EVALUATING POST-REMEDY AND REMEDY-IMPLEMENTATION RISKS AT A PCB-CONTAMINATED SITE: PRACTICAL EXPERIENCES

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ABSTRACT

In order to illustrate the value and challenges of risk-of-remedy analyses, a case study is presented in which risk-of-remedy and post-remedy risk analyses are employed to support the remedy selection for a New Jersey site that is contaminated with polychlorinated biphenyls (PCBs) in both terrestrial and aquatic habitats. Based on the assessment of current and reasonably likely future site conditions, applicable technologies, and regulatory requirements and precedence, the preferred remedy consists of targeted removal/off-site disposal of soil and sediment containing high concentrations of PCBs, with on-site consolidation of soils and sediments containing lower concentrations of PCBs. In addition, consideration has been given to restoring a portion of the Site for limited recreational use.

To ensure that the proposed remedial action would address the human health concerns identified in the baseline risk assessment, a post-remedy human health risk assessment was performed considering the baseline exposure scenarios (workers and trespassers), as well as a post-remedy recreational visitor scenario. Exposure point concentrations for chemicals of potential concern in each exposure unit were recalculated to reflect the targeted off-site removal/on-site consolidation of PCB-containing soils. The analysis showed that predicted risks to all human receptors would be within acceptable target risk levels for the Site, thus indicating that the proposed remedy would be protective of human health. Similarly, to ensure that the proposed remedial action would address the ecological concerns identified in the baseline risk assessment, and would result in the least adverse impact on the ecosystem, a qualitative assessment of net environmental benefits was also performed, considering: (1) residual ecological risks posed by Site contaminants before and after implementation of the selected remedy; (2) changes in the functional values of each habitat expected to result from implementing the proposed remediation; (3) rate of recovery for the biological community following remediation and certainty of that outcome; (4) designated uses impaired during recovery; and (5) the likelihood that the remedy will achieve remedial action objectives. These implementation and post-remedy risk analyses demonstrated that the selected remedial alternative would result in the greatest net human health and environmental benefit among the alternatives considered for the site, including mitigating unanticipated risks to workers and nearby residents during remedy implementation and avoiding costly delays for substantial remedy modifications, habitat restoration, or even abandonment of an incomplete remedy.

INTRODUCTION

The 1990 National Oil and Hazardous Substances Pollution Contingency Plan, as well as several risk assessment guidance documents and guidelines issued by the U.S. Environmental Protection Agency, explicitly cite potential remedy implementation risks as an important consideration in the process of selecting remedies at Superfund Sites. With few exceptions, however, both the regulated and the regulatory communities are firmly entrenched in the baseline risk assessment framework, wherein potential risks to human health and the environment are only considered under the No Action alternative, as part of the remedial investigation. Risk-of-remedy analyses, performed as part of the feasibility study, are among the least used but most powerful applications of both conventional and innovative risk assessment tools, in that they can compellingly communicate the overall benefits and costs of each remedial alternative.
Post-remedy and remedy-implementation risks were evaluated as part of the remedy development process for an active manufacturing facility in New Jersey. The Site occupies 85 acres, of which 30 acres are operational. The Site is bordered by a major river, undeveloped lots, and residential properties. Much of the Site lies within the river’s floodplain, which is dominated by forested wetland habitat. Historically, PCB-containing wastes were used as fill on-site, and metals and PCBs were released to outfall ditches which ultimately drain to the river. Baseline human health and wildlife risk estimates indicated a need for soil remediation in certain areas of the site. No significant baseline risks to aquatic life or aquatic-feeding wildlife were identified for the river, however. Sediment remediation was proposed for one of two active drainage ditches for source control purposes and one former drainage ditch for protection of amphibians.

Two aspects of the feasibility study for on-site soil and drainage ditches are highlighted below. First, a post-remedy risk analysis was conducted to ensure that the soil remedy would be protective of human health and wildlife. Second, a qualitative net environmental benefits analysis (NEBA) was conducted for forested wetland habitat, to draw attention to environmental costs of excavating within this sensitive habitat type.

**POST-REMEDY RISK ANALYSIS**

The development of remedial action objectives for on-site soils initially focused on protection of human health. Based on the results of the baseline human health risk assessment, and a review of regulatory requirements and precedence, the remedy developed for soil included excavation and off-site disposal of soil containing greater than 500 mg/kg total PCBs, and consolidation of soil containing between 25 and 500 mg/kg PCBs within a capped, on-site disposal area located outside the floodplain (Figure 1). In addition, consideration has been given to restoring a portion of the Site for limited recreational use. This remedial approach formed the basis for conducting post-remedy risk evaluations and risk-of-remedy (i.e., implementation risk) evaluations described below.
Human Health Risks

A baseline human health risk assessment was initially performed to evaluate potential health effects due to chemicals in soil and ground water within the delineated limits of soil and sediment contamination. The baseline risk assessment considered current and reasonably likely potential future exposures to Site workers and trespassers, assuming no remedial action is performed. The estimated cumulative risk for each receptor was compared to USEPA’s cancer risk range of $10^{-6}$ to $10^{-4}$ and noncancer hazard index (HI) limit of 1. For workers and trespassers, the estimates of risk from exposures to PCBs in surface soils were above the target cancer risk range and/or above the target noncancer limit. Based on these results, it was concluded that existing soil contamination presents an unacceptable risks to these receptors.

FIGURE 1. Site Features and Remediation Areas

Following the scoping of a remedy for PCB-containing soils and sediments, a post-remedy risk evaluation was conducted to demonstrate that residual contamination remaining on-Site following completion of the remedy would not present an unacceptable risks to current receptors (workers and trespassers) and other future receptors (recreational visitors). The potential exposure routes for each receptor are as follows:
• **Routine Workers** – The largest receptor population at the Site consists of workers who are engaged in routine manufacturing activities. Routine workers could potentially be exposed to surface soil in the developed areas in the future if pavement is removed or not maintained. In addition, routine workers could potentially be exposed to volatile constituents in shallow and intermediate ground water if those constituents volatilize and migrate through cracks in concrete building foundations into indoor air.

• **Outdoor Workers** – Workers perform maintenance activities in the undeveloped areas of the Site and within the limits of the on-site disposal area. Outdoor workers could potentially be exposed to surface soils in these areas.

• **Construction workers** – Workers occasionally perform subsurface utility or pavement maintenance at the Site. Construction workers could potentially be exposed to both surface and subsurface soils. In addition, construction workers could be exposed to shallow ground water.

• **Trespassers** – Potential exposure of trespassers on-site is possible, although fencing and security personnel control access to the Site. Trespassers could potentially be exposed to surface soils in the undeveloped areas and in developed areas if pavement or vegetation is removed or not maintained.

• **Recreational Visitors** – Under the post-remediation site conditions, a softball field could be constructed in an undeveloped, upland area of the Site, including the covered disposal area. A recreational visitor could potentially be exposed to surface soils in undeveloped areas.

The post-remedy risk estimates were calculated based on residual PCB concentrations in soil following removal of soils exhibiting PCB concentrations greater than 500 mg/kg and the consolidation and capping of soils containing PCB concentrations ranging from 20 mg/kg to 500 mg/kg. Thus under post-remedy conditions, direct exposures would be to soils containing maximum PCB concentrations less than 20 mg/kg, with an average exposure concentrations being much less than 20 mg/kg. The results of the post-remedy risk assessment indicated that the risks for all current and likely future receptors listed above would be within USEPA’s acceptable target risk levels, thus indicating that the proposed remedial actions would result in mitigating unacceptable risks identified in the baseline risk assessment.

**Ecological Risks**

The post-remedy ecological risk assessment for soil focused on two representative wildlife species, American woodcock (*Scolopax minor*) and mink (*Mustela vison*). Woodcock are inland sandpipers that inhabit both woodland and meadow habitat and feed primarily on earthworms. Mink are predators typically found near aquatic or wetland habitat but feeding on both aquatic and terrestrial prey. Mink are known to be particularly sensitive to PCBs.

Risks to woodcock were assessed by estimating PCB concentrations in earthworm prey, based on average residual PCB concentrations in surface soil and using a default
bioaccumulation factor (USEPA, 1999). Species-specific exposure parameters were taken from USEPA (1993), and a toxicity reference value was taken from a study of pheasant reproduction following PCB exposure (Dahlgren et al., 1972). With residual PCB concentrations in soil calculated to be less than 2 mg/kg, woodcock were found to be adequately protected.

The risk assessment for mink was more detailed, because a default bioaccumulation factor is not available to estimate PCB concentrations in mink prey. Mink are opportunistic predators, and their diet varies depending on prey availability. Food types that have been observed to comprise a substantial portion of the mink diet include fish, mammals (muskrats, mice and rats, ground squirrels, and rabbits), birds (ducks, other large birds, and eggs), frogs, and plants (USEPA, 1993). Total PCB concentrations in river sediments adjacent to the site are substantially lower than calculated post-remedy soil concentrations, and measured PCB concentrations in fish collected from the river are relatively low. Therefore, to be conservative, the mink diet was assumed to include a substantial terrestrial component. Specifically, mink were estimated to consume 30% fish, 45% terrestrial herbivores (e.g., mice), and 25% higher trophic level terrestrial prey (e.g., frogs).

A literature review was conducted to identify PCB uptake factors for mink prey, focusing on small mammals. Because only a single peer-reviewed data source was identified (Blankenship et al., 2005), “gray” literature was also explored (McKee, 1992; Moore et al., 2003; ARCADIS, 2004; LANL, 2004). Shrews were found to exhibit greater PCB bioaccumulation than other small mammals (Figure 2), presumably because they are carnivorous, whereas the other small mammals sampled are primarily herbivorous. Although shrews are distasteful and are not typically consumed by predators (Gottschang, 1981), they serve as a surrogate for other higher trophic level prey species. Uptake factors identified from Figure 2, together with measured fish tissue data and species-specific exposure parameters (food ingestion rate, body weight), served as the basis for estimating dietary exposure of mink to PCBs.

A toxicity reference value for mink was identified from data compiled by Fuchsman et al. (2007). Among more than 50 tests measuring PCB exposure and mink reproductive success, toxicity was never observed at concentrations below approximately 50 µg total PCBs per kg body weight per day (µg/kg-day) (Figure 3). Note that a less variable dose-response relationship is observed when the composition of PCB mixtures is available to estimate internal doses of exposed mink (Fuchsman et al., 2007); however, such information is not available for terrestrial areas of the Site. The toxicity reference value used here is thus highly conservative, because in
many cases higher PCB doses did not adversely affect PCB reproduction. Comparing the estimated post-remedy dietary exposure to the conservative toxicity reference value, the proposed soil remedy was found to be protective of mink.

**NET ENVIRONMENTAL BENEFIT ANALYSIS**

The removal of contaminated sediment and soil has intuitive appeal: if PCBs and metals are removed and capped, they should no longer bioaccumulate within the food web, and chemical exposures and resultant ecological risks should be reduced. However, no available technology can remove every particle of contaminated sediment or soil, and removal technologies may in themselves impact ecological habitat. A qualitative NEBA was conducted to evaluate ecological impacts associated with the proposed remedy for the study area by comparing existing (i.e., baseline) ecological conditions with those of the remediated ecosystem. The goal of the NEBA was to determine whether the proposed remedy will yield a positive net environmental benefit, once the ecological harm caused by the remedial activities is weighed against the potential harm that would be caused by the continued presence of chemical contamination at the study area. The NEBA findings for forested wetland habitat are described below.

*Functional Value of Existing Habitat*

Approximately 18 acres of wetlands are located within the study area and along the river. The wetlands are drained by constructed but unlined drainage ditches associated with two permitted outfalls. A third, former outfall area now consists of intermittently inundated pools surrounded by forested wetland habitat.

The majority of the study area’s wetland habitat is mature bottomland hardwood forest. Forested wetlands are dynamic systems with distinct ecological functions that take hundreds of years to develop. Forested wetland functions relate to hydrology, water quality, and habitat. Factors such as climatic conditions, quantity and quality of water entering the wetland, and natural and manmade disturbances affect how well a forested wetland performs each function.

Hydrology is the main driving force in forested wetlands (Sharitz and Lee, 1985; Wharton et al., 1982). Key hydrologic functions of forested wetlands are surface and subsurface water storage (i.e., flood control and ground water recharge). Surface water storage helps prevent flooding by temporarily storing water, allowing it to soak into the ground or evaporate.

**FIGURE 3. Dose-response relationship for mink exposed to PCBs**

![Graph showing dose-response relationship for mink exposed to PCBs.](image)
Water quality functions relate to water filtration and purification, nutrient cycling, particulate removal, sediment stabilization, and sediment and chemical retention. Water quality is improved by wetlands through the removal of nutrients, pesticides and other chemicals, and bacteria from surface waters as they are absorbed or broken down by plants, animals, and chemical processes within the wetland. Wetlands enhance the decomposition of organic matter, incorporating nutrients back into the food chain. By filtering out sediments and particles suspended in overland runoff water, wetlands reduce downgradient sediment loading, resulting in improved downgradient water quality.

Habitat functions of wetlands include growth of living matter and maintenance of ecological communities by providing food, water, shelter and breeding habitat for flora and fauna. The alternating wet-dry cycle characteristic of periodically flooded bottomland forests drives the decomposition of organic matter, producing detritus and other particulate organic matter critical to primary and secondary production. This productive and organic-rich environment with ample breeding and foraging habitat typically supports a highly diverse biological community. Floodplain forest also contributes to the quality of adjacent aquatic habitat, by providing shade and serving as a source of woody debris, an important substrate for aquatic animals.

Ecological Benefits of Remediation

Elevated concentrations of PCBs in forested wetland soils may adversely affect woodcock and mink. Excavation of some forested wetland soils is expected to reduce average exposures to levels that will not cause deleterious effects. Thus, the ecological benefit of the proposed remedy is reduced toxicity to wildlife populations. The principal ecological benefit of any remedial action within the former outfall area relates to the reduction of potential risks to amphibians. Because current PCB concentrations in the former outfall area are close to the low end of the range of protective concentrations, any PCB-related risks are likely limited. However, because risks to amphibians due to metals in the former outfall area sediment are uncertain, some ecological benefit would be realized by excavating former outfall area sediment.

Ecological Costs of Remediation

Ecological costs incurred by excavation would result from:

- **Removal of vegetation** – Dredging would require removal of terrestrial vegetation, both in excavated areas and along access corridors. The existing vegetative structure would not likely be reestablished for decades, even after restoration.

- **Increased habitat patchiness** – Removal of vegetation would create disturbed corridors that would increase habitat patchiness and the amount of edge habitat. Such changes generally decrease wildlife diversity and allow expansion of invasive species.

- **Modification of microtopography** – Because topography influences hydrology, which in turn drives bottomland forest ecology, the success of restoration of the forested wetlands is uncertain.
• **Aquatic habitat degradation** – Tree removal exposes the river to direct sunlight and reduces the supply of woody debris to the river. Decreased density of benthic invertebrates translates to reduced food sources for certain fish and wildlife.

The costs of habitat alteration within the forested wetland will be commensurate with the extensiveness of remediation. Thus, remediation and restoration activities within the forested wetland will need to be carefully planned and executed in order to minimize adverse effects on the bottomland forest habitat and ecology. Further, additional wetland impacts associated with any potential increase in the scope of remediation should be considered by risk managers when reviewing the desired margin of safety for ecological receptors.

**CONCLUSIONS**

Post-remedy risk analyses were useful in demonstrating that a remedy leaving some PCB-containing soils in place will be protective of human health and the environment. The analysis of remedy-related effects on forested wetland habitat is expected to inform both the risk management process and the selection of remedial technologies. Ultimately, the focus on optimally balancing risk reduction and wetland protection should result in a remedy that is both environmentally and economically efficient.

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**REFERENCES**


