

# Public health impacts of floods and chemical contamination

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## Abstract

**Introduction** Flooding accounts for about 40 per cent of all natural disasters that occur worldwide. In 2002–2003 many counties in England experienced severe floods. Floods are particularly important in public health terms as they may have multiple environmental consequences.

**Methods** Details of floods reported to Chemical Hazards and Poisons Division, London [CHaPD(L)] were analysed and a literature review was undertaken to identify published reports of flood-related chemical incidents that have had an impact on public health.

**Results** Epidemiological evidence shows that chemical material may contaminate homes and that in some cases flooding may lead to mobilization of dangerous chemicals from storage or remobilization of chemicals already in the environment, e.g. pesticides. Hazards may be greater when industrial or agricultural land adjoining residential land is affected. Less evidence exists to support the hypothesis that flooding that causes chemical contamination has a clear causal effect on the pattern of morbidity and mortality following these flooding events.

**Conclusion** In the light of this evidence, a checklist/pro forma for public health response to and investigation of flooding events that may result in chemical contamination was needed. This is available from CHaPD(L).

**Keywords:** flooding, chemical, health, contamination, risk, pollution

## Introduction

Flooding accounts for about 40 per cent of all natural disasters that occur worldwide making it probably the most common natural disaster.<sup>1</sup> These are particularly important in public health terms as they may have multiple environmental consequences. These may include direct contamination of homes and other buildings, contamination of drinking water sources with either infectious or chemical material and disruption of sewage systems (residential and industrial) and of its domestic collection and disposal. The mobilization of chemicals either from storage (e.g. underground fuel tanks) or by remobilization of chemicals already in the environment, e.g. pesticides, may occur during floods.<sup>2,3</sup> The hazards may be greater when industrial or agricultural land adjoining residential land is affected.<sup>4</sup> Flooding could also potentially increase the amount of chemicals that

run off from farms, lawns and streets into rivers, lakes and coastal waters.<sup>5</sup> In addition Ohl and Tapsell<sup>6</sup> suggest that increased morbidity following a flood may result from heightened psychological stress.

In the autumn 2000, *The Times* reported that the Environment Agency (EA) had issued 14 severe flood warnings across 11 rivers, and a further 200 lesser warnings. Approximately 3000 homes had already been flooded and the EA was expecting things to get worse because large geographical areas had been affected. The Association of British Insurers estimated that between 950 000 and 1.2 million homes are in flood risk areas.<sup>7</sup>

Primary Care Trusts (PCT) and the Health Protection Agency (HPA)<sup>8</sup> have a statutory responsibility to protect the public's health from environmental hazards. However, public health professionals may have limited experience in chemical incident management. Consequently, there is a need for guidance and procedures to help public health professionals in chemical incident management. These procedures will allow a more timely, effective and coordinated response to be provided in the event of a chemical incident, in order to protect both public health and the environment. In the autumn of 2000 such procedures covering the broad scope of chemical incident management following a flooding event did not exist. Therefore, the aim of this paper was to evaluate the significance of public health risks from chemical contamination following flooding. We have reviewed in depth three recent floods related to chemical incidents in England and undertaken a literature review of flooding events that resulted in chemical contamination in order to develop a checklist to assist public health professionals.

## Methods

The specific research objectives were: (1) to perform a literature review (1960–2002) to identify published reports of flood-related chemical incidents that have resulted in a public health

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**Table 1** Summary of the epidemiological evidence for adverse health effects following chemical contamination resulting from floods

Flooding type and country	Study design and period	Pollutant and source(s)	Public health outcomes observed	Subject selection criteria	Type of environmental sampling undertaken and results	Reference
1. Unprecedented rains, Iowa, USA, 1993	Telephone survey of 99 county PH officers in the state to assess PH impact of flood	Carbon monoxide poisoning reported by seven counties representing 14% of the state population ( $\pm 2.7$ million)	Seven counties reported carbon monoxide poisoning showing evidence of risk associated with indoor use of generators	All health counties within the State ( $n = 14$ )	None?	MMWR, 1993 <sup>3</sup>
Summer floods, Missouri, USA, 1993	PH surveillance & telephone survey of medical examiners and coroners in 71 disaster counties	Unknown	Dermatitis, rashes	71 disaster counties	None?	Schmidt <i>et al.</i> 1993 <sup>24</sup> ; MMWR, 1993 <sup>2</sup>
2. Hurricane Floyd, North Carolina, USA, 1999	Emergency department surveillance data (20 hospitals in 18 flood affected counties of North Carolina)	Carbon monoxide	Carbon monoxide poisoning reported in 10 cases. Statistically significant increases recorded for dermatitis (RR = 1.4; 95% CI = 1.2–1.6) and asthma (MMWR, 2000)	Emergency department surveillance data	Environmental samples at 75 sites 150 chemicals. Used polyethylene plastic that mimics chemical accumulation in tissue. Negative in waterways for PAHs, pesticides, PCBs and chlorinated pesticides. Positive for hydrocarbons. (Shea and Potter)	Shea and Potter, 2000 <sup>25</sup> ; MMWR, 2000 <sup>26</sup> ; Curry <i>et al.</i> , 2001 <sup>27</sup>
Hurricane Mitch, Honduras, 1998	Public health follow-up of 440 households	Pesticides (chlorinated pesticides and organophosphates), herbicides	Headaches, tiredness/weakness, skin rash, abdominal pain, fever, decreased appetite, chills and nausea. Elevated levels found in biological samples including banned chlorinated pesticides and OPs	440 households (3100 residents) in a badly hit area	Water samples, soil samples, biological samples. Traces of chemicals found in environmental samples, especially land	Balluz and Moll, 2001 <sup>28</sup>
Tropical Storm Alberto, SE USA, 1994	National Water Quality Assessment Program (NAWQA) Survey	Agricultural chemicals	None?	Environmental samples of affected area	Water samples. Elevated levels of pesticides observed	Hippe <i>et al.</i> , 1997 <sup>29</sup>
3. River flood, SW Iowa, USA, 1998	US Geological Survey,	Agricultural chemicals	None?	Environmental samples of affected area	Water samples. Elevated levels of chemicals found	USGS, 2000 <sup>30</sup>
4. Flooded canals, river, Rotherham, UK, 2000	MAFF, NRA surveys pre2000; British waterway survey	Dioxin	None?	Environmental samples of affected area	(1994–1997) Elevated levels of dioxin in river sediment. (2000) Sediment samples elevated concentrations of dioxin observed	NRA, 1994 <sup>31</sup> ; ENDS, 1994 <sup>32</sup> ; MAFF, 1997 <sup>33</sup> ; ENDS, 1999 <sup>10</sup>

Overflowed sewerage system, Greater London, UK, 1998	Biological and environmental	VOCs, heavy metals	Sore throat (OR 11, 95% CI = 2.22–60), eye irritation ( $p = 0.04$ )	Households affected by sewerage ingress, control sample and clean-up team	Soil, water and air bag samples for VOCs and heavy metals	MacArthur <i>et al.</i> , 2000 <sup>34</sup>
5. Chronic mine contamination of agricultural irrigation, Japan, 1950	Environmental and biological sampling	Cadmium, lead, zinc	Itai Itai disease: osteomalacia caused by chronic exposure to cadmium	Communities within 3 km radius of mines	Soil, vegetable and human samples. Results showed relationship between proximity to mines and disease	Kobayashi, 1970 <sup>35</sup> ; Pearson, 1999 <sup>36</sup>
Mine dam flood, Baia Mare, Romania, 2000	Environmental sampling	Cyanide, heavy metals	To be determined, massive fish kill	Environmental samples and community samples	Water samples for cyanide and heavy metals	UNEP, 2000 <sup>37</sup>
Mine dam flood, Aznalcollar Mine, Spain, 1998	Environmental sampling	Acidic waste water, heavy metals, sulphides	Fish kill, gross soil contamination of farm land	Environmental samples of area	Soil samples for heavy metals, water samples	Short, 1998 <sup>38</sup>
Mine flood, Truro, Cornwall, UK, 1992	Environmental sampling	Heavy metals	Contamination of river	Environmental samples of affected area	Water samples for heavy metals	Mine water, waste env. Dis. of recent years, 1997 <sup>39</sup>

impact; (2) to summarize and review three recent flood-related chemical incidents reported in England; (3) to devise procedures to ensure a consistent approach to chemically contaminated flood incident management, which will contribute towards an effective and rapid response.

Incidents with actual or potential human health effects or environmental damage were included. The search was limited to English language articles of incidents that occurred anywhere in the world.

The chosen subject specific search terms were: chemical\*; flood\*; health; risk; contam\*; pollution.

The literature search included English language journal reports, the Internet, and chemical incident databases including MHIDAS, MEDLINE, Toxline and BIDs.

Only flooding events resulting in chemical contamination with the potential to affect public health, either as the primary (soil or water) or secondary media (e.g. homes) or mechanism of contamination were considered. An incident was defined as an event where one or more chemicals were found in land, homes, flooding sediment or water in concentrations above, or suspected to be above, UK or other country water or soil guideline levels and with the potential to cause adverse health effects. Within this definition both acute and chronic threats to public health were included.

## Results

'Incidents' showing evidence of chemical contamination are summarized below as UK case study summaries. Table 1 lists the various categories of possible flooding events, i.e. (1–3) 'naturally occurring' floods and (4–5) 'man-modified' flooding: (1) flash floods following periods of abnormal rainfall locally or within a catchment area; (2) flooding following adverse weather conditions such as hurricanes or tropical storms; (3) flooding following rivers bursting their banks; (4) flooding following overloading of sewers or similar sewer malfunctions; (5) flooding following dam engineering failure.

### Case study summaries of flooding incidents reported to Chemical Hazards and Poisons Division, London [CHaPD(L)]

#### *Yorkshire flood 2000*<sup>9</sup>

Between the 28 October and 8 November 2000 Yorkshire experienced high rainfall leading to severe flooding. When floodwaters receded, the British Waterways Board raised concerns with Rotherham Borough Council (RBC) about safety to workers involved in clean-up operations from possible dioxin contamination of flood sediments. This was based on experience of elevated levels of dioxin in this area as a result of previous heavy industry. Public health were contacted by the local authority (LA) once results became available. An Incident meeting was convened with public health, RBC, the Health and Safety Executive (HSE) and CHaPD(L).

Composite samples were taken from sediment in the area at risk and along stretches of a towpath and tested for dioxin/furan, heavy metal and organic content. However, it is not specifically known if the flooding that occurred in the area was from the River Rother or caused by local sewage drainage.

2,3,7,8-TCDD was detected in concentrations up to 58 ng/kg in the samples. Further sediment samples of the river Don flood found concentrations of between 14 and 20 ng/kg I-TEQ. Samples along the riverbank found levels of dioxins and furans of 210 ng/kg I-TEQ. Garden (grass and soil) dioxin levels ranged from 14 to 28 ng/kg I-TEQ. A single residential under-floor sample measured 4.9 ng/kg I-TEQ. The EU limit value for dioxins and furans in sludge is set as 100 ng/kg dry matter toxic equivalents (TEQ) of 2,3,7,8-TCDD.<sup>10</sup>

Evidence was found that dioxin residues accumulated in rivers, canals, storm water and sewage drains and may become mobilized and deposited in areas and in gardens where human exposures can potentially occur. If dioxins are suspected of being deposited in gardens the Food Standards Agency publish standard precautionary advice for residents. Residents in high risk areas affected by flooding must be advised to take basic food hygiene precautions such as wearing gloves during clean-up operations and not eating produce grown or affected by floodwaters.<sup>11</sup> More efficient methods of site-specific health risk assessment following flooding of homes is required.

#### *Gloucestershire fire and floods<sup>12–18</sup>*

In October 2000 a fire and an explosion was reported at a private UK waste management and recycling firm. The site is located within the floodplain of the river Severn. The fire destroyed drums containing approximately 160 tonnes of hazardous waste containing a wide range of chemicals including cyanide, resins and adhesives, pesticides, solvents, low-level radiation waste and asbestos. A few days later the area suffered severe flooding. Aluminium selenide and arsenic were reported to have leaked into floodwaters with other chemical residues onsite. Floodwaters entered and damaged nearby houses causing residents to be concerned that their houses had become chemically contaminated. Sixty people were evacuated from their homes during the fire and again a few days later during the flooding.

Public Health were contacted on the day of the incident and undertook two health surveys to assess the impact of the incident on the health of the community. One hundred and thirty residents complained of a variety of health effects including sore throat, nausea, stinging faces and stomach pains. Most of the symptoms had resolved 4 weeks after the incident, but some were still evident 7 months later. Raised anxiety among residents about chemical contamination was a major issue.

Samples of air, floodwater and silt were analysed for VOC, dioxins, furans and other chemicals. Preliminary results showed no evidence of significant pollution within homes, although, traces of chemicals were observed.

The HSE and EA launched the initial investigation and the company licence was suspended. Later a parliamentary debate

was called by the Environment Secretary. This series of incidents is still under investigation.

Improved co-ordination between response services, and, more efficient methods of site specific health risk assessment following flooding of homes, and emergency plans for industrial sites within flood plains were identified as significant issues.

#### *Kent floods<sup>19</sup>*

In October 2001, the river Ouse breached flood defenses. River water then became trapped behind flood defenses. Six hundred and thirteen residential, 207 business and 16 public buildings were flooded. Vast amounts of oil waste were mobilized by the floodwaters. One hundred and forty people were evacuated to rest centres, and over 1000 displaced. Initial public health involvement included provision of public health advice on clean-up and avoiding contamination. A health impact survey was undertaken by the public health department in July 2002 undertaking an assessment and monitoring of health of those evacuated following the event.

Following an incident meeting the public health department took responsibility for answering health questions from local residents, especially concerns about children and pets playing in contaminated gardens.

As flood waters receded oil became concentrated in one watercourse. The EA boomed and removed approximately 70 000 l of waste and heating oil. The flood also stirred historically contaminated land. Concerns were raised about methane and asbestos and there were reports of elevated levels of nitrates in drinking water. The health survey showed significant impact on people's psychological health and an increase in self-reported symptoms including earache, skin rashes and gastrointestinal upsets.

More effective methods of flood warning, dedicated plans and pro-active response to public health concerns were highlighted. The value of personal visits by EHOs was noted. Inter-agency flood plans with public warning systems were suggested for floodplains, as evidence showed that the flood caused spread of chemical contaminants. However, there was no evidence that elevated levels of chemicals entered homes and caused increased levels of health effects.

#### **The role of public health protection**

The role of public health in the investigation of a flooding event that has caused chemical contamination can be broadly defined as one of public health risk assessment and protection. Key public health activities immediately following a flooding event will most likely include:

- (1) Hazard identification.
- (2) Planning, including the emergency response guidelines, local on and off-site plans, and liaising with their Health and Emergency Assessors or Planners.
- (3) Liaising/networking with other relevant responder agencies, e.g. Fire Brigade, LA, HSE and EA.

- (4) Provision of advice on health aspects including aspects of toxicology, decontamination, provision of antidotes and necessary equipment and supplies.
- (5) Follow-up of exposed casualties.
- (6) Reviewing/developing further emergency plans for flooding in high-risk areas.

CHaPD (London) is able to offer a full Flooding Chemical Event Checklist for Public Health Departments (<http://www.medtox.org/cirs/checklists.asp>) containing the following guidance:

- (1) Questions to ask the notifying organizations to enable the public health practitioner to characterize type of contamination/environmental investigation already undertaken/required.
- (2) Priority areas for public health.
- (3) Chemical hazards for flood clean-up work/workers.
- (4) Sampling procedures.
- (5) Guidance for residents returning to their homes.
- (6) Food and water hygiene issues.
- (7) Management of confirmed chemical contamination of household goods.
- (8) Guidance for public health practitioners on chemical risks resulting from flooding for residents returning to their homes.
- (9) A table of common problems found in drinking water supplies following flooding and appropriate analyses to consider or request.

In order to make a quick assessment of potential health risks following a specific flooding event we include an extract from the checklist available at the above web address. Table 2 shows that potential contaminants in floodwater may be predicted if the source of the floodwater is known.

## Discussion

The results of this investigation shows that the health impact of floods may be substantial, affecting many people at the same time and causing them to be displaced, physically injured and exposed to biological and chemical hazards. The incidents reviewed in Table 1 show evidence of chemical contamination following flooding events. A review of each incident allows us to determine the public health risk, the benefit of actions taken and what lessons can still be learned. Unexpected chemical exposures, e.g. to carbon monoxide from indoor equipment use, may have significant public health impact. However, it is also clear that generally very little if any environmental sampling is undertaken following flooding events. A principal component of concern in studies reviewed thus far has been the use of proxy exposure measurements rather than direct measures. Effective environmental data collection and monitoring would greatly enhance future health research studies.

The experience of CHaPD(L) is that most industries outside

the Control Of Major Accidents and Hazards (COMAH) regulations do not have emergency plans. Nor are emergency chemical inventories of chemicals stored and used on-site, available for immediate review by blue light responder units (e.g. fire brigade) who may be the first to attend a flooding event. Toxicological risk assessment is difficult to predict and rescue/remediation is challenging to undertake.

Many small establishments such as petrol stations (often sited either in or near residential areas) do not fall within the COMAH regulations and may under certain circumstances such as flooding have potential to cause environmental contamination. There are currently 13 065 petrol stations in the United Kingdom.<sup>20</sup> Future legislation may well be needed to cover broader categories of industrial establishments that potentially pose a threat to public health. Any such regulations are unlikely to be as inclusive or complex as the COMAH regulations or the Seveso directive,<sup>21</sup> but may enable responding agencies to predict potential public health risk and manage incidents more efficiently.

Water companies are controlled under the Water Supply Regulations Act, which amongst other things requires companies to inform the public of any possible problems. This requirement has become even more stringent with the introduction of the Human Rights Act in late 2000, which requires that the public be informed even if there is a potential threat to human health as a result of industrial activities.

The health impact of floods may also cause anxiety and have psychological impacts. People returning to their homes may experience trauma whilst cleaning up, making repairs and dealing with stressful activities such as insurance claims. Anxiety may be further exacerbated by suspected and unknown biological and chemical contamination of homes and gardens especially in industrial locations that are known or suspected of being contaminated. Media reports speculating about long-term health risks may further exacerbate concerns.

Flooding accounts for a very large proportion of all natural disasters worldwide and is expected to increase in the future. The EA, quoted by the Environmental News Service<sup>22</sup> warned that climate change is linked to UK floods. Sufficient evidence of chemical contamination caused by flooding events exists to develop improved systems for future response to flooding causing chemical contamination with the potential to cause significant harm to public health, controlled waters or the wider environment.

## Conclusion

In the United Kingdom there has been an improvement in chemical incident management<sup>23</sup> but environmental sampling is an area that requires attention. The key to successful incident management is interaction and training so that lessons learnt by individuals are disseminated to others.

The HPA is empowered to provide public health protection. In the event of potential chemical contamination of gardens and

homes following a flooding event the HPA and its local and regional services may be called on to undertake a health risk assessment if elevated levels of contaminants are likely to present an unacceptable health risk to the population potentially

exposed. The public health department may also be requested to collaborate in a multidisciplinary forum to evaluate the risks that contaminants may pose to the water environment, ecological receptors or the built environment.

**Table 2** Hazard identification using the source of the floodwater

The source of the contaminated floodwater will often predict the type of chemical contamination

### 1. Storm water floods

Contaminants in run-off from roads, motorways and bridges may generally include:

Sediment: these may contain pollutants such as heavy metals or pesticides

Hydrocarbons, oils and grease leak onto road surfaces and pavements, spills at petrol stations and fuel depots. Iridescence is a sure sign within run-off of spilled petroleum products

Heavy metals: from car exhausts, worn tyres and engine parts, brake linings, paint and rust

Road salts: may contribute to high sodium and chlorine concentrations in water

Fertilizers, pesticides and herbicides: in rural and peri-urban areas seasonally elevated concentrations of these chemicals may be washed into waterways

### 2. Overloaded sewers (backflow) in combined sewer system

In older cities sewer pipes may be a combination of either residential, industrial or storm water

Where waste water is combined the system is called a combined sewer system

When these sewers are overburdened or flooded they may cause combined sewer overflows containing a variety of residential, industrial and storm water waste

Waste water will normally be discharged into a waterway and may potentially contain a variety of contaminants from domestic and industrial sources

Consider chemicals within sewers as a residue of consented industrial discharges (EA/LA will regulate discharges and are a source of information)

Consider chemical contamination within residential sewers, canals or residential rivers that have collected (as a sludge) as a result of run-off that may be remobilized

### 3. Hazardous landfill sites

May cause acute events resulting in either physical contamination or emit odours of public health significance from chemicals such as hydrogen sulphide and mercaptan

Persistent chemicals such as asbestos within hazardous landfill sites are able to withstand natural degradation for long periods and can be dispersed by water

Mercury can bioaccumulate, often in fish, wildlife or humans, and possibly cause deaths, congenital anomalies, cancers, mutations, or acute and chronic disease

Public health departments should identify former and current hazardous waste sites within their boundaries and liaise with EHOs to monitor these carefully during a flooding event

Many former waste sites were generally not adequately planned, designed, constructed, maintained or legally permitted to securely hold their toxic waste in a public health context

### 4. Waste water lagoons

Known to be sensitive to floods and may be the cause of a flooding event if the structure fails

Elevated levels of contamination are in some cases still present in soil, sediment or groundwater and can include VOCs, PAHs, dioxins or persistent chemicals, e.g. wood preservative used in industries such as timber yards

### 5. Acid mine drainage (AMD) and public health risk from flooding

The United Kingdom has a long legacy of mining and AMD from abandoned mines especially coal mines. The EA estimates in their State of the Environment Report that there are in excess of 1700 abandoned metal mines in south-west England alone. Under normal operating conditions abandoned or closed mines were constantly drained with large pumps, however, post closure they are susceptible and may flood

Where mine water is exposed to fresh air at the face, sulphides may be allowed to oxidize leading to the formation of sulphuric acid with pH ranging between 2 and 3 being common

Heavy metals may dissolve and thus potentially become more mobile and available

Typical minerals and metals found in mines include; aluminium, arsenic, cadmium, cobalt, copper, iron, lead, manganese, nickel, silver and zinc

The aim of this project is to evaluate the significance of public health risks from chemical contamination following flooding. The epidemiological literature does not show strong evidence of contamination and attributable morbidity and mortality following flooding that resulted in chemical contamination. However, CHaPD(L) considers there is sufficient evidence of contamination to warrant continuing and improved public health planning and vigilance during such events. In order to facilitate this, a checklist/pro forma for a public health response to flooding events that may result in chemical contamination has been designed and is available at <http://www.medtox.org/cirs/checklists.asp> for testing and feedback.

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