Reclamation of Markedly Acidic Minestone Waste Tips Using Sewage Sludge as a Soil Forming Material

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ABSTRACT

The West and South Yorkshire coalfields generate some markedly acidic minestone wastes. Spoil tips restored by the conventional methodology of liming, adding nutrient in the form of inorganic fertilisers and perhaps a thin top-soil cover prior to seeding, frequently undergo acid regression which ultimately destroys the vegetation and reinstates the problem of erosion. Some fourteen years ago, Yorkshire Water, the Ecological Advisory Service and Kirklees local government authority began working together to solve this problem. This paper details both the experimental pot trials and the subsequent restoration of one such site that, within three years of conventional restoration, had regressed to having a surface pH of 1.9. The trials monitored substrate pH, the uptake of potentially toxic elements (PTE), Cr, Ni, Cu, Zn, Cd and Pb and measured biomass productivity. The results show that the technique developed can provide a sustainable, stable restoration of markedly acidic minestone tips, provided that the sewage sludge is carefully chosen and applied in sufficient quantity to control acid generation. The uptake of PTEs into the vegetation is demonstrated to occur in quantities significantly less than both phyto- and zootoxic levels. The technique developed, which utilises an application rate of 600 - 700 t.DS sewage sludge per hectare, has now been adopted by several local government authorities and has been used to restore approximately 100 hectares of previously derelict colliery waste tips.

INTRODUCTION

Conventional methods of reclaiming minestone waste tips, which include liming to counter potential acidity, adding nutrient in the form of inorganic fertilisers and perhaps a thin (100mm) top-soil cover, are undoubtedly effective on mildly acidic spoils. Unfortunately however, many such tips in West and South Yorkshire have a high pyrite content and are consequently of an extremely acidic nature. All too frequently these tips, when subjected to conventional restoration methods, susequently undergo acid regression to the point at which vegetative cover is totally destroyed and erosion and gulleying once more set in.

Emley Moor was one such case, a mere three years after reclamation, and despite regular interim applications of lime, the pH of the surface material had fallen to 1.9 and rainwater percolating through the spoil and hitting a compaction pan was breaking out as acid springs of pH 1.6. Vegetational cover had been completely destroyed by the hostile conditions on both the southern and eastern slopes and regression of the plateau area was also evident.

In 1980 a joint project between Yorkshire Waters' Plant Growth Trials Unit, Kirklees M.C and their technical consultants, the Ecological Advisory Service began to investigate the use of consolidated sewage sludge as a soil forming material on colliery waste tips. The technique developed had proved to be successful in providing sustainable, stable restorations of other acidic colliery waste tips [1, 2, 3] and it was decided to investigate, through pot trials, its' application to the extremely acidic minestone waste tip at Emley Moor.

LABORATORY/GREENHOUSE POT TRIALS [4]

Methods

A control soil, graded sub-surface spoil from Emley Moor and consolidated sewage sludges from four sewage treatment works were obtained. The sludges put under test were Mitchell Laithes lagoon dried, North Bierley fresh and mature lime conditioned press cakes and press cakes from Bradley and Lowfields. The completed design is shown below.

Design		Code
Soil Control		O
Spoil/Soil Control	1:1 v/v	SO
Spoil/Soil + NPK Control	"	SO+
Spoil/Mitchell Laithes LDS	"	SML
Spoil/North Bierley fresh PC	"	SNBF
Spoil/North Bierley mature PC	"	SNBO
Spoil/Bradley PC	"	SB
Spoil/Lowfields PC	"	SL

10 replicates per test, a total of 80 x 18cm pots.

The soil and sludges were sieved to pass a 13mm mesh prior to mixing and samples of all materials were air dried, crushed and sent to Yorkshire Waters' divisional laboratory for analysis of their nutrient and potentially toxic element (PTE) contents. The analytical results are shown in the appendix Table 1.

The pots were mixed to design, limed (if necessary) to pH 6.5 and placed in randomly arranged saucers, to prevent leaching losses, on a bench in a cool greenhouse. The pots were sown with Nickersons Red Circle agricultural ley mixture seed at a rate equivalent to 20 gm m^{-2} in January 1986.

A 28 day growth period was allowed prior to cutting. Pots were harvested by cutting at a standard 1.5 cm above 'soil' level and the grass dried in a moisture extraction oven at 100°C for 24 hours then weighed to enable dry matter production to be determined. The dried samples were composited by test, milled to pass a 1mm mesh screen using a Tecator Cyclotec mill and despatched to the divisional laboratory for PTE analysis. PTE determinations were carried out by acid digestion of the sample followed by atomic absorption spectrophotometry.

The full experiment ran for two years and certain tests were retained for further study for an additional period of four years.

Results

Dry Matter Production:

The average yields of each full trial test are shown in the appendix, Tables 2 and 3, in which the total yields are expressed as both gm DM pot^{-1} and t. DM ha^{-1}. The yields for the retained trial over the full six year period are shown in Tables 4 - 6.

PTE Uptake:

The PTE uptake into the plant tissues during the first two years is shown in the appendix, Tables 7 and 8. The uptake during the next four years of the retained trial is shown in Tables 9 - 12.

Discussion of results

The results of the dry matter production tests are shown in histogram form as t. DM ha^{-1} below. Figure 1 shows the first two years of the full trial and Figure 2 the results of the retained tests over six years.

Figure 1. Annual Biomass Production, Years 1 & 2, expressed as t . DM ha^{-1}

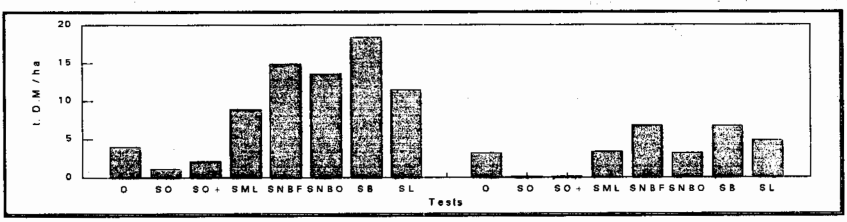
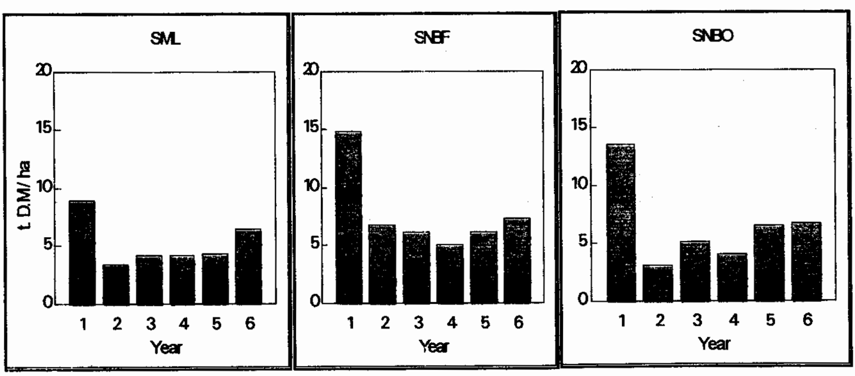


Figure 2. Annual Biomass Production, retained trial, expressed as t. DM ha^{-1}



These figures clearly demonstrate the advantage of using a soil forming material such as sewage sludge to reclaim a spoil as acidic as Emley Moor. All the spoil/sludge tests consistently out-performed even the pure soil control due largely to the higher nutrient status of the sludges.

The spoil/soil controls failed to produce a viable crop virtually from cut 6 onwards due to the high acid production of the spoil. The pH, when checked at this time, proved to have dropped to <3.0 from the original pH of 6.5. The spoil/sludge tests had retained the original pH and indeed continued to do so throughout the duration of the experiment.

Organic matter has been demonstrated to prevent the oxidation of pyrite[6] and one of the chief benefits of using sewage sludge is that, as it consists of 40-50% organic matter, it supplies large quantities of organic material to the spoil. The second major benefit is the sludges' nutrient content, which effectively provides a large reservoir of nitrogen, phosphorus and, to a lesser extent, potassium in slow release form capable of promoting several years sustainable growth without the necessity for further nutrient amendment.

In terms of yield alone, the sludges producing the highest performance were those from North Bierley and Bradley S.T.Ws.

Statistical examination of the biomass results by analysis of variance reveals that the differences between the means are highly significant having F ratios of 278.0 and 190.2 in years one and two respectively. In both cases the F probabilities are significant to a level of <0.00005.

A second statistical technique, the Scheffe test, which relies on a greater difference between the means than oneway ANOVA, was then employed to subgroup the tests into those whose means were not significantly different from each other. This analysis indicated that in year one, the soil and spoil/soil tests fall into two distinct sets; adding inorganic fertiliser to the spoil/soil produces a mean placing this test in both of the first two sets; the spoil/sludge tests each form individually significant sets dependant upon the source of the sludge, however maturation of the North Bierley sludge exerted no significant effect upon the productivity of the grass as both the fresh and mature sludges fall within a single subset.

In the second year, the grouping of the tests alters considerably. The two spoil/soil tests, in which production had virtually ceased, naturally form one set. The lagoon dried sludge from Mitchell Laithes and the matured North Bierley press cake mixed with the spoil form a set with fertile topsoil. Lowfields sludge remains as an individual set and the final set having the greatest mean biomass production consists of the fresh press cake from North Bierley and the Bradley press cake.

In terms of biomass production alone the two sludges producing the greatest probability of a successful and sustainable reclamation of the Emley Moor colliery waste tip were therefore considered to be those from Bradley and the fresh press cake from North Bierley STWs.

PTE Uptake:

When discussing PTE uptake it is important to define certain concentration criteria against which the results can be assessed. Table 13, drawn from various sources summarises these criteria.

Table 13. Background concentrations, To, Upper Critical concentrations, Tc $mgkg^{-1}$ Dry Tissue in plants and Upper Critical levels, Ta, $mgkg^{-1}$ Total Diet, for Livestock [6, 7, 8]

PTE	Ni (P)	Cu (P)	Zn (P)	Cr	Cd (Z)	Pb (Z)
To	2.0	11.0	50.0	1.0	0.5-<1.0	3.0
Tc	14.0	21.0	221.0	10.0	10.0	35.0
Ta sheep	50.0	50.0	900.0	50.0	3.0	3.0
Ta cattle	50.0	50.0	900.0	50.0		10.0

P = Phytotoxic Z = Zootoxic

The upper critical concentration, Tc, is defined by Beckett and Davis as the level of the element in the plant tissue at which yield would begin to diminish, it is not the level at which the grass would die.

All the sludges tested produced PTE uptake results below the upper critical concentrations during the first two years growth save for Mitchell Laithes which was retained for further testing. Bradley sludge supply could not be guaranteed in quantity, therefore the two sludges from North Bierley were also retained.

When these absolute concentrations of PTEs are plotted as log equivalents they can be used to provide a framework onto which the tissue concentrations in the test grasses can be plotted in a similar manner. This provides a clear demonstration of the relationship between the criteria and plant uptake, Figures 3 - 11.

These figures clearly demonstrate that the Mitchell Laithes sludge gave rise to uptake levels which could cause yield reduction. Since the designated after - use of the Emley Moor site was for low intensity sheep grazing, it was also felt that cadmium uptake could prove to be deleterious in the long term.

Both of the North Bierley sludges gave rise to acceptably low concentrations of PTEs throughout the six years of testing, particularly with regard to cadmium which remained at, or below, normally occurring background levels.

The apparent increase in the uptake of lead from month 67 onwards in all the retained tests may be disregarded since it merely reflects a change in the style of reporting by the central laboratory, which began expressing results as < 5.0 $mgkg^{-1}$ Dry Tissue.

Figure 3. Plant tissue concentrations of Ni & Cu - log mg/kg D.T. Emley Moor, SML

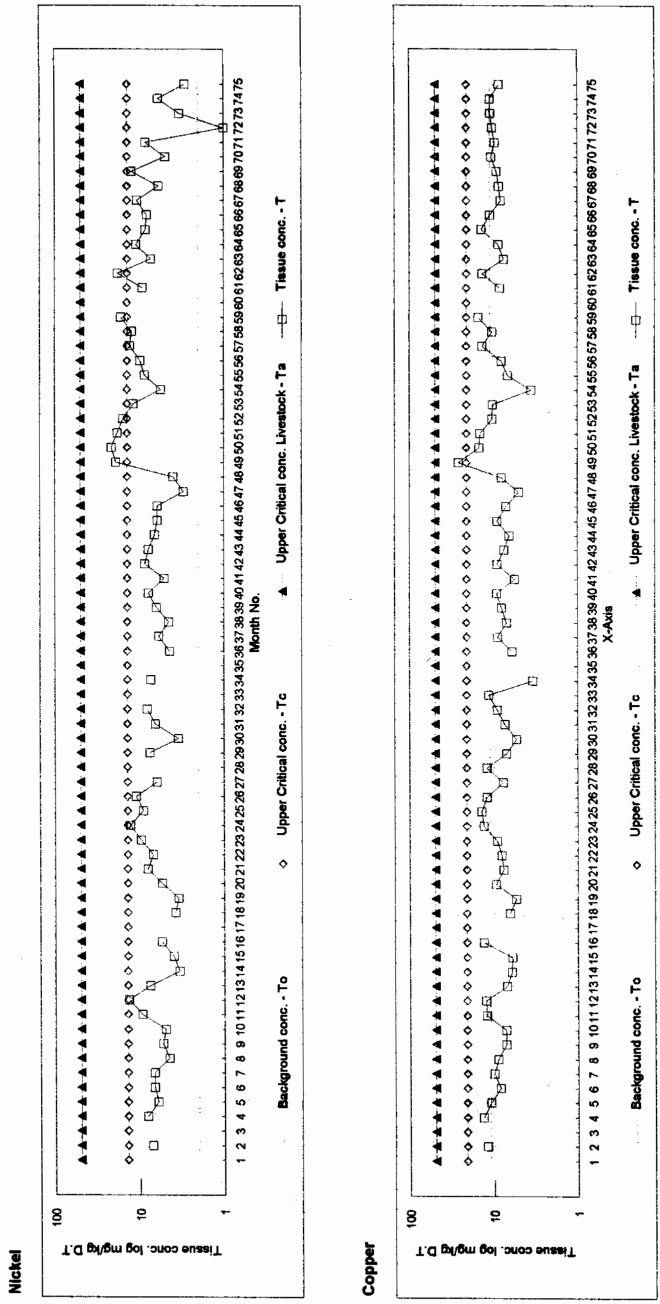
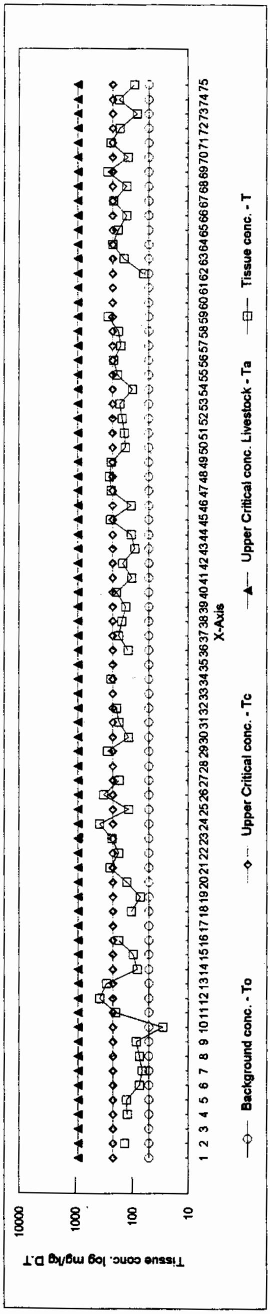
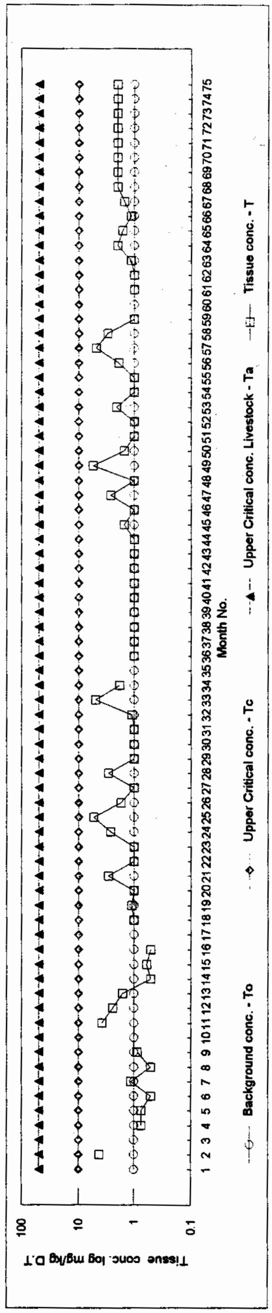


Figure 4. Plant tissue concentrations of Zn & Cr - log mg/kg D.T. Emley Moor, SML

Zinc



Chromium



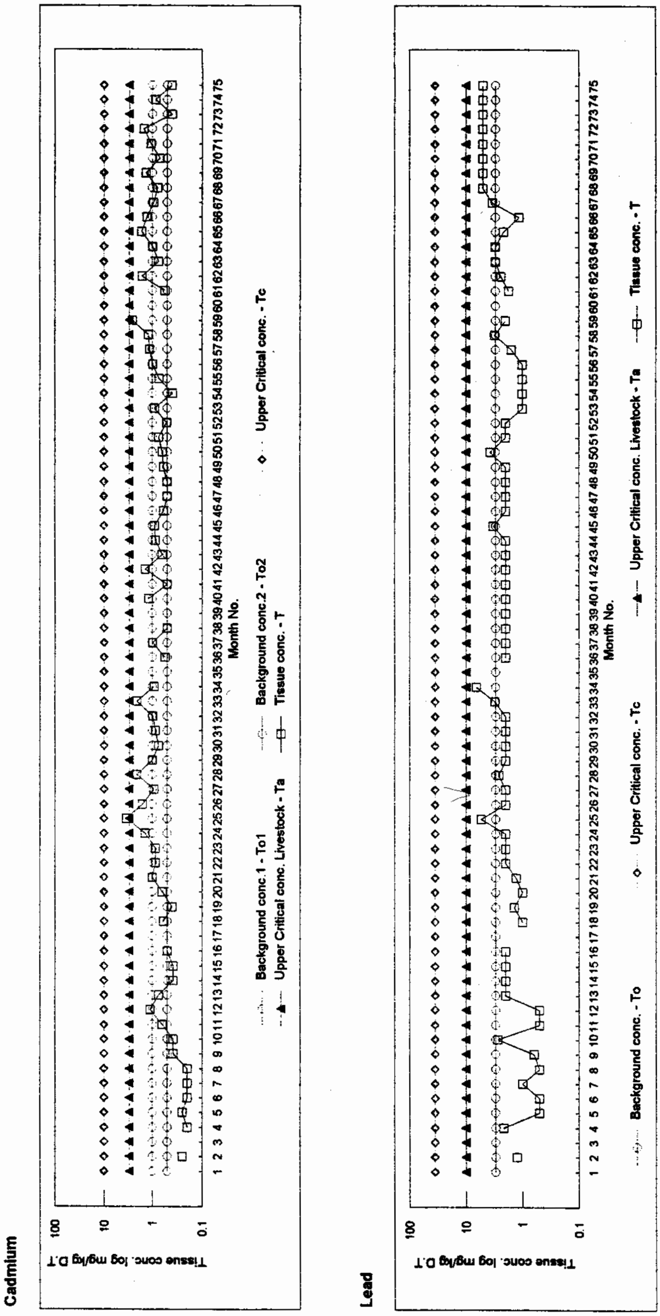


Figure 5. Plant tissue concentrations of Cd & Pb - log mg/kg D.T, Emley Moor, SML

Figure 6. Plant tissue concentrations of Ni & Cu - log mg/kg D.T, Emley Moor, SNBF

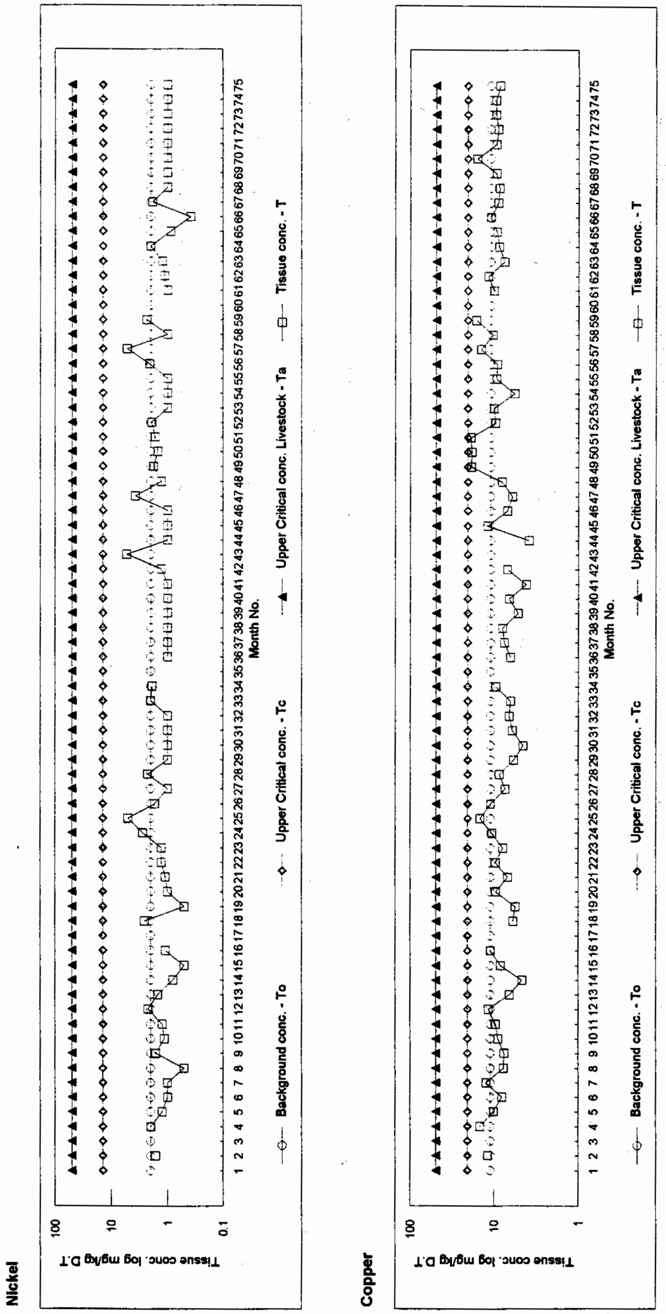


Figure 7. Plant tissue concentrations of Zn & Cr - log mg/kg D.T. Emley Moor, SNBF

Zinc

Chromium

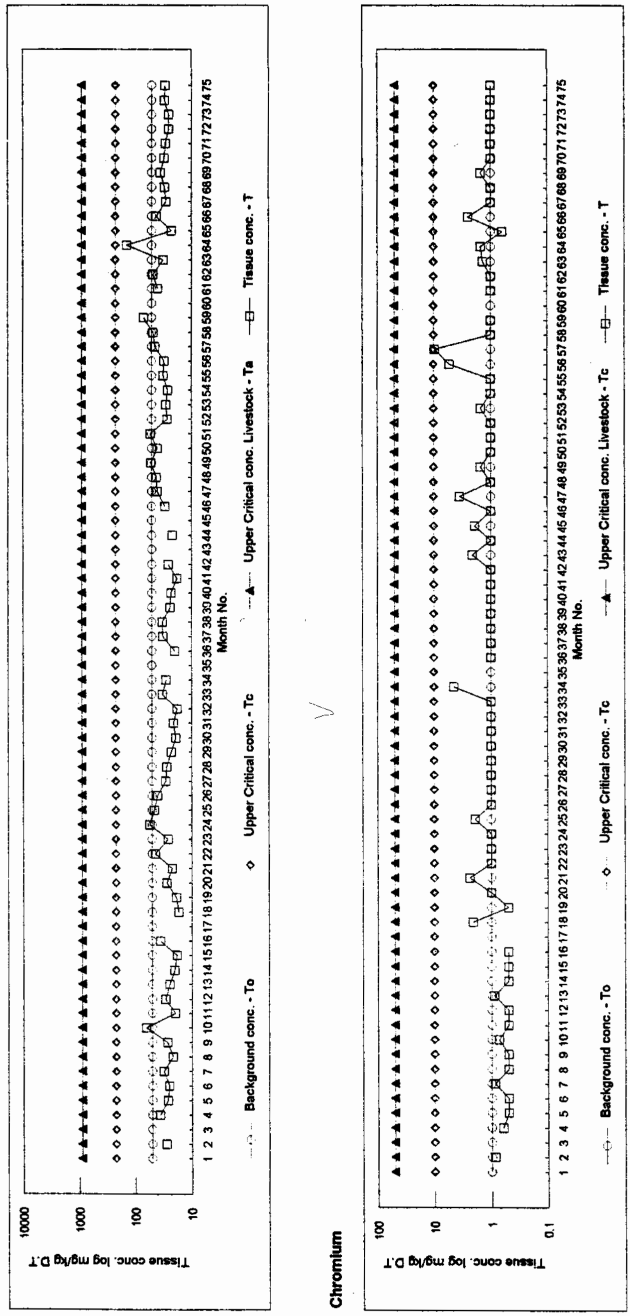


Figure 8. Plant tissue concentrations of Cd & Pb - log mg/kg D.T. Emley Moor, SNBF

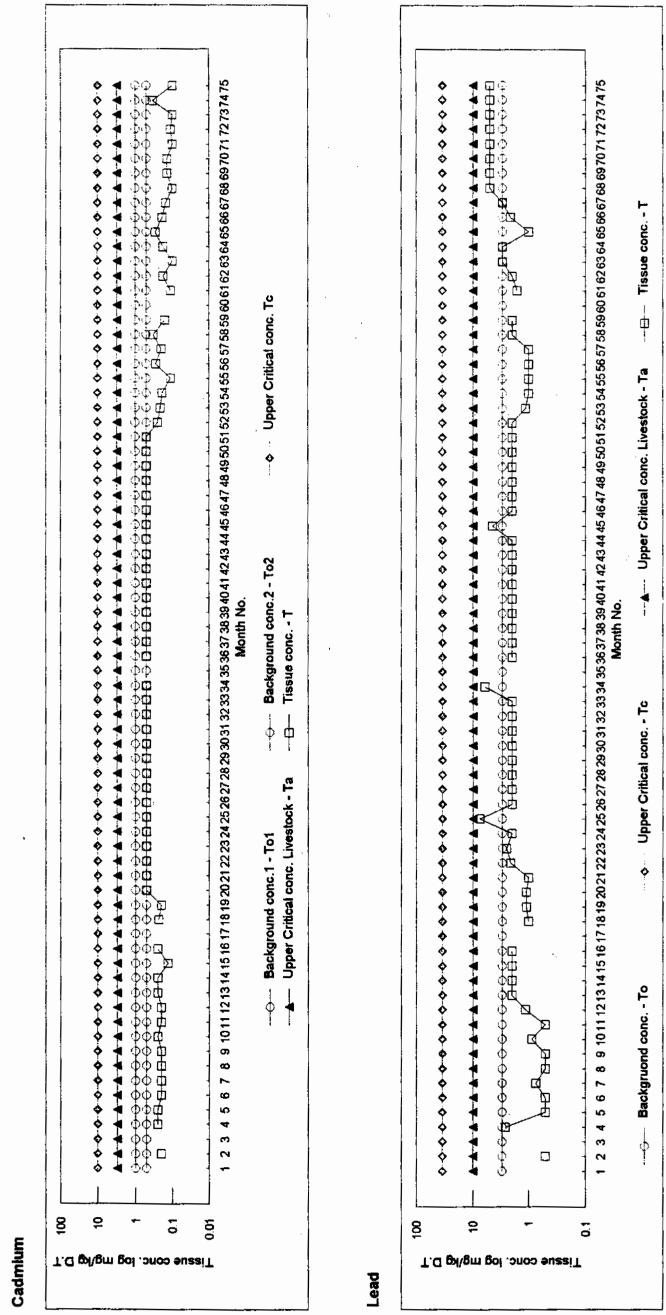


Figure 9. Plant tissue concentrations of Ni & Cu - log mg/kg D.T, Emley Moor, SNBO

Nickel

Copper

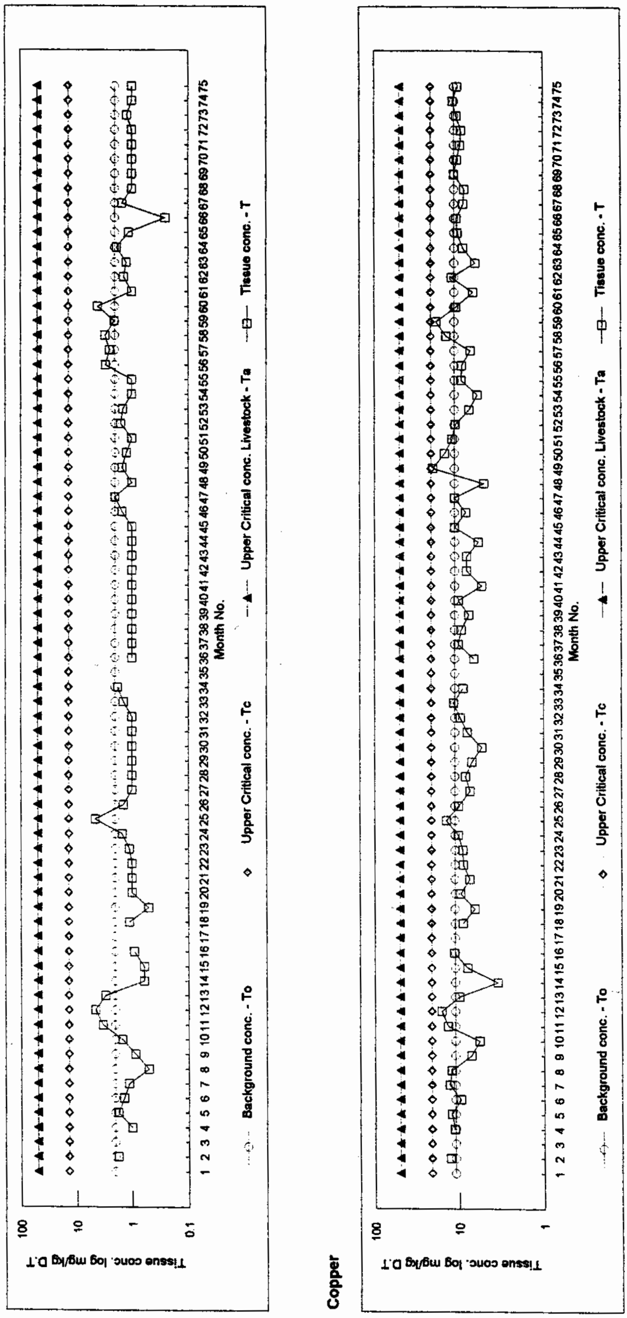


Figure 10. Plant tissue concentrations of Zn & Cr - log mg/kg D.T. Emley Moor, SNBO

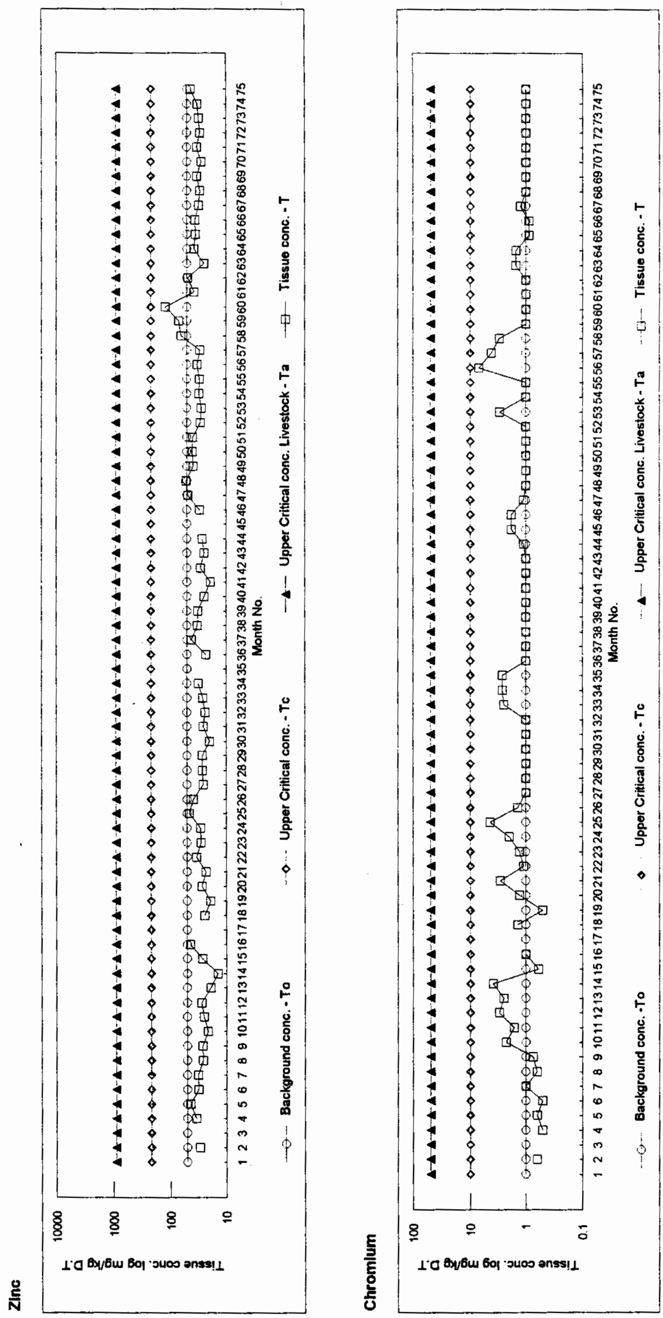
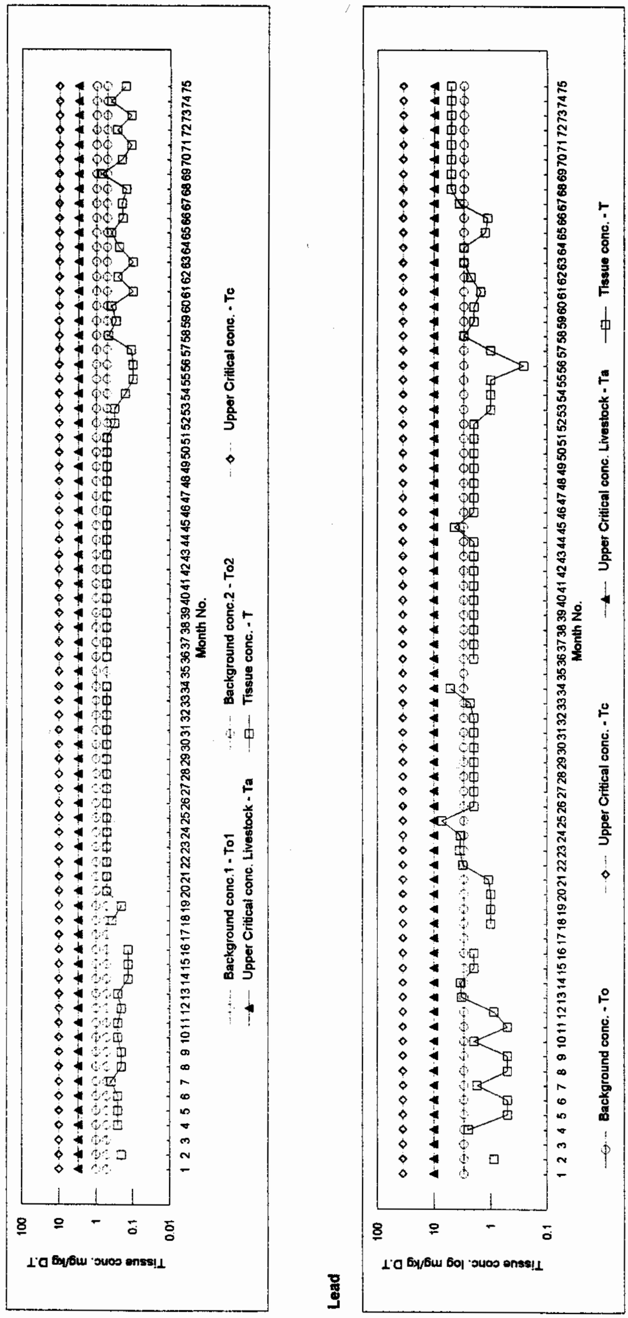


Figure 11. Plant tissue concentrations of Cd & Pb - log mg/kg D.T. Emley Moor, SNBO

Cadmium

Lead



FIELD TRIAL [4]

Site Reclamation

When the experiment commenced in 1986 the Emley Moor tip was still associated with an operational mine, although the tip itself was disused. As the tip adjoined the colliery, there was, at that time, no opportunity to landscape in order to reduce the steep south-eastern slope. The future of the colliery was subject to discussion during British Coal's restructuring exercise and Kirklees M.C suspended their reclamation programme pending the outcome of these negotiations. By 1988 the colliery had ceased operation and the mine buildings had been demolished giving an additional area into which the spoil could be moved. This permitted the slope to be reduced, by pushing the spoil forward over the abandoned pit yard the elevation of the tip was lowered, the slope shortened and its gradient altered to allow the traverse of machinery.

When the contouring operation was completed, the surface was regraded such that finer material formed the surface layer into which the sludge could be cultivated. During April - Jun 1989, 7,860 wet tonnes of fresh press cake were transported from North Bierley STW and spread to a depth of 100mm over the surface of the 5.5 ha site. This was then cultivated into the surface 100mm of the spoil to create a seed bed composed of a 1:1 wet volumetric mixture of spoil and sludge. At 45.5% Dry Solids, this was equivalent to an application rate of 650 $tDSha^{-1}$ of the sewage sludge.

The pH of the regraded spoil prior to the incorporation of the sludge was 5.5 and that of the fresh press cake 9.0, The pH of the resulting seed bed was 7.2.

The site was left to settle until July 1989 when it was seeded. Unfortunately the contractor seeded the site with Red Seal rather than the Red Circle used in the experiment. Factors such as pH and soil organic matter content govern PTE availability to plants but uptake has also been shown to be genetically controlled and hence the experiment could no longer be regarded as wholly predictive of the results expected of the site herbage.

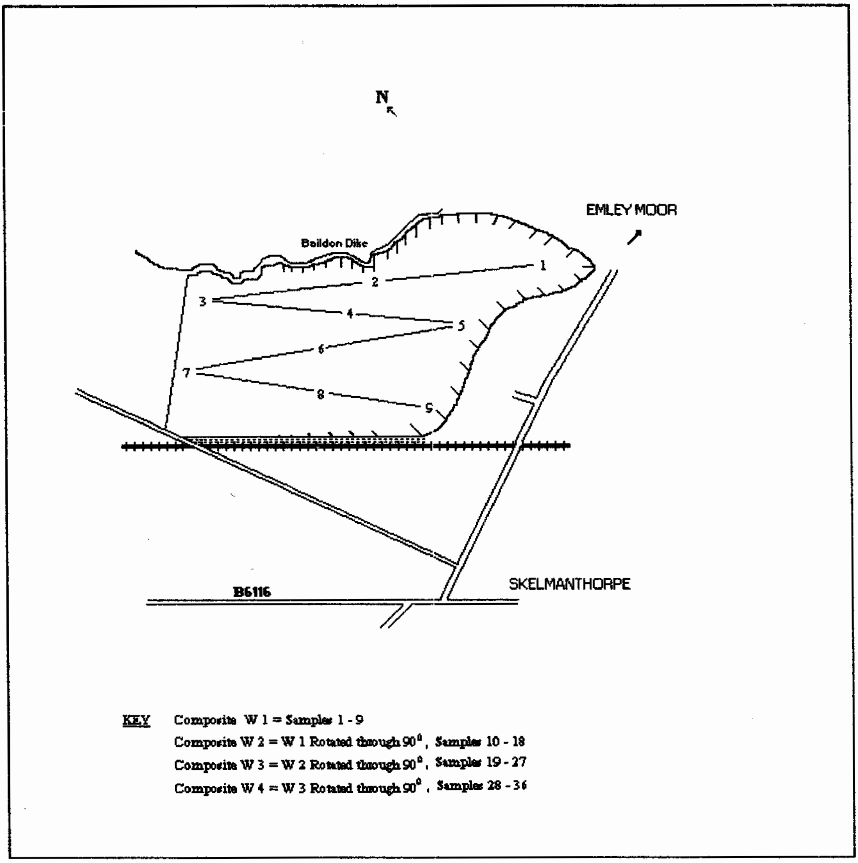
A dense, even cover of sward established rapidly save for areas of the edge between the plateau and the slopes. A later examination of these areas showed that the contractor had bladed the sludge over the edge of the plateau and onto the slopes exposing patches of virtually bare spoil in which acidity would subsequently develop. This was later remedied by re-treating these areas with localised applications of sludge to achieve the desired seed bed standard.

Unfortunately, policy changes within the water industry following privatisation reduced field sampling to a minimum in comparison to that undertaken at previously reclaimed sites. [1, 2, 3] For this reason, the results presented in this paper must be taken as an indicative, rather than comprehensive, overview of the site performance.

Site survey methods

Site sampling commenced in October 1989. Nine herbage samples, of approximately 30gm fresh weight, were taken in each of four W sampling pathways, the W being rotated through 90° each time as shown on the plan, Figure 12.

Figure 12. Emley Moor, sampling pattern



Seed bed pH was recorded at each sampling point.

Each sample collected was returned to the laboratory in a sealed, numbered polythene bag for preparation prior to analysis. The samples were washed to remove surface dust, dried and then composited to form one sample for each of the four sampling pathways. The composite samples were milled and reduced by progressive quartering before being forwarded for analysis of their PTE contents.

On four occasions, samples of the seed bed were also taken at each sampling point. These were composited to form one sample for each of the pathways, pH was determined on an aliquot of the composite and the remainder was air dried before being forwarded for analysis.

Results

The results of the soil and herbage analyses are shown in Tables 14 and 15 respectively.

Table 14. Average 'soil ' analysis, Emley Moor 1989 - 1991

mgkg^{-1} Dry Soil

Date	Site pH	Ni	Cu	Zn	Cr	Cd	Pb
17.10.89	7.17	26.3	89.5	106.0	57.0	6.2	66.3
21.11.89	7.17	31.5	83.3	118.0	55.0	5.3	70.5
16.01.90	7.16	26.5	158.3	208.0	108.8	3.0	120.0
15.11.91	7.08	37.5	156.0	211.0	113.8	0.3	105.3
Site Average	7.14	30.4	121.8	161.0	83.6	3.7	90.6

Table 15. Average herbage analysis, Emley Moor 1989 -1991

mgkg^{-1} Dry Tissue

Date	Site pH	Ni	Cu	Zn	Cr	Cd	Pb
17.10.89	7.17	4.4	28.3	60.5	5.1	<0.5	7.3
21.11.89	7.17	5.2	28.5	61.8	7.0	0.8	7.8
13.05.90	7.17	1.5	10.4	30.5	<1.0	<0.5	<2.0
12.06.90	7.13	1.4	10.8	41.3	<1.0	<0.5	<2.0
17.05.91	7.05	2.9	11.8	29.5	4.0	0.1	2.1
14.06.91	7.08	2.7	10.4	39.3	4.3	0.1	1.3
19.07.91	7.05	2.1	4.8	21.9	3.7	0.1	1.1
Site Average	7.12	2.9	15.0	40.7	<3.7	<0.4	<3.3

Discussion of results

PTEs in the seed bed:

Samples of the sludge taken to Emley Moor had the following analysis, Ni 38, Cu 430, Zn 535, Cr 53.4, Cd 4.0 and Pb 180 $mgkg^{-1}$ Dry Solids. A 1:1 volumetric mixture of spoil and sludge has a dry weight composition of 2.4 parts of spoil to 1.0 part of sludge. It is therefore possible to calculate an approximate analysis of the prepared seed bed in the following manner.

$$\frac{2.4 \times \text{PTE content of spoil} + 1 \times \text{PTE content of sludge}}{3.4}$$

Table 16 contrasts the calculated and observed average PTE contents of the seed bed with the maximum permissible concentrations in permanent grassland soils having a pH of 6.0-7.0 at a monitoring depth of 7.5 cm.[9]

Table 16. Calculated and observed PTE content of the Emley Moor Seed Bed

$mgkg^{-1}$ Dry Soil

PTE	Ni	Cu	Zn	Cr	Cd	Pb
Calculated concentration	23.2	157.0	182.0	164.0	1.9	82.0
Observed concentration	30.4	121.8	161.0	83.6	3.7	90.6
Maximum permissible	125.0	225.0	500.0	600.0	3.5	300.0

It must be remembered that when sampling a substrate composed of two such diverse materials as spoil and sludge it is difficult to obtain representative samples. Each sample taken will contain differing amounts of the two materials, particularly if the incorporation was not evenly achieved. Nevertheless, the above table shows that the observed PTE content is similar to the calculated values and, more importantly, within the legislational limits that currently apply.

The cadmium level in the seed bed is somewhat difficult to explain. The spoil had a cadmium content of <1.0, the sludge contained only 4.0 $mgkg^{-1}$ DS and yet four of the sixteen analyses from the seed bed have cadmium contents <7.0. All four of the high cadmium analyses show on sampling runs W3 and W4 in the first two months, both of these sampling runs share sample 1. It is not unknown for materials other than colliery spoil to be 'dumped' in colliery tips and it may be that the spoil in that area was contaminated by other waste materials.

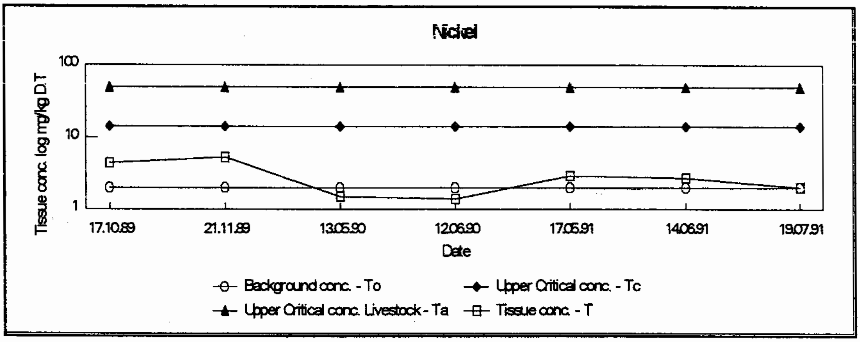
Seed bed pH:

It is evident from table 14 that incorporating consolidated sewage sludge into the spoil at Emley Moor created a seed bed of neutral pH and that this endured throughout the period over which the site was monitored. This is in distinct contrast to the failure of the traditional methods employed when the site was first restored in 1979. In this exercise, despite the initial addition of 15 tonnes of lime per hectare, the pH fell to 3.0 within six months with the consequent loss of vegetational cover. Two and a half years after the site was treated with sewage sludge, the seed bed pH was still between 7.0 and 7.2 and five years later the site has remained fully vegetated with no evidence of acid regression occurring.

PTE uptake:

Figure 13 shows the uptake of PTEs plotted in a similar manner to that previously described.

Figure 13. Plant tissue concentrations of PTEs - log mgkg^{-1} DT, Emley Moor, 1989 - 1991



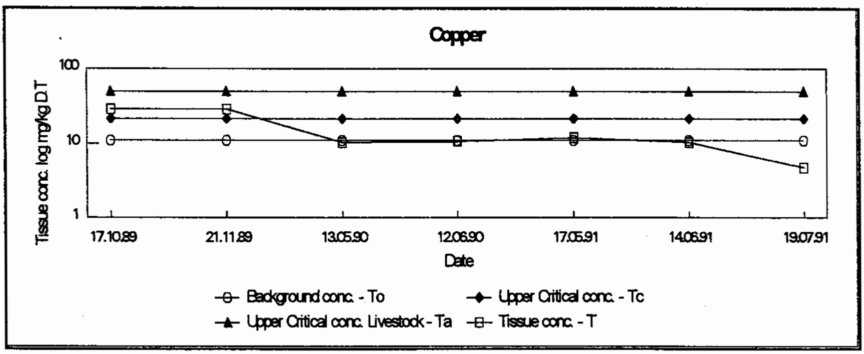
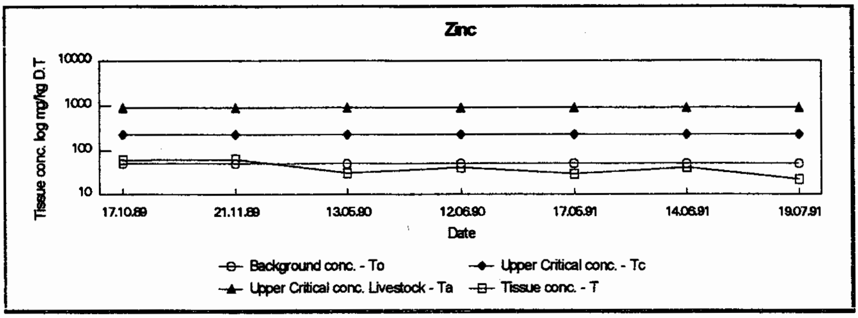
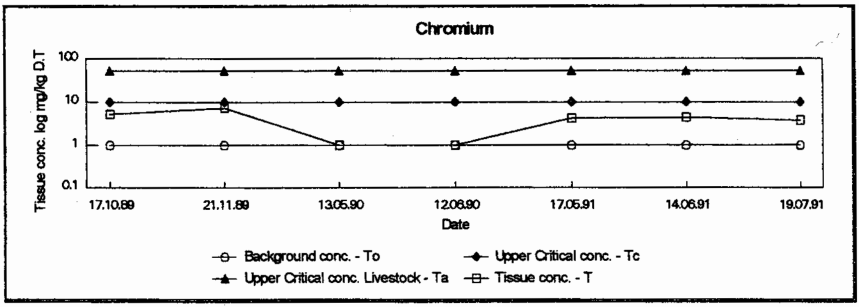


Figure 13 cont. Plant tissue concentrations of PTEs - log mgkg^{-1} DT, Emley Moor, 1989 - 1991





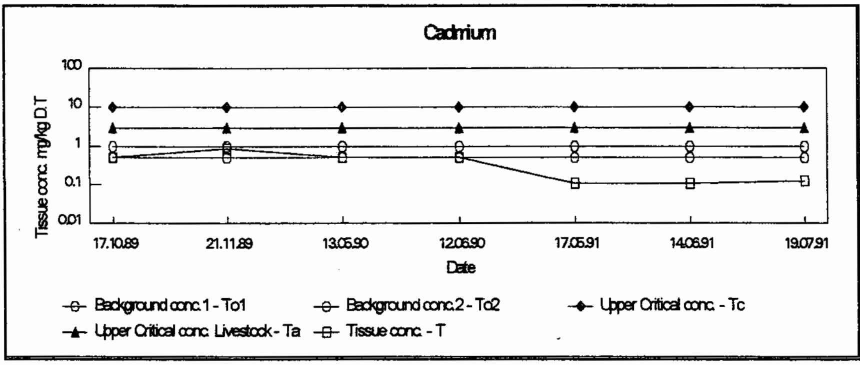
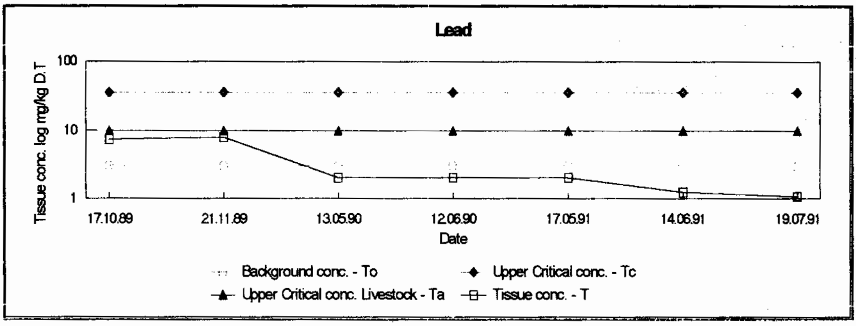


Figure 13 cont. Plant tissue concentrations of PTEs - log mgkg^{-1} DT, Emley Moor, 1989 - 1991



The upper critical concentrations, Tc, shown in these graphs may be slightly inaccurate as Red Seal was sown at Emley Moor rather than the Red Circle seed mixture normally used. Red Seal does contain ryegrass but neither the cultivar nor its percentage composition are known and plant genotype is known to govern plant uptake of PTEs.[10]

It is evident from these graphs however that plant uptake of all the PTEs is at a maximum during the first two months following germination of the seed. Copper in particular exceeded the level at which yield reduction would occur, a phenomenon not observed in the pot trial, see Figure 6. The sludge used to reclaim Emley Moor contained 430mg Cu kg^{-1} DS as opposed to the 334 mg Cu kg^{-1} DS in the press cake used in the experiment, moreover this additional 100mg kg^{-1} appears to be readily available to the grasses. North Bierley STW has, in the past, received illegal discharges of pig slurry and it is possible that this occurred before the sludge was taken to Emley Moor. Certainly the analysis of the sludge is, in this respect, atypical. It is however equally clear that the available copper is quickly removed and that the analysis of the grass tissues returns to the expected level. Six months after germination the levels of all PTEs in the grass tissues is acceptably low, tending, in the majority of elements, to be at or below the normally occurring background levels.

Plant uptake of PTEs may also be used to determine how far a site has progressed toward toxicity. This involves the calculation of the relative pollution hazard, **I**.

I is defined by the following calculation:

$$I = \frac{\log T - \log To}{\log Tc - \log To}$$

Where To and Tc are the normal background and experimentally determined upper critical, (the level at which yield begins to reduce), concentrations and T is its concentration in the test plant [6]. Using those levels determined by Davis and Beckett [7] gives values of the relative pollution hazard for Emley Moor as shown in Table 17.

Table 17. Values of relative pollution hazard, I, Emley Moor 1989 - 1991

Date	Nickel	Copper	Zinc
17.10.89	0.41	1.46	0.13
21.11.89	0.49	1.47	0.14
13.05.90	-0.14	-0.09	-0.33
12.06.90	-0.18	-0.03	-0.13
17.05.91	0.19	0.11	-0.36
14.06.91	0.15	-0.09	-0.16
19.07.91	0.03	-1.28	-0.56

From this table it may be seen that the values for the relative pollution hazards of nickel and zinc do not approach the level at which yield would reduce, an I value of 1.0. The first two values of I for copper indicate that there would have been some early reduction in yield due to this element however subsequent values, four of which are negative i.e below normally occurring background levels, clearly demonstrate that the site is not progressing toward toxicity.

CONCLUSIONS

The pot trials undertaken clearly demonstrate that the normal reclamation practice of liming and covering the spoil with a 100mm layer of topsoil was unsuitable for the reclamation of such a highly acidic spoil as Emley Moor. Control tests of spoil/soil 1:1 by volume became acidic within six months of mixing, despite the addition of sufficient lime to raise the original pH to 6.5, the pH fell to <3.0. The sludge/spoil mixtures by contrast were successful in maintaining a pH between 6.0 and 6.5 for the entire six year duration of the experiment.

The site at Emley Moor was let to a grazing tenancy, thus the overriding consideration in choosing a suitable sludge was the PTE uptake into the herbage. In this respect Mitchell Laithes lagoon dried sludge, whilst successful at other sites, was regarded as unsuitable as it produced the greatest uptake of chromium, nickel and zinc, which would limit grass production, and it was also felt that cadmium could prove to be deleterious in the long term.

The most suitable sludges in respect of PTE uptake proved to be North Bierley, Bradley and Lowfields. In respect of herbage production, the maximum sustainable yields were obtained from North Bierley and Bradley sludges. The final choice of North Bierley sludge for the site reclamation was made for purely operational reasons in that the supply in quantity could be guaranteed.

Although the data from the field trial is sparse it nevertheless demonstrates that, in sharp contrast to the traditional reclamation technique previously applied, sewage sludge, when carefully selected, can provide a successful reclamation of an extremely acidic colliery waste tip.

The seed bed created has given rise to a self sustaining sward of low PTE content which has resisted acid regression for five years. The site has required neither lime nor nutrient addition since its establishment and is managed purely by its grazing regime.

There is evidence to show that if insufficient sewage sludge is applied, acid production from the pyrite cannot be suppressed and pH will fall. A trial set up in the Midlands coalfield using an application rate of 250mt DS ha^{-1} reported a fall in pH from 8.3 to 3.5 over a three year period [11]. Although not stated, there is little doubt that phytotoxic symptoms would also have appeared in the vegetation, due to the mobilization and uptake of PTEs. The reason for the 250 $mtDSha^{-1}$ application rate quoted was in order to comply with the PTE limits set upon agricultural land.

The seed bed at Emley Moor was created using an application rate of 650 $mtDSha^{-1}$ and yet the PTE content of the seed bed was well within compliance with these same guidelines.

The alternative method for reclaiming these markedly acidic spoils is to cover the spoil to a sufficient depth to prevent oxygen reaching the underlying material and it is generally accepted that this requires a layer of approximately 0.5m in depth. Local government authorities, dependant upon public grant aid for reclamation schemes, could not acquire the necessary funding to employ this technique even if sufficient capping material were locally available.

The technique of using consolidated sewage sludge in sufficient quantity to provide a substitute for topsoil in reclamation schemes has had the acceptance and support of the regional office of the Department of the Environment for some twelve years in Yorkshire and it is estimated that its use reduces the capital cost of importing materials by some 40%. In addition, there are on-going cost savings in that sites treated in this manner do not require maintenance liming or subsequent applications of inorganic fertiliser.

In the USA, sewage sludge has been used in the revegetation of mined land for the preceding twenty years, at application rates of up to 997 $tDSha^{-1}$, to great effect [12] and evidence continues to be produced to support its use in the UK.

A recent survey, conducted under government sponsorship, predicts that increased quantities of sewage sludge will be generated as the 1991 E C Directive on Wastewater Treatment is implemented and that annual production in the UK will rise from 1.1mtDS in 1991 to 2.15mtDS by the year 2006 [13]. There is therefore a vital necessity to find alternative, and preferably beneficial, disposal routes for sewage sludge. The reclamation of derelict colliery spoil tips, providing grazing and public open space whilst enhancing the environment for local population, would seem to be one such beneficial use.

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APPENDIX

Table 1. Materials analysis Emley Moor

Material	%N	%P	%K	Cu	Ni	Zn	Pb	Cd	Cr
				mg/kg Dry Solids					
Soil	0.26	0.18	0.24	27.0	14.0	77.0	77.0	1.00	22.0
Spoil	1.15	0.52	1.03	44.0	17.0	35.0	41.0	<1.00	10.0
ML Sludge	1.19	1.97	0.43	305.0	49.0	1185.0	441.0	4.50	1460.0
NBF Sludge	1.12	1.85	0.19	334.0	21.0	388.0	183.0	2.50	560.0
NBO Sludge	2.85	1.38	0.22	322.0	43.0	471.0	232.0	4.00	342.0
B Sludge	1.70	1.89	0.23	230.0	67.0	815.0	430.0	6.00	1040.0
L Sludge	1.15	2.44	0.22	116.0	23.0	950.0	417.0	3.50	120.0

Sludge ex. ML = Mitchell Laithes NB = North Bierley, F =fresh, O = old
B = Bradley L = Lowfields

Table 2. Emley Moor. Av DM Production gm/pot & t/ha , Year 1

Cut	O	SO	SO+	SML	SNBF	SNBO	SB	SL
1	0.180	0.039	0.052	0.061	0.105	0.075	0.048	0.049
2	0.194	0.005	0.047	0.412	0.437	0.261	0.033	0.027
3	1.081	0.397	0.567	2.288	2.254	1.346	0.550	0.947
4	1.236	0.311	0.671	3.364	4.190	2.436	0.958	2.091
5	1.954	1.090	2.071	4.085	6.090	5.800	3.570	3.938
6	1.202	0.498	1.100	3.117	6.930	9.183	9.183	5.392
7	0.553	0.048	0.131	1.323	2.367	2.484	2.942	1.706
8	0.900	0.190	0.268	2.091	4.223	4.889	3.079	5.775
9	1.010	0.096	0.098	1.863	3.859	3.375	12.533	3.161
10	0.440	0.007	0.018	1.249	2.494	1.331	5.796	1.853
11	0.558	0.000	0.021	0.909	1.643	0.804	3.909	1.491
12	0.137	0.000	0.053	0.583	1.022	0.597	1.301	0.909
Tot gm/p	9.445	2.681	5.097	21.365	35.614	32.581	43.902	27.339
Tot tDM/ha	3.935	1.117	2.124	8.902	14.839	13.575	18.293	11.391

Table 3. Emley Moor. Av DM Production gm/pot & t/ha , Year 2

Cut	O	SO	SO+	SML	SNBF	SNBO	SB	SL
13	0.234			1.077	1.630	0.967	1.464	1.212
14	0.080	0.007	0.047	0.396	0.811	0.256	0.584	0.530
15	0.368	0.019	0.037	0.351	0.702	0.293	0.538	0.497
16	0.412		0.007	0.535	1.549	0.669	1.673	0.942
17								
18	3.128		0.055	1.259	3.398	0.641	3.375	2.551
19	1.119			1.098	2.631	1.398	2.704	1.741
20	0.822		0.085	1.044	1.925	1.009	1.977	1.416
21	0.598			1.083	1.814	1.229	1.811	1.300
22	0.357	0.009	0.019	0.571	0.956	0.523	0.917	0.676
23	0.150			0.294	0.485	0.280	0.541	0.313
24	0.311			0.345	0.414	0.249	0.459	0.352
Tot gm/p	7.579	0.035	0.250	8.053	16.315	7.514	16.043	11.530
Tot tDM/ha	3.158	0.015	0.104	3.355	6.798	3.131	6.685	4.804

Table 4. Emley Moor. Av. DM Production, Test SML gm/pot &t/ha, Years 1-7

Year	Cut 1	Cut 2	Cut 3	Cut 4	Cut 5	Cut 6	Cut 7	Cut 8	Cut 9	Cut 10	Cut 11	Cut 12	Tot gm/pot	Tot t/ha
1	0.081	0.412	2.288	3.364	4.085	3.117	1.323	2.091	1.863	1.249	0.909	0.583	21.365	8.902
2	1.077	0.396	0.351	0.535		1.259	1.098	1.044	1.083	0.571	0.294	0.345	8.053	3.355
3	0.622	0.143	0.190	0.916	1.401	1.361	1.091	1.007	0.743	0.783	0.309	1.389	9.955	4.148
4	0.634	1.289	1.353	1.558	1.087	0.440	0.567	0.378	0.276	0.347	0.555	1.569	10.053	4.189
5	1.252	0.744	0.270	0.667	0.586	0.364	0.543	1.246	1.417	2.424	0.749	0.093	10.355	4.315
6	2.266	1.327	1.944	1.843	1.341	0.677	0.956	0.893	1.168	0.986	0.893	1.182	15.476	6.448
7	1.731	2.078	1.395										5.204	2.168

Table 5. Emley Moor. Av. DM Production, Test SNBF gm/pot &t/ha, Years 1-7

Year	Cut 1	Cut 2	Cut 3	Cut 4	Cut 5	Cut 6	Cut 7	Cut 8	Cut 9	Cut 10	Cut 11	Cut 12	Tot gm/pot	Tot t/ha
1	0.105	0.437	2.254	4.190	6.090	6.930	2.367	4.223	3.859	2.494	1.643	1.022	35.614	14.839
2	1.630	0.811	0.702	1.549		3.398	2.631	1.925	1.814	0.956	0.485	0.414	16.315	6.798
3	0.646	0.225	0.323	1.547	2.642	2.535	1.496	1.252	0.722	1.019	0.341	2.014	14.762	6.151
4	0.942	1.633	1.624	1.597	1.353	0.465	0.549	0.404	0.331	0.376	1.118	1.717	12.109	5.045
5	1.147	0.713	0.235	0.578	0.714	0.477	0.904	1.829	3.251	3.905	0.835	0.141	14.729	6.137
6	2.433	1.640	2.059	1.861	1.473	0.711	1.041	1.138	1.358	1.289	1.096	1.417	17.516	7.298
7	1.823	2.104	1.402										5.329	2.220

Table 6. Emley Moor. Av. DM Production, Test SNBO gm/pot &t/ha, Years 1-7

Year	Cut 1	Cut 2	Cut 3	Cut 4	Cut 5	Cut 6	Cut 7	Cut 8	Cut 9	Cut 10	Cut 11	Cut 12	Tot gm/pot	Tot t/ha
1	0.075	0.261	1.346	2.436	5.800	9.183	2.484	4.889	3.375	1.331	0.804	0.597	32.581	13.575
2	0.967	0.256	0.293	0.669		0.641	1.398	1.009	1.229	0.523	0.280	0.249	7.514	3.131
3	0.589	0.134	0.223	1.323	2.011	1.924	1.289	1.201	0.813	0.856	0.167	1.760	12.290	5.121
4	0.825	1.388	1.175	1.473	1.084	0.386	0.469	0.268	0.270	0.316	0.783	1.413	9.850	4.104
5	1.075	0.530	0.212	0.413	0.766	0.675	1.489	2.527	3.505	3.771	0.603	0.156	15.722	6.551
6	2.375	1.520	1.984	1.702	1.266	0.603	1.027	1.104	1.238	1.144	0.944	1.176	16.083	6.701
7	1.540	1.976	1.170										4.686	1.953

Table 7. Emley Moor - Metal uptake, Year 1

Metal :- Chromium

Treatment	Cut 1	Cut 2	Cut 3	Cut 4	Cut 5	Cut 6	Cut 7	Cut 8	Cut 9	Cut 10	Cut 11	Cut 12
O		0.75		0.75	<0.50	0.50	1.13	0.50	<0.50	<0.50	1.63	1.51
SO		0.50		0.63	<0.50	<0.50	<0.50	0.89	0.53			
SO +		0.63		<0.50	0.75	<0.50	<0.50	0.75	<0.50			3.72
SML		4.13		0.75	0.75	<0.50	1.13	0.50	0.88	10.50	3.75	2.38
SNBF		0.88		0.63	<0.50	<0.50	0.88	0.50	0.50	0.75	<0.50	<0.50
SNBO		0.63		<0.50	0.63	<0.50	1.00	0.63	0.75	2.25	1.63	3.00
SB		4.38		3.88	0.50	<0.50	4.25	0.88	<0.50	1.63	1.25	<0.50
SL		<0.50		1.75	0.50	<0.50	<0.50	<0.50	<0.50	<0.50	0.75	0.88

Metal :- Nickel

Treatment	Cut 1	Cut 2	Cut 3	Cut 4	Cut 5	Cut 6	Cut 7	Cut 8	Cut 9	Cut 10	Cut 11	Cut 12
O		3.75		4.25	2.88	3.88	4.63	2.00	3.25	3.00	4.25	5.76
SO		3.50		6.13	4.63	5.75	7.39	26.10	38.30			
SO +		4.13		5.88	3.50	6.13	8.97	25.20	27.70			28.40
SML		7.13		8.13	6.13	6.75	6.75	4.50	5.38	5.00	9.38	13.60
SNBF		1.63		2.00	1.25	1.00	1.00	<0.50	1.63	1.13	1.25	2.25
SNBO		1.75		1.00	1.75	1.38	1.13	0.50	0.88	1.50	3.38	4.63
SB		2.75		1.88	1.50	1.38	1.50	0.75	1.75	1.50	1.75	1.50
SL		1.13		0.63	0.88	1.38	1.00	<0.50	0.88	0.88	0.75	1.13

Metal :- Copper

Treatment	Cut 1	Cut 2	Cut 3	Cut 4	Cut 5	Cut 6	Cut 7	Cut 8	Cut 9	Cut 10	Cut 11	Cut 12
O		11.00		10.00	7.88	6.13	32.90	5.38	7.00	7.63	14.40	16.40
SO		5.88		9.88	6.13	6.25	19.90	9.38	5.75			
SO +		9.13		9.88	6.25	5.88	14.50	9.50	4.00			11.50
SML		12.00		13.40	10.90	8.38	10.00	9.00	7.13	7.13	12.10	12.40
SNBF		11.90		14.85	10.10	8.00	12.50	7.62	7.50	8.88	9.50	11.80
SNBO		12.60		11.30	12.10	9.50	12.90	12.10	7.13	5.75	13.50	15.90
SB		11.00		10.30	10.40	11.40	11.00	11.80	12.50	11.00	9.50	11.60
SL		7.88		8.25	9.00	7.38	8.60	6.00	5.75	9.63	7.75	11.00

Metal :- Zinc

Treatment	Cut 1	Cut 2	Cut 3	Cut 4	Cut 5	Cut 6	Cut 7	Cut 8	Cut 9	Cut 10	Cut 11	Cut 12
O		55.00		41.90	37.60	37.00	31.90	22.00	39.40	74.40	60.40	74.90
SO		23.80		31.00	23.60	35.80	51.70	189.00	333.00			
SO +		33.80		32.90	27.90	36.90	43.60	188.00	257.00			249.00
SML		137.00		121.00	127.00	73.40	66.50	73.80	84.30	28.10	197.00	377.00
SNBF		28.10		36.60	26.90	25.40	31.80	21.80	27.50	63.90	19.90	29.50
SNBO		30.00		34.90	44.00	31.70	32.00	26.10	26.90	21.30	25.40	28.00
SB		44.40		40.30	56.40	54.50	49.50	57.50	63.80	40.10	33.00	40.10
SL		33.80		39.00	50.50	56.40	41.80	26.10	36.40	25.00	29.60	48.90

Metal :- Cadmium

Treatment	Cut 1	Cut 2	Cut 3	Cut 4	Cut 5	Cut 6	Cut 7	Cut 8	Cut 9	Cut 10	Cut 11	Cut 12
O		0.38		0.25	0.25	0.25	0.38	0.25	0.38	0.25	0.50	0.98
SO		<0.20		0.25	<0.20	0.25	<0.20	2.50	4.52			
SO +		<0.20		0.25	0.25	0.25	0.25	2.50	3.85			3.00
SML		0.25		<0.20	0.25	0.20	<0.20	<0.20	0.38	0.38	0.63	1.13
SNBF		<0.20		0.25	0.25	<0.20	<0.20	<0.20	<0.20	0.25	<0.20	<0.20
SNBO		<0.20		0.25	0.25	0.25	0.38	<0.20	<0.20	0.25	0.25	<0.20
SB		<0.20		<0.20	<0.20	0.25	0.25	<0.20	<0.20	0.38	0.25	0.75
SL		<0.20		<0.20	<0.20	0.20	<0.20	<0.20	0.38	<0.20	0.25	<0.20

Metal :- Lead

Treatment	Cut 1	Cut 2	Cut 3	Cut 4	Cut 5	Cut 6	Cut 7	Cut 8	Cut 9	Cut 10	Cut 11	Cut 12
O		1.38		1.50	<0.50	<0.50	<0.50	<0.50	1.13	1.13	<0.50	1.96
SO		0.88		2.75	<0.50	0.63	<0.50	1.38	2.00			
SO +		1.38		2.50	<0.50	<0.50	<0.50	0.75	1.13			8.11
SML		1.25		2.13	<0.50	<0.50	1.00	<0.50	0.63	2.75	<0.50	<0.50
SNBF		0.50		2.63	<0.50	<0.50	0.75	<0.50	<0.50	0.88	<0.50	1.13
SNBO		0.88		2.50	<0.50	<0.50	1.75	<0.50	<0.50	2.00	<0.50	0.88
SB		2.63		4.13	<0.50	0.63	2.00	<0.50	0.50	1.25	<0.50	<0.50
SL		0.75		6.00	<0.50	<0.50	<0.50	<0.50	0.88	0.63	<0.50	<0.50

Table 8. **Emley Moor - Metal uptake, Year 2**

Metal :- Chromium

Treatment	Cut 13	Cut 14	Cut 15	Cut 16	Cut 17	Cut 18	Cut 19	Cut 20	Cut 21	Cut 22	Cut 23	Cut 24
O	0.50		0.50	<0.50		1.00	<0.50	1.10	2.00	1.30	1.00	1.30
SO												
SO +												
SML	1.60	0.50	0.60	<0.50		1.00	1.10	1.00	2.90	<1.00	<1.00	2.60
SNBF	0.90	<0.50	0.50	0.50		2.10	<0.50	<1.00	2.40	<1.00	<1.00	<1.00
SNBO	2.50	3.90	0.60	1.00		1.40	0.50	1.30	2.90	1.10	1.30	2.00
SB	2.10	1.00	1.30	0.50		0.75	3.30	1.00	2.80	<1.00	9.00	1.80
SL	1.30	<0.50	<0.50	<0.50		1.50	<0.50	1.00	2.30	<1.00	<1.00	1.00

Metal :- Nickel

Treatment	Cut 13	Cut 14	Cut 15	Cut 16	Cut 17	Cut 18	Cut 19	Cut 20	Cut 21	Cut 22	Cut 23	Cut 24
O	2.60		2.50	5.30		3.90	3.30	2.50	2.40	2.10	1.90	2.60
SO												
SO +												
SML	7.50	3.40	4.00	5.50		3.80	3.50	5.40	8.00	6.90	9.60	12.90
SNBF	1.50	0.80	0.50	1.10		2.60	<0.50	<1.00	1.10	1.30	1.30	2.80
SNBO	3.00	0.60	0.60	0.90		1.10	<0.50	<1.00	<1.00	<1.00	1.10	1.50
SB	1.50	0.80	0.50	1.00		0.50	1.10	<1.00	<1.00	<1.00	2.00	1.40
SL	1.40	<0.50	<0.50	<0.50		2.00	<0.50	<1.00	<1.00	<1.00	<1.00	1.10

Metal :- Copper

Treatment	Cut 13	Cut 14	Cut 15	Cut 16	Cut 17	Cut 18	Cut 19	Cut 20	Cut 21	Cut 22	Cut 23	Cut 24
O	7.30		5.60	14.00		8.90	8.10	9.50	8.50	9.80	7.80	11.00
SO												
SO +												
SML	7.00	6.10	6.00	13.10		6.40	5.40	9.40	7.60	8.00	9.10	13.10
SNBF	6.50	4.60	8.30	11.00		5.90	5.50	9.50	6.80	9.60	7.80	10.60
SNBO	9.90	3.50	7.90	11.30		9.00	6.50	9.50	7.40	8.80	8.90	10.10
SB	6.90	4.80	4.40	12.60		5.60	6.60	9.40	8.10	7.30	11.30	9.80
SL	4.90	2.80	4.80	10.80		6.10	6.90	8.80	6.90	8.10	7.30	7.80

Metal :- Zinc

Treatment	Cut 13	Cut 14	Cut 15	Cut 16	Cut 17	Cut 18	Cut 19	Cut 20	Cut 21	Cut 22	Cut 23	Cut 24
O	37.40		35.40	76.50		46.00	35.60	33.10	48.60	48.80	24.60	48.40
SO												
SO +												
SML	284.00	81.80	95.90	175.00		103.00	71.30	125.00	249.00	173.00	231.00	375.00
SNBF	24.80	20.30	18.40	36.00		17.00	18.90	27.60	22.30	44.00	26.50	55.50
SNBO	19.30	14.30	26.90	44.00		24.40	19.10	27.50	22.90	34.30	28.40	28.90
SB	32.40	31.30	29.00	65.80		19.30	24.90	35.60	33.50	35.90	35.60	48.30
SL	31.00	17.40	29.00	38.90		20.80	25.40	30.90	25.60	39.00	29.40	38.80

Metal :- Cadmium

Treatment	Cut 13	Cut 14	Cut 15	Cut 16	Cut 17	Cut 18	Cut 19	Cut 20	Cut 21	Cut 22	Cut 23	Cut 24
O	0.25		0.13	0.13		0.49	0.31	<0.50	<0.50	<0.50	<0.50	<0.50
SO												
SO +												
SML	0.75	0.38	0.38	0.50		0.60	0.40	0.63	1.00	0.88	0.88	1.40
SNBF	0.25	0.25	0.13	0.25		0.24	<0.20	<0.50	<0.50	<0.50	<0.50	<0.50
SNBO	0.25	0.13	0.13	0.13		0.36	<0.20	<0.50	<0.50	<0.50	<0.50	<0.50
SB	9.25	0.13	<0.10	0.25		<0.20	<0.20	<0.50	<0.50	<0.50	<0.50	<0.50
SL	0.25	0.13	0.13	0.25		<0.20	<0.20	<0.50	<0.50	<0.50	<0.50	<0.50

Metal :- Lead

Treatment	Cut 13	Cut 14	Cut 15	Cut 16	Cut 17	Cut 18	Cut 19	Cut 20	Cut 21	Cut 22	Cut 23	Cut 24
O	<2.00		<2.00	<2.00		1.60	1.50	<1.00	1.40	5.90	2.00	2.50
SO												
SO +												
SML	<2.00	<2.00	<2.00	<2.00		1.00	1.40	<1.00	1.30	<2.00	<2.00	2.00
SNBF	<2.00	<2.00	<2.00	<2.00		<1.00	1.10	1.10	1.00	2.10	2.50	<2.00
SNBO	3.30	3.40	<2.00	<2.00		<1.00	1.00	<1.00	1.10	3.10	3.50	3.40
SB	<2.00	<2.00	1.90	<2.00		<1.00	2.00	<1.00	1.10	3.50	9.40	3.90
SL	<2.00	<2.00	<2.00	<2.00		<1.00	1.30	<1.00	<1.00	2.90	2.40	4.50

Table 9. Emley Moor - Metal uptake, Year 3

Metal :- Chromium

Treatment	Cut 25	Cut 26	Cut 27	Cut 28	Cut 29	Cut 30	Cut 31	Cut 32	Cut 33	Cut 34	Cut 35	Cut 36
SML	5.30	1.70	<1.00	2.90	<1.00	<1.00	<1.00	1.10	4.90	1.80	<1.00	<1.00
SNBF	1.90	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	4.50	<1.00	<1.00
SNBO	4.40	1.40	<1.00	1.00	<1.00	<1.00	<1.00	<1.00	2.50	2.60	<1.00	<1.00

Metal :- Nickel

Treatment	Cut 25	Cut 26	Cut 27	Cut 28	Cut 29	Cut 30	Cut 31	Cut 32	Cut 33	Cut 34	Cut 35	Cut 36
SML	9.10	11.00	6.20	18.00	7.50	3.50	6.50	8.10	17.10	7.40	5.40	4.40
SNBF	5.10	1.70	<1.00	2.30	<1.00	<1.00	<1.00	<1.00	2.00	1.90	1.90	<1.00
SNBO	4.60	1.40	<1.00	1.00	<1.00	<1.00	<1.00	<1.00	1.40	1.80	1.40	<1.00

Metal :- Copper

Treatment	Cut 25	Cut 26	Cut 27	Cut 28	Cut 29	Cut 30	Cut 31	Cut 32	Cut 33	Cut 34	Cut 35	Cut 36
SML	14.00	12.00	7.70	12.00	7.00	5.30	7.30	9.10	11.50	3.40	5.00	6.00
SNBF	14.90	11.00	7.30	8.60	5.80	4.50	6.00	6.60	6.30	9.50	6.30	6.30
SNBO	13.90	10.00	7.30	8.30	7.00	5.30	7.90	9.50	11.50	8.80	7.00	6.60

Metal :- Zinc

Treatment	Cut 25	Cut 26	Cut 27	Cut 28	Cut 29	Cut 30	Cut 31	Cut 32	Cut 33	Cut 34	Cut 35	Cut 36
SML	116.00	319.00	171.00	645.00	275.00	116.00	171.00	190.00	515.00	240.00	180.00	117.00
SNBF	45.80	40.00	29.00	28.00	23.00	19.00	21.00	18.00	32.90	28.40	25.00	20.00
SNBO	45.40	39.00	26.00	27.00	27.00	20.00	26.00	24.00	26.10	31.60	26.00	23.00

Metal :- Cadmium

Treatment	Cut 25	Cut 26	Cut 27	Cut 28	Cut 29	Cut 30	Cut 31	Cut 32	Cut 33	Cut 34	Cut 35	Cut 36
SML	3.50	1.60	0.92	2.10	1.00	0.75	0.88	0.99	2.10	0.93	0.63	0.56
SNBF	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	0.50	<0.50
SNBO	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	0.50	<0.50

Metal :- Lead

Treatment	Cut 25	Cut 26	Cut 27	Cut 28	Cut 29	Cut 30	Cut 31	Cut 32	Cut 33	Cut 34	Cut 35	Cut 36
SML	5.40	<2.00	<2.00	2.60	<2.00	<2.00	<2.00	<2.00	3.10	6.60	<2.00	<2.00
SNBF	7.60	<2.00	<2.00	<2.00	<2.00	<2.00	<2.00	<2.00	<2.00	6.10	<2.00	<2.00
SNBO	7.30	<2.00	<2.00	<2.00	<2.00	<2.00	<2.00	<2.00	2.30	5.10	<2.00	<2.00

Table 10. Emley Moor - Metal uptake, Year 4

Metal :- Chromium

Treatment	Cut 37	Cut 38	Cut 39	Cut 40	Cut 41	Cut 42	Cut 43	Cut 44	Cut 45	Cut 46	Cut 47	Cut 48
SML	<1.00	<1.00	<1.00	1.00	<1.00	<1.00	<1.00	<1.00	1.50	<1.00	2.60	<1.00
SNBF	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	2.10	<1.00	1.90	<1.00	3.50	<1.00
SNBO	1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	1.10	1.80	1.80	1.10	<1.00

Metal :- Nickel

Treatment	Cut 37	Cut 38	Cut 39	Cut 40	Cut 41	Cut 42	Cut 43	Cut 44	Cut 45	Cut 46	Cut 47	Cut 48
SML	5.90	4.50	6.30	7.80	5.10	8.60	7.80	6.60	6.10	6.10	3.00	4.00
SNBF	<1.00	1.00	<1.00	1.00	<1.00	1.30	5.40	<1.00	1.00	<1.00	3.80	1.30
SNBO	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	1.00	<1.00	<1.00	1.50	2.00	<1.00

Metal :- Copper

Treatment	Cut 37	Cut 38	Cut 39	Cut 40	Cut 41	Cut 42	Cut 43	Cut 44	Cut 45	Cut 46	Cut 47	Cut 48
SML	8.90	7.00	8.00	9.20	5.60	9.10	7.50	6.50	9.10	7.10	5.00	8.00
SNBF	7.50	7.90	5.10	6.60	4.10	6.90	19.00	3.80	12.00	6.90	6.00	8.00
SNBO	10.00	9.30	7.50	10.00	5.30	8.00	8.00	5.80	11.00	8.25	11.00	5.00

Metal :- Zinc

Treatment	Cut 37	Cut 38	Cut 39	Cut 40	Cut 41	Cut 42	Cut 43	Cut 44	Cut 45	Cut 46	Cut 47	Cut 48
SML	173.00	153.00	128.00	189.00	102.00	148.00	89.00	103.00	243.00	104.00	233.00	251.00
SNBF	32.00	33.00	24.00	23.00	18.00	26.00	105.00	22.00	164.00	29.10	40.00	42.00
SNBO	42.00	33.00	32.00	25.00	19.00	29.00	25.00	27.00	203.00	30.00	48.00	52.00

Metal :- Cadmium

Treatment	Cut 37	Cut 38	Cut 39	Cut 40	Cut 41	Cut 42	Cut 43	Cut 44	Cut 45	Cut 46	Cut 47	Cut 48
SML	0.99	<0.50	9.78	1.20	<0.50	1.40	0.63	0.88	0.91	0.60	<0.50	0.50
SNBF	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
SNBO	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50

Metal :- Lead

Treatment	Cut 37	Cut 38	Cut 39	Cut 40	Cut 41	Cut 42	Cut 43	Cut 44	Cut 45	Cut 46	Cut 47	Cut 48
SML	<2.00	<2.00	<2.00	2.00	<2.00	<2.00	<2.00	<2.00	3.30	<2.00	<2.00	<2.00
SNBF	<2.00	<2.00	<2.00	<2.00	<2.00	<2.00	<2.00	<2.00	4.50	<2.00	<2.00	<2.00
SNBO	<2.00	<2.00	<2.00	<2.00	<2.00	<2.00	<2.00	<2.00	4.30	<2.00	<2.00	<2.00

Table 11. **Emley Moor - Metal uptake, Year 5**

Metal :- Chromium

Treatment	Cut 49	Cut 50	Cut 51	Cut 52	Cut 53	Cut 54	Cut 55	Cut 56	Cut 57	Cut 58	Cut 59	Cut 60
SML	5.50	1.51	<1.00	<1.00	2.08	<1.00	<1.00	1.88	4.88	3.00	<1.00	
SNBF	1.50	<1.00	<1.00	<1.00	1.50	<1.00	<1.00	5.33	9.63	<1.00	<1.00	
SNBO	1.00	<1.00	<1.00	<1.00	2.94	<1.00	<1.00	6.96	4.13	3.00	<1.00	<5.00

Metal :- Nickel

Treatment	Cut 49	Cut 50	Cut 51	Cut 52	Cut 53	Cut 54	Cut 55	Cut 56	Cut 57	Cut 58	Cut 59	Cut 60
SML	19.00	21.30	18.30	15.60	11.70	5.54	8.64	9.79	13.00	12.30	16.60	
SNBF	1.80	1.50	1.68	1.93	<1.00	<1.00	<1.00	2.14	5.28	<1.00	2.39	
SNBO	1.50	1.25	1.00	1.59	1.44	<1.00	<1.00	2.95	2.51	3.00	2.05	4.10

Metal :- Copper

Treatment	Cut 49	Cut 50	Cut 51	Cut 52	Cut 53	Cut 54	Cut 55	Cut 56	Cut 57	Cut 58	Cut 59	Cut 60
SML	26.00	14.80	14.50	10.40	10.20	3.54	6.70	7.96	13.60	10.40	15.10	
SNBF	19.00	18.80	19.30	9.63	10.10	5.65	9.34	9.16	14.40	10.40	16.60	
SNBO	20.00	14.50	11.80	10.80	7.46	5.97	9.16	9.04	7.13	13.80	18.10	10.50

Metal :- Zinc

Treatment	Cut 49	Cut 50	Cut 51	Cut 52	Cut 53	Cut 54	Cut 55	Cut 56	Cut 57	Cut 58	Cut 59	Cut 60
SML	235.00	132.00	136.00	150.00	164.00	97.80	179.00	214.00	158.00	175.00	268.00	
SNBF	52.00	40.00	52.60	26.60	28.10	26.20	31.50	30.20	44.00	47.30	70.00	
SNBO	39.00	40.50	39.30	28.70	27.60	30.20	29.70	33.00	29.40	63.90	69.90	121.00

Metal :- Cadmium

Treatment	Cut 49	Cut 50	Cut 51	Cut 52	Cut 53	Cut 54	Cut 55	Cut 56	Cut 57	Cut 58	Cut 59	Cut 60
SML	0.60	0.63	0.75	0.51	0.91	0.39	0.74	0.98	1.15	1.21	2.57	
SNBF	<0.50	<0.50	<0.50	0.25	0.21	0.19	0.11	0.28	0.20	0.33	0.16	
SNBO	<0.50	<0.50	<0.50	0.31	0.31	0.16	<0.10	<0.10	0.11	0.46	0.29	0.38

Metal :- Lead

Treatment	Cut 49	Cut 50	Cut 51	Cut 52	Cut 53	Cut 54	Cut 55	Cut 56	Cut 57	Cut 58	Cut 59	Cut 60
SML	<2.00	3.73	<2.00	<2.00	1.00	<1.00	<1.00	<1.00	1.56	3.08	<2.00	
SNBF	<2.00	<2.00	<2.00	<2.00	1.13	<1.00	<1.00	<1.00	1.00	<2.00	<2.00	
SNBO	<2.00	<2.00	<2.00	<2.00	<1.00	<1.00	<1.00	<1.00	1.00	2.99	<2.00	<2.00

Table 12. **Emley Moor - Metal uptake, Year 6**

Metal :- Chromium

Treatment	Cut 61	Cut 62	Cut 63	Cut 64	Cut 65	Cut 66	Cut 67	Cut 68	Cut 69	Cut 70	Cut 71	Cut 72
SML	<1.00	<1.00	1.13	2.00	1.63	1.13	1.50	<1.00	<1.00	<1.00	<1.00	<1.00
SNBF	<1.00	<1.00	1.38	1.50	0.63	2.50	<1.00	<1.00	1.51	<1.00	<1.00	<1.00
SNBO	<1.00	<1.00	1.50	1.50	0.88	0.88	1.25	<1.00	<1.00	<1.00	<1.00	<1.00

Metal :- Nickel

Treatment	Cut 61	Cut 62	Cut 63	Cut 64	Cut 65	Cut 66	Cut 67	Cut 68	Cut 69	Cut 70	Cut 71	Cut 72
SML	9.13	18.10	7.25	10.90	8.38	8.13	10.60	5.88	12.30	4.89	8.38	<1.00
SNBF	1.00	1.13	1.25	2.00	0.88	0.38	1.88	<1.00	<1.00	<1.00	<1.00	<1.00
SNBO	1.00	1.38	1.25	1.88	1.13	<0.25	1.50	<1.00	<1.00	<1.00	<1.00	<1.00

Metal :- Copper

Treatment	Cut 61	Cut 62	Cut 63	Cut 64	Cut 65	Cut 66	Cut 67	Cut 68	Cut 69	Cut 70	Cut 71	Cut 72
SML	8.38	13.60	7.50	8.75	13.90	11.00	8.25	8.61	9.12	10.60	9.63	10.30
SNBF	10.10	11.90	7.50	8.75	9.25	11.10	9.00	8.61	9.35	16.10	9.38	8.88
SNBO	6.63	11.90	6.25	8.75	10.10	10.40	8.63	8.36	11.00	10.20	9.38	9.13

Metal :- Zinc

Treatment	Cut 61	Cut 62	Cut 63	Cut 64	Cut 65	Cut 66	Cut 67	Cut 68	Cut 69	Cut 70	Cut 71	Cut 72
SML		62.50	138.00	219.00	178.00	124.00	211.00	125.00	270.00	118.00	240.00	163.00
SNBF	39.30	47.10	31.30	138.00	22.50	41.30	28.50	29.80	35.00	30.50	28.60	25.40
SNBO	37.30	48.50	25.00	37.50	35.00	36.30	30.80	29.50	33.50	27.90	33.30	29.50

Metal :- Cadmium

Treatment	Cut 61	Cut 62	Cut 63	Cut 64	Cut 65	Cut 66	Cut 67	Cut 68	Cut 69	Cut 70	Cut 71	Cut 72
SML	0.56	1.64	0.75	0.98	1.68	1.30	0.94	0.78	1.34	0.71	1.08	1.50
SNBF	0.11	0.18	<0.10	0.18	0.29	0.19	0.15	<0.10	0.14	0.14	<0.10	0.11
SNBO	<0.10	0.26	0.10	0.24	0.39	0.19	0.20	0.15	0.70	0.20	0.11	0.27

Metal :- Lead

Treatment	Cut 61	Cut 62	Cut 63	Cut 64	Cut 65	Cut 66	Cut 67	Cut 68	Cut 69	Cut 70	Cut 71	Cut 72
SML	1.75	2.38	<3.00	<3.00	2.13	1.13	3.38	<5.00	<5.00	<5.00	<5.00	<5.00
SNBF	1.63	<2.00	<3.00	<3.00	1.00	2.13	<3.00	<5.00	<5.00	<5.00	<5.00	<5.00
SNBO	1.50	2.25	<3.00	<3.00	1.25	1.13	3.63	<5.00	<5.00	<5.00	<5.00	<5.00