This is a paper presented at Dioxin 2012, 26-31 August 2012, Cairns, Queensland, Australia.

Citation for the published paper:

The need for inventories of reservoirs of persistent and toxic substances (PTS) in the face of climate change
URL: http://www.dioxin20xx.org/ohc_database_search.htm
THE NEED FOR INVENTORIES OF RESERVOIRS OF PERSISTENT AND TOXIC SUBSTANCES (PTS) IN THE FACE OF CLIMATE CHANGE


1POPs Environmental Consulting, Ulmenstrasse 3, Göppingen, Germany, 2Department of Chemistry, Umeå University, Sweden, 3Institute for Water Quality, Resources and Waste Management, Vienna University of Technology, Karlsplatz 13, 1040 Wien, Austria; 4Public Interest Consultants, Swansea, UK, 5International HCH and Pesticides Association (IHPA), Elmevej 14, Holte 2840, Denmark

Introduction

Persistent Organic Pollutants (POPs) and other Persistent Toxic Substances (PTS) have accumulated in landfills, dumps, stockpiles contaminated sites and in soils and sediments mainly over the last century1-3. These reservoirs of POPs/PTS present a challenge to society and, if they are not adequately addressed, are a threat to present and future generations1-3. The more soluble POPs/PTS such as PFOS/PFCs, hexachlorocyclohexane (HCH), but also polychlorinated biphenyls (PCBs) and Hexachlorobenzene (HCB), along with heavy metals are a major pollution challenge in this respect. Historically, chlorinated POPs were mostly related to pesticides or industrial uses (such as PCB) and over the past decade Stockholm Convention initiatives (www.pops.int) have established inventories and initiated the management of these stockpiles and wastes. Fluorinated, brominated and other PTS are now increasingly produced4 and used in consumer goods. This production and associated discharges of POPs/PTS has polluted soils and sediments around the factories3,5.

As products containing these chemicals reach the end of their life these hazardous compounds end up in the waste stream. Even today most developing, and some developed, countries have very limited recycling, treatment and destruction capacity and many countries have relied heavily on sanitary landfills or even dump sites. Consequently the quantities of POPs/PTS in municipal waste landfills has increased over the last two decades and these sites are joining chemical landfills and other POPs contaminated as reservoirs of POPs. There are not yet any comprehensive estimates of which reservoirs (landfills, contaminated sites, contaminated sediments and contaminated soils) contain the largest POPs inventory or which present the largest risk for future releases.

Because of their persistence and relative mobility, however, these compounds will persist in these reservoirs for extended time-frames and probably for centuries4. Furthermore it has been established that a wide range of chemicals which are generally considered ‘non-persistent’ degrade only very slowly in landfills and are a source of continuing releases5. Other chemicals can act as POPs precursors in landfill conditions and thus increase the hazards from future discharges1a,6a. Over these extended timescales, consideration needs to be given to the impacts of climate change and extreme weather events. This is likely to include increased flooding, posing problem with the integrity of the containment systems, and likely increasing the rate of future leakage from landfills1 as well as increasing the mobilisation of pollutants from soils and sediments6b. Furthermore the sea level is expected to rise nearly a metre by 2100, together with storm surges between 10 and 20 times more frequently, and this will inevitably result in permanent flooding of some coastal areas. Low lying inland areas will also risk inundation7. Landfills and contaminated sites in these areas can be expected to be compromised by these changes.

The current paper highlights the importance of the known and potential releases of POPs and other PTS from reservoirs and emphasises the importance of urgently developing national inventories of such sites; of assessing the flooding risks considering the impact of climate change scenarios; and assessing the related impacts on the safety of food and drinking water.

Results and discussion

Considerations on POPs & PTS in landfills and dump sites

A large proportion of historic POPs have been disposed in landfills1a,3 or remain in contaminated sites1b. Over extended time frames landfill engineering systems, including basal and capping liners together with gas and leachate collection systems, will inevitably degrade and loose their abilities to contain contamination. Climate
change is likely to result in higher temperatures, increasing the volatalisation of semi-volatile and volatile compounds. In some areas, higher UV exposure with longer periods of low rainfall may enhance drying or dessication of surface (or liner) caps, increasing erosion and cap failure giving more opportunity for the escape of gases together with higher infiltration of precipitation into waste deposits. In other areas, higher intensity rainfall events and increased flooding can be expected to impose risks on the integrity of landfill containment systems and depending upon the lining system, may result in increased leachate production and leakage. It is therefore, likely that climate change and warming will cause higher levels of leaching into ground or surface water and to the atmosphere by volatilisation thus ultimately contaminating rivers, lakes and the larger environment.

Selected case studies on POPs and mobilisation
A number of cases have been documented in recent years linking POPs releases to flooding and examples include:

Experience with PCB
In recent years the Swiss government has screened their entire river systems and has compiled more than 1,000 fish sample data to establish levels of PCB contamination. For two rivers (Saane and Birs) the fish were frequently found above EU dioxin-like PCB limits for human consumption. For the Saane River the source of the contamination was found to be a landfill (La Pila) which contains approximately 20 t PCB (in e.g. condensers) distributed within 270,000 m³ waste. This site was – and still is - regularly flooded after heavy rain events. The landfill is currently being remediated with an estimated cost of €9 million for the initial steps (http://admin.fr.ch/pila/).

Experience with HCH in deposits
Between four and seven million tonnes POPs HCH waste have been deposited/dumped around historic lindane production sites. Isomers of HCH exhibit moderate to high water solubility and moderately high vapour pressure and can therefore enter the environment by volatilisation into the atmosphere and/or by leaching into ground and surface water. This migration has, over time, turned some HCH waste deposits into POPs contaminated megasites with much larger pollution footprint in soil and ground water than the original landfill/dump. In the case of the Elbe where four lindane/HCH production sites are located increased HCH levels were observed in fish after the 2002 flooding around production sites.

Experiences with HCB in landfills
More than 11,000 tonnes of HCB by-product from a carbon tetrachloride/tetrachlorothene manufacturer in Kalush (West-Ukraine) has been dumped in a landfill site very close to the Sivka River. A Joint United Nations – EU Commission Environmental Emergency Response Mission visited the site in early 2010 to evaluate the risk of leaching into Sagopiv river a tributary of the Dniester River which is a major water resource of West Ukraine and Moldova. Also other landfills and contaminated sites have impacted or are impacting European rivers with HCB and other POPs.

Case study DDT production at Lago Maggiore tributary
A DDT production facility located on a tributary to the Lago Maggiore contaminated the lake with DDT and mercury. A large water treatment plant was constructed end of the 1990s. The plant functioned successfully and minimised discharges of contaminants from the production site to the river (and lake) during normal day-to-day operations. In October 2000, however, a heavy flood occurred and lake waters exceeded the maximum flooding level of about 2.5 m for 10 days, the highest levels in the 20th century. During this period DDT residues were transported from contaminated soils and river sediments into the lake. This was confirmed by the increase of DDT content in water and sediments in Baveno Bay and inflowing river downstream of the chemical plant. Another study compared DDT concentrations in the soft tissues of zebra mussel at several sampling stations after 2001 with those collected at the same sampling stations in the preceding years. The results confirmed increased DDT pollution due to transport from contaminated sediments and soils still present in the closed chemical plant site. The flooding event and further work revealed that capacity of the first groundwater treatment plant (400 m³/h) was too small to cope with heavy rain events and it had been necessary to enlarge the plant to a capacity of 850 m³/h in a second construction stage in 2001.
Contamination of soil and sediments and transfer from land to rivers/sea

Sediments and soils are important reservoirs for POPs\textsuperscript{2a,b}. Industrial activities, and thus associated contaminated sites, are often located on rivers\textsuperscript{13} and coasts due to their needs for process and cooling water as well as effluent discharges. Extreme weather events, especially flooding, significantly increase the risks of soil to sediment transfer of contaminants from these sites. It is not only the contaminated mega sites\textsuperscript{10,10-11} that are relevant but urban areas with mixed industrial activities will also contribute to a shift of contaminants from land to rivers and the sea. One example reported by Sundqvist et al.\textsuperscript{18} is the release of PCDD/Fs from saw mills to the Bothnian Sea in the Baltic. In this case fingerprint analysis clearly demonstrated that the source composition of PCDD/Fs found at saw mill historic PCP-preservatives use can be found in the upper core of sediment samples\textsuperscript{18}. Increased flooding events and associated run-off will significantly contribute to this.

The challenge of managing polluted sediments is well documented for rivers such as the Rhein\textsuperscript{5,19c} and Elbe\textsuperscript{5,13}. The river sediments, especially close to the sea or open water (notably Rotterdam and Hamburg harbours), need to be carefully managed – and this is an expensive process\textsuperscript{5,19c}.

Linking (potential) pollution sources with impact on food and drinking water supply

Reservoirs of POPs have a current and important impact on food contamination\textsuperscript{10,16,20,21}. Mobilisation by flooding\textsuperscript{1a,6a,9,12,16,21} and by construction measures, including sediment dredging or by landfill mining\textsuperscript{13}, are mechanisms for increased releases. These releases of contaminants into the aquatic chain can lead to increased exposure and subsequent bioaccumulation of contaminants in fish and other aquatic foods\textsuperscript{10,9,12,18}. Increased leaching and (partial) erosion of old municipal solid waste landfills during flood events has been found that approximately one third of the old and active sites are potentially at risk yet 95% of these sites have no flood protection measures in place. It has recently been shown that contaminants in sediments transferred to flood plains can contaminate grazing animals both directly and via fodder\textsuperscript{21}. Depending on the water solubility of the contaminant drinking water can also become impacted (e.g. for PFOS/PFCs or the more water soluble chlorinated organics like HCBD, PERC or Vinyl chloride) either via surface or groundwater contamination\textsuperscript{5,19a,b,c}.

At the same time human reliance on water resources and food (including fish) supply will increase with growing population. Therefore the current and potential future impact of POPs/PTS deposits and contaminated sites towards food and drinking water safety need to be assessed considering the impacts of climate change and particular the higher risks from flooding events and increasing sea levels.

National approach of inventory of landfills considering flooding risk

Increased leaching and (partial) erosion of old municipal solid waste landfills during flood events has been observed in Austria\textsuperscript{14}. As a result an inventory of these landfills has been established\textsuperscript{15}. The potential risk of the sites flooding was evaluated using national flood risk zone data and a 1 in 200 years event threshold \textsuperscript{15}. It was found that approximately one third of the old and active sites are potentially at risk yet 95% of these sites have no flood protection measures in place. It has been claimed that the release of typical contaminants from these landfills during flood event is not a major environmental concern. However these conclusions are less likely to be robust for POPs with their tendency to migrate and then bioaccumulate or for hazardous and chemical landfills with different substance inventories. In general, there is little knowledge about the emission behaviour of landfills under flooded conditions and current data do not allow for realistic estimates of substance mobilisation rates from the waste under such conditions. This is even more pronounced for emissions in the aftermath of flooding, as biochemical reactions in the landfill body can be promoted by the ingress of water during flooding. Therefore, in addition to national flood risk inventories for landfills, efforts to investigate mobilisation processes for problematic substances contained in the deposited waste during and after the flood event are needed to assess environmental risks associated with flooded landfills.

Future steps

In order to evaluate the associated risks for human exposure and exposure to ecosystem via exposure pathways resulting from POPs/PTS deposit releases, inventories of POPs and PBTs reservoirs need to be established. Their locations should be comprehensively mapped and matched with future flooding scenarios to predict potential contamination of food and resources and to assess risks of exposure for humans and biota. Further remediation plans should be developed after being informed by this inventory and related assessment.

This interdisciplinary task will require the co-operation between the Government’s Environment, Agriculture and Industry Ministries, POPs/PTS researchers, geotechnical engineers, contaminated site/landfill experts, water management specialists and possibly geo-scientists working on climate change and flooding.
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