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ORIGINAL PAPER

Achieving attainable outcomes from good science in an untidy world: case studies in land and air pollution

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Abstract While scientific understanding of environmental issues develops through careful observation, experiment and modelling, the application of such advances in the day to day world is much less clean and tidy. Merseyside in northwest England has an industrial heritage from the earliest days of the industrial revolution. Indeed, the chemical industry was borne here. Land contamination issues are rife, as are problems with air quality. Through the examination of one case study for each topic, the practicalities of applied science are explored. An integrated, multidisciplinary response to pollution needs more than a scientific risk assessment. The needs of the various groups (from public to government) involved in the situations must be considered, as well as wider, relevant contexts (from history to European legislation), before a truly integrated response can be generated. However, no such situation exists in isolation and the introduction of environmental investigations and the exploration of suitable, integrated responses will alter the situation in unexpected ways, which must be considered carefully and incorporated in a rolling fashion to enable solutions to continue to be applicable and relevant to the problem being faced. This integrated approach has been tested over many years in Merseyside and found to be a robust approach to ever-changing problems that are well described by the management term, "wicked problems".

Keywords Land contamination · Contaminated land · Air pollution · Public involvement · Public health risk assessment · Wicked problems · Environmental public health · Applied science

Gary Mahoney died suddenly during the revision of the paper. His wit and wisdom in air quality issues will be sorely missed at the local and national level.

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Introduction

The North West of England has a long history of industrial activity. Although this is now much reduced from the Victorian heydays, there is a heritage of land contamination by heavy metals and organic pollutants, which is regulated or controlled through planning permits or under the UK contaminated land legislation. Industrial and commercial activity is still sited very close to, and in some places within, residential areas.

Emissions to air from industrial or commercial traffic movements make important contributions to current air quality management issues. Recognition of adverse effects on health of air pollution continues to grow (e.g. Lozano et al. 2012; Vedal et al. 2013; Lippmann et al. 2013; REVIHAAP 2013; Miranda et al. 2014), as does local communities' awareness of how environmental issues can affect health. This awareness drives and/or complicates the work of local government officers striving to improve health and reduce the impact of pollution.

Much of the modern guidance on indicative limit values for pollutants in air, land or water, comes from academic research, made by focussed efforts on particular situations stripped to the essentials. However, the application of these academic insights in the real-world setting of regulation, planning and living can be challenging. In this untidy and complex setting, legislative constraints, political pressures, deprivation, ill-health and family life add to the mix that shapes the context of the pollution and can transform the approaches and ideas of those involved, whether resident, professional, regulator or regulated. There are times when this untidy complexity needs a more multifaceted approach than that with which reductionist science is comfortable.

The concept of "wicked problems" has been around in management science for a long time (Churchman 1967), but is now beginning to be considered in other areas to enable the development and understanding of complex issues (CogNexus Institute n.d. Wicked Problems. http://www.cognexus.org/id42.htm Accessed 25 October 2014; Head and Alford 2013; Redford et al. 2013). Wicked problems, in this characterisation, have the following attributes:

- They are ongoing problems, which do not have one conclusive solution
- They cannot be solved by traditional linear approaches
- The understanding of the problem or situation changes with each attempt at a solution
- They demand shared understanding and shared commitment from a wide number of people and disciplines
- Solutions are not right or wrong but rather "better", "worse", "good enough" or "not good enough".

It is through wrestling with the complex dilemmas of life, not just through clear cut scientific dissection of a reduced segment of a problem, that we deepen our understanding of the issues, their interactions and answers. Science thus meets the real world and engages with the lives of local communities. Without such untidy engagement, there can be no meaningful applied science.

Without being aware at the time of the concept of wicked problems, in Cheshire and Merseyside, we developed and reported a multifaceted Public Health Risk Assessment and response 10 years ago (Reid et al. 2005; Fig. 1) that provides a ready-made, appropriate and well-tried response to such situations. This approach takes the basic scientific or technical risk assessment and adds to this a scrutiny of all the relevant contexts plus an appreciation of the differing agendas of interested individuals, organisations and other parties. Once these three diverse aspects had been gathered (integration is not always achieved), then a multidisciplinary approach to resolving or managing the problem can be developed.

The technical risk assessment (Fig. 1a) is given as hazard-exposure-risk assessment (hazard recognition, risk calculation, communication of results), which is similar to a source-pathway-receptor approach. Both are linear and allow quantification, where possible, of the risk(s), although a semi-qualitative assessment may be the best that can be achieved.

The scrutiny of as many contexts as possible around the technical risk model (Fig. 1a) allows the recognition in the Public Health Risk Assessment of constraints and drivers of the situation. Such constraints and drivers may, if not recognised and answered, distort or even derail the application of the technical risk assessment, to the discomfort and despair of all concerned.

Similarly, if the differing agendas of concerned parties and participants are not recognised and understood (not necessarily agreed with), then resulting work to respond to the technical risk assessment may collapse or disappoint and become counterproductive, to the discomfort and despair of many concerned.

Such a multidisciplinary and multi-agency approach to environmental issues may involve local authority Environmental Health Officers, the Cheshire and Merseyside Public Health England Centre (formerly the Health Protection Agency) and local Public

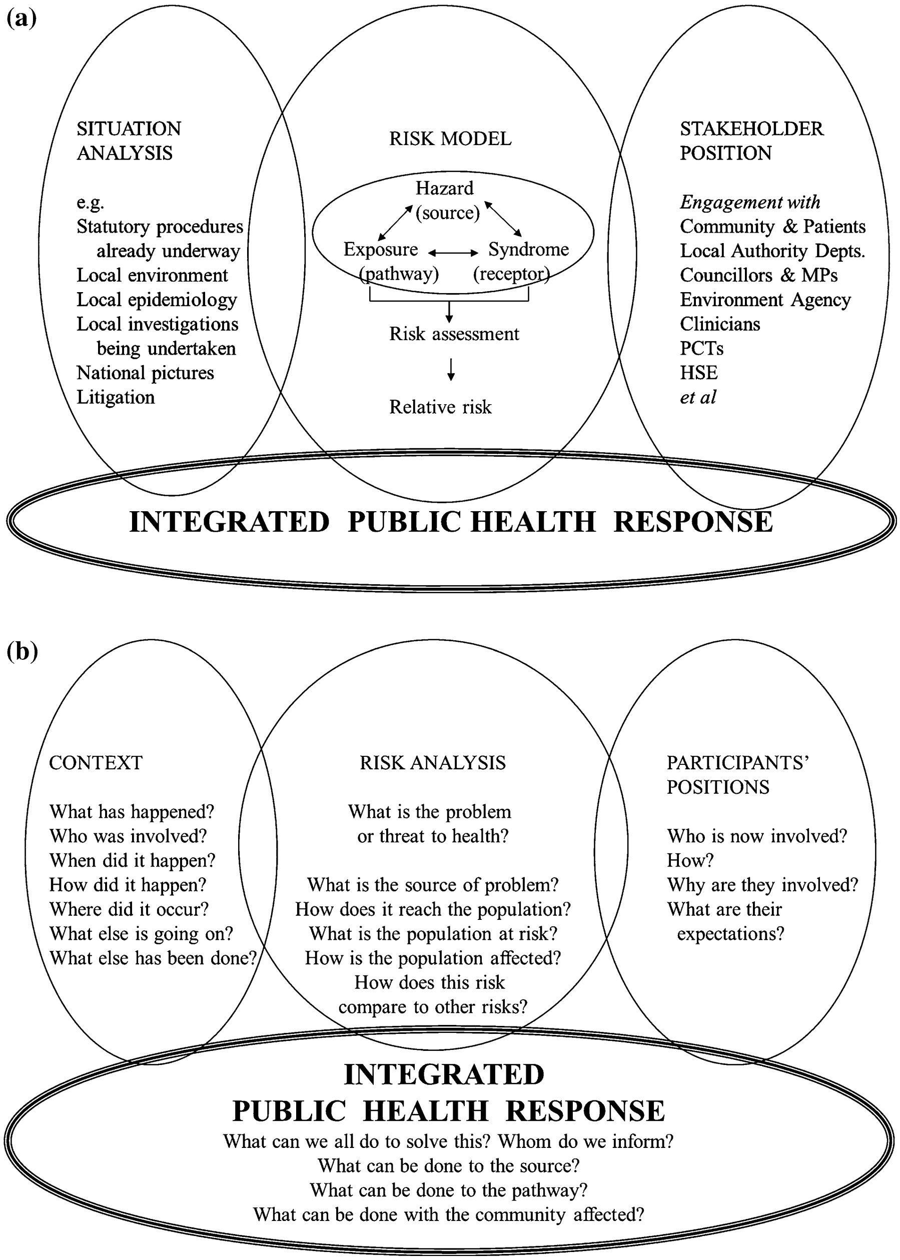

Fig. 1 Integrated Public health risk assessment and response. **a** Outline: adapted from Reid et al. (2005). **b** Application: questions to help the practical application (this paper)

Health teams (which were formally based in Primary Care Trusts (Health Authorities) but, since 2013 are based in local authorities). To these may be added environmental consultants and professionals from other agencies (such as planners, environmental staff from the Environment Agency, or epidemiologists from local or national health registries) as appropriate.

In developing such a robust Public Health Risk Assessment around difficult situations, the multidisciplinary, multifaceted approach to the control or management of the hazard and risk may not satisfy everyone. However, the communications associated with the risk management can be targeted to inform as wide a range of stakeholders and community as possible, thus reducing criticism and possible mistakes. No approach is perfect, and we do not claim that for our Public Health Risk Assessment, only that it is a tried and tested approach to complex environmental (and, indeed, other Public Health) problems.

The model provides a new way of exploring problems for local authority officers where responses have traditionally been framed by the requirements of legislation and dealing with specific problems in what could be described as a compartmentalised way.

By assessing the context and identifying agendas, the Public Health Risk Assessment approach is able to respond to the changing nature of the problem, the developing understanding and the answers, and all at the same time. This is despite the fact that the answers may never be final and complete, but can be adequate and useful and enough to bring the hope and security a community looks for, while answering, or at least, responding to, enough of the questions in a reasoned and rational way.

We present two case studies, which we then place in their wider contexts alongside consideration of the interests of various relevant parties to illustrate the Public Health Risk Assessment approach.

Case study 1: contaminated land in St Helens

Problem outline

Each local Council in England and Wales has a legal duty to identify contaminated land, as defined by Part 2A of the Environmental Protection Act 1990 (in summary, land that causes or can cause significant harm), to ensure that potential public health problems are managed in an appropriate manner. In line with the supporting Statutory Guidance of the Act, St Helens Council (one of several local authorities in Merseyside in North West England—Fig. 2) prioritised all sites within the Borough that posed a potential health risk from contaminated land. Prioritisation criteria were (a) proximity to human receptors and (b) a history of past industrial land use.

This case study consists of the northern zone of a site that lies within a cluster of high-risk locations, which were identified during the prioritisation strategy (Fig. 3). The full site (Tickle Avenue site) is currently residential, containing both houses with gardens (290) and flats with communal areas (20 blocks), while the case study zone comprises 99 residential houses with gardens.

Between 2007 and 2012, several detailed, intrusive investigations and assessments were undertaken across the full site, including the north zone. The objectives of the investigations were to:

- Establish the ground conditions across the site
- Collect an adequate number of samples per property to enable a robust decision, which would withstand legal scrutiny, to be made on a property-by-property basis
- Develop the conceptual site model to inform the risk assessment and enable a robust response
- Undertake a risk assessment for near surface soils (to a depth of two spade depths, 0.6 m) to establish the level of risk posed to residents
- Establish appropriate remedial action(s)
- Ensure open and transparent communication with all stakeholders

Assessment

Across the north zone, 584 samples were taken and analysed for 53 chemicals and elements (Table 1 shows results for the top three contaminants found). Not all samples were analysed for all contaminants. The site investigation showed that the local surface soil was heavily contaminated with arsenic ("contaminant of concern"—CoC), at concentrations which could give rise to a potential public health problem. Elevated concentrations were widespread across the north zone of the site (case study area): 90 % of soil samples exceeded the soil arsenic guideline value (SGV) (32 mg/kg) (Table 1). The mean concentration per garden ranged from 714 to 8062 mg As/kg soil, while across the wider site the mean was 337 mg As/kg. It was clear that resolving the arsenic contamination would resolve any other contamination.

Currently, there is no agreed method or statutory guidance in the UK on how to assess the potential risks from acute exposure to contaminants present within soils. Following an extensive literature review and liaison with public health professionals and toxicologists, a pragmatic approach was taken to derive an acute threshold concentration for the site.

Bioaccessibility data were determined by the in vitro Unified BARGE Method (UBM) (NERC

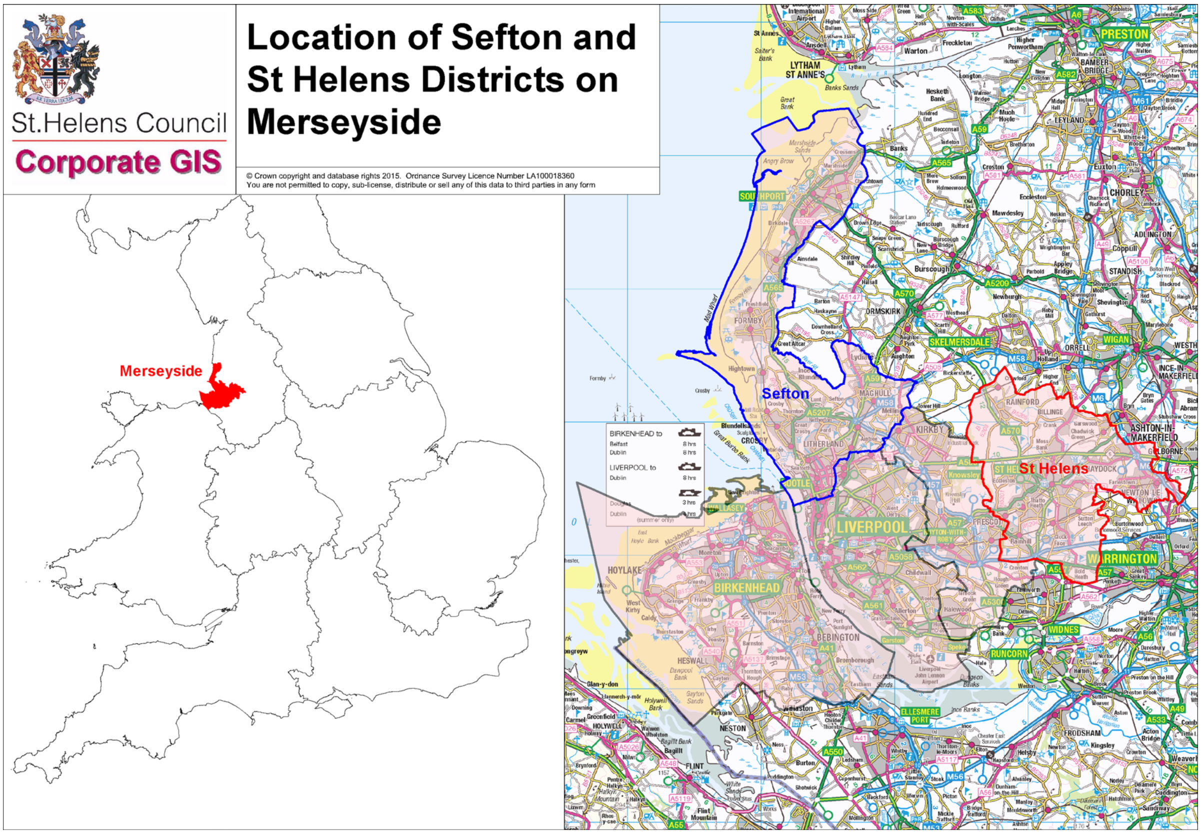

Fig. 2 Local authorities in Merseyside, North West England, including Sefton and St Helens

2014, Barge, http://www.bgs.ac.uk/barge/home.html Accessed 25 October 2014; Wragg et al. 2011; Denys et al. 2012) and validated against bioaccessibility data obtained for an adjacent site, which had the same site history and ground conditions encountered. This was combined with estimates of the ingestion of soil in a child with pica (5 g soil by a 10 kg child; US EPA 1985) to derive an acute threshold value which was compared with the measured concentrations of arsenic in the soil. This enabled the differentiation of the site into areas where (a) soil arsenic concentrations gave a "significant possibility of significant harm" (SPOSH) to human health from acute exposures and remediation was needed (22 properties) and (b) areas where the soil arsenic concentration was not deemed high enough for there to be a "significant possibility of significant harm" (77 properties).

Determining "significant possibly of significant harm" is a value judgement, based on soil contamination measurements and resulting possible health outcomes (including death, disease, serious injury, genetic mutation, birth defects or reproductive impairment). While it is recognised that technical risk assessments alone cannot answer the policy question about what is acceptable or unacceptable, in the view of the UK Department for Environment, Food and Rural Affairs, local decisions should be firmly based on a technical, scientific risk assessment and take into account the purpose of the legislation and the local context in which the decision is being made (DEFRA 2008).

Nevertheless, in accordance with Part 2A of the Environment Act 1990, the Council needs to demonstrate that a site presents a significant possibly of significant harm with respect to risks to human health for it to meet the legal definition of Contaminated Land.

Context

St. Helens is currently a fast changing, modern, developing Borough, one of the five local authorities

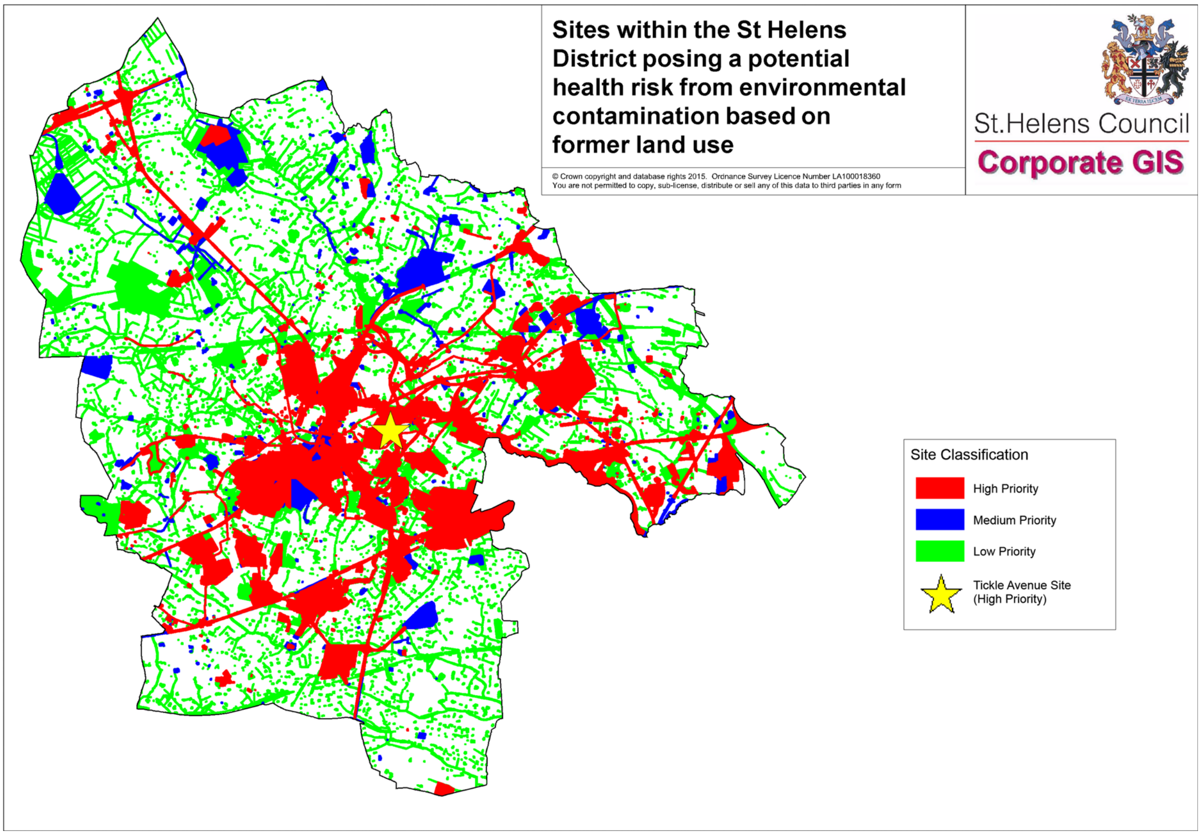

Fig. 3 Location of case study 1 site (Tickle Avenue, contaminated land) in St Helens, North West England in relation to other potentially contaminated sites

Table 1 Top three contaminants in St Helens soil in northern zone of Tickle Avenue (case study site)

All analytical data as mg/kg	As	Benzo(a)pyrene	Total aliphatic hydrocarbon C21-35
Lowest measurable concentration	11.0	0.2	8.0
Maximum	40,000.0	110.0	360.0
Mean	337.7	3.6	56.3
SD	1901.9	9.0	83.0
Lab detection limit	–	<0.10	<8.0
Generic assessment criteria (GAC)	32	0.96	25
Number of samples (*n*)	584	462	139
Number less than detection (*n*)	0	47	83
Exceedances of GAC (*n*)	523	306	27
Exceedances of GAC (%)	89.6	66.2	19.4

in the Merseyside region and home to 176,114 residents [Office of National Statistics (ONS) Mid-year estimate for 2012]. Located midway between Liverpool and Manchester, the Borough enjoys a strategic position at the heart of the North West. The Borough covers a total of 135 square kilometres, of which approximately half is rural and half is urban. An extensive road, bus and rail network provides excellent accessibility for people travelling to and from St. Helens for work, leisure, to live or to visit friends and family.

The history of St Helens is inextricably linked with the industrial revolution, coal mining and a world-famous glass industry, which employed many of the local residents. From the late 1970s onwards, these industries began to decline in importance, with a corresponding reduction in jobs, business opportunities and subsequently an increase in morbidity and mortality (Table 2). The legacy of heavy industry and the fundamental shift in employment patterns have been at the heart of many of the challenges facing the Borough since this time.

The north zone lies within an area, which was previously occupied by the Henry Baxter Chemical Works, which started as the operator of Parr Chemical Works in St Helens in the nineteenth century. After 10 years, Baxter developed the expertise and capital to expand into the alkali business. The alkali works operated from 1849 until it ceased trading around 1937–1938. The site then remained unused until it was redeveloped for residential properties in 1948; the redevelopment was completed in 1970s (Fig. 4).

It is reasonable to assume that most of the waste associated with the local alkali industry in and around St Helens was produced by the very inefficient LeBlanc process (Gillispie 1957), a two-stage process for the production of sodium carbonate from sodium chloride through sodium sulphate. One of the most important uses of sodium carbonate is the manufacture of glass, for which St Helens is famous, but also the production of soap and dyes in the local early chemical industry. The LeBlanc process released hydrochloric acid into the atmosphere and left a solid waste (galligu) of no economic value but full of arsenic and other heavy metals. Galligu was spread over hundreds of hectares in and around St Helens and nearby Boroughs and weathered to release hydrogen sulphide, often leaving the ground unstable (Barker and Harris 1954; Barker 1960; Johnson et al. 2003).

St Helens is the 51st most deprived local authority in England (out of 326), with a reduced life expectancy in both men and women (Table 2), possibly related to its industrial history. The main causes of death contributing to this reduced life expectancy are circulatory disease, cancer, respiratory disease, accidents, chronic liver disease and suicide. The all-age

Table 2 Comparison of health indicators and income deprivation for England, the borough councils of St Helens and Sefton and wards within Sefton council (Linacre, Blundellsands, Molyneux)

	Life expectancy (men) (years)	Life expectancy (women) (years)	Standardised rates				Income deprivation (% of population)
			Coronary heart disease <75 years (SMR)	COPD (SAR)	Respiratory disease (SMR)	Lung cancer (SIR)	
England	78.9	82.8	100	100	100	100	14.7
St Helens borough council	77.1	81.2	130.5	137.4	139.3	121.5	18.7
Sefton borough council	77.5	82.4	105.0	118.0	107.0	124.1	16.9
Sefton wards							
Linacre	69.9	76.5	238.8	298.1	211.3	237.8	40.5
Blundellsands	80.9	84.3	69.2	56.0	83.6	84.9	8.5
Molyneux	81.2	85.4	64.5	91.4	70.7	138.2	9.9

All standardisation is by age and sex. A standardised rate of 136.5 is 36.5 % greater than the national rate

SMR standardised mortality rate, *SAR* standardised admission rate (to hospital), *SIR* standardised incident rate, *COPD* Chronic Obstructive Pulmonary Disease

Source: Public Health England: Local Health http://www.localhealth.org.uk. (Accessed 25 Oct 2014). Data is for 2008–2012 (Coronary Heart Disease, Respiratory Disease), 2008/9-2012/13 (COPD), 2007–2011 (Lung Cancer)

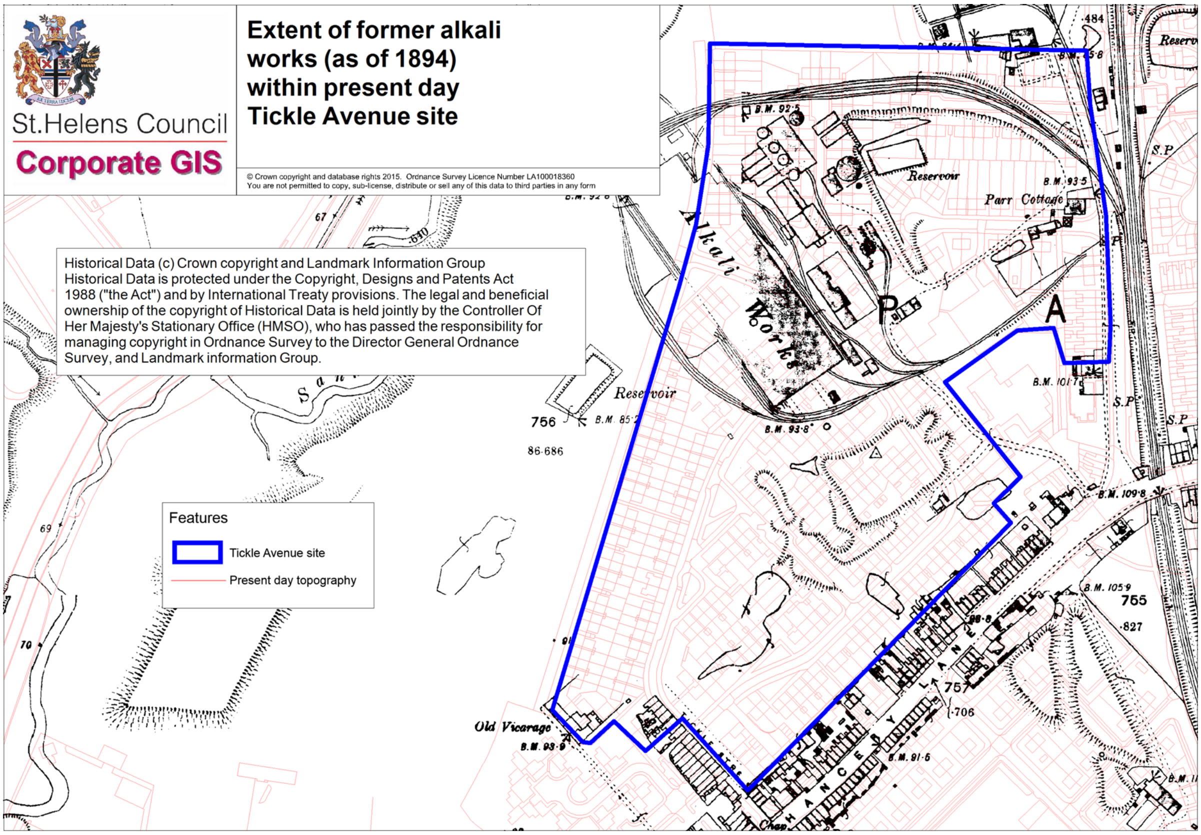

Fig. 4 Historical detail of case study 1 site (Tickle avenue, contaminated land) in St Helens, North West England

all-cause mortality (rate per 100,000 population) (2012) is higher in St Helens (603) than for England (524) (St Helens Council. Share http://share.sthelens.gov.uk/IAS/ Accessed 25 Oct 2014).

Stakeholders

The properties on the north zone were 50 % housing association owned and 50 % owner occupiers, offering a diverse range of reactions to the disclosure of information that they were living on contaminated land. The reactions varied from a lack of interest (mainly housing association tenants), assuring us that we could do what we wanted to their properties, to major concerns over health, to requesting options for their patio to be grey flagstones or sandy colour (mainly owner occupiers).

Investigations across the wider site and the remedial work in the northern zone were undertaken by three environmental consultants, because of Council procurement rules, with cost as the most important driver, adding levels of complexity to the overall process.

Integration

Having identified this site as “contaminated land”, there were three outstanding principles that underpinned the method chosen to communicate to all stakeholders. The principles were as follows:

- Disclosure of all information to the affected parties
- Open discussion of all information
- Empathy, concern, commitment to the residents alongside effective listening

A multidisciplinary Health Advisory Group was set up through the Health Protection Agency (since April 2013 part of Public Health England) to provide the Council with answers to questions about the nature of the health risks and to ensure that adequate information from experts was available. Membership included the local Director of Public Health, health analyst (for epidemiology), toxicologist, the council contaminated land officer and senior Environmental Health staff, as well as a Public Health doctor from the Health Protection Agency who had special interest in environmental issues. The Group reviewed the health of the community in comparison with other similar communities around Merseyside to determine whether the local health was adversely affected by the contamination. They ensured that human health was paramount in any response to the contamination and advocated the installation of short-term protective barrier measures (e.g. ground cover to reduce dust) to ensure that the residents were aware and were protected while awaiting more permanent protective barrier measures to be installed.

A series of public meetings/open workshops were held to provide information to and gather information from local residents and property owners. At the beginning, there was a lot of specific information to give, and thus, very early engagement with residents on the site was encouraged. It was found (by Nattalie Kennedy) that the more familiar they were with the issues the more likely they were to accept the situation and therefore influence the process.

Inevitably, as the project progressed, more detailed information was provided to stakeholders. Not every person in the same stakeholder group reacted in the same way, so before we presented the information we had internal Council meetings to consider the different possible outcomes. Stakeholder reactions varied and depended on their understanding of the situation, their past experiences and their future hopes. Some were only interested in small details such as the colour of the flagstones to be used to cover the contaminated ground; others were concerned about the risk of poor health for their family. We endeavoured to be open and honest with bad news as with good news and noted that the way we engaged and presented the information influenced their reaction.

The housing association was very supportive and provided vital information and resources, yet did not want to have any direct involvement with communicating with their own tenants. This may actually have provided clarity for residents as there was one point of contact through a lead (Council) officer with a dedicated phone line. This single point of contact proved beneficial to the residents who were still uncomfortable with the housing association following the transfer of ownership from the Council to the housing association as long ago as 2002.

As the Council contaminated land officer responsible for the work, Nattalie Kennedy observed,

> I tried to ensure that the message was tailored to members of the community with transparent communication outward endeavouring to establish trust from the Local Authority to the public. However, I found that effective outward communication could not be divorced from good listening. It became quite evident that good understanding of people's current knowledge, beliefs and opinions was an absolute prerequisite for effective outward communication and trust. Subsequently, I wanted the residents to trust that the Council was doing this project "for them" not "to them". I immersed myself in the community, attending regular social events (i.e. coffee mornings, estate meetings, Christmas socials, and bingos) and established a good working relationship with the Tenants' Resident Association Chair for the estate. She had lived on the estate for over 50 years and her family were one of the first tenants on the newly built estate in the 1950s. As the Tenants' Resident Association Chair she produced a newsletter, in which we retained a regular slot to provide updates regarding the project and reminders of any scheduled open days. Furthermore, I listened and engaged with both young and old on the estate; I also liaised with representatives of the housing association and local elected Ward Councillors. Additionally, there was a large population of residents who would not or could not (i.e. some vulnerable adults) engage in the project, and therefore an individual programme was devised, with a major door knocking and home visit exercise.

Comment

During the later stages of the project, there was a significant amount of unexpected conflict between residents and the Council, and, surprisingly, conflict from residents with residents, largely related to aspects of the reinstatement of gardens. The issues were resolved through discussions and the Council's complaints process. These conflicts may have arisen from worry, uncertainty and upheaval due to time delays, changes of contractor teams and restrictions brought on by weather conditions.

A distinct lack of expertise in dealing with the social dimensions of a community affected by contaminated land has been reported (Becker 1997). Becker argues that professionals with psychosocial expertise should be available to provide assistance to communities dealing with contaminated land. Contaminated land is very much a social issue and needs to be handled sensitively, as the residents' health and how they understand the various diverse issues can be greatly affected by the stress and worry as by the potential contamination in the ground.

Case study 2: Sefton air pollution

Problem outline

The UK National Air Quality Strategy and Local Air Quality Management (LAQM) Regulations provide health based standards and objectives for seven key air pollutants and a framework for reviewing and assessing air quality in a local authority's area. Local authorities have a statutory duty to undertake Review and Assessments and, where National Air Quality Strategy Objectives are not complied with, declare Air Quality Management Areas. In such areas the Council is required to develop Action Plans to work towards compliance.

Residents of the southern part of the Borough of Sefton, in Merseyside, have a strong belief that local air pollution affects their health. It is important to understand if this is really the case, because, if true, it would mean that air pollution is having effects beyond, as well as within, defined Air Quality Management Areas. This would mean that:

- Effects of air pollution occur below air quality objectives, or
- Non-"statutory" pollutants are involved, or
- Other factors (e.g. composition of particulate matter) are important, or
- Air pollution exacerbates the impact of other factors such as the deprivation of an area or individual lifestyle decisions such as smoking, or
- There is some combination of all of these at work.

If it is not correct that local air pollution is affecting the health of local residents, it is important to be able to demonstrate this in a way that residents can understand and accept, because this belief in the effects of air pollution influences how health protection messages about lifestyles are received by the local community.

Assessment

Determining if air pollution is having an impact on health demands an understanding of the nature of the local air pollution in the south of the Borough through monitoring, modelling and analysis of air quality, using a variety of techniques.

Sefton Council currently has five real time pollution monitors measuring nitrogen dioxide (NO_2) and particulate matter (PM_{10}), situated in four of the Air Quality Management Areas and on the site of a former school facing the nearby Port of Liverpool. This last monitor was originally sited there because of the presence of the school, but now acts as an urban background site for the local area. The results from this monitoring are given in Tables 3 and 4.

There is also a network of 100 diffusion tubes throughout the Borough measuring NO_2; some of these tubes are located on residents' properties as part of a programme called "Community Airwatch", in which residents are responsible for changing tubes and returning them to the Council for analysis, allowing trends over time to be monitored at a finer resolution. There has been a continuing slow decrease in local air pollution over the past decade.

The Council also has "sticky pad" airborne dust monitors (DustScan http://www.dustscan.co.uk/ Accessed 25 Oct 2014), Frisbee and British Standard deposited dust monitors that can be deployed for specific projects or in response to complaints. Currently, the Council is working with atmospheric and geographic scientists from Exeter University who are using geomagnetic techniques to analyse airborne and deposited dust samples (Booth et al. 2006).

Emissions inventory and air pollution modelling

The Merseyside Atmospheric Emissions Inventory (run in the Airviro air quality management system, http://www.smhi.se/airviro Accessed 25 Oct 2014) is a database of estimated pollution emissions from all

Table 3 Automatic monitoring for NO_2 and PM_{10} in Sefton, Merseyside: comparison with annual mean objective (2008–2013)

Site ID/location	Pollutant	Within AQMA?	Valid data capture for full calendar year 2013 %	Annual mean concentrations (μg m^{-3})					
				2008	2009	2010	2011	2012	2013
CM1/Former St Joan of Arc School, Bootle	NO_2	N	99.2	33.4	32.3	36.7	32.3	32.3	31.4
	PM_{10}	N	85.5	26.1[a]	22.9[b]	22.4	24.6	27.1	28.5
CM2/Crosby Road North, Waterloo	NO_2	N	99.9	35.3	35.4	39.4	33.1	36.1	35.4
	PM_{10}	**Y**	96.1	27.3	26.1	27.0	31.3	25.4	28.3
CM3/Millers Bridge, Bootle	NO_2	**Y**	99.9	**41.3**	38.1	39.7	36.8	37.9	36.3
	PM_{10}	**Y**	94.0	33.3	29.9	28.4	29.8	26.1	28.1
CM4/Princess Way, Seaforth	NO_2	**Y**	97.2	**46.0**	**45.8**	**44.0**	**48.0**	**45.9**	**42.8**
	PM_{10}	**Y**	83.4	26.3	24.3	23.1	27.8	24.9	26.5
CM5/Hawthorne Road, Litherland	NO_2	**Y**	98.7	n/a	n/a	**43.0**[c] **46.7**[d]	**42.6**	**41.5**	39.0
	PM_{10}	N/A	–	–	–	–	–	–	–

Exceedances shown in bold

AQMA Air Quality Management Area, *N/A* not applicable

[a] June–December 2010

[b] Annual mean adjusted for short-term monitoring

[c] January–September

[d] March–December

Table 4 Automatic monitoring for NO_2 and PM_{10} in Sefton, Merseyside: comparison with short-term objective (2008–2013)

Site ID/location	Pollutant	Within AQMA?	Valid data capture for full calendar year 2013 %	Number of exceedances NO_2: 1-h mean (200 μg m^{-3}) PM_{10}: daily mean (50 μg m^{-3})					
				2008	2009	2010	2011	2012	2013
CM1/Former St Joan of Arc School, Bootle	NO_2	N	99.2	0	0	0	0	0	0
	PM_{10}	N	85.5	5[a]	0[b]	1	4	5	18[c]
CM2/Crosby Road North, Waterloo	NO_2	N	99.9	0	0	0	0	1	1
	PM_{10}	**Y**	96.1	14	10	16	31	18	17
CM3/Millers Bridge, Bootle	NO_2	**Y**	99.9	2	2	1	0	0	0
	PM_{10}	**Y**	94.0	33	11	20	25	13	17
CM4/Princess Way, Seaforth	NO_2	**Y**	97.2	0	0	0	2	3	0
	PM_{10}	N	83.4	15	7	6	20	15	12[d]
CM5/Hawthorne Road, Litherland	NO_2	**Y**	98.7	n/a	n/a	1	0	0	0
	PM_{10}	N/A	–	–	–	–	–	–	–

AQMA Air Quality Management Area, *N/A* not applicable

[a] January–September

[b] March–December

[c] 90.4th Percentile of daily means = 44 μg m^{-3}

[d] 90.4th Percentile of daily means = 43 μg m^{-3}

significant sources across Merseyside, collated from local and national sources. The database provides (a) spatial information on emissions, for example from a specific road or industrial process, and (b) emissions totals, either by sector, such as transport, or by geographic area, such as local authority. Emissions can be further broken down, for example transport emissions can be presented by vehicle type, allowing in depth analysis of pollution sources. Outputs are compatible with MapInfo, allowing them to be displayed spatially with other data, for example health or deprivation statistics.

Emissions data from the Merseyside Atmospheric Emissions Inventory is combined with meteorological and topographical information in the Council's air pollution dispersion model. Dispersion modelling provides local councils with information on air quality over a wide area, filling in the gaps between monitors (e.g. when modelling traffic management plans) or exploring potential changes in air quality due to residential or commercial developments. It allows apportion of total emissions to each local authority in Merseyside, by sector (domestic, agricultural, transport, industrial and commercial) for different pollutants (e.g. NOx, PM_{10}, CO_2), by road network at 200 m resolution, or by differing combinations of these and other factors. For example, the output has been used to assess the impact of Local Transport Plan actions on pollutant emissions.

Context

Sefton Metropolitan Borough Council is another of the five Merseyside local authorities in NW England. Sefton has a population of 273,790 (2011 census) and covers an area of 59 square miles (153 km^2), with 22 miles (35 km) of coastline extending the full length of the Borough, from Southport in the north to Bootle in the south (Fig. 2). A key feature of the Borough's geography is its elongated shape, only 1.5–7 miles (2.4–11 km) east to west.

The Borough contains both some of the most affluent and some of the most deprived districts in the country: 18 % of Sefton's residents are within the most deprived decile in England, with 5 % within the least deprived decile. Specific localities in the south of the Borough continue to receive targeted UK Government and European funding for initiatives in recognition of the social, economic and physical regeneration needs of these areas. Differences in the percentages of the population suffering income deprivation in different wards in Sefton are shown in Table 2, highlighting the stark differences between wards that are close together.

Unlike the more affluent central part of the Borough, the southern part has an industrial heritage. Today, the largest operational part of the very busy Port of Liverpool lies within the Borough's boundaries. The port is close to some of the deprived communities, and the main traffic routes to and from the port cross these communities. The main sources of air pollution in Sefton are road traffic, in particular traffic linked to the Port, and localised industrial processes within the port. Statutory Reviews and Assessments carried out by the Council have led to the declaration of five Air Quality Management Areas under UK law, based on 2008 EU Directive (Ambient Air Quality Directive 2008/50/EC); three of these Air Quality Management Areas are related solely to NO_2, one solely to PM_{10} and one to both. All the Air Quality Management Areas are in the deprived south of the Borough.

Taken as a whole, Sefton shows worse health outcomes in many areas than those for England as a whole (Table 2). However, health outcomes in some wards (electoral districts within local authorities and represented by one or more councillors) in the south of Sefton are much worse than those for Sefton as a whole and there are considerable differences between wards, some of which are within 10 miles of each other. Table 2 compares health outcomes in Linacre Ward, the most deprived ward in Sefton and close to the Port of Liverpool, with those in two nearby Sefton wards, which are in the least deprived decile for England: Blundellsands and Molyneux wards.

Health outcomes in the south of Sefton are likely to be influenced by many factors, including lifestyles (for example, high prevalence of smoking and alcohol consumption, poor diet and social support), deprivation and unsatisfactory housing conditions. Although the social determinants of health (including social class differences, stress, early life contributions, social exclusion, work, unemployment and social support) are often the focus of the aetiology of health (Marmot 2005; Marmot et al. 2012; Inquiry Panel on Health Equity for the North of England 2014), there is a growing acknowledgement that environmental issues interact (Barton and Grant 2006). It is known, for example, that air pollution is implicated in: lung cancer as a carcinogen (Hart 2014), the causation or exacerbation of pulmonary disease (Grunig et al. 2014), cardiovascular disease (Lee et al. 2014) all-cause and respiratory mortality (Atkinson et al. 2014) and neurotoxicity (Costa et al. 2014).

In Sefton, it is unclear whether the social determinants are enough to explain the totality of the poor health without consideration of the history of local environmental pollution. Therefore, the suspicions and concerns of the local community regarding their air pollution history are taken seriously. However, the detailed links between health effects and air pollution in Sefton remain unclear.

Stakeholders

Over time, work to establish an understanding of the interaction of air pollution with health and the determinants of health in Sefton has led to the development of relationships between stakeholders that are helping to explore how air pollution affects health in the deprived south of the Borough.

The recent (2013) move of Public Health Departments, which had been part of Primary Care Trusts (local health boards) for many years, into local authorities has been of benefit to the Councils. An indicator of mortality due to particulate ($PM_{2.5}$) pollution has been included in the nationally established Public Health Outcomes Framework (PHOF) (http://www.phoutcomes.info/ Accessed 25 Oct 2014). This is helping focus the local health agenda at Borough Council level.

Public Health Departments have detailed knowledge of local health issues, including the determinants of health that are acting locally (Barton and Grant 2006). Officers from Public Health can support air quality officers in understanding how health impacts are determined, quantified and reported. They provide an overview that greatly assists other departments in local Councils in identifying where and how local air pollution fit with other health determinants, and in particular with those determinants of health that are influenced by decisions in other departments in the Council.

Air quality officers provide the Council with information on pollutant concentrations and emissions, compliance with objectives and sources and spatial distribution of pollutants. In Sefton, air quality officers have a long standing partnership with Public Health. Together, they developed the Sefton Air Quality Information and Alert System to provide routine information and pollution alerts to the local community (local media, schools, GPs, local hospital chest units, elected Council members, the Director of Public Health and other Council Departments) when the Air Quality Index is "high" or "very high". They also make joint presentations to Elected Members and Residents Groups to enhance understanding and interaction.

Academic institutions can provide specialist knowledge and undertake projects that other agencies, particularly public bodies, do not have the time or resources for. Sefton has worked with academic bodies by commissioning work and by supporting student research.

The public is a key constituency in understanding the impacts of air pollution in south Sefton. While a variety of screening techniques are used to identify areas where there may be air quality issues, responding to enquiries and complaints from the public about areas where they have concerns about pollution is important. These complaints are often accurate, and provide a valuable source of intelligence based on local knowledge and experience.

Integration

An important aspect of the work on air quality undertaken by the Council is gaining the trust of the local community and their ownership of issues. In beginning to earn this trust, the Council has adopted a policy of transparency and availability. To ensure transparency the Council has undertaken that all monitoring results and all reports, technical and related to Local Air Quality Management, will be made publically available. Data from real time monitors is automatically updated on the Council's Breathing Space website every hour and, where samples are sent away for analysis, results are posted manually as soon as they are received by the Council. Reports are posted on the website once they have been approved by Elected Members. Regular reports on air quality issues are given to Council Cabinet Member for Environment, and to Council committees: Overview and Scrutiny Committee and the relevant Area Committees. Air quality officers are always available to attend residents', community or interest groups upon request and will meet with individuals with specific requests.

This policy has improved relationships, but there can still be tensions where public expectations can exceed what the Council is legally or scientifically able to deliver. In these situations it is important that Council staff and elected members meet with members of the public and explain the limitations that the

Council works under, while listening to the issues raised by the public. This may not give complete satisfaction with the outcome, but, at the very least mutual understanding of why the Council has acted as it has and why the public has concerns can be fostered.

The Local Air Quality Management regime has requirements for consultation built into it concerning the results of Review and Assessment and when Air Quality Management Areas are declared or revoked. In many ways this is a good thing, but it has tended to focus consultation in these areas, perhaps to the detriment of more general engagement.

An interesting point that has become apparent through the Local Air Quality Management process is that many air quality officers, while technically and scientifically very competent, have no training in engagement and consultation with the public. They have struggled with this aspect. It has been realised that in order to do their job properly air quality officers not only need to develop relationships with health and other technical disciplines but also with communications and engagement professionals.

Comment

Although contributing to the measurement of air pollution through hosting of diffusion tubes, the public have not been as fully involved recently as previously in the processes that are important to understand and respond to air pollution. The Sefton Air Quality Information and Alert System and the policy of transparency and accessibility was possibly a victim of its own success, since the residents became reassured by various answers and discussions and engagement declined. A local area committee for the Linacre and Derby wards, comprised of elected members and representatives of residents and other groups and open to the public, took an interest in receiving regular reports and questioning Council officers. This gave rise to investigations into a putative cancer cluster, calls to Environmental Health and further questions to the Council.

The committee was enlarged to cover other wards; with wider issues to address, less time is available to consider the finer points of air pollution and health in the more restricted area of the first committee. The Linacre and Derby communities have less control over the current dialogue. Nowadays, not only are questions not asked, but the relationship between the community members of the committee and Environmental Health officers is more distant. Issues around the expansion of the nearby Liverpool Port only intensify the overshadowing of air pollution and health questions by other issues.

Re-engagement of the community will be an important step forward in developing both the understanding and responses to local air quality issues. We are still in the process of exploring how best to take this forward, but an important aspect of this is to understand the role of air pollution in the relative poor health status of the local people.

As a start, health has become a standing item on the agenda of Merseyside Air Quality Management Group meetings coordinated by Sefton Environmental Protection staff in conjunction with other nearby local authorities; a representative of Public Health England attends on a regular basis. Recently, representatives of nearby non-Merseyside Councils have also begun to attend. This has allowed the group to hold health-themed meetings [e.g. on the Public Health Outcomes $PM_{2.5}$ indicator (Gowers et al. 2014)], which has supported air quality officers and Public Health officials across the participating Councils to raise awareness and develop responses to air pollution in their own Council's strategies.

Links with planners on Merseyside Councils are also being strengthened in order to tackle some air pollution issues at source. To achieve their aims to ensure sustainable economic development and a better environment, planners need to thread a pathway through many disparate, and potentially conflicting, issues and laws: another form of wicked problem! The real changes here need to take place at a national level, where planning guidance is initiated, in order to enable better integration between planning, health and air quality issues.

Discussion

We have presented two case studies from England (contaminated land; air pollution) to illustrate the complexities introduced during the application of environmental science in the "real world", where problems are messy, intractable, subject to multiple interpretations, and often without easily identifiable solutions. We believe that the lessons from these case studies are applicable to other contamination situations, within the UK as well as outside, even although the legislative regime may be different.

Many of these complexities, such as the history of the community and the local environment, current social complexities (e.g. deprivation, health) and differing interests of different parts of the community, not only interact, but change over time, often due to the very interventions designed to solve what was perceived as the initial problem. Such interlinked complexity has previously been described in management science as "wicked problems" (Churchman 1967), a concept that is relevant to understanding environmental issues such as contaminated land and air pollution and the differing perceptions of these problems.

Examining the need for effective interactions that tackle the links between health and air pollution, Giles et al. (2011) have called for a new framework that integrates regulations with the perspectives of both communities and individuals, while continuing to work within an evidence-based multidisciplinary public health approach. We suggest that the tried and tested structure of the Public Health Risk Assessment (Reid et al. 2005) offers such a framework (Fig. 1).

To enable this approach (Fig. 1a) to be applied easily by others, we have outlined questions that can be asked in each aspect of the framework to identify and explore the components that surround the more technical risk assessment arising from analyses of the environment and health (Fig. 1b). The integration of the wider contexts and an understanding of the agendas of stakeholders with the technical risk assessment enable a multidisciplinary group to tackle the wicked problems that present as pollution and health issues to local authorities and other agencies tasked to protect or improve health.

Too often the answer to such wicked environmental issues has been to tinker ineffectively, or even to ignore them as "too hard". Although, as can be seen in our case studies, our approach does not guarantee complete success, it allows considered and viable answers to be found to at least some of the issues, while enabling further development or understanding to be explored and integrated by relevant authorities.

While the concept of wicked problems was first explored in social policy planning (Rittel and Webber 1973), and was later generalised in the points made above (ongoing problems without one solution; not solvable by traditional linear approaches; understanding changes with each solution; shared understanding and commitment from many is needed; solutions are not right or wrong), it would appear that there is a need to apply the thinking to the interface between environmental planning, health and pollution issues.

To make progress requires developing an understanding of the many factors involved that can only come from combining a variety of analytical techniques and tools and the bringing together of committed people from various agencies and the public to share their knowledge and understanding. The Public Health Risk Assessment model offers a way of working that is most appropriate for dealing with the multidisciplinary and flexible responses that are required by wicked problems. If this model was adopted at the start of a response to a particular problem or project, it could be used as a way of identifying and bringing together those individuals and agencies required to address the problem. It would also serve as a method for identifying the need to engage with and involve the public and provide a framework for communication.

The weakness of this approach is that, on its own, it does not necessarily address and change the complexity of environmental wicked problems. However, it provides an approach and mechanism to ease the difficult issues of (a) defining the problem widely enough, (b) obtaining enough or relevant scientific evidence, or deciding where scientific gaps remain, (c) identifying interested partners, friends and opponents and their concerns and attitudes, (d) decision making in the light of conflicting interests and quoted scientific evidence, (e) and risk communication.

Communication issues are often, as noted in the case studies, the hardest to deal with. Risk communication can too easily become the transfer of a number, probability or a statement that "the risk is minimal". None of these may mean much to the general public, or to other professionals who, outside their own area of expertise, are no more informed than lay people. Both groups should be considered as intelligent but uninformed, and approached in a fitting manner. A statement that the risk is minimal, while scientifically accurate in that it is almost impossible to state the risk is zero, can leave the hearer worried that the risk exists and is likely to give rise to problems. So the very communication that was expected to be supportive of the hearers becomes a message of doom and hopelessness.

Communication partly depends on both parties understanding each other. Community perceptions of environmental risks often differ from that of the professional, and can be too easily dismissed and yet they can provide accurate and fresh insight into problems (Stewart et al. 2010). Communication issues are not limited to those between professionals and the public. In multidisciplinary work, all parties are laity to each other and prone to misunderstandings. Multidisciplinary working thrives in small groups and meetings (Stewart et al. 2012).

Bioaccessibility of arsenic is an example of the difference a multidisciplinary group approach can bring. At the time of writing, bioaccessibility has not been endorsed by some agencies, including Public Health England. Accordingly, any review by Public Health England of data that includes bioaccessibility can lead to difficulties in discussions with other professionals who accept the validity of the approach. However, through working together and understanding each other's constraints, the integrity of differing views can be amicably maintained in a manner that allows the project to progress.

Multidisciplinary approaches through a Public Health Risk Assessment to wicked problems also help deal with the different uncertainties that are faced in making environmental decisions. In these situations, uncertainty has been classified into three types (IOM 2013): (1) statistical variability and heterogeneity (also described as aleatory or exogenous uncertainty), (2) model and parameter uncertainty (epistemic uncertainty), (3) deep uncertainty (uncertainty about fundamental processes or assumptions underlying risk assessments). The report focusses on deep uncertainty in the natural environment; however, the concept could comfortably be expanded to cover the uncertainty that arises in decision making from contextual and stakeholder issues, for which the Public Health Risk Assessment approach (Reid et al. 2005) provides a practical way forward.

Conclusions

Considering the air pollution issues in Sefton, Gary Mahoney, principal environmental protection officer concluded,

> It is important that we understand the perceptions and concerns of residents. Ultimately, the purpose of our work is to protect and improve their health. If the perceptions and concerns of the public are valid, then there may be issues that are not being identified by our current methods that must be examined and responded to. If the concerns prove to be unfounded we must still try to find ways to demonstrate that we have investigated them thoroughly, and present our findings in understandable and transparent ways, securing the ongoing trust and cooperation of residents.

Considering the land contamination issues, Nattalie Kennedy, the responsible scientific officer concluded,

> The first lesson learnt was that when delivering a message to a diverse audience, what matters is what they hear and understand which may be very different from what you thought you said. Secondly, never set timescales that are dependent on organisations, people or resource inputs that are outside of your control (i.e. Government funding, mobilisation of contractors). Thirdly, don't overload stakeholders with information; only contact people when you have something to say. Fourthly it is essential to have good working relationships with all stakeholder groups. It is essential to have good people involved on the ground, who understand the local people and their issues alongside a working knowledge of social, economic and demographic factors of the area.
>
> Finally, and most importantly, pleasing everybody is not possible. However, the potential benefit of obtaining external expertise providing psychosocial support for the residents affected by the contaminated land should not be forgotten.

Overall, we would argue that a multidisciplinary evaluation and response to the application of environmental science into the real-world works. The problems might be messy and appear intractable, but improvements which work can be made through a careful and nuanced approach that responds to as many different perspectives as possible while taking wider issues into account.

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