ICRCL Guidance Note 70/90
First Edition
February 1990

INTERDEPARTMENTAL COMMITTEE ON THE REDEVELOPMENT OF CONTAMINATED LAND

Notes on the Restoration and Aftercare of Metalliferous Mining Sites for Pasture and Grazing

ICRCL

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NOTES ON THE RESTORATION AND AFTERCARE OF METALLIFEROUS MINING SITES FOR PASTURE AND GRAZING

SUMMARY

In some cases where land has been contaminated with residues from base metal mining activities, the operator, landowner and mineral planning authority may decide that it might be reclaimed or restored for pasture and grazing. In such cases account should be taken of the possible risk of toxicity to plants and animals. This paper provides guidance on concentrations of potentially toxic elements in soils and on management practices to minimise their effects. The guidance on the range of tolerable concentrations of particular elements does not hold for other situations and does not apply to arable land. If it is not possible to meet the guidelines the land should not be used continuously for agricultural purposes.

Typical concentrations of potentially toxic elements in uncontaminated soils are compared with values found in various mining areas of England and Wales. Maximum ("action trigger") concentrations which will avoid phytotoxicity have been derived from a study of total and easily extractable metal concentrations in minespoil materials. Under most circumstances phytotoxicity is unlikely at pH 6.0 and above at the concentrations given. The risks of toxicity to plants and grazing livestock are discussed.

Threshold trigger concentrations, below which problems are unlikely, are given. Action trigger concentrations of elements in soil on which livestock are grazed assume stock are <u>continually</u> grazed on the land and only ingest herbage with <u>relatively low levels of soil contamination</u>. The suggested guidelines for avoiding toxic and phytotoxic effects should be monitored in practice to assess their validity and suitability. As a consequence of experience gained in practice it may become necessary to issue revised guidance from time to time.

Management practices for use before, during and after restoration are suggested. These practices will minimise concentrations of potentially toxic elements in "topsoil" and limit their effects upon livestock and plants.

BACKGROUND

This paper originally appeared as "Proposals to reduce the effects of toxic elements on former metalliferous mining sites", issued by the Agricultural Development and Advisory Service (ADAS) in January 1988 and prepared by ADAS Soil Scientists in consultation with Veterinary Officers, Land Management Advisors and Food Scientists in MAFF; input was also received from DOE officials. The present paper embodies the ADAS proposals and presents them in the style of other papers in the series of ICRCL Guidance Notes on the redevelopment of contaminated land. The Note was prepared in response to requests for advice when dealing with the restoration of metalliferous mining sites for pasture and grazing and does not apply in the cases where agricultural after use would not be appropriate. The guidance is based on current information and on operational experience and is designed to assist in dealing with problem sites. It is not intended to represent a Code of Practice and will if necessary be subject to future amendment in the light of on-site experience.

Enquiries on the guidance given in this Note or on the restoration and aftercare of specific former metalliferous mining sites for pasture and grazing should be addressed to ADAS rather than to ICRCL.

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NOTES ON THE RESTORATION AND AFTERCARE OF METALLIFEROUS MINING SITES FOR PASTURE AND GRAZING

1. INTRODUCTION

The guidance given in this Note is for situations where a decision has been taken to reclaim a former metalliferous mining site for continuous pasture and grazing. It should not be taken to indicate that this is the only, or necessarily most desirable, after-use for such sites; indeed in perhaps the majority of cases, agricultural after-uses will not be appropriate and other types of after-use should be considered. The responsibility for deciding the intended after-use of a mineral working rests jointly with the applicant, the landowner and the mineral planning authority (or, for some types of after-use, the local planning authority) taking due account of national policies. General advice on planning considerations, consultations and conditions which are relevant to the reclamation of mineral workings is given in the DOE's Mineral Planning Guidance Note 7, "The Reclamation of Mineral Workings" (DOE 1989(a)).

It must be emphasised that the guidance given in this paper applies only to the reclamation of and use of former metalliferous mining sites for continuous pasture and grazing and not in other circumstances. The Minerals Planning and Land Reclamation Division of DOE intends during 1990/91 to commission a research project which will review other available literature, information and experience with the aim of providing guidance on the reclamation of such sites to other after-uses, particularly forestry and a wide range of amenity uses.

Mining for base metals may contaminate land with elements that can be toxic to plants and/or animals. Where natural vegetation has developed into a close-knit sward, there are usually no problems of toxicity to grazing animals, although on soils of low pH lead may present a risk. However, when unvegetated areas are to be reclaimed or when contaminated land is reworked and then restored, the risk of toxicity is higher and hazards may be posed by certain elements if they are present in high concentrations.

This Note provides technical guidance on concentrations of potentially toxic elements in soil that has been affected by minespoil, and outlines suitable management practices to minimise their effects. The guidance takes into account the effects of these inorganic contaminants on:

- The risk of phytotoxicity to grasses and clover - and hence the effect on pasture production.
- The intake of toxic elements by grazing animals, through ingestion of herbage, soil or dust contaminated by those elements.

Additional information on the establishment of vegetation on metal mine wastes, and on environmental aspects of metal mining that affect revegetation decisions, can be found in Williamson et al. (1982), and in Johnson et al. (1987).

Where the contamination is not the result of metalliferous mining or where access by humans, especially children, is likely to occur, other ICRCL Guidance Notes should be consulted (see back cover for list). For land to which sewage sludge is applied, use of sludge should be in accordance with the Sludge (Use in Agriculture) Regulations 1989 (Statutory Instruments 1989 No 1263) and the Code of Practice for Agricultural Use of Sewage Sludge (DOE, 1989(b)).

2. TYPICAL TRACE ELEMENT CONCENTRATIONS IN UNCONTAMINATED SOILS

Knowledge of the average trace element concentrations of "uncontaminated" soils can help to assess the significance of contamination at sites where reclamation is envisaged.

Data on trace element concentrations in soils in England, Wales and Scotland, have been collected from systematic pedological studies, investigations of trace element deficiency problems or pollution surveys. However, no general study of the soils of England and Wales had been undertaken until 1973 when it was decided to analyse the soils taken from randomly selected farms as part of the ADAS "Representative Soil Sampling Scheme". Around 1,500 representative soil samples were analysed but for some samples not all elements were measured; the results have been summarised by Archer and Hodgson (1987). The data relating to the elements under consideration in this Note are summarised in Table I.

TABLE I Trace element concentrations in representative agricultural soils. (Taken from Archer and Hodgson, 1987)

Element	No of Samples	Concentrations	
		Mean (Log derived)	"Typical" Range
As (Total)[1]	222	11.0	2.3 - 53
Cd (Total)[1]	1392	0.6	<1.0 - 3.9
Cu (Total)[1]	1468	19.0	5.8 - 62
Cu (Extractable)[2]	1477	4.9	1.2 - 19
Pb (Total)[1]	1521	39.8	10.9 - 145
Zn (Total)[1]	1520	78.1	29 - 210
Zn (Extractable)[2]	782	5.6	1.5 - 21
F (Total)[3]	-	-	30 - 300

1 Soil digested with $HNO_3/HClO_4$ (MAFF (1981)); concentration as mg/kg air dry weight.
2 Soil extracted with EDTA (MAFF (1981)); concentration as mg/dm^3.
3 Data for fluorine taken from Allaway (1968); concentation as mg/kg air dry weight.

3. TOXIC ELEMENTS IN CONTAMINATED SOILS

In and around metalliferous mining sites concentrations of particular metals and certain other elements in soils tend to be high. Dispersion by wind, water and man's activities may result in wide variations in concentrations both horizontally across an area and vertically through the soil profile. Thornton (1980) estimated that possibly some 4000 km^2 of land in England and Wales had been affected to some degree by mining activity.

The major factors that affect concentrations of elements in contaminated soils are:

- Concentration and form of the element in the original ore or in the spoil.
- Subsequent processing of the mined material eg whether smelting took place or whether the area contained washery settlement ponds.
- Distance from major mining activities.

- Dispersion by wind and water.

- Dispersion by man along trackways where mined ore was transported.

- Whether the spoil or the area has been reworked or generally disturbed.

There are large variations in actual concentrations, and different orefields are associated with particular suites of minerals. Table II lists the metals and other elements that occur in areas where mining activity may have significantly increased the concentrations in soils. Metalliferous ores usually contain the minerals as sulphides and/or carbonates.

TABLE II Major orefields and characteristic elements

Area	Main and Associated Elements*
North Pennines	Pb, Zn, F, Cd, [Ba]
Lake District	Cu, Pb, Zn, [W]
South Pennines	Pb, Zn, F, Cu, Cd [Ag]
North Wales	Pb, Zn, Cu, Cd, [Ba, Au]
Central Wales	Pb, Zn
Mendips	Pb, Zn, Cd
Cornwall, Devon	[Sn], Cu, Pb, Zn, [Ag, W]
West Shropshire	Pb, Zn

* [ ] elements not considered a problem for agriculture.

Examples of the concentrations that may be found are given in Appendix I.

4. METHODS OF ANALYSIS

Different reagents are used to determine the concentrations of elements in soils. Those used by ADAS (MAFF 1981) are:

- 0.05M EDTA for "extractable" metals. The concentrations found are interpreted in terms of plant availability to assess the risk of phytotoxicity.

- A mixture of HNO_3 and $HClO_4$ for "total" metals. These concentrations are useful to assess the long term implications of contamination in terms of risk to grazing stock.

In a recent study (Williams, 1984) soils were collected from different parts of the country where metal mining had taken place, and analysed for total and extractable metals. Significant statistical correlations were found between the two sets of concentrations for the different metals. Using these correlations it is possible to estimate the "total" metal concentration which will cause phytotoxicity without having to determine the "extractable" value in every case. The correlations were used to compile the values given in Table III (see Section 6). When the "total" values are close to the phytotoxic threshold or where other evidence suggests it is necessary, a separate analysis for "extractable" metal should be carried out. For instance, not all sites will conform to the general relationships. As a guide an "extractable" value of 130 mg Zn/dm^3 soil or 70 mg Cu/dm^3 soil indicates possible phytotoxicity.

5. UPTAKE BY PLANTS AND POTENTIAL TOXICITY TO PLANTS AND ANIMALS

Uptake of elements by plants is determined by a number of factors including:

- Concentration and speciation (chemical form) of the elements in the soil.
- Size of the mineral particles.
- Soil pH (generally, the solubility and plant availability of elements increases with decreasing pH).
- Species and varieties of plants.

Some elements may affect plant growth eg zinc and copper. Others such as cadmium, lead, arsenic and fluorine are not usually toxic to plants at the concentrations normally encountered even in contaminated sites. The latter group may be absorbed by plants or be present in dust on their leaves in such amounts that they could prove harmful to grazing animals.

Most grazing animals ingest varying amounts of soil with the herbage they eat. In areas where the soil contains high concentrations of lead or copper this may be a hazard even in the absence of reworking or restoration. Surface contamination of herbage by fine particles of soil is usually a more important route of element intake than uptake into the plant tissue.

<u>Zinc</u>

Zinc is an essential trace element for crop growth but in high concentrations it is phytotoxic. It is readily taken up by plant roots and translocated into leafy parts. In excess it causes severe chlorosis of the whole plant, restricts photosynthesis and affects the metabolism of other elements such as iron. These symptoms usually manifest themselves long before there is any risk to animal health.

Phytotoxicity to clover has been observed in other situations at "extractable" concentrations which correspond approximately to 1000 mg/kg "total" Zn. Productive grasses are relatively more tolerant and concentrations up to 2000 mg/kg may be acceptable depending on soil pH.

Concentrations greater than 2000 mg/kg in soil could give herbage concentrations greater than 220 mg/kg dry matter which is likely to have a significant effect on copper metabolism in livestock (Allaway, 1968).

In areas contaminated by minespoil, zinc is usually found in association with lead. In England and Wales when lead ores are found in association with limestone the spoil will often have a pH greater than 7.0, which reduces the phytotoxic effect of the zinc.

<u>Copper</u>

Copper is not so readily taken up into the leafy parts of plants as zinc but may accumulate in the roots with limited translocation above ground. Soil pH seems to have little effect on plant uptake of copper except in very acid conditions (less than pH 4.5) when it appears to be mobilised and taken up by acid tolerant species. Although copper is an essential plant nutrient, it can be phytotoxic at high concentrations. A total concentration of 250 mg/kg in soil is likely to cause phytotoxicity to clover when soil pH is lower than 6.0.

In such situations, uptake into the leaf and also the risk from soil ingestion may lead to excessive intakes by sheep and lambs. The significance of a given concentration of copper depends upon dietary interactions with other elements, notably molybdenum, sulphur, calcium, iron, cadmium, and zinc (ARC, 1980). At a soil pH of 6.0 or above a total soil concentration of copper of 500 mg/kg would be acceptable for the productive grasses but, above this concentration, the concentration of copper in herbage is likely to exceed the toxic threshold for sheep and lambs.

Lead

In slightly acid and neutral soils lead accumulates in roots but may be translocated into the aerial parts of some plants to a small degree. In acid soils translocation can be a potential hazard. It is rarely phytotoxic above pH 6.0 but the ingestion of soil contaminated herbage can be a hazard to stock at all pHs. In alkaline soils (pH > 7.0) lead is probably precipitated as the carbonate but following ingestion of contaminated soil by grazing animals it may become available and thus can be absorbed by them.

It is desirable to avoid concentrations of lead in the diet in excess of 50 mg/kg dry matter. Assuming a low level of 5% soil contamination of herbage (on a dry weight basis) a total soil concentration of 1000 mg/kg can result in a dietary concentration greater than 50 mg/kg and raise lead accumulation to a value where toxic effects may occur (Allcroft and Blaxter, 1950; Clegg and Rylands, 1966; Stewart and Allcroft, 1956), or where residues in offal for human consumption exceed recommended action levels.

Cadmium

Cadmium is often found in association with lead and zinc ore deposits. It may be taken up by plant roots and translocated into the leafy parts but this effect is greater at low pH.

No cases of cadmium toxicity in grazing animals have been reported but there may be sub-clinical effects and accumulation in offal intended for human consumption. Contamination by soil with a total cadmium concentration in excess of 15 mg/kg, could give a herbage concentration of cadmium greater than 2 mg/kg dry matter, leading to reduced growth rate in weaned lambs, defective bone development and impaired copper metabolism (Mills et al, 1980).

Cadmium in minespoil is less available to plants than contamination present in soil from other sources such as sewage sludge and industrial waste. In minespoil the commonly associated high concentrations of zinc will have a much greater direct effect.

Arsenic

Arsenic is absorbed and accumulated by plant roots and in high concentrations it may kill them. However, it is not readily translocated to leaves or stems. Little is known about the factors that affect the availability of arsenic to plants although there is some indication that the risk of phytotoxicity can be minimised by raising soil pH to 6.0-6.5. A total soil concentration of 250 mg/kg is not likely to cause any ill effects in plants or animals, but levels in excess of 500 mg/kg could give rise to herbage containing arsenic at more than 25 mg/kg dry matter and cause poisoning in stock or be phytotoxic (Thornton, 1980).

Fluorine

Fluorine in soils is normally present as insoluble calcium fluoride and in this form is not readily taken up by plant roots. Fluorosis in livestock can occur if soil contaminated herbage is ingested over a sufficiently long period of time.

Assuming a low level of soil contamination of herbage (5%), a total soil concentration of fluorine of 1000 mg/kg could give herbage which exceeds the safe threshold of 50 mg/kg dry matter (Underwood, 1977, 1981; Burns and Allcroft, 1964; Allcroft, 1965; Phillips, 1960).

6. CLASSIFICATION OF SOIL CONTAMINANTS

As discussed in section 5 above, except for cadmium and zinc, high concentrations of inorganic contaminants in minespoil contaminated soils do not markedly influence the concentrations in herbage - provided the soil pH is 6.5 or above. The contaminants are either present in forms which are relatively unavailable for absorption by roots or they are not readily translocated from roots to shoots.

For most elements, the risk to livestock depends almost entirely on the amount of soil ingested and the toxic element concentration in that soil. The amount of soil contamination on herbage will vary with the type of sward, its density, the time of year, weather conditions, stocking density and management. In a close knit sward, where a surface mat has developed, soil contamination of herbage may be less than 3% by weight of dry matter. In reseeded pastures, with an incomplete vegetation cover, soil contamination is commonly as high as 10% or more.

The risk to livestock also depends on:

- Variations in dietary intake over the year.
- Differences in element availability to stock.
- Type, species, age and health of stock.
- Length of exposure.
- Provision of supplementary feedstuffs.

Early studies on the toxicity of elements to stock were of short duration and resulted in over-optimistic assessments of tolerance in different animal species. Studies were also done using soluble salt additions to the diet - but this does not realistically reflect the naturally occurring situation where the elements are often present as insoluble compounds (Mills et al, 1980). Reliable information on livestock tolerance to metals and other contaminants is scarce. Therefore only a broad classification for soil concentrations can be attempted based on herbage concentration and animal intake, assuming a specified proportion of soil is ingested in the diet.

Suggested guidelines for avoiding toxic and phytotoxic effects are given in Table III.

The "threshold trigger concentration" of an element is defined as that below which the soil is considered to be safe, ie, the concentration present should not give rise to phytotoxic or zootoxic effects. In areas contaminated with mine waste, concentrations of elements in soil will naturally exceed these limits in most cases. The maximum or "action trigger" concentration is that above which there is a very high probability of phytotoxic or zootoxic effects which may result in the death of stock if the quoted concentrations are continually exceeded. Alternative strategies are discussed in Section 7.

In between these two trigger concentrations, there is a band of concentrations of elements in soil which can only be described as "uncertain" and where there may be some sub-clinical effects in animals. The risk of damage to stock health will depend on soil pH, sward cover, type of stock management and length of exposure. To minimise the risk, it is essential to follow the recommendations given in section 7. Experience indicates that higher concentrations are acceptable if only occurring on part of the restored area, with areas containing correspondingly lower concentrations available elsewhere. The concept of trigger concentrations as part of the strategy underlying the redevelopment of contaminated land is described fully in ICRCL Guidance Note 59/83 (ICRCL, 1987) and in Beckett and Simms (1986).

TABLE III Guidelines for toxic element trigger concentrations in minespoil - contaminated "soils"

Total Element Concentration (mg/kg air dry weight)

Element	Threshold Trigger Concentrations (a)	Maximum (Action Trigger) Concentrations (Values not to be exceeded for use as specified)	
		For grazing livestock (b)	For crop growth (c) (risk of phytotoxicity)
Zinc	1000	3000 (d)	1000
Cadmium	3	30 (d)	50
Copper	250	500	250
Lead	300	1000	-
Fluoride	500	1000	-
Arsenic	50	500	1000

(a) These concentrations are acceptable only where the soil contamination is derived from mine spoil. In other situations the elements may be present in forms which are more available to plants and animals when lower trigger concentrations will be appropriate.

(b) For calves, sheep and horses - assuming that plant uptake is normal, the stock are continuously exposed to these concentrations and that it is proposed to manage the sward in such a way that only a **relatively low level of soil contamination** of herbage will occur. In such case, soil may comprise up to about 5% of dry matter intake. Under less favourable conditions soil ingestion may be much higher. See Section 7 Grazing access. (The corresponding EDTA - extractable phytotoxic limits for Zn and Cu are 130 and 70 mg/dm^3 soil respectively. Soil material should be considered a phytotoxic risk if either the total or EDTA - extractable limits are exceeded).

(c) For clover and the more productive, sown grass species assuming a soil pH of at least 6.0. Metal tolerant cultivars are available, but these are intended for amenity/recreation after-uses and advice should be sought before they are used in agricultural seed mixtures.

(d) The possibility of sub-clinical antagonistic effects on copper metabolism cannot be ruled out if concentrations of zinc and cadmium in soils exceed 2000 and 15 mg/kg respectively.

The guidelines given in Table III should not be regarded as standards to which concentrations of contaminants in the soil could be raised if this were avoidable. On heavily contaminated sites or where there is a lack of suitable soil forming materials, reclamation of the land for pasture and grazing is not acceptable and more appropriate end uses should be considered.

7. MANAGEMENT AND AMELIORATIVE MEASURES

The sites affected are commonly in upland or semi-upland areas, though in some areas they can be surrounded by intensively managed grassland. There are basically three situations to consider:

- Restoration and aftercare following reworking of old minespoil for further mineral extraction.
- Reclamation of derelict tips.
- Improvement of existing poorly productive grassland.

In all cases the primary aim must be to establish a close knit grass cover as rapidly as possible in order to minimise herbage contamination and soil ingestion by stock.

Pre-working/Pre-restoration Procedure

Before any working takes place the different soil layers and any potential soil forming materials should be analysed for the potentially toxic elements likely to be present. Where this shows lower concentrations in the surface humus/litter layer than in other horizons this zone should be carefully stripped prior to working and preserved in soil storage heaps. If the heaps are to remain for longer than about six months, they should be fertilised on the basis of pre- working analyses and sown with a grass/clover mix. Any deeper layers which have concentrations below the maximum values in Table III should also be considered for separate storage.

If possible, the least contaminated materials should be used as the topmost layer at restoration. Where possible the existing subsoil should be made available for replacement or failing this an acceptable substitute be identified from the materials on site.

All storage mounds should be so sited and constructed as to minimise the risk of run-off of water and erosion of contaminating materials into water courses or onto surrounding uncontaminated land. Care should be taken at all stages to prevent any increase in the area of contaminated land.

Restoration and aftercare

The most appropriate restoration procedure should be adopted according to the texture and depth of the various layers. The aim should be to relieve any compaction but to leave a relatively level surface to both the subsoil and the surface layer avoiding creation of hollows where water can accumulate. In some situations it will be possible to rip the replaced subsoil material to 45 cm depth using a wing-tined subsoiler with tine spacing no greater than 90 cm. Following this, material which is relatively uncontaminated should be spread as "topsoil" using vehicles exerting a low ground pressure. On other sites such subsoil ripping would leave a very uneven surface and, particularly if only a relatively thin top-soil material is available, it may be advisable to spread all the materials before ripping. The depth and spacing of this operation may need to be modified. Cultivations should be carried out in time to allow for suitable sowing dates.

A grass/clover seeds mixture (an example is given below although it should be noted that this may not necessarily be suitable for use on all sites) should be sown and the appropriate fertilisers applied based on post-working soil analysis. The use of metal tolerant cultivars in agricultural mixtures should only be considered on highly contaminated sites in the light of specialist advice. A non-agricultural after-use will probably be more appropriate. The pH of the "topsoil" should be raised, if necessary, to 6.5 or greater to reduce the availability of toxic elements to plants - particularly cadmium, and zinc. If high concentrations of zinc are present, a pH of 7.0 is desirable.

Example of a suitable seed mixture

10 kg Talbot perennial ryegrass
10 kg Perma perennial ryegrass
7 kg S48 or Farol Timothy
10 kg Dawson Red Fescue
10 kg Melle perennial ryegrass
2 kg Grasslands Huia White Clover
1 kg Kent Wild White Clover

Used at 50 kg/ha

If no material is available on site with less than the maximum element concentration the existing topsoil should be preserved and respread during restoration. The existing structure and fertility of this material will provide the best chance of obtaining rapid grass cover. However, in this situation if the site is to be used for agricultural purposes, the effects of the contaminants present should be minimised in the following ways:

- By importing a blanketing layer of 20-50 cm to give partial isolation from contaminants and to provide an alternative growing medium to normal soil or a base upon which good quality subsoil or a shallow layer of topsoil can be spread. Suitable materials will include colliery waste that is essentially free of pyrites, waste from most hard and soft rock quarries and pits overburden and natural shales and clays. Other by-products and waste may be suitable but specialist advice should be sought.

- By covering the contaminated material with imported uncontaminated topsoil or good quality subsoil, preferably to a depth of 15-20 cm. Where this is not possible a shallower layer (10 cm) will effectively reduce the risk of toxicity but will limit future soil management on the site.

- By diluting the contaminated material with sewage sludge cake (preferably limed cake). The latter should be spread at up to 200 t/ha dry solids and thoroughly mixed into the top 10 cm. This material provides a good store of slow release nitrogen, adequate phosphate and organic matter. Specialist advice should be sought in relation to acceptable sources of sludge for such an operation.

- If a supply is available the contaminated material may be diluted with pulverised fuel ash at 150-200 t/ha mixed into the top 10 cm. To avoid phytotoxicity, the fuel ash should contain less than 9 mg/kg hot water - extractable boron.

The resultant "soil" should be analysed for nutrients and potentially toxic elements prior to reseeding - to assess fertiliser needs and possible risks to stock. It may be necessary to carry out trials to determine the optimum seed mixture and fertiliser combination before embarking upon large scale restoration (Figure 1).

Where none of these procedures is considered practical or economic the level of contamination should be considered in relation to the likely sward growth. If this is poor so that even under controlled grazing and with other uncontaminated land available there will be a substantial risk to stock, alternative, non- agricultural, land use should be sought.

All restored areas should be contoured so as to minimise run-off of water and erosion although final surface gradients should be steep enough to allow surface drainage; slopes within the range 1:8 to 1:25 may be appropriate. Surface and/or sub-surface drainage systems may also be required and in some cases it may be appropriate to encircle the site with drainage ditches provided with silt traps, especially adjacent to outfall positions. Advice should be sought according to site conditions; ADAS Field Engineers and Soil Scientists can advise on land drainage matters with regard to restored sites. The local water authority and the National Rivers Authority should also be consulted about drainage from the site.

Surface Improvement

When attempting to improve existing grassed areas it is unlikely to be worthwhile undertaking major soil stripping and replacement. The surface humus/litter layer should be retained, thus restricting treatment to application of herbicides and shallow surface cultivation. If this surface layer contains high concentrations of toxic elements, a covering of soil or dilution with sewage sludge or pulverised fuel ash may need to be considered (see above). Lime and fertiliser applications should be based on analysis of soil samples taken to 15 cm depth.

In situations where the topmost "soil" layer is contaminated with fairly high concentrations of toxic elements, it is very important to develop a dense close sward as quickly as possible to minimise soil ingestion by livestock. This means that extra care is required in preparing a seed bed in order to ensure a full and rapid germination. Livestock should be kept off the land until the sward has developed sufficiently.

X The appearance of opencast workings before and after restoration is shown in Figures 2 and 3 respectively. X

Subsequent Management

(1) First year after reseeding

Although grazing is normally regarded as the best technique available for the production of a close sward, the high risk of ingestion of certain elements makes it inappropriate in the minespoil situation above the threshold trigger concentrations. Short term grazing with adult beef cattle is a possibility, but sheep and horses must be excluded particularly where lead is present above threshold trigger concentrations. Regular mowing may have to be used initially to encourage a dense sward provided the micro- relief is suitable and the surface is stone-free.

Allowing a growth of grass suitable for silage or hay results in an open sward. To minimise this effect a cut should be taken in early May when the grass is relatively short. Analysis of the conserved grass is advisable to check the concentrations of any elements resulting from soil contamination before feeding to stock. Later in the year, regular mowing with clippings being returned will be advantageous.

(2) In second and subsequent years after establishment

When a denser sward has developed, a more normal silage cutting regime can be followed and grazing under careful management can be introduced. Where silage is made on sites of high risk particularly above maximum (action trigger) concentrations for livestock, a long stubble should be left and a "pick up" type of harvester used rather than one which has a "hoovering" action as this will reduce the amount of soil contamination. Such contamination not only inhibits microbial fermentation but can increase the risk of toxicity to stock due to the presence of particular elements in the silage; again, chemical analysis is advisable to assess any such risk.

It must be stressed that satisfactory drainage conditions should be provided. Poor drainage will lead to poaching by grazing stock and thus contamination of the herbage with soil.

Grazing management should be adjusted to avoid poaching and over-grazing both of which increase soil ingestion and destroy the vegetation mat.

(3) Grazing access

The maximum (action trigger) element concentrations in soil in Table III relate to continuous grazing. Where satisfactory swards can be established and maintained at higher concentrations of elements, stock may be grazed on the land provided that uncontaminated land is also available for rotational or alternating management. In these circumstances it is even more important to avoid poaching and overgrazing of the contaminated site.

It may be safe to reduce grazing access pro-rata with increasing element concentrations. Further advice should be sought from ADAS in individual circumstances according to the site conditions and the form and degree of contamination. Pre-working analysis may indicate that the final concentrations of elements will be in excess of the suggested maximum concentrations. When rotational grazing cannot be adopted, then cutting management should be considered or a non-agricultural use sought for the land.

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Appendix I - Examples of concentrations of elements in minespoil contaminated areas (Total concentrations (mg/kg) except where shown)

Area	Sample	Statistic	Element						Reference
			As	Cd	Cu	F	Pb	Zn	
N Pennines/ Cumbria	Spoil	Range	-	-	-	-	500-22800 mg/l (EDTA)	32-2770 mg/l (EDTA)	Harvey, 1984
Derbyshire	Soil/Spoil	Mean	-	-	-	11747	7800	1105	ADAS, unpublished
		Range	-	-	-	260-38500	308-32000	72-2975	
		Mean	-	35	96	2161	352500	3325	
NE Anglesey	Soil	Range	-	-	20-500	-	12-3800	-	ADAS, unpublished
NE Clwyd	Soil	Mean	-	6.1	18	-	886	728	Davies and Roberts, 1978
		Range	-	0.4-540	2.3-252	-	35-47995	10-4939	
NE Wales	Spoil	Mean	-	630	140	-	52500	78750	ADAS, unpublished
Mid Wales	Soil	Mean	-	-	-	-	1419	455	Alloway and Davies, 1971
		Range	-	-	-	-	90-2900	95-810	
	Spoil	Mean	-	-	-	-	22870	8100	
		Range	-	-	-	-	20670-6666	586-54720	
Mendips (Shipham)	Garden Soil	Mean	-	97	-	-	2382	8867	Thornton, 1988
		Range	-	2-360	-	-	108-6540	250-37200	
Cornwall and Devon	Contam. alluvium	Range	90-9000	-	35-2000	-	60-1008	114-1020	Thornton, 1980
	Upland mining area	Range	66-2500	-	29-2000	-	62-850	58-380	
	Spoil	Mean	6225	-	2100	-	22000	212	ADAS, unpublished

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Figure 1
Trial plots to determine optimum seed mixture and fertiliser combination before embarking upon large scale restoration

Figure 2
Opencast lead and fluorspar workings at Longstone Edge, Peak Park, 1975/76

Figure 3
Restored opencast fluorspar workings, 1986. Restoration using non-toxic mine waste and a synthetic topsoil made from sewage sludge mixed with fine process tailings. This technique requires careful research and confirmation before being used in practice

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