

## **1. INTRODUCTION**

### **1.1 Site description**

Bold Moss Tip is a 55 ha colliery spoil tip located to the east of St Helens, Lancashire. The site was purchased from British Coal by The Groundwork Trust in 1990 and is to be restored to create a communally managed open space.

### **1.2 Project Specification**

Reclamation of Bold Moss Tip poses some of the most difficult problems that can be found in relation to colliery spoil and hydrology. On 28th February 1992 The Groundwork Trust commissioned the Department of Environmental & Geographical Studies, Manchester Polytechnic to supply:

1. A morphological map of the tip using a base map supplied by the client.
2. Information on the stratigraphy of the tip based on a series of boreholes.
3. Information on the physical properties of the tip based on surface and borehole samples.
4. Information on the chemical properties of the tip materials and of surface and ground waters.
5. Information on the hydrology of the site.
6. Recommendations for further work.

The work was needed as a matter of urgency and an initial reporting date of Friday 27th March was set.

The work project was co-ordinated by Mr M.G.Healy and Professor J.Gunn. Morphological mapping was undertaken by Mr L.Humblett and by Mr S.Boult (Manchester University) who also undertook the geochemical analyses.

## **2 MORPHOLOGY**

### **2.1 General Morphological Form.**

A morphological map showing the principal landforms on the site has been prepared (Figure 1) using a base map supplied by the client. The general morphology of the tip can be described as weakly dome-shaped, with steep to medium elevation slopes which describe its boundary. The distribution of the main morphological forms is random, with the exception of the two 'lagoons' or wash-ponds. The tip is widely traversed by vehicular trackways, which often serve as runoff rivulet paths for surface water. Excavated drainage ditches collect water/sediment flows and are a feature particularly of the northern perimeter of the site. Random depressions on the tip surface tend to temporarily retain water but most water runoff is achieved through an extensive network of channels/gullies of various, but often substantial, dimensions.

### **2.2 The Wash-Ponds.**

The most distinctive morphological forms on the tip are the 'lagoons' or wash-ponds. Of these one is significantly larger than the other. Both are contained within structural perimeter banks made of the surface waste material and are broadly rectangular in shape. The wash-pond beds are undulating and exhibit channelisation. In the larger pond isolated areas support a very patchy herbaceous vegetation. Within the smaller of the ponds the surface morphology is more variable than in the larger. Here the channels are excavated to a depth in excess of 40cm at some points. In the north-eastern section of this pond there is a distinct depression which retains water for extended periods to the level governed by an outflow drain. A range of vegetation is present here including grasses, sedges, shrubs and some trees.

### **2.3 The Northern Perimeter.**

The northern perimeter of the site is defined by a drainage ditch which is at an elevation lower than both the tip and the raised bog area immediately to the north. The ditch would appear to have been dredged on at least one occasion in the past. The tip slopes adjacent to this ditch are irregular and morphologically diverse in their detail. However, the general trend is however clearly south to north with a slight inclination to the west. The slopes along the perimeter are punctuated by weak channels/gullies, some of which contain limestone blocks of dimensions up to 20cm long axis. These are ephemeral features of anthropogenic origin. Other channels/gullies are the product of active surface-water runoff processes and the number and extent of these increases westward.

### **2.4 The Western Perimeter.**

The most heavily eroded area of the site is at the western end where the upper slope margins are mostly featureless and bare. Here, water runoff has caused channels/gullies in excess of 50cm to be cut into the convex slopes along the highest elevations. There is associated evidence for the movement of significant quantities of fine sediments through these routes onto the bog surface below (see stratigraphy of borehole 6, Section 3.2), leaving the coarser and thus less transportable materials residual on the tip surface in this area of the site. The majority of the slopes in this area are convex in nature and very susceptible to prevailing processes.

### **2.5 The South-Eastern and Eastern Perimeter.**

These areas are relatively stable morphologically, though relict channels/gullies can be easily detected even on the best vegetated slopes. During periods of high rainfall the reactivation of some of these features has been observed. The south-eastern area of the site serves as a drainage point for the larger of the wash-ponds. This process is characterised by a substantial channel superimposed on the surface through which both water and sediments are transported and subsequently redeposited at lower elevations.

## **2.6 Summary on Morphology.**

The tip site is morphologically diverse. The most active areas are those along the northern and western perimeter. The tip slopes exhibit the most variable morphological formations which respond to active processes of surface deformation. Broad areas of the tip are relatively homogenous. The likelihood and extent of any future dynamic changes on the latter surfaces are at this stage unknown. Within the wash-ponds the currently active processes relate primarily to drainage. The results of such activity are reflected in variable elevations and channelisation.

## **3 STRATIGRAPHY**

### **3.1 General Stratigraphy.**

The stratigraphy, or layering of materials, describes the nature of sediment accumulations at various points across the tip surface. Stratigraphy was proved at six points located within variable environments (Figure 1). Excavations were carried out using a manually operated boring rig. Materials retrieval was achieved using a variety of augur heads. Maximum effort was made to retrieve continuous cores representative of the materials accumulation as represented by discrete layers through time. Each core was logged, wrapped and returned to the laboratory for analysis. Samples used for subsequent testing were drawn primarily from the material yield of the boreholes described below. Where appropriate, piezometers were inserted in the borehole chambers to collect subsurface water samples. A total of four such piezometers were installed (Figure 1).

### **3.2 Borehole Stratigraphies.**

#### **Borehole 1.**

Borehole 1 is located on the northern perimeter of the site adjacent to the drainage ditch. The borehole is excavated in a layer of reddish-brown material which forms the ditch bed. Though the excavation penetrated to a depth of 170cm, the nature of the materials remained unchanged.

Materials:

000-170cm Consisting wholly of homogenous, stiff, red-brown silt-clay. Very occasional gravel-sized clasts were noted. Nodulised material was retrieved. This crumbled readily under finger pressure.

Borehole 2.

Borehole 2 is located in the north-eastern corner of the smaller of the two wash-ponds. Here, stratigraphy was proven to a depth of four metres. The materials were predominantly composed of silt and clay. At the base shards of mud/siltstone along with quartz-based pebbles were encountered.

Materials:

000-100cm Consisting of intermixed matrix of silt and clay with poor differentiation.

100-200cm Consisting of silty, sandy material, poorly sorted.

200-300cm Return to primarily a silt-clay. No differentiation was noted. Strong smell of sulphur.

300-400cm Poorly retrieved, difficult to penetrate. Resistance began at 270cm. Materials at this depth consisted of a grey-brown matrix dominated by clay-silt sized materials but containing shards of crushed siltstone.

A piezometer was inserted to a depth of 2.5 metres into the borehole chamber. No distinct water table was encountered.

Borehole 3.

Borehole 3 is located inside the larger wash-pond close to the perimeter. Stratigraphy was proved to a depth of 170cm.

Materials:

000-040cm Fine grained material, blackish colour. Discolouration to green-brown when oxidised.

040-060cm Distinct clay content.

060-090cm Almost pure clay material in this layer.

090-100cm Material more sandy, still primarily clay.

100-115cm 3 parts clay to 1 part sand.

115-150cm 3 parts clay to 1 part sand. Smell of sulphur.

150-160cm 2 parts clay, 1 part sand, 1 part shaly shards.

160-165cm 1 part silty clay, 3 parts gravel-size shards.

No further progress was possible through this material. A piezometer was inserted to a depth of 170cm.

#### Borehole 4.

Borehole 4 is located closer to the centre of the larger lagoon. Here stratigraphy was proved to a depth of 5 metres.

#### Materials:

000-100cm Contains thin interbeds of silty clay and sandy silt. The interbeds are discrete and exhibit clear boundaries. Material black/blue.

100-200cm Sediment laminated. Interbeds continue as above. Cleaves easily along contact boundaries.

200-300cm Major interbeds of sand and clay-silt layers easily discernable. Moisture appears to increase at 270cm.

300-400cm Interbeds of finer and coarser materials continue. These are sometimes fine, more often gross. Changes in material tend to be sharp.

400-500cm Material coarsening downward. Towards base a distinct increase in sandiness and occurrences of siltstone shards.

No further progress was possible after 500cm. A piezometer was installed to a depth of 4 metres.

#### Boreholes 5 and 5A.

Borehole 5 was excavated on the north-facing slope of the tip close to the position of Borehole 1. Having penetrated to a depth of 50cm at Borehole 5 a major obstruction was encountered. Borehole 5A was then excavated adjacent to Borehole 5 so that the full stratigraphy could be established.

#### Materials:

000-050cm Mixed deposit of shard-like material bound into a weak matrix of clay, silt and sandy components. A heavily cemented layer was encountered at 50cm.

050-070cm Material as above. No variations in component elements identifiable on a physical basis. At 70cm a layer of impenetrable material as described above was encountered. The stratigraphy as described appears homogenous to the point where it contacts the layer described for Borehole 1.

#### Borehole 6.

Borehole 6 was excavated at the slope base on the north-west of the site. The purpose of putting in this boring was to examine the extent of runoff materials deposited on the bog surface.

#### Materials:

000-040cm Sludge of silty clay mixed into standing water on bog surface. Some shards of siltstone and coal present. Product of runoff from channels/gullies.

040-100cm Clay overlying peat. Peat occurs at 60cm.

100-130cm Peat gives way to red-brown stiff clay as encountered at Borehole 1.

### **3.3 Comments on Stratigraphy.**

The stratigraphy as proved shows that the material which makes up the majority of the tip is a coarse material consisting primarily of shards of coal, siltstone, mudstone and shale. There is also a significant quantity of 'fill' or dumped material which is not part of the mine waste. Most of the coarse grained materials can be crushed relatively easily.

Within the wash-ponds the range of materials is considerably finer, consisting primarily of silt and clay with considerable quantities of sand sized material.

While an effort has been made here to describe the materials in as close an approximation as possible to naturally occurring sediments, it should be strongly emphasised that environments

such as that at Bold Colliery Tip are not inherently natural, though they are affected by surface processes in common with other environments which do occur naturally.

#### **4 MATERIALS PHYSICAL PROPERTIES**

##### **4.1 Physical Properties Examined.**

Three key physical properties have been examined:

Moisture Content

Particle Size Range Distribution

Sediment Plastic Limit

##### **4.2 Moisture Content.**

The moisture content of the tip sediments varies considerably across the site. There is particular contrast between the values found within and outside the wash-pond areas. This is reflected in Tables 1 and 2. It should be noted that the values presented here reflect 1) only selected points within the tip area and 2) figures for a brief period in time. As a result these values provide only an indication of the tip moisture balance. Comprehensive quantification will require a more detailed survey.

##### **4.3 Particle Size Range Distribution**

Particle size was examined for two cores taken from Boreholes 4 and 5/5A. All procedures employed were standardised according to the British Standard 1377 'Soils for Engineering Purposes'. The results of these analyses are presented in Table 3 for Borehole 4 and Table 4 for Borehole 5. Table 3 values reflect the material properties described in Section 2 (Stratigraphy). Sediments are concentrated towards the fine end of the spectrum, with particles of less than 0.5mm diameter representing the majority of the material in most cases. These figures indicate that, given sufficient moisture content in an unrestrained environment, there are considerable implications for the geotechnical stability of these sediments.



**Table 1. Record of Moisture Loss on heating to 105 Celcius :  
Borehole No 4**

<u>Metre 1</u>		<u>Metre 2</u>		<u>Metre 3</u>		<u>Metre 4</u>		<u>Metre 5</u>	
<u>Depth</u>	<u>%Loss</u>	<u>Depth</u>	<u>%Loss</u>	<u>Depth</u>	<u>%Loss</u>	<u>Depth</u>	<u>%Loss</u>	<u>Depth</u>	<u>%Loss</u>
<u>(cm)</u>		<u>(cm)</u>		<u>(cm)</u>		<u>(cm)</u>		<u>(cm)</u>	
00- 10	26	100-110	25	200-210	25	300-310	26	400-410	22
10- 20	25	110-120	25	210-220	21	310-320	26	410-420	20
20- 30	24	120-130	25	220-230	21	320-330	24	420-430	24
30- 40	27	130-140	25	230-240	21	330-340	26	430-440	25
40- 50	24	140-150	25	240-250	20	340-350	26	440-450	25
50- 60	21	150-160	25	250-260	23	350-360	24	450-460	25
60- 70	00	160-170	23	260-270	24	360-370	24	460-470	25
70- 80	24	170-180	23	270-280	25	370-380	20	470-480	24
80- 90	22	180-190	24	280-290	25	380-390	23	480-490	22
90- 99	22	190-200	22	290-300	26	390-400	22	490-500	23

**Table 2. Record of Moisture Loss on heating to 105 Celcius :  
Borehole No 5/5A**

<u>Depth</u>	<u>% Loss</u>
<u>(cm)</u>	
0- 10	11
10- 20	12
20- 30	9
30- 40	6
40- 50	9
50- 60	8
60- 70	10

**Table 3. Particle Size Range Distribution (mm):  
Borehole No 4**

<u>Depth</u> <u>(cm)</u>	<u>&gt;0.5</u>	<u>0.5-0.25</u>	<u>0.25-0.125</u>	<u>&lt;0.125</u>
020-030	36.20	24.00	15.21	22.09
040-050	28.28	27.29	17.64	23.90
070-080	33.64	26.80	17.52	19.20
090-100	33.84	27.21	16.98	19.21
120-130	21.96	30.98	19.29	24.86
140-150	31.72	24.19	17.33	26.47
160-170	33.50	27.56	19.96	18.00
190-200	39.80	26.60	12.86	19.60
220-230	47.36	28.16	15.32	08.00
230-240	58.45	27.90	08.73	05.25
240-250	66.64	21.00	06.56	05.00
280-290	46.40	20.46	12.81	18.16
290-300	52.72	17.27	12.88	16.60
310-320	58.53	17.34	09.68	13.96
350-360	70.24	10.28	08.96	10.96
390-400	34.80	26.11	23.05	13.84
420-430	51.23	16.61	13.26	16.73
440-450	45.92	17.80	14.80	16.68
460-470	47.17	20.55	11.79	18.12
480-490	32.46	34.00	22.22	09.04

**Table 4. Particle Size Range Distribution (mm):  
Borehole 5/5A**

<u>Depth</u> <u>(cms)</u>	<u>&gt; 0.5</u>	<u>0.5-0.25</u>	<u>0.25-0.125</u>	<u>&lt;0.125</u>
20-25	88.00	07.98	4.30	1.18
35-45	82.14	10.15	6.34	2.09
45-50	84.00	09.07	4.70	3.93
50-55	80.67	12.39	3.96	3.81
55-60	83.73	10.55	3.47	1.80
60-65	81.22	09.51	6.84	3.51

#### Comment on Particle Size Range Distribution.

The size of a sedimentary grain is a function of many factors, for example its mineralogy, its structure and its history of weathering. These factors combine to produce particles of different sizes. The particles are then sorted according to their size by processes of transportation and deposition. Their ultimate distribution in the environment is related to their size and the processes and conditions prevailing at individual sites. Any controls on these parameters such as the human impacts evident at Bold Colliery will serve to influence the particle distribution pattern. This will in turn have implications for the subsequent behaviour of materials, including an influence on their inherent stability patterns.

The figures presented in Tables 3 and 4 are based on samples of standard size (100g). The % values provided represent 100% of each sample, less any material lost in the physical sieving process.

Samples were not chemically pre-treated prior to analysis. It was considered important to examine physical properties as they exist in the field environment as far as possible. Physical crushing of the sediments was carried out on a limited basis to assist particle distribution. No effort was made to break down shard-type material (mainly siltstone and mudstone ) though this would have been easily achieved. The results presented in the tables represent as close an approximation as possible to the distribution of materials as encountered at the tip site.

#### **4.4 Sediment Plastic Limits.**

The plastic limit of a sediment is a measure of the minimum quantity of moisture required so that the sediment will achieve plastic properties of deformation. When a sediment has achieved such a set of properties it is capable of deformation in response to pressure. Such pressure may result from various sources, but in the context of this report is most likely to occur as a result of landuse change which may involve surface loading. On reaching its plastic limit sediment is capable of pressure flowage in the absence of any restraining mechanism. The addition of moisture in excess of the plastic limit can lead to the material reaching its liquid limit, at which point properties of fluid motion may be achieved. Liquid limit evaluations were not considered within the brief of this report.

**Table 5. Materials Plastic Limits:  
Borehole No 3**

<u>Depth</u> (cms)	<u>Plastic Limit</u> % Water	<u>Description</u>
000-010	-----	Granular. Non- Cohesive. Non-plastic.
015-025	19.78	Cohesive. Very high plasticity
025-030	21.92	Cohesive. Very high plasticity
030-040	-----	Granular. Non- Cohesive. Non-plastic.
040-050	-----	
050-060	-----	Granular. Low plasticity.
060-075	20.24	Cohesive. Very high plasticity.
075-082	27.33	Cohesive. Medium plasticity.
082-090	23.31	Cohesive. High plasticity.
090-100	-----	Granular. Non- Cohesive.
100-115	26.76	Cohesive. Medium plasticity.
115-130	-----	Weak plasticity.
130-140	26.50	Cohesive. Medium plasticity.
140-150	22.05	Cohesive. High plasticity.
150-160	15.29	Cohesive. Very high plasticity.
160-165	15.45	Cohesive. Very high plasticity.
165-175	15.64	Cohesive. Very high plasticity.

Comment on Sediment Plasticity.

Those sediments which achieve plastic properties at the lowest moisture thresholds are those with highest plasticity.

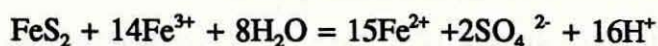
**4.5 Conclusion on Physical Properties.**

A wide range of physical properties are exhibited by the sediments of Bold Colliery Waste Tip. While the results presented here provide an initial survey, they do not provide any comprehensive evaluation of the site materials. There are strong indications of potential implications for material stability with the advent of changes in landuse patterns, particularly if this requires morphological changes to the tip surface or additional pressure loading from any source. A full assessment of these problems will require additional work as outlined in the recommendations included in this report.

## 5. CHEMICAL PROPERTIES OF THE TIP MATERIALS

### 5.1 Introduction

Mining is a process of extraction and disaggregation. Consequently, in the case of coal mining, materials formed under anoxic reducing conditions are both brought into an oxic environment and greatly increased in surface area. The waste from such mining operations will therefore be to some degree "active", that is thermodynamically unstable. The chemical driving force behind this instability is iron pyrites,  $\text{FeS}_2$ , a mineral formed under anoxic conditions. Oxidation of iron pyrites results in a free energy change only slightly less than that for coal combustion and in the production of large amounts of sulphuric acid:



The above reaction, one of a possible series, is that responsible for most rapid acid production. It is dominant at low pH and is catalysed by aerobic chemoautotrophic bacteria. The large amount of acid produced is responsible for lowering pH to levels that may :

- 1) cause nutrient depletion by loss of cation exchange capacity.
- 2) be directly phyto-toxic.
- 3) cause rapid weathering and allow weathering products to be in such high concentrations in solution as to be toxic, or allow weathering of toxic materials.

In the case of Bold Colliery each of the above will be of direct concern in the context of on-site establishment of vegetation, but off-site implications such as contamination of surface and groundwater must also be considered.

### 5.2 Factors controlling the acidity of the waste.

The activity of the waste and its potential for toxicity will be controlled by:

- 1) The amount of pyrite. This is a very time consuming analysis if done accurately.
- 2) The surface area. This is usually assessed from grain size.
- 3) Availability of water which is a reactant, a reaction medium and a product transport solvent. An assessment of available water can be made from the porosity and permeability of the waste.
- 4) Availability of oxygen which is a reactant and is essential for biotic catalysis. An

assessment of oxygen availability can be made from the porosity and permeability of the waste.

- 5) Amount of carbonate minerals present. These minerals control the buffering capacity of surrounding material.
- 6) Presence of toxic metals or those liable to be at toxic concentration at low pH.

Prediction of the acid generation and metal mobilization potential of mine waste has been the subject of a large number of studies which have been reviewed by Salomons and Forstner (1988). The models that have been developed require the input of substantial amounts of high quality data concerning at least the six principal controls outlined above. As the present survey deals with a very small sample size and it was not possible to assess each control it can be regarded as no more than a guide for further work and an indicator of potential problems.

### **5.3 Surface and groundwater sampling and analysis**

Surface waters were sampled at 10 sites, W1-W10 (see figure 1), as follows:

- W1 - bog surface
- W2 - brook water
- W3 - small pond
- W4 - small pond
- W5 - rivulet draining boggy area
- W6 - drainage rivulet
- W7 - stream
- W8 - stream
- W9 - drainage rivulet
- W10 - standing water in lagoon.

Groundwater samples were taken from two of the boreholes, BH1 and BH5 (Figure 1).

The samples were filtered through a 0.45 micron filter and those to be analysed for metals were acidified on site. The suspended solids were not analysed. Analysis for cations and total sulphur was by inductively coupled plasma (ICP) spectroscopy. Analysis for sulphate was by ion chromatography (IC). Conductivity and pH were recorded at certain sites using a Ciba-Corning portable meter.

#### 5.4 Waste material sampling and analysis

Six boreholes were excavated into the waste materials (figure 1) and samples were taken from four of them at various depths as follows:

BH1: 0-10 cm

BH4: 3- 6 cm, 150-155 cm, 300-305 cm, 430-435 cm, 495-500 cm

BH5: 10-20 cm, 25- 35 cm, 70- 75 cm

BH6: 0- 5 cm

The samples were dried at 105 degrees Celcius and the following analyses were undertaken:

- 1) Organic carbon - by loss on ignition at 425 degrees C.
- 2) Carbonate - by loss on reaction with 2M HCl (Briggs 1980).
- 3) Available anions and cations (i.e. those dissolved in soil water) - by washing 1g material with 50g distilled water, filtering through a 0.45 micron filter, and analysing by IC and ICP.
- 4) Exchangeable anions and cations (i.e. those held on the surfaces of colloidal particles) - by kjeldahl digestion in 2.5% acetic acid for 1 hour, filtration and ICP analysis.
- 5) Weatherable anions and cations - by kjeldahl digestion in concentrated nitric acid for three hours, filtration and ICP analysis.

The three extractions water, acetic, nitric were not sequential but were done on separate sample material. The analyses are presented as ELEMENTAL MICROGRAMS per GRAM OF SPOIL.

Short cores (as deep as it was possible to penetrate without boring) were also taken at 7 sites (figure 1):

C1 - grassed

C2 - moss covered

C3 - bare

C4 - shrubs and grass

C5 - shrubs and grass

C6 - bare lagoon

C7 - thin grass

The bulk density, specific gravity and porosity of the cores, either as a whole or in sections, were determined (Briggs 1980) as was their pH (2g material : 50ml 0.01M CaCl<sub>2</sub>).

### **5.5 Acidity of the waste materials**

The pH of the waste materials is variable (Table 6). Several samples were below pH 4 suggesting that there is very little buffering capacity but others were above 5.5. This is indicative of heterogeneity in waste material composition. The only sample with a pH ideal for cultivation is the top few cm of C1 which consists of dumped topsoil from off the site. Acidity would be expected to decrease with depth as pyrite oxidation should decrease away from the surface. This is not apparent at C1 because of the exotic soil at the surface but may be the case at C7 giving an indication of the depth of the oxidation front.

### **5.6 Acidity of the surface waters**

The surface water pH's (Table 7) are all relatively high bearing in mind the low pH within the waste material. Conductivities are high to very high. This implies that runoff does not enter the active regions of acid production, an inference which is supported by field observations of overland flow and gulying. However, neutralised soluble sulphates, produced by pyrite oxidation at the surface and subsequently neutralised by carbonates, are washed from the surface spoil. The water analyses confirm the presence of high concentrations of sulphate, calcium and magnesium ions.

### **5.7 Chemistry of the waste materials**

There are various inconsistencies in the results presented here due to the one-off nature of the analyses which did not allow assessment of ideal dilutions to match up with the ICP's detection limits. At the dilution used the ICP is at its detection limits but the IC is not. This is the reason why total sulphur in the distilled water fraction may have an apparent concentration less than that of sulphate sulphur. Also, the limited number of samples meant replicates could not be run to give an assessment of within sample variation which may have been high causing other inconsistencies. This may partly explain the significant levels of arsenic in the water washed samples compared to the zero levels in some corresponding acid digests. However, a large amount of precipitate was observed in some digests, possibly due to the extremely high coal content, and this may have prevented some metals being in solution.



**Table 6. pH and physical characteristics of cores**

SITE	LENGTH	pH	LENGTH	BULK DENS	SPC GRAV	POROSITY
	cm		cm	g cm <sup>-3</sup>	g cm <sup>-3</sup>	%
C1	6	6.5	6	1.34	2.03	44
	8	6	18	1.83	2.34	22
	10	4.3				
C2	12	4.42	12	1.51	2.19	31
C3			15	1.41	1.76	20
			10	1.41	3.07	55
			13	1.24	2.94	58
C4	21	3.75	5	1.94	3.05	36
			16	1.39	2.84	51
C5	10	5.53	24	1.37	2.65	48
	14	5.22				
C6	10	3.4	23	1.1	1.89	42
	13	3.77				
C7	9	4.9	9	1.18	2.75	67

**Table 7. Chemistry of Surface Waters**

SITE	pH	COND mS	Fe	S total	S SO4	Ca	Mg
W1	7.11	4.03					
W2	7.44	2.83	0.49	680.29	599.40	315.14	135.16
W3	5.35	1.11					
W4	5.46	7.98					
W5	5.80	1.94	0.30	354.86	349.65	234.17	106.66
W6	7.08	1.25					
W7	6.50	1.85					
W8	6.60	1.85	0.39	202.93	206.46	109.78	86.72
W9			1.08	374.76	356.31	197.94	97.43
W10			3.46	35.31	79.92	33.48	12.91
SITE	As	Pb	Cd	Mn	Cu	Zn	Al
W1							
W2	0.00	0.12	0.14	0.19	0.13	0.00	0.00
W3							
W4							
W5	0.00	0.20	0.29	0.29	0.00	0.00	0.00
W6							
W7							
W8	0.00	0.00	0.35	0.25	0.00	0.00	0.00
W9	0.57	0.51	0.27	4.05	0.18	0.81	3.90
W10	0.45	0.62	0.33	1.06	0.19	0.43	3.13

**Table 8. Pyrite and carbonate contents of tip materials**

SAMPLE	%FeS <sub>2</sub>	CO <sub>3</sub>	% C
BH4	1.37	5.26	57.50
BH4	3.91	4.40	49.00
BH4	2.62	5.03	65.00
BH4	0.47	4.78	43.00
BH4	2.56	5.22	49.50
BH5	1.27	2.50	21.50
BH5	0.46	2.90	36.00
BH5		3.92	8.30
BH1		6.39	1.65
BH6		4.04	30.00

The levels of organic carbon (Table 8) are very high in the samples taken from the lagoon borehole. This is due to the large amount of waste coal rather than to humus or fresh plant material. In borehole 5 outside the lagoon, levels are lower but, on inspection, appear again be due to fossil organic material. Borehole 4, in the reddish clay layer at the tip base, has a low organic content. The actual figure may well be less than 1.65% as some of this may constitute water lost from the clay matrix. As expected, borehole 6 which was excavated into the bog surface contains a significant amount of fresh plant material although fine coal particles have also been washed in.

The pyrite concentrations in Table 8 have been calculated on the basis of the following assumptions:

- 1) Sulphur is only present in the spoil either as sulphate or as iron sulphide.

- 2) All sulphate is soluble and therefore removed by washing with distilled water.
- 3) Sulphide is completely converted to sulphate by nitric acid digestion, so becoming soluble and detectable by ICP.

No pyrite concentrations are shown for the final three digested samples in Table 3 as they kept blocking the ICP despite centrifugation and filtration and hence could not be analysed.

From the few samples taken it is apparent that pyrite is present in significant quantities (c. 0.5 - 3.9 %; Table 8). The levels in the lagoon materials (Borehole 4) would be expected to be higher than at other places because the pyrite is associated predominantly with coal. Within the lagoon there seems to be a decrease in pyrite at the surface, probably due to oxidation, but there also seems to be a pyrite poor horizon below the surface; heterogeneity of the spoil is again implied. Carbonate levels are sufficiently high to presumably counteract some of the acidity in the lagoon spoil. In borehole 5, which is perhaps more representative of the whole tip than is borehole 4, the pyrite levels are lower but so also are the levels of buffering carbonate.

These results are similar to those quoted for a Bold colliery spoil by Bradshaw (1980): pyrite 3.71%, carbonate 2.73%. The quoted pH of the sample was 5.9, this being attributed to the buffering effect of the carbonate. Bradshaw (1980) also demonstrated that the acid generation potential over 50 days was only as great as that of a spoil containing 0.8% pyrite and very little carbonate.

The Department of the Environment has designated trigger values for the concentrations of certain metals in materials underlying parks, playing fields and open space, at which investigation should be undertaken. For As, Cd and Pb the values are 40, 15, and 2000ppm. In the Netherlands the values are lower: 30, 5 and 150ppm respectively. The nitric acid digested samples of Bold waste (Tables 9,10,11 & 12) are the results that should be compared to these standards. However, the problems with the technique which are discussed above mean that anomalous zero or low values were obtained from some samples. Comparison, can be made instead with either of the other extractions bearing in mind that the **total** levels (given by successful acid digest) would almost certainly be higher. This being the case, it is clear

that the levels of toxic metals in these few samples are high enough to at least warrant further investigation. Although the total toxic metal content of the tip materials may prove to be near to or within at least the DoE trigger values, the concentrations in borehole (Table 9,12) and surface (Table 7) waters exceed their corresponding standards. For example, in the Netherlands concentrations of 0.03, 0.0025 and 0.005 ppm of As, Cd and Pb respectively would be cause for investigation of groundwater. The UK Environmental Quality Standards for freshwaters are 0.05 0.005 and 0.004-0.02 (according to water hardness) ppm of As, Cd and Pb. It should be noted that the detection limits of the ICP for As, Cd and Pb are about 0.2ppm. In most samples exchangeable and available levels of Al and Mn are sufficient to be phytotoxic (Tables 9,10,11), their high levels being possible because of the low pH.

**Table 9. Chemical analysis of materials from Borehole 4**

DATE	DEPTH cm	Extract.	Fe	S total	S SO4	Ca	Mg	% CaCO3 HCl 2M	% C ignition
10-Mar	3	WATER	10.26	0.00	333.00	58.02	0.00	5.26	57.5
10-Mar	150	WATER	0.00	0.00	499.50	282.48	308.13	4.4	49
10-Mar	300	WATER	4.88	0.00	333.00	196.77	32.55	5.03	65
10-Mar	430	WATER	0.00	0.00	166.50	41.53	0.00	4.78	43
10-Mar	500	WATER	14.64	0.00	166.50	107.59	0.00	5.22	49.5
10-Mar	3	ACETIC	184.57	0.00		62.36	20.35		
10-Mar	3	NITRIC	2336.78	3993.42		334.37	150.42		
10-Mar	150	NITRIC	8189.05	10915.36		2409.96	1661.02		
10-Mar	300	NITRIC	7120.43	7308.55		4027.65	854.26		
10-Mar	430	NITRIC	2833.33	1419.62		685.20	420.67		
10-Mar	500	NITRIC	8629.69	6983.11		4944.02	1283.76		
13-Mar	WATER		25.04	610.15	666.67	164.74	226.48		

DATE	DEPTH cm	Extract.	As	Pb	Cd	Mn	Cu	Zn	Al
10-Mar	3	WATER	0.00	0.00	7.49	0.00	0.00	0.00	0.00
10-Mar	150	WATER	22.65	0.00	0.00	0.98	0.00	0.00	5.87
10-Mar	300	WATER	21.02	0.00	0.00	0.00	0.00	0.00	18.48
10-Mar	430	WATER	17.05	0.00	0.00	0.00	0.00	0.00	13.97
10-Mar	500	WATER	44.32	33.63	20.97	0.00	0.00	0.00	45.51
10-Mar	3	ACETIC	2.95	4.45	0.36	2.24	0.62	2.30	19.74
10-Mar	3	NITRIC	0.00	0.00	0.00	8.29	50.92	19.10	748.00
10-Mar	150	NITRIC	0.00	0.00	3.90	98.85	101.83	36.76	2606.32
10-Mar	300	NITRIC	0.00	114.76	5.37	81.03	58.20	31.41	1668.10
10-Mar	430	NITRIC	0.00	51.86	0.00	41.02	53.84	22.54	524.28
10-Mar	500	NITRIC	0.00	85.73	0.00	134.44	65.99	35.22	3469.53
13-Mar	WATER		3.62	2.48	0.17	6.30	0.00	1.31	0.00

(continuation of Table 9 from page 22)

**Table 10. Chemical analysis of materials from Borehole 5**

DATE	DEPTH cm	Extract.	Fe	S total	S SO4	Ca	Mg	CaCO3	% C
								HCl 2M	ignition
10-Mar	7	WATER	4.88	0.00	166.65	112.31	0.00	2.5	21.5
10-Mar	35	WATER	19.27	2004.43	3829.50	3982.19	74.20	2.59	36
10-Mar	70	WATER	0.00	0.00	1000.00	1010.39	69.38	3.92	8.3
10-Mar	7	ACETIC	133.87	0.00		144.27	56.01		
10-Mar	35	ACETIC	527.28	2970.71		1489.99	177.23		
10-Mar	70	ACETIC	0.00	884.44		975.28	296.26		
10-Mar	7	NITRIC	24058.42	3543.98		422.04	2067.99		
10-Mar	35	NITRIC	13283.87	5064.87		2795.20	453.47		
DATE	DEPTH cm	Extract.	As	Pb	Cd	Mn	Cu	Zn	Al
10-Mar	7	WATER	29.55	39.38	0.00	1.44	0.00	0.00	0.00
10-Mar	35	WATER	21.38	0.00	0.00	8.64	6.54	15.20	11.85
10-Mar	70	WATER	17.82	19.77	0.00	0.00	0.00	0.00	0.00
10-Mar	7	ACETIC	7.35	2.03	6.68	14.46	2.41	7.93	12.29
10-Mar	35	ACETIC	0.00	0.00	2.27	9.90	1.85	8.54	236.75
10-Mar	70	ACETIC	17.26	8.67	2.52	0.00	0.69	0.00	0.00
10-Mar	7	NITRIC	0.00	145.44	0.00	112.79	58.86	32.65	5070.60
10-Mar	35	NITRIC	116.60	123.43	0.00	23.99	40.41	21.00	2223.19

**Table 11. Chemical analysis of materials from Borehole 1**

DATE	DEPTH cm	Extract.	Fe	S total	S SO4	Ca	Mg	CaCO3 HCl 2M	% C ignition
10-Mar	5	WATER	91.52	0.00	100.00	233.35	95.88	6.39	1.65
10-Mar	5	ACETIC	0.00	0.00		1229.81	78.82		
DATE	DEPTH cm	Extract.	As	Pb	Cd	Mn	Cu	Zn	Al
10-Mar	5	WATER	0.00	16.70	8.39	0.96	0.00	0.00	112.62
10-Mar	5	ACETIC	13.36	15.68	8.52	0.00	0.00	0.00	0.00

**Table 12. Chemical analysis of material & water from Borehole 6**

DATE	DEPTH cm	Extract.	Fe	S total	S SO4	Ca	Mg	CaCO3	% C
10-Mar	5	WATER	9.63	0.00	300.00	193.91	57.81	4.04	30
10-Mar	5	ACETIC	525.36	458.08		1025.49	686.99		
13-Mar	WATER		1.98	473.21	466.00	230.85	129.03		
DATE	DEPTH cm	Extract.	As	Pb	Cd	Mn	Cu	Zn	Al
10-Mar	5	WATER	18.26	0.00	0.00	0.48	0.00	0.00	0.00
10-Mar	5	ACETIC	0.00	0.00	40.49	155.79	1.41	10.46	16.95
13-Mar	WATER		8.54	1.82	0.15	1.30	0.00	0.27	0.00



## **6. HYDROLOGY OF THE TIP**

### **6.1 Surface drainage**

There is abundant evidence of channeled (rill and gully) and unchanneled (sheet) overland flow across much of the tip site. Rills and gulleys are particularly well developed on the western and north-western margins. This flow is a consequence of the low infiltration capacity of the surface materials which is itself partly a result of compaction by vehicles and partly a function of the physical characteristics of the materials. In addition to these 'natural' ephemeral drains there is also a complex network of man-made drainage channels on the northern slopes of the site. The origins of these channels, some of which clearly conduct water on a regular basis is unknown but should be the subject of further study. Most of the channels are partially filled with limestone blocks presumably to reduce acidity.

The main surface drain for the site is a channel which has its origin at the lagoon outlet and runs along the eastern and northern margins. On 21st March flow was estimated to be c. 35 litres/second. The northern section of the channel may once have been natural but it has subsequently been straightened and dredged. The southern and western slopes of the site drain directly into the moss.

### **6.2 Groundwater**

The limited time period of the study precluded the placement of sufficient boreholes to obtain a clear picture of groundwater movement on the site. In addition the piezometers installed should have been levelled and tied to O.D. Nevertheless, observation of water levels in the six piezometers two weeks after their emplacement has provided some information:

**Borehole 1:** Into dredged channel. Water at the same level as surface stream.

**Possible leakage?**

**Borehole 5:** Although only a few metres from 1 this was dry.

**Borehole 2:** Small lagoon. Water c. 120 cm below ground surface.

Borehole 3: Large lagoon. Water c. 90 cm below ground surface.

Borehole 4: Large lagoon. Water c. 270 cm below ground surface.

Borehole 6 : Bog. Water close to ground surface.

These results suggest that there is no integrated water body in the tip materials which is not surprising as the physical analyses suggest that they are of very low permeability. This is particularly the case in the two lagoons which would function as lakes had the artificial drains not been dug.

## **7. OVERVIEW AND FURTHER WORK**

### **7.1 Morphology.**

The geomorphological map provided (Figure 1) represents the major morphological forms present on Bold Colliery Waste Tip. Should any work be envisaged to particular localised areas of the tip which are likely to be affected by the underlying morphology, it is advisable to commission geomorphological mapping of that area at a scale which is suitable for the representation of more subtle surface forms.

### **7.2 Stratigraphy.**

The stratigraphy reported here represents findings based on a very limited number of boreholes. While every effort was made to ensure that the most diverse areas on and around the waste tip were examined, limitations imposed by time dictated that this preliminary survey can be used only as a general approximation of the stratigraphy from selected areas of the site. It is recommended that a much more detailed analysis of the overall stratigraphic accumulation be undertaken. This is a recommendation firmly based on the findings reported here. Further, in order to fulfil the recommendations for the analysis of physical properties, a detailed programme of sediment sampling should be linked to stratigraphic work.

### **7.3 Physical Properties.**

The analyses of physical properties presented in this report indicate that the physical structure and distribution of the waste materials may have implications for any development work which may be carried out on the tip site. These implications relate in particular to the strength and stability of the sediments. It is strongly recommended that further testing of materials strength be carried out, in particular tests of materials liquid limit. To do this further particle size distribution analysis will be necessary. It is recommended that the test be carried out in close association with any stratigraphic work envisaged.

### **7.4 Chemical properties of water and materials**

This initial survey has revealed the need for a thorough investigation of the material leaving the site in ground and surface waters. The site may already be an active exporter of toxic metals which should be of concern to the National Rivers Authority. If any landscaping and/or earthworks are undertaken then mobilisation is likely to be increased physically by exposure of more porous and/or toxic metal enriched layers and chemically by enhanced pyrite oxidation and acid production.

Having ascertained that pyrite oxidation and its subsequent effects are occurring to a significant degree on the site further work should now be done along two lines:

- 1) An attempt should be made to assess the oxidation depth across the site by pH measurement and sulphate / sulphide analysis.
- 2) An attempt should be made to assess the acid generation potential of the spoil within the oxidation depth by pyrite and carbonate chemical analyses and by particle size analysis; by long term oxidation experiments and by searching of the relevant literature. Lime addition and plant growth experiments are a more pragmatic approach that may in the end prove to be cost-effective. Bradshaw & Chadwick (1980) quotes the response to liming of Bold Colliery spoil as 1.16 (shoot dry weight produced at a liming rate of 20 tonnes per hectare divided by that produced at 5 tonnes).

## 7.5 Hydrology

Our initial survey suggests that surface water runoff is quantitatively much more important than groundwater; that the majority of the site drains to a single channel and that the remainder provides more diffuse flow to the bog. However, the limited timescale of the present investigation precluded any analysis of the temporal variability of surface and groundwaters. It is recommended that a measuring weir be installed at the catchment outlet and that regular measurements be made of the depth of water here and in the piezometers installed as part of this investigation. It may also be useful to undertake a set of infiltrometer measurements to confirm the suggestion that infiltration capacity is low.

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