CL:AIRE

SUB 3

(March 2007)

subr:im bulletin

CL:AIRE's SUBR:IM bulletins present practical outcomes of research by the SUBR:IM consortium which have direct application to the brownfield and contaminated land communities. This bulletin considers the impact of climate change on contaminated land and brownfield regeneration.

Climate Change, Pollutant Linkage and Brownfield Regeneration

1. INTRODUCTION

There is little doubt that our climate is changing. Proper management of contaminated land must require an understanding of the magnitude of this risk to current, and future, pollutant linkages between source and potential receptors. It is almost inevitable that changes in environmental conditions and processes will affect the standards of remediation required to ensure receptors are not significantly impacted in the future. Remediation choices being made should be influenced by future land use, climatic conditions and societal demographics. Tools and guidance are needed now to assist the remediation industry in developing and adapting techniques so that they will be sustainable into this future. This bulletin summarises the work carried out as part of the SUBR:IM (Sustainable Urban Brownfield Regeneration: Integrated Management) research consortium. It examines current stakeholder perspectives and strategies, provides preliminary technical evidence of potential impacts of climate change on contaminated land and remediation systems and discusses potential technical adaptation strategies.

2. STAKEHOLDER PERSPECTIVES AND STRATEGIES

Two stakeholder groups given prominence in government reports on adaptation to climate change are local authorities and the development industry. These two sets of organisations are crucial to the production and management of the urban environment and to the take-up and implementation of climate change mitigation and adaptation measures. This is especially true in relation to strategies and measures that might be applied to the remediation of contaminated land. As such they were the focus of a study, using survey techniques, to determine how aware and prepared they are in respect of the likely impact of climate change for brownfield remediation.

When responses of the 'developers' group towards climate change are examined (Figure 1) it suggests that the potential impacts of climate change on site remediation are not considered to be as substantive as they are on master plan/site layout; building design, construction and choice of materials phases of the building lifecycle. However, there were some group differences and residential developers placed more importance on remediation impacts than choice of materials or the construction process. Similarly, most developers believed that subsidence, flooding and storms were more important than either higher temperatures or the increased risk of remediation schemes failing (Figure 2). Finally, in relation to remediation options, developers suggested that there was still some concern over the issue of future climate change. They would therefore be more likely to either reject a particular option and use an alternative, or switch, if there were no additional costs. This suggests that developers are currently cost-driven in this respect.

To follow up the survey work, six interviews were conducted with three practitioners and three developers. Generally, and unsurprisingly, the level of knowledge regarding the impact of climate change on remediation was greater amongst the first group than the latter. As one consultant put it:

'My own personal view is that there are still a lot of question marks about the use of cover systems and the retention of contaminated materials on site and I suspect that in a number of cases not adequate consideration is given to the real cost of ensuring long term durability of those systems'.

Several developers were aware of potential future problems, but tended to treat the issue as connected to wider concerns over flooding. As one developer suggested:

'for instance... most of the issues to do with climate change are obviously to do with flood risk and flood risk assessments, so therefore on our site...you'd be looking at all of the problems you have and then it would be an holistic approach to the design solution.'

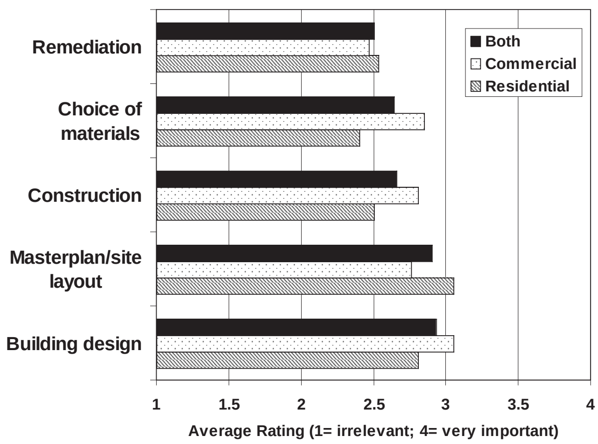

Figure 1. Climate change and impact on stages of the development process.

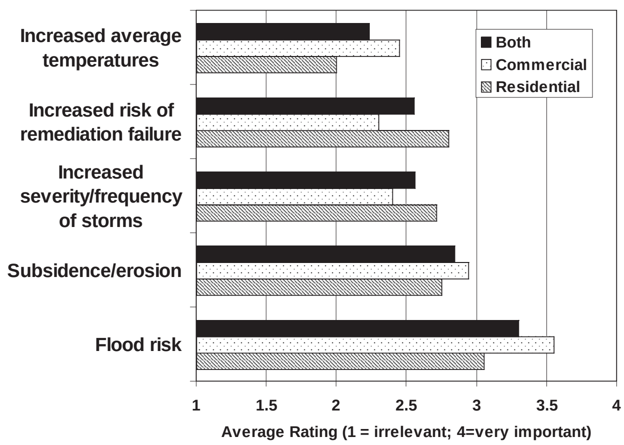

Figure 2. Type of climate change impact.

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A survey of local authorities revealed that just over half have a dedicated climate change officer and a similar proportion considered themselves adequately informed of climate change impacts. Significantly fewer (42%) are confident about their knowledge of climate change adaptation practices. There is an encouraging sign that local politicians are becoming more aware of climate change issues with 65% of respondents acknowledging that local authority members were giving it more priority, albeit from a low and variable base-level. Despite this increase in interest, only 36% of the respondents' authorities had signed the Nottingham Declaration on Climate Change and 23% had an adopted climate change strategy. In terms of the provision of information on climate change, that originating from government agencies (including the UK Climate Impact Programme (UKCIP)) and regional networks are perceived as most reliable and widely used. This has implications for the effective dissemination of information on contaminated land remediation processes and appropriate adaptation measures.

As Figure 3 illustrates, land remediation is seen as a relatively important issue in relation to climate change impacts, even though it is given a lower priority than some, more obvious, issues such as flooding and flood plain development. Notwithstanding this, taking that concern through into action has been less notable, with only about 10% of local authorities undertaking an appraisal of the robustness of contaminated land remediation measures and just 15% adopting measures to improve the robustness of past remediation works. In a more positive light, about a third of our respondents said that they were considering introducing measures to improve the robustness of past remediation.

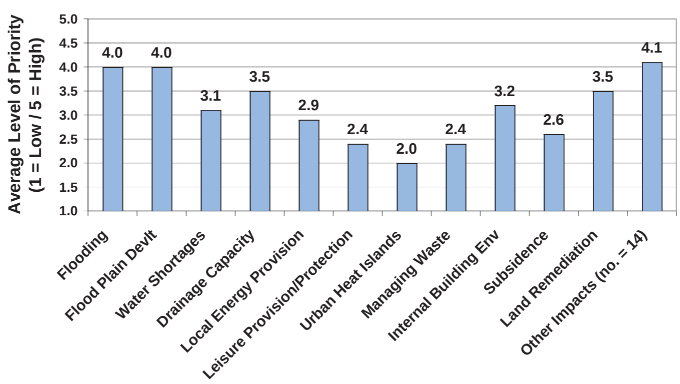

Figure 3. Priority given to climate change impacts.

Many local authorities are considering changing specific mechanisms to assist in climate change adaptation and these are illustrated in Figure 4. They clearly show the potential role of the planning system in making improvements to the land remediation process through the imposition of more stringent conditions on planning permissions, the use of legal agreements with developers or strengthening the requirements in environmental assessment. This opportunity for local authorities to (re)shape land remediation processes is in keeping with the government's vision of integrated 'spatial' planning.

The review of policy and practice within the development sector and local authorities suggests that there is a growing awareness of the generalities and specific implications of climate change for land remediation policy and procedure. However, that awareness and action has risen from a very low base and many developers and local authorities are still largely ignorant of the issues and inactive on developing strategies and mitigation/adaptation measures to deal with climate change. Although land remediation is given some priority in the list of relevant issues, most developers and local authorities are currently operating according to a 'business as usual' model. Overall the survey findings support the view that there is still much to be done by planning and property professionals to address the impact of climate change on brownfield remediation strategies, procedures and techniques.

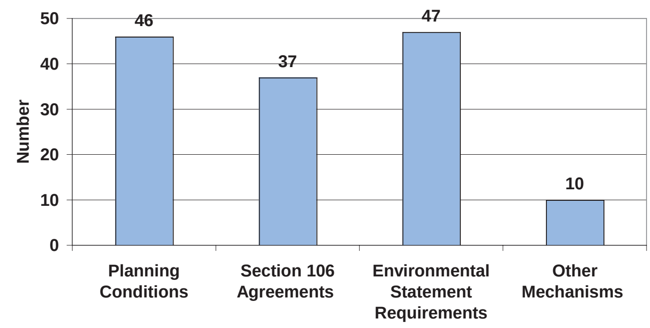

Figure 4. Number of local authorities who have considered changing mechanisms in relation to contaminated land remediation.

3. EVIDENCE OF POTENTIAL IMPACTS

Lack of stakeholder understanding is expected because there is currently very little experimental evidence of potential direct impacts of climate change on contaminated land and remediation systems. The following sections give examples from the literature and our work within SUBR:IM of effects which are likely to impact pollutant linkage and remediation methods.

Bio-chemical considerations
Surrogate evidence is available from studies which have investigated and compared the impacts of different climatic regions on biological and chemical properties of contaminated soils and contaminant behaviour. These studies show that warmer conditions favour biologically driven degradation of compounds amenable to degradation while drier conditions have the opposite effect. On the other hand, heavy metal soil contaminants, whose movement is more related to issues of leachability, present less risk in higher temperature and drier climates due to increased soil cation exchange capacity and pH. The chemical speciation of contaminants and sorption properties of soils are major considerations when assessing risk of pollutant linkage occurring as both fundamentally affect contaminant solubility and bioavailability. Chemical speciation is itself primarily determined by soil conditions such as organic carbon content, pH, anion concentrations, redox potential and ionic competition. Understanding the significance of the impacts of changing climatic conditions on contaminant speciation and adsorption is therefore fundamental to the development of sustainable risk mitigation strategies. For example, increased redox potentials associated with drier soil conditions might lead to the oxidation of reduced metal species (which are generally insoluble) and increase their solubility.

Physical considerations
In addition to bio-chemical effects, changes in our climate are also likely to highly impact physical movement of contaminants through wind and water erosion processes. Greater wind speed events could significantly increase the concentrations of wind blown dusts. Equally, predicted increases in rainfall intensity are likely to increase the erosion of contaminated soils especially after dry periods. In order to consider the magnitude of these effects, and using water erosion as an example, the RUSLE2 model (Foster, 2004) was used together with the UKCIP02 climate change predictions (Hulme et al., 2002) to forecast the effects of climate change on contaminant sediment movement via soil erosion processes by water. Erosion estimates were modelled for a spoil tip on a disused tin mining site located in the southern part of the Tamar Valley in south-west England. The contaminant source was a highly erosive coarse (1-2 mm) sandy spoil with significantly elevated levels of arsenic, lead and cadmium. The spoil tip was steep sided (54%) and completely devoid of vegetation. The effects of climatic changes under the two scenarios tested (low and high emissions) showed a significant and gradual increase in erosion rates with time (Figure 5). Predicted changes for a contrasting climate (East Sussex) were used to model the impacts had the site been situated in south-east England (Figure 5). Erosion rates for the site (SW) were up to twice those that a similar site would have generated in the SE, demonstrating how contrasting regional variation in

predicted changes in climate could significantly influence soil erosion processes. This highlights the need for modelling at a localised scale. Taking the average across the low and high emission scenarios, the results suggested that soil erosion rates could increase to nearly 25% by the 2080s.

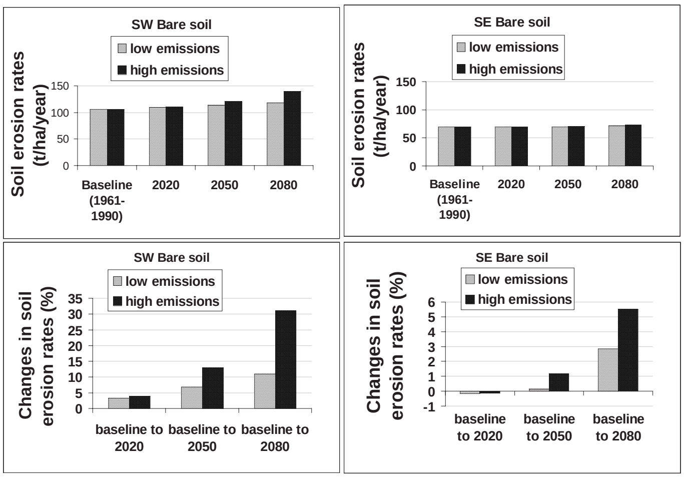

Figure 5. Bare spoil absolute and relative erosion rates for a contaminated site located in the Tamar Valley (SW, left) and for a similar site which would have been located in East Sussex (SE, right). Results are presented for the periods 1961 to 1990 (Baseline), 2011 to 2040 (2020s), 2041 to 2070 (2050s), 2071 to 2100 (2080s).

Using contaminant concentrations in the spoil, the mass of contaminants which would be generated via sediment production was calculated. The worst case climate scenario (high emissions) for the 2080s showed a 31% increase in arsenic mobilisation from 3.6 to 4.8 $t.ha^{-1}.yr^{-1}$ (Figure 6, SW Bare spoil). The results of this study demonstrate the high significance of changes in climatic conditions to physical pathways and the risks of pollutant linkage. Simulated vegetation establishment on the spoil showed that a well established vegetation cover on the sites would cause a dramatic reduction (by two orders of magnitude) in the amount of metals mobilised as sediments, reducing the mobilisation well below existing levels (Figure 6, SW Grass).

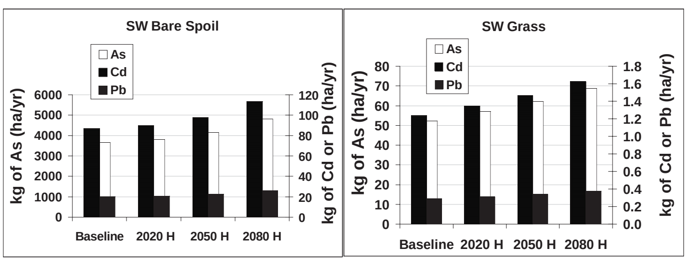

Figure 6. Metal mobilisation in the sediments before (SW Bare Spoil, left) and after vegetation establishment (SW Grass, right) for the high emissions scenario. Results are presented for the periods 1961 to 1990 (Baseline), 2011 to 2040 (2020s), 2041 to 2070 (2050s), 2071 to 2100 (2080s).

Containment system considerations

Changing environmental conditions also threaten the physical integrity of containment systems. Engineered cover systems and stabilised/solidified soil systems are two of the most studied remediation techniques relevant to understanding climate-related impacts. Both systems have been shown to become extensively damaged under severe wet-dry and freeze-thaw cycles, significantly reducing their mechanical properties and hence effectiveness. Figure 7 shows a typical cover system damaged by desiccation (Benson, 1999).

Preliminary evidence of the impacts of climate-related effects on a range of contaminated land systems has also come from work carried out under the SUBR:IM programme. The systems investigated included: (i) stabilised/solidified contaminated and uncontaminated soils, (ii) aged-stabilised/solidified contaminated and uncontaminated soils, (iii) compacted clay and sand-bentonite cover systems (iv) contaminated soil amended with compost, (v) contaminated soil amended with compost and bioaugmented and (vi) bioremediation site soil. Extreme seasonal temperatures as predicted by UKCIP (Hulme et al., 2002) were applied to these soil systems, together with a range of precipitation scenarios representing dry summers, summers with intermittent rainfall, summers with frequent rainfall, flooded winters and dry winters. Two years in real time were investigated and a range of physical, chemical and biological properties were tested at different time intervals. Figure 8 shows the typical and different type of physical damage that was observed in some of the stabilised/solidified soil samples tested. Figure 9 shows the effect of different 2080 climate scenarios on the biological activity of a bioremediated soil (System 1) and an amended and bioaugmented soil (System 2), compared to baseline conditions. The 2080a scenario included dry summers with no rainfall while the 2080b scenario included intermittent summer rainfall (wet-dry conditions).

Figure 7. Damaged compacted clay cover system in southern Wisconsin caused by desiccation (Benson, 1999).

Figure 8. Damage on stabilised/solidified soil samples following different imposed climate scenarios.

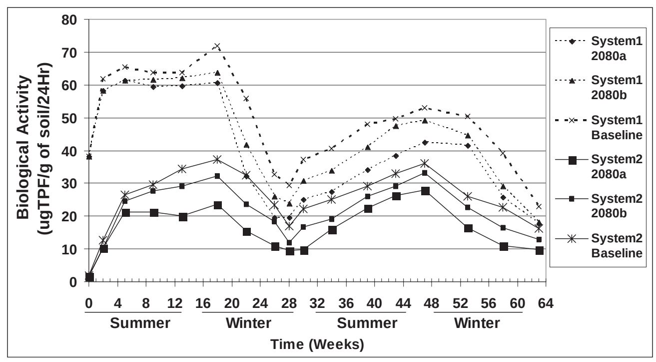

Figure 9. Effect of two different 2080 climate scenarios on the biological activity a bioremediated soil (System 1) and an amended and bioaugmented soil (System 2), compared to baseline conditions.

The experimental work showed that certain climate change scenarios or combinations of scenarios give rise to potentially significant impacts on the different soil systems investigated. For the stabilised/solidified soil systems, wet-dry conditions were found to be the most damaging. Damage was most severe in the first season of severe climate conditions and ageing of the system was found to be an advantage. In the compacted clay cover system, more damage was observed after the winters than the summers with an increase in permeability of one order of magnitude. Combining the results with model predictions (using the model HELP: Hydrologic Evaluation of Landfill Performance (Schroeder et al., 1994)) enabled the assessment of the longer-term impact of exposure to severe climate conditions. For the amended or bioremediated contaminated soils, the results show that the changes were more pronounced between seasons and between different soil systems compared to between the climate change scenarios imposed but that the overall changes are a combination of all those changes combined with long-term natural changes in soil conditions.

The findings should have an impact on the way contaminated land and existing remediation systems are managed, as well as the management and design of future systems. For example, a permeability value of 10^{-9}m/s is usually required for both engineered cover and stabilised/solidified systems. Hence the design of future systems might require much lower initial permeabilities to be achieved to allow for orders of magnitude of potential increases over time due to climate change conditions. Containment systems with improved technical performance and which are more durable and sustainable, and hence likely to offer an improved resistance to climate change conditions, are currently being investigated and developed.

4. TECHNICAL ADAPTATION AND RISK MANAGEMENT STRATEGIES

The current approach to risk assessment and management for brownfield sites is based upon the source - pathway - receptor model of pollutant linkages (CLR 11, 2004). This defines the site-specific approach which should be adopted in addressing climate change for contaminated land. The key items are as follows:

- The impact of climate change should be based upon site specific conditions, as at present.
- The adaptation strategy for each site should take as its starting point the current situation based on CLR 11.
- The impact of climate change should be addressed through the conceptual model of pollutant linkages at each stage of the strategy, use of relevant information and data from UKCIP is necessary.
- The assessment of climate change impacts should take into account localised climate factors.

The adaptation strategy requires a detailed adaptation methodology which is set out in the four stages given below. It is important that the methodology works sequentially through from Stage 1 to Stage 4, although some degree of iteration may be required.

Stage 1: Risk assessment based on current situation: key requirements

The following steps need to be completed at this stage:

- Carry out a risk assessment, use CLR 11, using specific models or guidance to determine risks to humans (e.g. CLEA models), plants, water and property (e.g. BRE Special Digest 1 (BRE and The Concrete Centre, 2005)).
- Determine and report the risks of historic contamination on the site.
- Develop a conceptual model of pollutant linkages as part of risk assessment, including all sources, pathways and receptors.

This stage is based upon the current approach to risk assessment; experienced and fully qualified practitioners will need to be involved at this stage.

Stage 2: Risk assessment based on climate change

The following steps need to be completed at this stage:

- Use future climate scenario information, using at least two contrasting climate change scenarios for the particular site location and considering the periods for 2020, 2050 and 2080.
- Make a qualitative assessment of the impact on sources, pathways and receptors; and determine potential impacts on the pollutant linkages in the conceptual model.
- Readdress the quantitative risk assessment through, for example, changing input parameters to human health risk assessment, or address guidance on the impact of contamination on building foundation materials.
- Redefine the conceptual model of pollutant linkages based upon the periods 2020, 2050 and 2080. Redefine soil levels on the site based on the climate change risk factors from UKCIP and adjust site trigger levels as appropriate. Compare revised values with soil guideline values for human health, water, buildings and other receptors.
- Report the results and the revised conceptual model of pollutant linkages.

Stage 3: Risk management current position

The current risk management needs to be based on a thorough risk assessment (stage 1). The following steps need to be completed at this stage:

- Use a technology-based approach, either through excavation and removal, containment or treatment of either sources or pathways. For property, address the materials used to ensure receptors are resistant to the contamination.
- Non-technical measures for managing sites may be used, and on-going monitoring or maintenance may be required.
- Follow best practice in risk management and determine verification requirements for the remedial work.

Stage 4: Risk management based on climate change

The starting point is risk management using the current approach presented in stage 3 and all other information gathered during stages 1 and 2. The following steps will then need to be considered at this stage:

- If stage 2 has demonstrated a potential increase in the risk, then reassess the risk management options in stage 3. If no greater risk is perceived, then no action is required.
- If the risk is determined as being greater, then undertake further assessment of the remediation options. Use modelling if possible of the additional risk from climate change over 2020, 2050 and 2080. Alternatively use qualitative judgement to address the requirements of remediation options.
- Any remediation technology that removes or destroys the contamination, without a time dependent factor, will remove the climate change risk. The use of such technology will not therefore be subject to the impact of climate change
- Containment and some treatment technologies will need to be addressed as to the impact of climate change. Over time, changes to the materials used in cover systems, slurry walls and geomembranes from temperature and moisture changes are likely to be significant. Design changes to the technologies or a change of technology may be required.

5. CONCLUSIONS

From the evidence available in the literature and collected as part of the study presented here it is clear that certain climate change scenarios will have significant impacts on current and future contaminated land and remediation systems. Examples include severe physical damage to soil cover systems and stabilised/solidified soils, and extensive soil water erosion and associated contaminant transport. These impacts will have major effects on the future management of contaminated and remediated sites and are expected to influence both the way risk is managed on those sites and the design of future remediation strategies. A conceptual adaptation strategy has been developed highlighting four stages to be considered when addressing the impact of climate change in the current risk-based contaminated land management regulatory framework in the UK. The results of the surveys carried out on the development industry and local authorities clearly demonstrate that these stakeholders are still largely unaware of the issues surrounding climate change and its impact on contaminated land management and redevelopment. They are therefore not yet fully considering potential impacts of climate change and related evidence in their decision-making process. However, the work begun during the SUBR:IM programme has shown the value of a combination of experimental and modelling approaches, which together look able to deliver the most robust solutions for the remediation industry.

Acknowledgements

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