Contaminated site risk and uncertainty assessment for impacts on surface and groundwater

A large number of contaminated sites threaten the water resources worldwide. The means available are insufficient to cover the expenses associated with investigation and remediation at all these sites. Site managers are therefore posed with the challenge of distributing the financial resources available between sites and choosing between the need for further investigation or remediation. This is a question of prioritizing the sites that pose the greatest risk, and it is a matter of making decisions under uncertainty. Both tasks require a structured assessment of the risk posed by the contaminated sites.

In a conventional risk assessment of a contaminated site, risk is evaluated by assessing whether a concentration guideline is exceeded at a specific point of compliance in the water resource of interest. If the guideline is exceeded, it is concluded that the site poses a risk. However, a contaminated site may pose a threat to multiple water resources, or multiple contaminated sites may threaten a single water resource. For more advanced risk assessments, it is therefore relevant to develop methods that can handle this challenge. In this thesis, four contributions are made to the field of contaminated site risk assessment. They include: 1) the use of mass discharge estimates in the assessment of the impact of old unlined landfill sites in clay till geology on multiple water resources; 2) the characterization of the spatial variability and attenuation of the leachate from landfills located in clay till geology and the impact on streams; 3) the characterization of the dominating anthropogenic stressors in headwater streams at catchment scale and 4) the development of a method for assessing the uncertainty in conceptual site models.

Advances in risk assessment methods for contaminated sites have shown that mass discharge estimates are useful when considering the impact of a contaminated site on multiple water resources and between multiple sites. Mass discharge estimates were applied at Risby landfill, an old and unlined landfill located adjacent to Risby stream. Old unlined landfill sites can be especially challenging in a risk assessment context, because they often are located near streams and wetlands, and because the source can be very heterogeneous both with regards to strength and composition. In addition Risby landfill is located in an area with a complex geological setting dominated by clay till. A mass balance approach was developed in order to estimate the impact of old unlined landfills on multiple water resources. The contaminant mass discharge was estimated for three leachate indicators: chloride, dissolved organic carbon and ammonium. From the landfill, the mass discharge of chloride was estimated to 9.4 ton/year. This resulted in an impact on the deep limestone aquifer of 1.4 ton/year. The impact on Risby Stream located down-gradient of Risby Landfill was approximately 31 kg/year, causing elevated concentrations of leachate indicators (chloride, dissolved organic carbon and ammonium) in the groundwater and the stream. Based on the results of the mass balance method, significant spatial heterogeneity was expected in the contaminant mass discharge pattern to Risby Stream. To obtain a better understanding of this impact, a detailed investigation was conducted. The investigation involved an array of methods including studies of the site hydrogeology, groundwater and surface water discharge and landfill leachate composition and distribution. The methods included driven wells, seepage meters, grab samples, measurement of the temperature gradient in the stream bed and samples collected in traditional groundwater boreholes. The detailed investigation revealed considerable variation in source composition, source strength and redox parameters. The variation was caused by the complex clay till geology and the heterogeneous nature of the landfill source. The impact on Risby Stream, based on the detailed investigation, showed significant seasonal variation and was largest during the dry summer season. Only a small part of the contaminant mass discharge in the stream could be explained by discharging groundwater. It is therefore likely that other sources such as seepage from ponds and surface run-off contribute to the impact on the stream. The analysis of the chemical effect of Risby landfill on the groundwater and surface water improved the basis for conducting investigations and risk assessments at landfills located in clay till and adjacent to streams. But they did not take into account the potential effects of the stream ecology, required under the European Water Framework Directive (WFD) (2000/60/EC).

The ecological effect must be studied at the catchment scale, and an approach was developed and applied for the Hove catchment, which contains Risby landfill. The ecological effects of identified anthropogenic stressors were studied in 11 headwater streams. Headwater streams are sometimes disregarded for mitigation activities under the European WFD, despite their importance for supporting the ecological quality in higher order streams. The anthropogenic stressors in the catchment include agriculture, residential settlements (urban discharges) and multiple contaminated sites. In all streams, ecological impacts were documented, including the physical quality of the habitats (hydromorphology), water quality (chemical) and impairment of the benthic macroinvertebrate community. A robust rank-ordering of the anthropogenic stressors, however, could not be made. This suggests that targeted mitigation efforts on single stressors in the catchment are unlikely to substantially improve the conditions these streams. The results of the catchment scale investigation suggest that headwater streams are important to consider in mitigation plans, and need to be evaluated holistically. Risk assessments of contaminated sites are generally associated with large uncertainties, it is important to include these in risk assessment, because this allows for more robust decision-making. Uncertainty in risk assessments originates from multiple sources, including e.g. input and parameter uncertainty, and uncertainties associated with the conceptual site model (CSM). The CSM describes the most important fate and transport processes at the contaminated site in a simplified manner and is used to communicate how the site operates. The complexity of the CSM usually reflects the detail of the investigations. A literature review suggested that the most important type of uncertainty may be the uncertainty concerning the CSM but it is not routinely accounted for. In order to evaluate the uncertainty concerning the CSM, a Bayesian Belief Network (BBN) approach was developed. The approach determines the belief for each of several CSMs that may represent a given contaminated site. This is done based on a variety of data types and/or expert opinion. The method was applied to the Vadsbyvej 16A study site, located within the Hove Catchment. The geology at the site is similar to that at Risby landfill, i.e. dominated by clay till, in which sand lenses and fractures may create a complex network of preferential flow paths. The contaminant source consists of chlorinated solvents (PCE and TCE). Four different CSMs were developed that could potentially represent the contaminated site. Weights for each of the four CSMs were assessed sequentially.

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based on data from three increasingly detailed investigations (a screening investigation, a more detailed investigation, and an expert consultation). This demonstrates that the method is flexible and that the beliefs can be assessed based on different types and levels of detail in the data.

This work has addressed some important challenges in contaminated sites risk assessment and made great advances. These advances are now being applied by regulatory authorities, leading to improved management practices for contaminated sites.

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