic drivers and social and political considerations often influence decision makers on which remedial actions are implemented during the recovery phase of a chemical incident. To date, there is limited information in the literature on remediation strategies and recovery options that have been implemented following a chemical incident, or how successful they have been. Additional factors that can affect the approach taken for recovery are not well assessed or understood by decision makers involved in the remediation and restoration of the environment following a chemical incident. The identification of this gap has led to the development of the UK Recovery Handbook for Chemical Incidents to provide a framework for choosing an effective recovery strategy. A compendium of practical evidence-based recovery options (techniques or methods for remediation) for inhabited areas, food production systems and water environments has also been developed and is included in the chemical handbook. This paper presents the key factors that should be considered when developing a recovery strategy with respect to how these may impact on its effectiveness. The paper also highlights the importance of these factors through an evaluation of recovery strategies implemented following real chemical incidents that have been reported in the literature.

1. Introduction

Chemicals have an important role for the development of human society (Peña-Fernández, 2011; Peña-Fernández et al., 2013, 2014; Russell and Simpson, 2010; Wong et al., 2012). Conversely chemical accidents or incidents, though infrequent, can occur with severe consequences on human health, the environment and society (Duarte-Davidson et al., 2014; Peña-Fernández et al., 2013). In recent decades, high profile chemical incidents have led to increased recognition of the public health impact and the need for developing an effective recovery strategy in the aftermath of a chemical incident. Information on chemical incidents that have impacted on communities and have required remediation and restoration of the environment has been reviewed by Wyke-Sanders et al. (2012a) and some examples are presented in Table 1.

During the 1970's and 1980's different governments focussed their efforts on chemical safety to strengthen national capabilities including safety of production, storage and transport of chemicals. As a result, legislation (Regulation (EC) (1907/2006)) has been implemented across the EU to control and manage chemicals with the aim of protecting human health and the environment. More recently, attention and resources have focused on improving emergency response and, as a result, the plans for responding to such incidents are better defined, exercised and updated regularly (Chilcott, 2014; Hemsley, 2013).

However, the recovery and restoration process is not as well defined or practised, and until recently there were no specific guidelines to help decision makers with tailoring an effective remedial response. The UK Recovery Handbook for Chemical Incidents (UKRHCI) (Wyke-Sanders et al., 2012a) has been developed to o address this gap and to provide scientific and technical guidance to help inform decisions on the recovery and restoration of contaminated environments (Wyke-Sanders et al., 2012a, b).

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Table 1
Chemical incidents and accidents requiring extensive remediation.

Date	Country	Circumstances of incident	Incident summary	Remediation strategy summary
1976	Italy (Seveso) Fortunati, 1986. Ramondettaand Repossi, 1998	Industrial accident	The accident occurred at a chemical plant in Seveso (Northern Italy) manufacturing pesticides and herbicides. A reactor vessel used in the production of 2,4,5-tricholorophenol (TCP) had a safety plate rupture causing the release of a dense vapour cloud which contained chlorinated phenols and 2,3,7,8-tratrachloro-dibenzo-para-dioxin (TCDD) *commonly known as dioxin*. This resulted in an immediate contamination of ten square miles of land and vegetation. More than 600 people had to be evacuated from their homes and as many as 2000 were treated for dioxin poisoning.	Significant remediation of the affected area was required in several stages, including managing contaminated animals and farmland, contaminated soil, buildings and the factory plant itself. Strategies included; Implementing restrictions on animal breeding and entry into the food chain, administering supplements to concentrate rations and chelation therapy to animals. Soil washing, irrigation, ploughing in of standing crops, and biological degradation/decomposition were also implemented.
1978	USA (New York) Fletcher, 2002	Historical contamination	Over 21,000 tonnes of various chemical wastes were dumped at a 16 acre site from 1942–1952. The landfill site was extensively developed (including houses and a school) in 1953. Problems with odours and residues were reported in the 1960's increasing in the 1970's as the water table rose bringing contaminated groundwater to the surface. In 1978 a state of emergency was declared and 950 families were evacuated. In 1980 neighbourhoods adjacent to the site encompassing 350 acres were identified as contaminated as and an Emergency Declaration Area (EDA) was established.	Remediation was conducted in seven stages: initial actions and six major long-term remedial action phases, focusing on; 1) landfill containment with leachate collection, treatment and disposal; 2) excavation and interim storage of the sewer and creek sediments; 3) final treatment and disposal of the sewer and creek sediments and other Love Canal wastes; 4) remediation of the elementary School soils and removal of EDA soil 5) Permanent relocation from residential areas (compulsory purchase of 260 homes and other properties in the EDA) 6) Repair of a portion of the Love Canal cap. As a result of the landfill containment, leachate collection and treatment, groundwater monitoring and the removal of the contaminated creek and sediments and other clean-up efforts, the site is no longer a threat to human health and the environment.
1996	Wales (UK) Edwards and White, 1997. Colcomb et al., 1997. Lee et al., 1997. I.	Transport accident	On the evening 15/02/1996, the tanker Sea Empress ran aground on rocks at the entrance of Milford Haven harbour in south west Wales with more than 130,000 tonnes of light crude oil. Over the next week an estimated 72,000 tonnes of crude oil and 360 tonnes of heavy fuel oil were released into the sea, contaminated around 200 km of coastline. The main coastal (south coast of Pembrokeshire) cities affected were Milford Haven, Pembroke Dock, Tenby, and Saundersfoot, that suffered strong smells and complaints of symptoms from residents.	Several protection and remediation options were selected such as the implementation of an order under the Food and Environment Protection Act, ban on fishing, and a two cleaning process. The first cleaning/removal process on the shoreline involved about 1000 workers that removed the bulk oil from accessible shores and beaches, giving priority to the public and touristic beaches. The bulk oil involved on sand was scraped into trenches using vehicles fitted with rubber scraper blades and manual scrapers and was recovered using tractor and vacuum trailer units. The beaches affected were cleaned with high volumes of seawater at low-pressure to avoid pushing oil into the substrate. The secondary cleaning/removal involved different processes according to the characteristics of the beaches affected. For example, the oil adhered to rocks was removed manually by brushing or scrubbing in rocky shores. All wastes collected were processed in a nearby refinery.
1998	Aznalcóllar (Andalusia, Spain) Garrido, 2008; Peña-Fernández et al., 2013	Accidental industrial	The Aznalcóllar tailings dam at Boliden Apirsa's Aznalcóllar/Los Frailes Ag-Cu-Pb-Zn pyrite mine is an open-pit massive sulphide deposit located approximately 45 km west of Seville, Spain. On 25 April 1998 a retention wall of the tailing dam of the Aznalcóllar pyrite mine collapsed, resulting in the spillage of approx. 4 million m^3 of acid mine drainage and 2 million m^3 of toxic mud rich in heavy metals. Over the following days the spill flowed down-stream of the Agrio and Guadiamar rivers and threatened the Doñana Natural Park, a UN World Heritage Area and the largest reserve of bird species in Europe. A total area of 4286 ha was covered by a mud layer averaging 7 cm thickness, being 2557 ha devoted to agriculture activities. The agricultural soils and sediments along the river course were severely impacted by potentially highly toxic elements such as As, Cu, Cd, Pb, Zn and other sulphide-related trace elements.	Immediately after the mining accident, the Regional Administration (Junta de Andalucía) established and Emergency Actions Plan whose purpose was attenuation of the environmental and socio-economic effects and prevention of potential health risks. Extensive clean-up measures were applied just after the accident, and a surveillance system was created to protect the general population and workers who participated in the removal of the sludge. The programme of health monitoring included the control of both food and water consumption in the areas adjacent to the affected zone. A total of three cleaning/removal processes were applied as short-term remediation options for the contaminated ecosystem. However, more remediation and restoration measures were necessary. Thus, a long-term programme of phytoremediation has been implemented known as "*Ecological Green Corridor of Guadiamar*". Besides all the remediation options applied, large areas of soil and sediment still remained contaminated.

Within the context of this handbook, recovery is defined as the process of rebuilding, restoring and rehabilitating the community following an emergency (Strategic National Guidance, 2012). Actions need to be undertaken during the recovery phase, to promote an early return to 'normal living' (Nisbet et al., 2009). Therefore, a recovery strategy should consider, not only the expected consequences of implementing the strategy (e.g. the averted or reduced exposure, resources required including costs, likely duration, level of disruption), but also how the implementation of the strategy will contribute to the re-establishment of 'normality'.

Effective remedial actions must be based on credible understanding of processes that contribute to pollutant's fate, transport and accumulation (Thomann, 1995). However, limited evidence exists on the efficacy of recovery techniques implemented after chemical incidents due to insufficient documentation on what worked and what didn't work during the restoration of environments (Neuparth et al., 2012).

Human and environmental factors that may influence the efficacy of a recovery strategy include understanding the characteristics of the contaminated site (e.g. is the area accessible by road?); the physicochemical properties of the chemical involved; and how the chemical behaves