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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 provides an overview of how greenspace can be established and used in a sustainable regeneration context on brownfield land.

Integrated Remediation, Reclamation and Greenspace Creation on Brownfield Land

1. THE IMPORTANCE OF GREENSPACE

In an urban context, greenspace can take many forms, and serve many purposes (Table 1). At the heart of the concept, there is the expectation that greenspace has been created and continues to be managed for public good. In the UK, there is renewed interest at Government level in the quality of urban living, and greenspace has received considerable focus as a means of its improvement. In urban regeneration, almost inevitably involving the remediation and reclamation of brownfield land, greenspace is seen as an essential component of the new landscape (CLG, 2008a).

Table 1. Types of urban greenspace.

Types of urban greenspace	
Public/local parks	Allotments
Planned gardens	Sports fields
Domestic gardens	City farms
Church yards and cemeteries	Specialist parks, e.g. Victory parks, ecology parks
Urban forests/woodland parks	Riparian zones

Greenspace provides communities with open space for formal and informal recreation, sport, and if connected, safe and pleasant conduits for urban travel. Provision of greenspace for these activities can maintain and enhance human health and well-being by promoting physical activities which can improve cardio-vascular condition and reduce the risks of obesity, and through a psychological connection with the natural environment. The active participation of individuals and groups in the design, construction and management of greenspace can also engender community inclusion and cohesion. There is a range of other benefits that greenspace can potentially provide. For example, some have pointed to the role of greenspace in reducing the urban 'heat island effect', as well as providing shade to reduce the impact of heat stress and diseases such as skin cancer.

Urban wildlife habitats, by their construction or self-establishment on brownfield sites, are now regarded for their importance in protecting nationally as well as locally scarce species. Areas of greenspace within the town or city will reduce local rainwater run off but they may also serve as zones where surface water can be allowed to flood, rather than impacting upon residential or industrial areas. Flood mitigation is increasingly important for urban areas where climate change scenarios predict higher winter rainfall. Pollution modification is another important contribution that greenspace can make. Atmospheric pollutants are intercepted by vegetation and concentrations of particulate matter in the air are reduced, for the benefit of both human dwellers and city infrastructure such as buildings. Certain forms of vegetation may also sequester soil contaminants, such as metals, or help to degrade organic ones. Vegetation, especially woodland, can also reduce noise 'pollution' and enhance quality of life. Furthermore, urban greenspace may play a small part in carbon sequestration and in fossil fuel substitution if biomass is produced for heat and power generation. The concept of 'positive' greening is summarised in Figure 1. Whilst greenspace provision has become such a clear policy objective of brownfield development, there are conflicting views, and practices, over how to achieve sustainable greenspace in the context of land remediation. Often the remediation and vegetation establishment phases of land reclamation are considered separately and opportunities for re-use or recycling of 'soil-forming materials' in which to establish vegetation are lost. Contaminated sites are all too often cleaned up to generic levels and the formation of the final landscape occurs in isolation of the remedial process. In addition, the value of different forms of vegetation to break the source-pathway-receptor linkage is ignored or misunderstood to the extent that some vegetation types are prohibited from forming the after-use of the site.

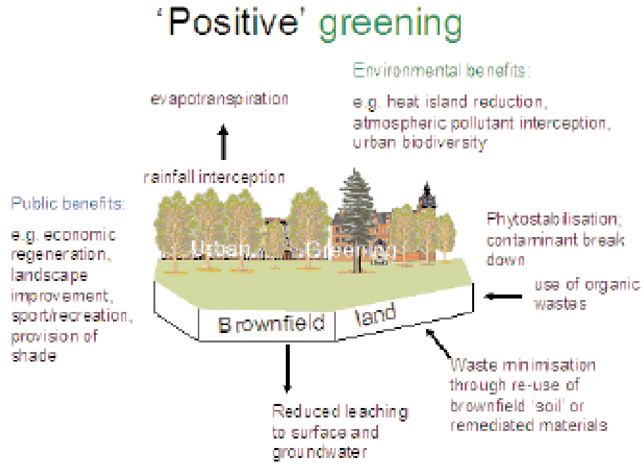

Figure 1. 'Positive' greening.

This bulletin provides an overview of how greenspace can be established and used in a sustainable regeneration context, and the limiting factors which affect establishment on contaminated and other brownfield land.

2. SETTING THE OBJECTIVES FOR GREENSPACE CREATION

The redevelopment of brownfield land to a hard-end use is never undertaken without consideration and purpose. In the same way, regeneration to greenspace requires definition of focussed objectives so that its design and composition can be optimised and the success of its establishment and delivery can be evaluated against these objectives. On a practical level, setting objectives facilitates design and, later, the management of the greenspace. But the objectives should also provide the criteria of evaluation to determine their delivery. An inherent assumption is that brownfield greening is sustainable and that the benefits of greenspace are intrinsic to its existence (rather than, for example, the way it is managed). Our research in the SUBR:IM consortium has demonstrated that the understanding of the concept of sustainability in relation to greenspace creation varies significantly between developers, site managers and other disciplines in land regeneration, to the detriment of successful and sustainable greenspace establishment (Doick *et al.*, 2009). We propose a standard list of sustainability objectives for brownfield greening projects (Table 2) and guidelines for their use, such that projects could be consistently directed – from remediation, through reclamation, to regeneration and long term land management – towards the successful establishment of quality, sustainable and multifunctional greenspace. Needless to say, the objectives must be met, monitored and evaluated as part of the regeneration and subsequent management of the greenspace to ensure successful delivery and to redirect management as required. A system in development will assist practitioners in determining attainable objectives and demonstrating that outcomes of the regeneration have been achieved (http://www.forestresearch.gov.uk/fr/INFD-7D4J9Q).

3. SITE INVESTIGATION FOR GREENSPACE ESTABLISHMENT ON BROWNFIELD LAND

Achieving sustainable remediation of brownfield sites is highly challenging. The heterogeneous nature of ground conditions and contamination types as well as existing social, ecological and archaeological resources on-site, the need for community engagement and involvement and the need to ensure the restoration will deliver the desired functionality all require consideration from the outset.

Table 2. Proposed list of sustainability objectives for brownfield greening projects.

Economic Objectives	Social Objectives	Environmental Objectives
Be economically efficient and self-supporting	Encourage social inclusion and cohesion	Minimise the use of un-recycled resources
Provide employment opportunities	Promote health and well-being	Promote land, water, soil and air quality
Promote local and regional economic regeneration	Provide good accessibility for all to greenspace and local facilities	Protect biodiversity and the natural environment
Promote attractive, functional landscapes	Facilitate education	Conserve natural and cultural heritage
Promote local affluence and community prosperity	Reduce crime and anti-social behaviour	Combat the impacts of climate change

Successful restoration requires that site commodities and liabilities are fully ascertained and understood prior to restoration or other forms of engineering. The site investigation process is an integral part of a greenspace development cycle as it provides foundation information which determines ecological and historical resources as well as hydrological, chemical and physical conditions. This will assist the developer in making informed choices when considering liabilities, remedial requirements, and appropriate soil, habitat and species choices. For detailed guidance on site investigation in relation to greenspace establishment see, for example, Hutchings *et al.* (2006) and Doick and Hutchings (2007).

4. THE SOIL RESOURCE

Urban soils differ considerably from their rural counterparts because physical and chemical disturbance has often resulted in conditions which will constrain vegetation growth. It is vital that restoration provides a soil resource which is free of compaction and toxic contamination and has a water holding capacity and nutrients to support the survival and growth of vegetation. The site investigation process must involve a review of historical land use, which should guide the user in determining soil materials which are of concern or, alternatively, represent a significant resource. Earth movement during the site redevelopment process offers a unique opportunity to remediate physical and chemical constraints and add materials to 'construct' soils which will be sustainable in the long-term.

The nature of soil, its potential to sustain vegetation and the consequences of these actions are fundamental to the success and sustainability of a greenspace establishment project. Consequently, Doick and Hutchings (2007) advised that the soil environment be considered the focal point of the site investigation and that four key questions should be repeatedly asked throughout the site selection and investigation processes:

1. Will the site support trees/vegetation? Particular consideration should be given to drainage and water holding capacity, presence of phytotoxic chemicals, fertility, physical soil characteristics, soil cover and rootable depth and topography of the site.
2. Will the establishment of the greenspace generate, amplify or negate risks and hazards?
3. Will vegetation establishment adversely affect the site?
4. How will the site be managed in the short and long-term?

5. INTEGRATED REMEDIATION, RECLAMATION AND GREENSPACE CREATION

Successful reclamation of contaminated sites to greenspace requires a thorough understanding of the interactions between soil conditions, contaminant behaviour, the vegetation, pollutant pathways, and their exposure and toxicity to receptors which collectively impact the risk of pollutant linkage.

The presence of contaminants and their 'controlled release' to the wider environment are acceptable under modern legislation as long as they do not pose a 'significant risk of causing significant harm' (DEFRA, 2006). Such principles are well tested and widely employed in other industries.

Elevated total concentrations of contaminants in a soil do not necessarily mean that they pose significant risk to a defined receptor. Therefore, generic soil guidelines (e.g. Soil Guideline Values 'SGVs' or Soil Screening Values 'SSVs') should only be used as a means of screening whether further investigation on potential pollutant linkage is warranted. Similarly, reducing soil concentrations to meet these levels during reclamation or remediation will not necessarily eliminate the risk of pollution or toxicity. Remediation of contaminated soil materials to meet such values will lead to targets which, in most cases, require over-engineered solutions or drive the 'removal', or transfer, of the contamination to landfill.

6. A 'BACK TO BASICS' APPROACH

A far more sustainable approach is to understand the risks that a contaminant poses to receptors based on exposure and toxicity. Exposure is influenced by many factors, but centrally consists of the following elements:

- The mobility of the contaminant;
- The availability of the contaminant;
- The pathway by which a contaminant reaches a receptor;
- Dilution and dispersion mechanisms which influence the concentration and availability of the contaminant at the point of exposure to a receptor;
- The pathway by which a contaminant enters a receptor;
- The duration over which a receptor is exposed.

Toxicity is receptor-specific and is influenced by:
- Species, age and provenance;
- Exposure pathway and effect within the specified receptor.

It is far more difficult to manipulate factors that influence toxicity than those which influence exposure, so most remediation techniques concentrate solely on achieving the latter. However, the establishment of new greenspace on contaminated land gives an opportunity to consider the use of plant species which are more tolerant of adverse soil conditions, limit the uptake of contaminants into the vegetation, reduce the mobility or availability of contaminants, and/or intercept contaminants before they can reach receptors.

Once the immediate exposure risks are understood for a specific site, consideration should be given to how the reuse of the soil materials or establishment of a vegetative cover could lead to breakage, enhancement or formation of exposure pathways. Targets for remediation should be set on the basis of exposure and toxicity (rather than generic soil concentrations) for the planned not the existing land-use. Targets for remediation can often be reached by modifying the contaminant exposure (e.g. by reducing their availability) without the need to remove contaminants.

Fitness-for-purpose principles should of course be employed at this stage. In the context of greenspace establishment, the following questions should be considered in addition to those normally addressed during the site investigation, restoration or remediation process.

a) What are the existing soil resources?
Soil materials are commonly disposed of during site redevelopment with no regard for their potential reuse for landscape creation. This leads to increased pressure on landfill and a requirement for topsoil importation.

Wherever possible, soils should be stripped and stored for reuse onsite. Failure to do so can put them at risk of cross contamination and compaction. Compaction has been identified as one of the major causes of vegetation failure, and avoidance is always more cost effective than cure. Guidance on the storage and placement of soils for greenspace establishment can be found in Foot and Sinnett (2006).

Mechanical disturbance of soils can often lead to an increase in the mobility and availability of contaminants. Such effects may only be short-lived but assessments should be made to evaluate the risks of such operations, and this should be considered during the risk assessment process. Most soil analytical methods use disturbed samples, so standard techniques should be adequate to assess the impacts of such mechanical processes.

b) Does the soil require amendment to improve its nutritional or physical ability to support vegetation?
Amendments can be used to convert many materials into soils by supplying essential plant nutrients and improving their physical characteristics (Table 3). Their application should be prescribed specifically for the habitat they will support, and extreme care should be taken that their application (often over application) does not cause soil or water pollution.

c) Would the stabilisation of contaminants through the addition of soil amendments break pollutant linkages?
Amendment application to improve nutrient levels will almost certainly impact upon the mobility and/or bioavailability of many contaminants. In many circumstances these attributes can be used to stabilise soil contaminants into immobile or non-bioavailable forms as the mobility of metal and organic contaminants may be reduced by the formation of insoluble complexes between the amendment and contaminant (Gadepalle *et al.*, 2007).

Table 3. Amendments used to improve the suitability of soil-forming materials and degraded soils for vegetation establishment (Kilbride, 2006).

Type	Fertiliser value N	Fertiliser value P	Fertiliser value K	C/N ratio	Organic matter content	Cost / availability	Other properties
Liquid sewage sludge	••	•	x	••	•	Free to users - transport costs to be paid	Generally unpleasant to use; biological pathogens likely although reduced in 'digested' sludges; heavy metals possible
Sewage sludge cake	••	••	x	••	••	Free. Most common biosolid currently available	Possible heavy metals, malodorous, pathogens likely if originated from undigested liquid sludge
Thermally dried sewage sludge	••	••	x	••	••	Comparatively expensive, limited availability	Liming properties
Alkali-conditioned sewage sludge	••	x	•	••	••	Cost charged, not commonly available	Increase soil pH, risk of nitrate leaching
Composted sewage sludge	•	•	•	••	••	Cost charged, not commonly available	Horticultural use
Greenwaste compost	••	•	•	••	••	Cost charged, available throughout UK	Mature composts provide slow release of N
Wood residues (various from forest industries)	xx	x	x	xx	••	Widely available in a range of types. High production costs.	Principally increases soil porosity and drainage, can cause N deficiency-addition of N fertiliser recommended
Animal manure (cow)	••	x	x	••	••	Readily available - mainly transportation costs	Different sources of origin e.g. cattle, pig. Properties vary, dependent on source. Potential loss of N through volatilisation of NH_4-N
Industrial by-products (paper mill sludge)	xx	x	x	xx	••	De-watered papermill sludges are widely available.. Generally provided free of charge	N immobilisation due to very high C/N ratio possible presence of fungicides/bactericides
Spent mushroom compost	••	•	••	••	••	Readily available - cost charged	Used as a surface mulch, can be detrimental to young plants
Straw	xx	x	x	xx	••	Commonly available - low cost	Can cause N deficiency
Blood and guts	••	x	x	•	x		Unpleasant origin

•• Very good, • Good or adequate, x no effect, xx may be detrimental

The use of composted organic soil amendments (e.g. municipal solid waste compost, biosolid compost, mature compost, cow manure) for restoring heavy metal and arsenic contaminated soils is becoming broadly accepted. Most research has demonstrated that the uptake of heavy metals and arsenic by plants is reduced by the addition of composted materials to the soil. However, experience gained during the SUBR:IM programme has shown that the response of soil contaminants to an amendment is both compost and soil specific, with some interactions causing an increase in metal solubility and bioavailability (van Herwijnen *et al.*, 2008). Leachate and/or soil extraction tests should be employed to determine potential risks (van Herwijnen *et al.*, 2008). Some amendments will reduce the mobility and/or availability of a contaminant at one site whilst increasing it at another.

Contaminants will also react differently. There are basic principles which can be employed to predict effects, but ultimately testing will be required to ascertain them on a site-specific basis.

It should also be considered that changes in mobility are not always synonymous with changes in bioavailability. For example, addition of compost materials in some soils can cause the formation of soluble metal complexes which may increase the uptake of metals into vegetation. Although this may be partly due to formation of soluble metal salts which will also have a high bioavailability, consideration should also be given to complexation of the metal with soluble organic phases such as humic acids. The availability of metal-humic complexes to most soil dwelling organisms is usually comparatively low, and therefore the risks to biological receptors may in fact be minimal.

Charcoals and natural zeolites have excellent potential for contaminant immobilisation due to their high ion exchange capacities and highly porous structures. Soil amendment with 'red mud' and other iron rich compounds have also been shown to immobilise labile metals and are especially effective at reducing arsenic bioavailability and improving plant performance (Friesl *et al.*, 2003). Red gypsum, phosphogypsum and other phosphate based amendments also have good abilities to adsorb lead.

d) Will the vegetation itself alter the pollutant linkage?

Choosing appropriate vegetation cover can help to stabilise the soil by reducing the risk of soil erosion and consequent transport of pollutants into surface waters or air. A dense grass sward can minimise soil erosion processes on brownfield land (De Munck *et al.*, 2008) and the generation of wind-blown dusts or over-ground particulate movement and trees can be used to intercept airborne particles (Beckett *et al.*, 2000). Vegetation can therefore be effectively deployed as means of preventing or breaking pollutant linkages which occur via erosion processes.

A complete vegetation cover effectively eliminates direct exposure of greenspace visitors to contaminants still present in the soil. However, exposure of soil materials by vegetation regression, and the risk of soil ingestion (pica), especially by children, can reduce confidence in greenspace health and safety. Covering remediated materials with a thin (c. 250 mm) layer of 'clean' soil or soil-forming material can do much to dispel these concerns, and help to increase the likelihood of vegetation longevity. Consideration should also be given to the planting or natural regeneration of vegetation types that bear edible fruits or nuts, and/or the risk of or to burrowing animals.

Soil acidity is crucial in the mobility and availability of contaminants and care must be taken to understand how such effects will impact upon the risks associated with forming or intensifying pollutant linkages. Conditions at the interface between the soil and plant roots (the rhizosphere), are different to those in the bulk soil itself. Species that restrict movement of contaminants, notably metals, into the shoots and leaves help to prevent transfer into the food chain and broader biosphere. Risks of food-chain transfer can be considered using appropriate models (Environment Agency, 2006; 2007a; 2007b) validated where necessary with ecotoxicological assessments using appropriate test organisms (Environment Agency, 2008).

e) Is containment a viable option?

There are many examples of successful vegetation cover on land remediated by means of capping or containment, especially over domestic landfill. Vegetation can intercept rainfall and help reduce infiltration into the contamination or landfill, thus reducing leachate and potential water pollution. It can also help to stabilise the soil cover from water and wind erosion, and protect the engineered capping system beneath. Nevertheless, the roots of some forms of vegetation, notably trees of certain species, can threaten the integrity of the capping system if the cap is inadequately constructed (e.g. engineered cap bulk density should exceed 1.8 g/cm^3) and is not protected by an adequate soil thickness. The soil layer must also be thick enough to provide sufficient plant available water resources to support the vegetation in the summer (e.g. some tree species may require a soil cover of over 1.8 m depending on location/average rainfall). Some caution against the planting of trees on containment systems because of the perceived risk of windthrow (in which a tree is blown over, causing the roots and soil to heave) and thus cap exposure. However, this risk can be minimised by good practice in landfill restoration and the choice of suitable species (CLG, 2008b).

Containment landfills require considerable monitoring and management, and owners are often reticent to permit access to the public, especially if landfill gas collection systems are in place. There is a risk of vandalism which could be extremely dangerous if gas explosion occurred. Hence greenspace on such sites may be beneficial for the visual appearance of the landscape, and as wildlife habitat, rather than providing facilities for recreation.

f) Can soil conditions be manipulated to degrade organic contaminants?

Bioremediation has become common practice for treatment of soils contaminated with organic compounds such as diesel range organics (DROs) and smaller polycyclic aromatic hydrocarbons (PAHs) (Lynch and Moffat, 2005). Degradation

Table 4. Effect of selected remediation technologies on some important soil properties.

Technique	pH	Available Water Capacity (AWC)	Nutrients	Organic Matter (OM)
Thermal desorption	pH raised as base cations released from OM. This can lead to the binding up of any P that is left and non availability of micronutrients such as Fe, Mn, Zn and Cu.	AWC will be reduced due to the absence of OM and reduced pore size.	Most major nutrients either mineralised or destroyed, in particular N.	Loss of OM leading to poor soil structure, nutrient retention and reduced AWC.
Bioremediation	pH may not necessarily be affected but the correct pH is vital for microbial activity. Below about pH 6 the microbial activity is curtailed so low pH substrates need to be amended to raise the pH.	As microbial and faunal activity proceeds then OM will be created and soil fauna such as earthworms will increase. This should lead to improved available water capacity.	Bacterial activity, such as nitrogen fixation will improve N levels. However, bacteria degrading contaminants may require more nutrients than are available, especially N. Nutrient levels may have to be supplemented for bacterial activity to be optimised.	OM will increase over time through microbial activity and possible faunal activity, but will depend on the time the soil spends being bioremediated.
Chemical extraction	If acidic solvents used then pH may drop considerably. Below 5.5, nutrient availability is restricted and bacterial activity curtailed. Low pH will destroy clay mineral structure and OM. Cation leaching will increase. At low pH, compounds are in a reduced state which can increase toxicity.	If soil structure is destroyed by strong REDOX acidic or organic reagents then AWC will be reduced through the collapse of pore space and size.	If the soil becomes acidified by the reagents used then nutrient availability will be reduced. There will also be increased loss through leaching as nutrient cations such as P, K and Ca become displaced and solubilised by H^+.	OM can be reduced as it is destroyed by decreasing pH and by the use of organic solvents.

can be promoted through stabilising the carbon to nitrogen ratio, buffering pH, providing essential nutrients and optimising redox conditions. Recent research by the SUBR:IM consortium points to marked improvements in microbial survival and activity, and hence organic degradation, through application of amendments such as charcoals which can adsorb toxic compounds and whose pore structure allows for effective microbial colonisation. There is good potential to use such techniques to both remediate and restore soils for reuse on contaminated sites.

g) Has the soil been treated thermally, physically or chemically?

Our research has demonstrated that there is potential for the use of materials remediated through thermal (thermal desorption), physical (soil washing) or chemical processes in supporting several types of vegetation. The application of organic and inorganic amendments to remediated soil-forming materials can aid vegetation establishment and in some circumstances help to remediate metal and organic contaminants further (van Herwijnen *et al.*, 2008). Remediated soils commonly lack organic matter and have low levels of essential macro/micro nutrients that plants need for sustained growth and health. In addition to probable contamination, they have characteristically poor physical structure and poor water holding capacity. Incorporation of organic materials into these soil materials prior to vegetation establishment can help to restore soil structure by providing organic matter and sustenance to invertebrates which can aerate and mix materials effectively over comparatively short time periods. Table 4 contains proposals for the suitability of some remediated soil materials, by type of remediation technology.

h) Is the site a former mineral working?

With the exception of some coal spoils which contain elevated levels of arsenic and PAHs, and metalliferous mine workings, most mineral workings do not present significant risk of metal or organic contamination. However, acute acidity due to iron pyrite oxidation on some sites can pose a risk of aluminium toxicity to plant roots, and to water draining from the site. Some restored mineral sites are comparatively large, with similar amplitude of relief, which make them at risk of soil erosion. This can have chemical as well as physical repercussions in chemically reactive materials. Greenspace created as a part of mineral reclamation can help in reducing risk of erosion and in blocking other pollutant pathways (De Munck *et al.*, 2008). Nevertheless, spoil materials often used in reclamation are usually infertile and vegetation regression will occur unless nutrient deficiency is addressed. Composts and/or sewage products have been used to great effect as a treatment before vegetation establishment, and further applications may not be necessary if appropriate types of vegetation are chosen.

7. CONCLUSIONS

There is little doubt that well planned, constructed and managed greenspace established on reclaimed brownfield land brings a wide range of public and environmental benefits. Soil contamination is widespread on such land, and a risk-based approach should be adopted which ensures that risks are adequately assessed and appropriate remediation standards are set. There is increasingly strong evidence that when the processes of site assessment, design and planning, remediation, soil formation and species choice are adopted collectively the sustainable regeneration of sites and is highly achievable, cost effective and sustainable.

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