COLLIERY SPOIL RECLAMATION: AN APPRAISAL OF TWO SITES IN WEST LOTHIAN

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THESIS SUBMITTED FOR THE DEGREE OF MASTER OF SCIENCE
NOVEMBER 1992

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ACKNOWLEDGEMENTS

I should like to thank by supervisors, Drs Ian Pulford and Gordon Dickinson for their help and encouragement during the research for and writing of this thesis.

My thanks also to Mr Alan Couper, of the Lothian Reclamation Unit, for providing the background information on the reclamation of the study sites.

This work is dedicated to my parents.

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SUMMARY

The work of this thesis is concerned with the effectiveness of the reclamation of two former colliery sites in West Lothian. Criteria for assessment were, the ability of the reclamation schemes to control pollution arising from the spoil material and the success of the spoil as a growth medium. The reclamation site at Foulshiels, on the periphery of the village of Stoneyburn, was also assessed with respect to the social benefits of the reclamation project, particularly in relation to visual benefit and amenity use.

The environmental, social and economic importance of derelict and contaminated land are discussed in Chapter One. The problems of defining contaminated land are reviewed. Derelict and contaminated land arising from coal mining activities is discussed in relation to its particular physical and chemical characteristics. These characteristics can influence the potential of spoil as both a resource or a waste material.

Possible solutions to the potential problems of colliery spoil are addressed in Chapter Two. Types of contaminated land treatment include physical, chemical and biological methods. Selection criteria for the different types of treatment are dependent on the concentrations of contaminants present, the proposed end use for the site and associated reclamation costs. Chapter Two concludes that, for colliery spoil heaps in rural areas, the most frequently chosen option for reclamation is to soft end use, where the site may provide amenity or recreational benefit in the area.

Case study site histories are presented in Chapter Three. Foulshiels Colliery was reclaimed during the

period 1972-1979. The proximity of the site to the village places emphasis on amenity value for the local community and this aspect was amongst the criteria taken into consideration in the reclamation design. Baads colliery, in comparison, is surrounded by farm land. The site was reclaimed in the mid 1970's. Spoil material at the site is high in iron pyrite (0.7-1.48% FeS_2) which, on weathering, is responsible for acid production and acid mine discharge associated with spoil material.

Assessment of the success of the spoil as a growth medium and pollution control were determined by laboratory and field studies. Chapters Four and Five review the suitability of the spoil as a growth medium with respect to pH and plant available copper, zinc, iron, manganese, calcium and magnesium. Comparison of analytical results with those obtained in 1976 indicate that ionic concentrations have declined with weathering and leaching, although the relationship between ionic concentrations and spoil pH has remained similar to those recorded during 1976.

Analysis of water collected from Foulshiels Burn is also discussed in Chapter Four. The effect of reclamation on stream water quality was determined analytically by comparison of soluble aluminium, iron, manganese, lead, nickel, copper, zinc, cadmium and chromium content and pH with values obtained by previous workers prior to, and directly after reclamation. Although the stream is still contaminated by the site, results indicate that pollution has declined in association with improved site drainage.

During the reclamation project a study was established to determine the effectiveness of different organic amendments on colliery spoil amelioration. Chicken manure, sewage sludge and Alginure, a commercial seaweed based amendment, were applied at different rates with varying applications of lime. The effectiveness of these treatments in ameliorating the problems associated with spoil as a growth medium are discussed in Chapter Five. Analysis of spoil from different trial plots shows that lime at the application rate at least of 50 t ha^{-1} is required for longterm counter-action of acidity, while organic amendments require regular application to be effective spoil conditioners.

The social benefits of the reclamation at Foulshiels are considered in Chapter Six. A survey conducted in Stoneyburn indicated site user patterns and opinions to the suitability of the reclamation project. The site is regularly used by a cross section of the community for a variety of informal activities from walking to motorbike scrambling.

Recommendations for the reclamation of former colliery sites to soft end uses and their subsequent management based on the findings of this work are given in Chapter Seven. Reclamation of colliery sites provide a valuable opportunity for wildlife habitat, natural history education, and informal recreation, while addressing the problems of environmental degradation arising from past mining activities.

CHAPTER ONE

1.0 Contaminated land: environmental, social and economic importance

1.1 Introduction

Since the industrial revolution Britain has witnessed widespread increase in the use of land for industrial processes. Such processes have included mining and quarrying of natural resources to a value product. Industrial activity, particularly when associated with the extraction of natural materials, usually has an impact on the landscape, with the result that such activities have often equated with squalor and degradation giving rise to the term 'derelict land'.

Almost invariably associated with raw material processing is the generation of waste products, in gaseous, liquid and solid form, which can give rise to contamination of air, water and land, and can lead to increasing areas of poor quality land. These substances, which may have detrimental effects on both living organisms and abiotic materials are the characteristic that distinguishes contaminated land from other forms of derelict or disused land. Clearly not all derelict land is contaminated and not all contaminated land derelict. Nevertheless, the two categories of land have similar origins in Britain's industrial past, and there is a common objective to overcome the poor environmental conditions associated with historical use, and return the land to its original status and beneficial use.

Although much of the hard core derelict and contaminated land can be attributed to the recent past, it is unrealistic to suppose that earlier forms of land misuse are entirely to blame. Fortunately there is growing awareness of the possibilities offered by schemes of land reclamation, not only from the point of direct financial returns, but increasingly in relation to the wider social and economic benefits which they can produce.

1.2 Defining contaminated land

A typically general description of the circumstances under which contaminated land may arise and the implications which exist in relation to redevelopment is given in the Interdepartmental Committee for the Redevelopment of Contaminated land (ICRCL), Guidance on the Assessment and Redevelopment of Contaminated Land (ICRCL 59/83), 1987 (page 3):

'The use of land for industrial purposes or for waste disposal may result in contamination of the soil. There are many possible sources of contamination: leakages and spillages form pipes and tanks; deposition of airborne particles; storage and disposal of raw materials, unwanted waste residues, and the application of sewage sludge to land.'

'The presence of some contaminants may pose immediate or long-term hazards to human health, plants, to amenity, to construction operations, or to any buildings and services. These hazards may be serious enough to limit or preclude development of the land.'

The lack of past incentives for industry to reduce or recycle process waste, combined with economic and industrial trends, has resulted in an inherited legacy of contaminated land found typically, but not exclusively, in urban or industrial areas. A recently completed international study on contaminated land adopted the following definition:

'Land that contains substances that, when present in sufficient quantities or concentrations are likely to cause harm, directly or indirectly, to man, the environment or on occasions other targets.'
(Smith 1985 page 1)

The British Standards Institution (BSI) draft Code of Practice (1988) on the identification and investigation of contaminated land uses a similar definition:

'Land that contains any substance that when present in sufficient concentration or amount presents a hazard. The hazard may

a) be associated with the present status of the land
b) limit the future use of the land
c) require the land to be specially treated before particular use.'

The Department of the Environment (DoE) (1991) in a new operational definition of contaminated land proposed:

'i) Land which because of its former uses now contains substances that give rise to the principal hazards likely to affect the proposed development, and which

ii) requires an assessment to decide whether the chosen development may proceed safely or whether it requires some form of remedial action, which may include changing the layout or the form of the development.'

These various but apparently similar definitions have had repercussions for the estimation of the scale of the problem of contaminated land. The exact format of each definition also provides some insight into how various authorities have regarded the subject.

In 1966 the government introduced the Derelict Land Grant, now administered in Scotland by Scottish Enterprise, formerly the Scottish Development Agency (SDA). Its purpose has been to promote the rehabilitation of derelict areas by public and private institutions. Criteria for selection, implementation and subsidising of the selected projects are fixed by Scottish Enterprise.

The amount of funding available varies according to zones:-

* 100% in established promotion zones (80% for private investors)

* 75% in national parks and natural reserves

* 50% in other areas

The Derelict Land Grant includes amongst other costs:

* the acquisition of land

* necessary costs of rehabilitating to convert an area into a green field situation

* limited funding for maintenance during the five year period following reclamation

New powers to enforce contaminated land clean-up have been introduced under the Environmental Protection Act 1990. The Water Act 1989 (enforced in Scotland under Part III of the Control of Pollution Act 1974) grants similar powers to the River Purification Boards to prevent the risk of pollution to controlled waters. This legislation has resulted in major changes in how contaminated land is perceived. Contamination had previously been an issue from the viewpoint of a site's end use. It is now seen in terms of the risk it poses to the environment as a whole. Therefore, not only are owners of contaminated sites now more likely to be required to treat them, but the standards of treatment imposed will be more stringent than in the past.

1.3 The coal industry and land contamination

Coal may be extracted from the earth by two methods, namely, surface (opencast) mining or deep mining. Surface coal mining was introduced by Britain during the Second World War when it provided a quick and relatively easy means of providing an energy source. With continued developments in mining technology combined with changes in mining economics, surface mining has become increasingly favoured as the method of extraction for coal deposits with an overburden:seam thickness ratio of up to 30:1 (U.S. Department of the Interior 1967).

The environmental impact of surface mining may be more drastic initially with, for example, the removal of vegetation, piling of topsoil and disturbance of the water table. However, most developed countries which use this method of extraction ensure that reclamation provision is an integral part of the mining process, with the result that long-term environmental impact is greatly reduced.

While world statistics on coal production provide an approximate guide to the changing pattern and volume of potentially derelict and contaminated land there is not a constant relationship between output, the amount of waste produced and the potential contamination arising from the extractive and refining processes. The volume of waste material arising from deep coal mining is dependant on geological structure and physical location of coal seams, techniques of extraction and refining, and methods of waste disposal related both to technical competence and the economics of alternative modes of operation.

Coal production has been in decline in Scotland since it peaked in 1913 at 43.2 million tonnes (15% of UK production). It totalled 6.4 million tonnes in 1989 (6% UK production). Since 1979 Scottish opencast production has expanded from 2.4 million tonnes to 4.2 million tonnes in 1989, becoming the major source as deep mined coal fell from 8.2 million tonnes to 2.1 million tonnes over the same period (Dargie and Briggs 1991). These national totals mask important interregional variations in output that have a bearing on the spread and volume of contaminated land.

Between the years 1921-1947 there was rapid growth in the amount of potentially contaminated land due to the contraction of the coal industry. Areas particularly badly hit were Central Scotland, North East England and South Wales. Serious though the rapid increase in derelict and contaminated land was, further complications arose from the severe social problems large scale unemployment brought to these areas. In comparison continuation of opencast coal mining, introduced as a short-term emergency measure in 1942, has produced little contamination or dereliction.

Sherwood (1987) states that colliery spoil production is currently about 60 million tonnes per year (from deep and opencast mining), this is added to an estimated stockpile of 3000 million tonnes. In 1978 approximately 88% of the annual waste produced was tipped on land of which 4 million tonnes was used in land reclamation and the rest forming spoil heaps. With respect to Scotland, colliery waste generation and disposal for the period 1978-79 is given in Table 1.1.

During the period 1871-1920 deep coal mining experienced a transition from the more primitive methods of extraction to the more mechanised present day state. As mechanised forms of tipping spoil were introduced waste heaps were often created in forms that made them less amenable to reclamation than was previously the case.

Mechanised mining has greatly added to the volume of waste because it is less selective than manual working in rejecting non-combustible material which used not

Table 1.1

Colliery Waste Generation and Disposal in Scotland during the Period 1978-79 (after Sherwood 1987)

Coal output	8.1 million tonnes
Waste output	2.4 million tonnes
Coal:waste ratio	3.4:1
Disposal to land	2.2 million tonnes
Number of active tips (at use at collieries)	30
Number of closed tips (original colliery still operating)	19
Number of disused tips	206
Number of collieries	16

to be brought to the surface. The trend towards fully mechanised mining in the UK has, therefore, added to the volume of waste brought to the surface at a time when total output of coal has been falling. In addition the proportion of coal mechanically cleaned at the surface has also increased (Commission on Energy and the Environment 1981).

Waste disposal did not constitute a significant problem during the first half of the nineteenth century as long as the shafts were relatively shallow and the coal worked manually. As techniques for cleaning were basic, very little waste required tipping at the surface, and the waste generated from cleaning was tipped manually, resulting in waste heaps that were both small and low. The progressive increase in pit depth and mechanised mining resulted in an increase in waste material. Initially this waste was tipped from tramway tubs and railway wagons producing gently graded spoil heaps which threatened to become excessively space consuming as they fanned out from the original dumping ground. The introduction of mechanised tipping solved the problem of spreading waste by allowing spoil heaps to rise to 50m or more in height. The mechanically produced conical or ridge tips became common features of the coalfield landscapes of the UK during the first half of the twentieth century. Technically these tips were not as satisfactory as first assumed, as the lack of compaction in the tipping process left large air-filled voids which made them prone to spontaneous combustion and instability.

It was the problem of spontaneous combustion which first aroused governmental concern about the surface disposal of colliery waste with the result, that in 1939 legislation was introduced to reduce the number of blazing spoil heaps. Under the legislation the colliery companies were obliged to attempt to extinguish or otherwise control the burning waste, but it was not until the passage of the Clean Air Act in 1956 that the National Coal Board was required to take every reasonable step to combat spontaneous combustion as opposed to just controlling the flames. In 1969 the Mines and Quarries (Tips) Act was passed in response to the Aberfan Disaster of 1966, with the intention that colliery spoil heaps should not constitute a hazard to life or property. The consequence of both these acts has been to substitute wagon tipping by other forms of mechanised waste disposal. Modern day tips are now created with rubber typed dump trucks which result in spoil heaps of a plateau-like structure, no more than 15m in height. Tipping in this manner enables the waste material to be easily compacted by the dump trucks as they run over the spoil heap, and the shape of the waste heap makes future reclamation easier (Commission on Energy and the Environment 1981).

Other forms of waste disposal that have been used, include tipping the spoil over the cliffs and into the sea in County Durham (Richardson 1975, Sherwood 1987), stowage of the waste in disused mine workings, or back stowage as practised in several collieries in Germany (Kommunalverband Ruhrgebiet 1986). Although underground stowage of waste is technically feasible in most collieries, arguments against this method of disposal becoming universal are purely economic. The cost of surface tipping in the past has been based on the expense of providing, operating and maintaining the tipping equipment. The cost of the land involved has not normally been included and the future cost of reclamation ignored.

An alternative to the creation of waste heaps is to find a market for the waste material. For some years the red shale extracted from burnt spoil heaps has been accepted as fill material for various types of civil engineering projects. Since 1968-9 black shale was also permitted to be used as fill. More recently spoil washing has proven a viable option for the older spoil tips where a sufficent size of coal material exists to make extraction financially rewarding. In some instances spoil washing has helped to finance reclamation schemes as the usable coal is extracted from the spoil heap prior to regrading.

Although these options for re-use of colliery waste sometimes exist, it is unlikely that there will be a market in the foreseeable future for all the spoil brought to the surface, to say nothing of making an impact on existing coal waste heaps.

1.4 Nature and properties of colliery waste

Colliery waste has two components, the solid rock brought to the surface during shaft sinking and the driving of roadways through the barren strata, and the solid residues produced by coal preparation plants at the pit head. The first source of waste is normally insignificant after the initial shaft sinking. Most of the colliery waste comes from the cleaning plants which separate the saleable coal from the waste residues.

Most spoil tips are relatively unvegetated. The major problems of colliery spoil as a biological growth medium are now reasonably well understood: physical characteristics arising from spoil texture, compaction, stability, moisture content, and lack of organic matter (Glover 1975, Richardson 1975, Hutson 1980); chemical problems associated with toxicity resulting from pyrite oxidation (Kimber et al. 1978, Pulford et al. 1982, Backes et al. 1985a, 1985b) and supply and maintenance of major nutrients, particularly nitrogen and phosphorus (Palmer and Chadwick 1985, Cornwell and Stone 1986, Pulford et al. 1988).

Coal spoil has a very variable texture, with some very coarse material, finer clays and lack of organic matter. Poor texture inhibits plant growth and may cause either drought or waterlogging. Compaction of the spoil material arising from the method of tipping, or where a bing (the Scottish colloquial term for coal spoil heaps) has burnt and the waste fused, inhibits vegetation growth until the surface material has weathered sufficiently to permit root penetration. Freeze-thaw action and reduction in particle size due to weathering aid the process of compaction. In such circumstances moisture penetration and retention can be severely affected while the problems associated with erosion and sediment yields in runoff may cause degradation of surface water quality.

The bare, unsheltered surfaces of a bing suffer extremes of climatic conditions. The black unburnt material, with its low albedo, can result in root collar burning and give rise to surface drought during the summer months. Surface stability will be affected by temperature and moisture variation. During winter months, freeze-thaw and frost heave actions will cause heaving and slumping of material, giving rise to down slope movement and the disturbance of any vegetation colonisation.

Acidity resulting from pyrite oxidation can be easily detected in both ferruginous mine drainage and vegetation dieback, leading to large areas of barren spoil. The complexity of pyrite oxidation in colliery spoil and the associated buffering characteristics are well documented (Williams 1975, Palmer 1978, Costigan et al. 1981, Backes et al. 1987, 1988). Williams (1975) discussed the implications of colliery spoil acidity with regard to form and level of supply of nitrogen to plants, and Palmer (1978) has demonstrated its effect on potassium levels in colliery spoil. Associated with acidity of spoil material is mobility and hence, availability of trace metals found in the spoil material. Survival of naturally colonising species depends on metal tolerance. Gregory and Bradshaw (1965) demonstrated that individual species have a wide range of tolerances, with tolerance to one metal not accompanied by tolerance to any other. Berg (1978) has given evidence concerning the effect of consequent aluminium and manganese toxicities on plant growth.

Most unburnt coal bings eventually attain some degree of cover irrespective of remedial measures and Bradshaw and Chadwick (1980) listed 105 plant species occurring naturally on 22 untreated colliery spoil bings in Yorkshire. They found that the number of species on a site increased with an increase in spoil pH, while site age had no influence. This contrasts with colonisation of other derelict sites where succession leads to an increase in species with time and site age being the main determining factor in the early years of colonisation.

Often it is necessary to reshape the bing to achieve the desired landform for redevelopment or landscape purposes. In such circumstances 'fresh' unweathered spoil, often unburnt, is exposed, presenting a new surface for active oxidation of pyrite and manifesting all the initial problems associated with spoil weathering.

Spoil variability between sites makes the concept of a standardised reclamation approach difficult. Not only is there variability between colliery spoil heaps, but variation within the spoil heaps themselves can occur as the result of mining operations spanning several decades. As the older waste material weathers so there are physical and chemical variations between the older and more recently deposited waste material. Occasionally, waste from a group of mines will be disposed of centrally, a practice which is common in the Ruhr area of Germany (Petsch 1974, 1975). Washeries may serve more than one mine, resulting in the further variation in the characteristics of the waste material.

1.5 Contaminated land: its environmental, social and economic significance

The scale of the contaminated land problem in Britain is considerable but varies regionally with the historical pattern of land use. In evidence presented to the House of Commons Environmental Committee Report on Contaminated Land (1990), the Department of the Environment estimated that a possible maximum total of 27,000 hectares of derelict land should be classed as potentially contaminated in England, whilst independent estimates of contaminated land put the figure at between 50,000 and 100,000 hectares for the UK (House of Commons Environment Committee 1990). For Scotland the consultation paper for contaminated land registers in Scotland (Scottish Office Environment Department 1991) states that the area of land in Scotland entered on registers is likely to be 'much greater' than the 7,400 hectares of derelict land identified in the pilot survey in 1988.

Throughout the 1970's and 1980's there has been increasing resistance to development on greenfield sites. Green Belts, established in consequence of the 1949 Town and Country Planning Act, have been vigorously defended around urban areas, while inner city programmes and government encouragement for the re-use of derelict and despoiled land has led to the large-scale redevelopment of land previously used for other purposes. In 1986 almost half of all new development took place on re-used land, particularly in inner cities and urban areas. (ICRCL Guidance Note 59/83 2nd Ed. 1987). Even in the current recession, in which there is pressure from commerce for the relaxation of certain pollution control regulations and requirements, protection of greenfield sites remains as strong as ever. The 1990's are likely to see even greater restriction on the development of these areas, especially with redevelopment of previously industrialised areas and the environment being high on the European Community Agenda.

It has always been important that the nature of contamination is known and taken into account in the redevelopment of land, particularly under the circumstances outlined above. Advice and guidance to local authorities and developers on the identification, assessment and development of contaminated land is offered in the DoE Circular 21/87 (Scotland Planning Advice Note No.33) Development of Contaminated Land. This encourages the identification of potentially contaminated sites at the earliest possible opportunity so that the necessary investigations can be carried out to allow informed decision making on what, if any, action is necessary to negate or ameliorate risk.

From the early 1980's, and certainly as far as the public funding of reclamation schemes is concerned, there has been a preference for redevelopment of 'hard' end-uses, such as commercial, industrial and residential, as opposed to 'soft' end-uses such as parks, amenity areas and gardens. Moreover, those groundworks which have taken place have been only those necessary to support the next redevelopment use. To this extent, the UK approach differs from that which is seen in the USA, the Netherlands (Moen 1988) and Denmark where the issue of redevelopment usage is less influential in determining the actions to be taken with respect of the contamination present at a site.

The possibility of reclamation for agricultural purposes has been weakened by surplus production. This has led to calls for diversification and the introduction of set-aside rather than demands for utilisation of reclaimed land. Attempts to find new uses for farmland are paralleled by the need to find alternative uses for reclaimed land, and where these are not hard end-uses with a economic return, the general aim is to carry out the reclamation on a low cost basis with minimal aftercare requirements.

The desire to carry out low cost reclamation with limited long term maintenance may be possible on substrate with a poor nutrient base. Although vigorous, high nutrient-demanding vegetation may not be supported, a low level maintenance regime may retain vegetation cover provided by pioneer species that are able to adapt to harsh aspects of the environment.

Sustained vegetation cover on a reclaimed site will generally reduce aerial particulate pollution caused by wind-blow although other pollution pathways may remain. Vegetation will enhance visual improvement and integration into the surrounding landscape. Afteruse of such sites may serve important functions with respect to providing for the needs of recreation and open space. Sites in less accessible locations may have low level active use but may still be of value in the landscape.

Public attitudes to dereliction and contamination of the environment are greater than even before, although how important these problems are to an individual is likely to be affected by other aspects of their immediate environment such as, housing quality, litter and noise. It has been claimed that for those living within close proximity of derelict industrial sites, the problems may not be given the high priority that might be expected, as the inhabitants of such localities may display a 'derelict mentality' which causes them to accept their surroundings as an inevitable accompaniment of the locality's past (Wallwork 1974).

Colliery spoil heaps can provoke an interesting attitude in relation to proposed reclamation projects. Often they are considered as a local landmark, and therefore worthy of retaining or reshaping rather than removing in their entirety. It has been suggested that the large scale reclamation of derelict sites endangers the preservation of industrial monuments and past reclamation projects intended for amenity provision have incorporated industrial sites, for example, the lead mines at Leadhills, Lanarkshire.

The ecology of such sites is also important. Growing awareness of conservation, habitat creation and protection suggests that reclaimed sites can make a positive contribution of ecological value, particularly where the presence of redundant infrastructure can act as wildlife corridors. Reclamation of contaminated land should therefore be looked upon as a valuable opportunity.

1.6 Aims of the thesis

Coal waste reclamation has occurred in most of the developed coal producing countries for the last twenty years or so. In the UK most of the sites that have been reclaimed have been carried out with the assistance of the Derelict Land Reclamation Grant.

Since the reclamation of the early sites there has been little assessment of the long term effects of the effectiveness of reclamation with respect to control of contamination, and the success of sites to fulfil their proposed end use. The purpose of this study is, therefore, to carry out an assessment of the effectiveness of the reclamation of two sites in West Lothian with the view to provide guidance on the most appropriate techniques and post reclamation management of sites contaminated by past coal mining activities. The criteria selected for the assessment have been based on the criteria the reclamation projects were intended to address, namely:

i) pollution control,

ii) the success of the spoil as a growth medium,

iii) the social benefits of reclamation, particularly with respect to visual benefit and amenity use.

CHAPTER TWO

2.0 Coal Mine Wastes: A review of the problems and solutions

2.1 Introduction

Modern industrial countries cannot survive without the products of mineral working. Although the forms of mining and the relative significance of the various minerals may change over time, the continuation of mining and quarrying has the potential to be an ongoing environmental problem.

Reclamation techniques developed to address the problems of land degradation have been applied to derelict and contaminated mineral extraction sites since the early 1970's. Literature on reclamation techniques relates to case studies and practical experience, as well as reporting of scientific investigations.

Contaminated, as opposed to just derelict, land involves a diversity of professional expertise, with the result that in recent years there have been a number of 'multi-professional' publications on contaminated land reclamation (Smith 1985, Cairney 1987).

Smith (1987) reviewed the information available in relation to contaminated soils. He suggested that once a site has been determined to be contaminated, the fundamental decision is whether to excavate or leave the materials in-situ and from this starting point various options are available.

Remediation and landscaping of contaminated land and derelict industrial sites in urban and rural zones is of great importance. For some regions in Scotland, reclamation of contaminated land has been a major activity in recent years. Others intend to reclaim land in the future. It is essential therefore, that the experience gained from past and present projects is reviewed to provide guidance on the most appropriate techniques for future use.

Derelict and contaminated land may be reclaimed to either 'hard' or 'soft' end uses. 'Hard' end uses are considered less sensitive, and involve developing the site for new building or associated hard surfaces, such as car parking facilities. There is little, if any, landscaping of such sites and the risk of contact with the contaminated material has generally been considered confined to building foundations and services which can be protected by engineering design. Developments to hard end uses are generally found in urban environments where land attracts a premium value. Reclamation of contaminated, urban sites has been based on the amount of work required to ensure the risk to man or animal life is low. Guidance on acceptable levels of contamination in soils is given in ICRCL 59/83, which addresses the risk of contamination in relation to threshold and action levels, for specific contaminants and the sensitivity of the proposed end use.

At present, where the presence of contaminative materials is so great that engineering design is unable, or would be too costly, to implement suitable protection of the new end use, the contaminated material may be removed for disposal either by landfill or incineration. In the case of landfill, this method of 'reclamation' results in transferring the problem elsewhere. When incineration is chosen atmospheric pollution may result.

Engineering methods used for the development of contaminated land involve the containment of contaminated material by using artificial barriers to prevent contamination migration. Initially, isolation of an area of contamination was limited to covering the surface, little attention was given to the movement of contaminants below the surface. More recently, such cover systems have been used in conjunction with vertical and horizontal 'in ground' barriers to achieve partial or total isolation. The latter involves complete enclosure of a site within a permeable barrier to prevent the ingress or egress of water and pollution in all directions. Such methods of treatment rely on the physical barriers retaining their integrity, and may therefore have a limited life expectancy.

While hard end use reclamation has been addressed by applying methods of containment, soft end uses, such as reclamation to open space or recreation facilities, have frequently been addressed by neutralisation of the contaminants of the soil or spoil material.

Since the limitations of containment as a means of reclamation of contaminated land have been realised, particularly in relation to the extent of land which appears to be contaminated by past industrial or associated usage, other more innovative methods of dealing with contamination are being developed which include physical, chemical and biological methods of treatment. In a recent Department of Trade and Industry publication Armishaw et al. (1992) reviewed innovative treatment technologies at pilot stage, and those currently available, for contaminated clean up. The review divides the types of treatment processes into five generic categories, namely, physical, chemical, biological, thermal and solidification. The first three of these categories currently have some commercial application and the principles of the treatments are outlined below.

2.1.1 Physical treatment

Physical treatments for soil contamination are reviewed by Rulkens et al. (1985). Methods include:

* extraction by leaching,
* mechanical separation (sieving, soil washing etc.)
* flotation

Physical treatments aim at separating, isolating or concentrating the contaminants, they do not destroy the contaminants themselves but have the ability to provide an effective process step towards a more efficient clean up route such as destruction or stabilisation.

Physical techniques involve both ex-situ and in-situ processes. Ex-situ involves particulate separation or extraction methods which transfer the contaminant to a liquid or gaseous phase to permit removal. In-situ processes also involve the transfer of the contaminants to a liquid or gaseous phase but include the control of the migration to the mobilised pollutants to the surface treatment plant (Armishaw et al. 1992).

A number of factors influence the ability of physical systems to work towards successful clean up, notably;

* the type of contaminants, their distribution and concentration
* the soil type and its relationship with the contaminants

* the hydrogeological conditions with respect to the containment

2.1.2 Chemical treatment

Chemical treatment processes for remediation are designed to destroy the contaminants or to convert them to a less damaging environmental form by chemical reaction. General requirements of chemical treatment include good mixing of the soil contaminants and the chemical agent, pre-processing for debris reduction and size reduction and the addition of excess chemicals to ensure that the presence of unreacted reagents does not in itself cause pollution problems, or attack the native soil structure.

Chemical treatment techniques are usually categorised according to the chemical processes involved, for example:

oxidation
reduction
extraction
neutralisation
precipitation
mobilisation

Oxidation can be used to treat organic contaminants. Typical oxidants are ozone, hydrogen peroxide and chlorine gas. The reaction rate may be increased with UV light. Reduction can potentially be applied to soils contaminated with metals, for example the reduction of Cr^{6+} to Cr^{3+}. Care must be taken that oxidation and reduction treatments do not result in partially degraded products which are still potentially hazardous.

Extraction of contaminants from a soil involves the application of a solvent followed by collection of the resulting extractant. Extraction systems can be used to treat contaminated waters, liquid wastes, slurries and soil. Extraction using acids can be used to remove metals, free cyanides and some inorganic compounds.

Neutralisation refers to adjustment of pH, a widely used example of this is the addition of lime to soil. A contaminant's hazardous characteristic may be rendered insoluble or immobile by this method. However, the implication is that changing site conditions may in time 'destabilise' the contamination (Smith 1985).

Mobilisation refers to the release of contaminants from a fixed (eg. precipitated) form and may be mediated by a decrease in pH. Precipitation followed by the removal of the precipitated contaminants is used to remove heavy metals from solution. Precipitation may also be carried out to reduce the availability.

Chemical processes may be applied either ex-situ or in-situ, but soil permeability and heterogeneity are limiting factors to in-situ remediation. Chemical processes in the soil may be impeded by the adsorption of treatment reagents to the soil structure, especially in clays.

2.1.3 Biological treatment

Biological treatment or bioremediation is currently attracting considerable attention as a remedial technique. This is primarily because other treatments by themselves, eg. immobilisation or containment, do not permanently solve the contamination problem. The process usually involves the stimulation of indigenous sub-surface micro-organisms to degrade chemicals on site. One advantage of the process is that soil excavation is not necessarily required.

Pre-treatment of metal-contaminated soils with bacteria of genus *Thiobacillus* in order to remove metal ions by leaching (Olson et al. 1990) is an area of development in the future of soil metal decontamination.

2.2 Factors inhibiting vegetation establishment on colliery spoil

This chapter reviews the different reclamation techniques that have been used to reclaim colliery sites in the past including those that were used on the case study sites in this thesis.

Many of the processes with the categories of treatment given above could be applied to former colliery sites and washery lagoons where the problems of large volumes of surface waste are not present. Treatment application to waste heaps is more restricted, principally due to the quantity and nature of the material involved. Rural location of many of the old mining areas limits commercial viability of the more expensive innovative treatments, due to the financial costs involved in relation to the proposed end use, which is frequently open space, amenity or woodland. There is, therefore, a general tendency towards using low cost technological methods of reclamation.

In some instances coal waste material may be incorporated into the landscape by complete regrading and burial under surrounding uncontaminated land. Future land use may then include agriculture or property development provided there is a suitable market, and the location and ownership of neighbouring property permit.

More frequently waste heaps receive minimal regrading, usually only sufficient to ensure stability of the slope material. The waste heaps are then reclaimed by revegetating. Early reclamation work using revegetation techniques usually endeavoured to address three principal issues:

i) the visual impact of the spoil heaps and associated colliery infrastructure;
ii) the social and economic impact of the cessation of mining in the local communities, by making the area more attractive, both physically and by using economic incentives, to encourage new business and hence new job opportunities;
iii) the health, safety and environmental consequences of the derelict site and associated waste material.

To enable these aims to be achieved the physical and chemical problems associated with spoil material had to be overcome.

2.2.1 Acid production due to pyrite oxidation

The most influential chemical characteristic of many colliery spoils in terms of both pollution generation and preventing effective reclamation using vegetative techniques is the presence of pyrite (iron sulphide). Pyrite was precipitated as the result of coal and shale formation under highly reducing conditions. Sulphur is converted to sulphide (S^{2-}) and the iron present is in the reduced, ferrous form (Fe^{2+}). Pyrite is stable until exposed to air and water, when it is oxidised to produce amongst other products, acid. Seasonality will affect the rate of the oxidation reaction. Pyrite in colliery spoil can be oxidised by either oxygen or ferric ions. The reaction with oxygen is slow, whereas with ferric ions it is fast and catalysed by the bacterium *Thiobacillus ferrooxidans*.

The overall reaction describing pyrite oxidation is usually written as:

(1) $4FeS_2 + 15O_2 + 14H_2O \text{ -----> } 4Fe(OH)_3 + 8H_2SO_4$

The end products of the oxidation reaction being a form of iron oxide and sulphuric acid. However, the actual pathway for the oxidation of pyrite is not a one-step mechanism, but a chain of reactions with a series of intermediaries. The following reactions have been suggested to describe the oxidation process (Backes et al. 1986):

(2) $2FeS_2 + O_2 + 4H^+ \text{ ------> } 2Fe^{2+} + 4S^o + 2H_2O$

(3) $4Fe^{2+} + O_2 + 4H^+ \text{ ------> } 4Fe^{3+} + 2H_2O$

(4) $Fe^{3+} + 3H_2O \text{ ------> } Fe(OH)_3 + 3H^+$

(5) $FeS_2 + 2Fe^{3+} \text{ ------> } 2S^o$

(6) $2S^o + 12Fe^{3+} + 8H_2O \text{ ------> } 12Fe^{2+} + 2SO_4^{2-} + 16H^+$

(7) $2S^o + 3O_2 + 2H_2O \text{ ------> } 2SO_4^{2-} + 4H^+$

Although reaction (2) is slow, this is the dominant pathway for the oxidation of pyrite on a reclaimed spoil heap where lime has been added to provide a pH of 6-7. The rate determining step is set by the diffusion of the oxygen supply into the surface layers of the spoil. When the spoil pH is greater than 3.5 the oxidation reaction follows stages (2), (3), (4) and (7) (Backes et al. 1986). At a pH less than 3.5 reaction (3) is very slow as the ferrous ions are more stable, and this reaction becomes the rate determining step (Singer and Stumm 1970). At low pH, reaction (3) can be catalysed by the presence of

Thiobacillus ferrooxidans which may increase the rate of oxidation by more than 10^6 (Singer and Stumm 1970); these bacteria are commonly found in acid mine drainage and acid sulphate soils. Sulphur oxidation, reaction (7), is also an acid producing reaction and may be bacterially catalysed (Pulford 1991b).

Therefore, in an acidic environment, a cycle of acid generation develops in which ferrous ions released from the pyrite are oxidised by *T. ferrooxidans* to ferric ions, which can then oxidise pyrite, generating more ferrous ions. This system, which can generate large quantities of acid can have various effects:

i) it may provide a very acidic substrate for plant growth preventing vegetation form becoming established;
ii) revegetation of reclaimed spoil heaps may revert as a result of acid regeneration, killing off any established vegetation;
iii) acid generation can result in acid mine drainage which in turn can acidify ground and surface waters and result in visual pollution by the deposition of metal oxides, most notably iron oxide, on stream beds.

2.2.2 Nutrient supply and trace metal release

The pH of the minerals quartz, kaolin, illite and chlorite, found in colliery spoil are neutral to slightly alkaline, while the carbonates of calcium and magnesium are alkaline to approximately 8.3 (Palmer 1978). Iron pyrite, because of its insolubility, has no influence in freshly mined spoils, and therefore, new colliery waste is always neutral to alkaline in nature.

High electrical conductivities of colliery spoil are often associated with high concentrations of sodium, calcium and magnesium (Doubleday 1971). The most common salts of these elements are carbonates, sulphates and chlorides, of which the chlorides are the most easily leached. Conductivity levels often drop as these salts are leached out of the surface layers. Doubleday (1971) reported a strong link between net percolation and salinity levels on colliery spoil. Despite the short-term nature of salinity problems because of the action of leaching, it is important to the reclamation process as landscaping usually exposes fresh spoil.

The consequences of un-neutralised acidity on colliery spoil can be severe for plant growth. Cation exchange sites will become dominated by hydrogen ions with the resultant loss of bases previously occupying the sites. At low pH iron, aluminium, manganese, copper and zinc will come into solution creating toxic conditions. Aluminium and manganese can be very toxic in low concentrations in acid conditions (Berg & Vogel 1968, 1973). Low pH can also affect the availability of major nutrients. Phosphate can be fixed and made unavailable to plants at low pH (Doubleday 1972, Pulford & Duncan 1975) and potassium may be made unavailable by the formation of jarosite (Palmer 1978). Even moderately low pH can cause aluminium and manganese toxicity and inhibition of microbial activity resulting in a build up of un-decomposed organic matter and inhibition of nitrogen mineralisation (Williams 1975).

Williams and Chadwick (1977) addressed the problems of seasonal fluctuations of plant available nutrients in acid spoil material, where macronutrients may be low and toxicity levels high. They state that such fluctuations may have considerable significance in the establishment and survival of vegetation, and that the effects of these fluctuations may be even greater in the surface layers of the spoil because of the variation in spoil temperature and moisture. Their study of Mitchell's Main colliery spoil heap in south Yorkshire showed significant seasonal variations in the levels of several elements in acidic colliery spoil and that addition of limestone reduced both the concentration of these elements and the seasonal variation. It was concluded that the solubility of aluminium, manganese, copper, zinc and iron are closely controlled by soil pH. The decline of pH during the summer months was considered to be the result of more favourable conditions for pyrite oxidation due to high soil temperatures. Accumulation of the reaction products then occurred due to the lower rates of leaching.

2.2.3 Physical characteristics

Reduction of the visual impact of the waste heaps often involves reducing the height of the material and changing the angle of slope to produce a landform that is both less obtrusive and more stable in gradient for vegetation development. Movement of substantial volumes of waste material results in the exposure of material previously buried at depths beneath the tip surface. This material, which has retained the characteristics of fresh spoil, starts to weather, and the problems of spoil toxicity, acidity and water pollution arising from drainage of leachate are enhanced.

Surface physical properties are worsened by the current practice of compacting spoils during landscaping to reduce voids and the likelihood of spontaneous combustion, subsidence and landslip. A number of workers have shown that root penetration may be impeded in compacted spoils (Doubleday 1971, Richardson 1975). Poor structure is due to a paucity of finer particles, or where these do occur, to their lack of aggregation which gives a dense, massive structure rather than an open crumbly structure. The lack of aggregation is due mainly to the scarcity of plant roots and organic matter which can bind the fine particles together into crumbs and thus 'open up' the matrix. The structure that may be present in spoil before reclamation may be easily destroyed or buried during the re-contouring of tips.

The lack of aggregation and compaction results in the spoil particles packing closer together. This reduces the pore space between particles and the lack of macropores gives the spoil a low infiltration rate since it prevents excess rainfall draining quickly through the spoil under the influence of gravity. The resulting surface waterlogging can lead to puddling which blocks the smaller surface pores and aggravates the drainage problem further. This usually leads to the presence of standing water on flat areas of spoil during wet periods and erosion effects brought about by the surface run-off of water on slopes. Lack of infiltration leads to low spoil moisture availability and drying. Following drying of the surface during summer periods, water stress to plants is increased. Lack of organic matter which could act as a moisture conserving material adds further to the problem. Such stress is intensified by high surface temperatures resulting from the albedo of the spoil surface.

The major site influences on surface temperature are slope, aspect and the nature of the spoil material. The importance of other factors varies with the season. In the northern hemisphere, south facing slopes are the first to warm in the spring but can produce conditions that become limiting to plant growth in the summer months. The nature of the spoil influences the amount of heat energy absorbed and its later dissipation by conduction and re-radiation. The darker the material the higher the albedo, and the greater the heat absorbed. The more mineral matter, or conversely less organic matter and water content, the greater the thermal conductivity. Thus the ideal spoil conditions for possible injuriously high temperatures to vegetation are very black spoils on sites with little organic matter and a low moisture regime. Temperatures of >50°C have been found on British spoil heaps in the summer (Richardson 1958). Direct temperature limitations to plants cannot be easily isolated from water stress in the field as temperatures and water are inversely related.

Stability problems are most severe with the older tips, due to the method of tipping, lack of drainage and in some instances their topographical locations. Spectacular erosion of tips is mostly associated with steep, long slopes, or localised patches of finer slurry and unconsolidated material from old washeries. Modern re-contouring has alleviated many erosion problems. Erosion rills can still occur even on flat slopes, due to inadequate provision of drainage for surface runoff. Surface runoff influences the degree of erosion by the duration and intensity of precipitation and the degree and length of the slope, The presence or absence of vegetation also exerts an influence. Plant cover reduces the rate at which rainfall reaches the surface, and improves structure and hence infiltration rates (Dennington & Chadwick 1978). If the intensity of rainfall exceeds the infiltration rate, then runoff or waterlogging will occur dependant on the topography.

Compaction due to tip consolidation and regrading reduces surface porosity which benefits the tip safety by lowering air and water infiltration, thus reducing the chances of spontaneous combustion and tip movement through internal drainage. The occurrence of a capped surface layer is believed to be due to the reorientation of finer particles, during and after rainfall, which are moved by the splash effect of raindrops. Such a surface is readily saturated by rain, and anaerobic conditions may occur, affecting the efficiency of applied fertilisers, particularly through denitrification.

2.3 Solutions to problems of vegetation establishment

2.3.1 Neutralisation of acidity

Control of pyrite oxidation and the generation of acid has, most commonly, been addressed by the addition of lime ($CaCO_3$ or $Ca(OH)_2$) to the colliery spoil, thus neutralising the existing acidity and controlling potential acidity by inhibiting the bacterial oxidation of pyrite. The presence of carbonate minerals such as siderite and ankerite in spoil can neutralise acidity being produced and thereby buffer the pH (Chadwick 1974, Palmer 1978). In neutralising the acidity secondary minerals such as gypsum ($CaSO_4$) and jarosite ($KF_3(OH)_6(SO_4)_2$) are produced. The acid neutralising capacity of spoils has been investigated by Costigan *et al.* (1981) who found considerable range in pH, pyrite content and acid neutralising capacity of 20 spoils. Despite the variations found Costigan *et al.* (1981) suggested determination of pyrite content and acid neutralising capacity as a means of estimating a realistic lime requirement for colliery spoil. Other problems associated with the application of lime are associated with the initially high applications required, and the consequent loss of the treatment by leaching. For example, Doubleday (1974) reported that a total rate of 100 t ha^{-1} of ground limestone in four applications over a two year period failed to control acidification at a Northumberland site.

Pulford (1991b) reviewed the alternative methods available to prevent pyrite oxidation. These include:

i) barrier methods designed to isolate pyrite from oxygen and water which have been applied to opencast mine reclamation projects, but are more difficult to apply to waste heap material;

ii) anti-bacteria methods (Backes et al. 1988) aimed at inhibiting the action of *T. ferrooxidans*, for example with the use of anionic surfactants, which although successful in laboratory trials may have undesirable effects in the field by inhibition of some beneficial reactions;

iii) additions of amendments to remove iron by precipitation or complexing (Vaughan et al. 1984, Backes et al. 1988), or inhibiting oxidation of ferrous iron to ferric (Backes et al. (1987);

iv) and more recently the use of artificially created wetlands as a treatment for acid mine drainage.

Method iv) has developed from the observation of sites where acid mine drainage has flowed through natural wetlands. Although the studies are by no means complete it would appear that this method of alternative land use has potential for pollution control in the future.

The pH of colliery spoil influences plant growth by its effect on the solubility and availability of metals and other ions, inducing both deficiencies and toxicities. At extremely low pH, below pH 4, the concentration of H^+ ions directly restricts the range of species which can grow.

Substrate acidity can be divided into:

* active acidity: the free hydrogen ion content which determines substrate pH;
* reserve acidity: the exchangeable hydrogen ion content which determines resistance to change in pH by buffering action;
* potential acidity: the acid generating power of the substrate, which determines acidification in the future.

The most common source of potential acidity in colliery spoil is pyrite and related iron-bearing sulphide minerals. The weathering of these minerals causes regeneration of acidity on spoils that were previously neutralised by lime (Doubleday 1971, Costigan et al., 1981). Leaching and weathering of old tips over many years will reduce extremes of acidity, while the pH of colliery spoils with little or no pyrite falls with time from about pH 7-8 to acidic pH 4-4.5 (Doubleday and Jones 1977). Combustion of spoil completely oxidises the pyrite, leaving an acidic substrate with no further potential for acidity (Gemmell 1977).

Acidity is treated by the application and incorporation of limestone at rates determined from the spoil pH and potential for acidity, and the neutralising capacity of the limestone. Very high rates of limestone application, in excess of 100 t ha^{-1}, are required for highly pyritic material (Costigan et al. 1981).

Addition of lime also reduces the problem of toxic metal mobility by limiting the solubility of many cations. The effectiveness of this type of treatment is generally assessed in terms of the effectiveness of subsequent vegetation establishment.

2.3.2 Supply of nutrients and trace metal release

An option available for vegetation establishment is to sow directly into the waste material, however, most spoil material is largely inert, devoid of organic material or humus and deficient in many of essential plant nutrients. Nitrogen deficiency is the major nutritional factor limiting plant growth, with phosphorus deficiency a long term factor.

Bradshaw and Chadwick (1980) undertook a variety of research projects to look at methods of overcoming these problems with respect to vegetation development. Deficient nutrients may be supplied by addition of organic amendments or by inorganic fertilisers. Agricultural fertilisers are available in conventional (soluble) and 'slow-release' (slowly soluble) forms, as fertilisers supplying one major nutrient or as compound fertilisers, supplying various proportions of each major nutrient. A detailed review of fertilisers is given in Coppin and Bradshaw (1982). Slow release formulations may rely on microbial action, and can be unsuitable for spoil material which has poor soil microbial populations. Major nutrient fertilisers, such as those used to supply nitrogen, are subject to leaching losses and so must be applied repeatedly in small doses, which is an expensive, long term commitment. Failure to maintain nitrogen supplies can lead to sward breakdown.

Sowing salinity-tolerant plants for what are transient conditions on most spoil heaps may, however, be unnecessary and Doubleday (1971) offers the alternative approach of waiting until conductivity has fallen to a satisfactory level.

The use of manures and ameliorants provides a means by which the physical and nitrogen status of the spoil may be improved. At Treorchy and Tredegar in South Wales, following experimental work in 1966-69 a system of revegetation using organic fertiliser from broiler house litter was applied at 12 t ha^{-1}, provided 285 Kg N, 265 Kg P_2O_5 and 172 Kg K_2O per hectare. The litter also constituted approximately 70% organic matter consisting of wood shavings, poultry droppings, feed waste and animal remains (Rogers 1971a). It was applied as a surface mulch after the seed mixture had been broadcast on the compacted colliery spoil, the surface was then chain harrowed and rolled. The very high nitrogen availability produced rapid initial growth achieving the engineering objective of an erosion resistant vegetation cover. Clover was included in the ryegrass seed mixture for a long term nitrogen provision, but in practice it did not produce sufficient to ensure continued growth of the grass and further applications of compound fertiliser were needed (Rogers 1971b). The limited establishment of clover may have been due to the very high initial nitrogen application and the vigorous competitive ryegrass sward that it encouraged.

Broiler litter contains a very high proportion of free ammonia which is rapidly oxidised in the soil to nitrate and some authors believe that nitrate can directly inhibit the germination of clover (Roberts & Bradshaw 1985). Consequently, the initial nitrogen supply was not maintained and without further applications of fertiliser the grass growth declined with the potential for erosion to occur. This approach to revegetation would be more suited to well-managed agriculture than low maintenance amenity use.

Other authors (Palmer and Chadwick 1985) have found legume species effective for accumulating nitrogen in spoil material. However, Jefferies et al. (1981), demonstrated that for a reclaimed derelict site to develop a self-sustaining vegetation cover particular attention to phosphorus availability and pH was required to maximise legume growth.

Lupins are a particularly useful genus of legumes for land reclamation use, since in addition to their nitrogen fixing capability, they have a greater stature than the other herbaceous legumes and can function as the 'shrub' component in a tree-shrub-ground layer vegetation structure. Lupins have formed a key role in the species succession in direct-seeding projects (Luke 1988). Herbaceous plants are used to provide an initial cover crop, followed by *Lupinus polyphyllos* and *Lupinus arboreus* which give a fast growing, nitrogen fixing shrub component to shelter the slower growing tree species. The annual lupins *L. angustifolius, L.alba* and *L. luteus* can be used as the initial cover crop.

Nitrogen fixing plants depend upon the presence of rhizobium bacteria in root nodules which convert atmospheric nitrogen to amino acids via ammonium (Wild 1988, Holland et al. 1969). This bacterium may be absent from colliery waste and so the seed should be inoculated with the correct cultured rhizobium. The suitability of a legume for a site depends on its preferred pH range and available calcium and aluminium content. Legumes vary considerably in their sensitivity to the toxic effects of aluminium ions (Wild 1988) which is particularly important in colliery spoil materials.

As organic matter builds up, the nitrogen cycle becomes established and phosphorus deficiency can become a serious long term problem. Phosphate fertiliser added during reclamation is strongly adsorbed onto iron oxides in the spoil (Duncan and Pulford 1985). Other macronutrients, such as potassium, calcium and magnesium are not usually deficient in spoil, unless strongly acidic conditions prevail. Although losses occur due to leaching, they are replenished by continued weathering of the parent materials. Trace elements tend to be present in more than adequate amounts, often to the point of toxicity.

2.3.3 Physical characteristics

The physical problems associated with colliery spoil arise from the rate at which the materials weather and the lack of humified organic matter. Although there is organic matter present in unburnt waste, it is not humified, with the result that the spoil lacks structure and suffers from related problems of moisture retention and compaction.

Early reclamation schemes (up until the late 1970's) addressed these physical problems in relation to vegetation establishment by the addition of topsoil. The spoil material was given a blanket cover with 100-500 mm depth of innocuous material such as topsoil, peat and sand, pulverised fuel ash or sewage sludge, and then sown with agricultural or amenity grass cultivars. Doubts were expressed at the time about the long term success of this approach (Johnson 1979). The problems were:

i) root development is confined to the surface amendment, instability, frost heave and contraction on drying can cause slippage of the surface material;

ii) secondary contamination can occur through upward capillary movement of metal salts and acid, with the accumulation of metal residues in decaying vegetation at the surface following uptake by plant roots.

The consequence of these problems may be the slow regression of the sward leading to eventual failure.

2.4 Vegetation establishment

The revegetation problems of derelict colliery sites, and the principles of reclamation have been reviewed in detail by many authors (for example, Gemmell 1973, Richardson 1975, Williams and Chadwick 1977, Kimber et al. 1978, Bradshaw and Chadwick 1980, Bloomfield et al. 1982, Duncan and Pulford 1985).

The choice of plant material for a site must be made after consideration of its suitability for:

a) the site conditions
b) the biological/ecological roles of the vegetation, and
c) the intended use of the vegetation and the site.

Site conditions must be assessed for each site in question, since colliery spoil heaps show a wide variation of physical and chemical characteristics. For example, the physical variation in substrate compaction and water retention both between and within sites and the range in pH and nutrient levels (Fitter et al. 1974). Stalljann (1983) concluded from investigations into the influence of microclimate on weathering and moisture contents that the most favourable time to sow grass on spoil heaps is early autumn.

A study of any naturally colonised vegetation present will indicate some of the site characteristics and the likely successful species. Further investigation including substrate analysis, will enable a suitable species list to be compiled. The biological role of the vegetation introduced on the site must be defined as part of the reclamation strategy. Introduced plants may be those intended as the climax community (Strzyszcz 1982), or as a stage in the process towards the final community. Plants may be chosen for a particular function eg. to stabilise a substrate, to tolerate contaminants or hostile conditions, as pioneer colonisers, fast growing nurse species, nitrogen-fixing soil developers or as climax species. It is important that the species selected are suitable for their intended part in the local ecosystem, as well as for their use and appearance, particularly in schemes where wildlife colonisation is to be encouraged. Species native to the locality will, therefore, play a major role. Studies of natural colonisation and succession in the locality of the site give valuable guidance in species selection for biological function.

The selection of plants for commercial, agricultural or forestry crop production would normally be made from agricultural or forestry species and varieties, bred or selected for high productivity under specific conditions.

In a report produced by the Forestry Commission describing a survey of their tree planting on man-made sites in Wales (Broad 1979), approximately 100 ha. of planted in-situ colliery spoil heaps were included. As the tips were relatively old and well weathered, no particular problems for tree establishment were encountered; climate, exposure and sheep trespass were considered the controlling factors. A small number of regraded or newer tips were also planted and these were found to have problems associated with the unweathered spoil, compaction and spoil acidity as well as exposure.

The species found to be most successful were Scots Pine *(Pinus sylvestris)*, Lodgepole Pine *(P. contorta)*, Corsican Pine *(P. nigra)*, and Japanese Larch *(Larix kaempferi)*. Management of the trees included the application of phosphate fertilisers which were applied by hand around each tree. Nitrogen fertilisers where not used and in many locations were reported as the limiting factor for growth.

Where the intended use of the site is for recreational or other 'amenity' purposes, such high levels or productivity are not necessary, and may be distinctly disadvantageous in terms of their high maintenance requirements and unsuitability for wildlife or public use. As the experience of planting on reclaimed sites grows, some results have been reported (Jobling 1981, 1987 (forestry); Jobling and Stevens 1980 (amenity); Richardson et al. 1971 (agriculture and forestry)).

2.5 Conclusions

Ground and water contamination arising from the presence of colliery spoil heaps can present a considerable environmental problem in areas of past, and in some instances present, coal extraction. The physical and chemical characteristics of the material make spoil heaps susceptible to combustion, instability and a potential source of heavy metals and sulphate, that are released during weathering processes.

Equally, there is nothing attractive about a colliery spoil, lack of vegetation and associated wildlife gives them little appeal. Many colliery spoil heaps are relatively young and natural colonisation has had little time to develop these difficult habitats, or to develop the larger vegetation which would give them scale and attractive cover (Bradshaw 1979). Appropriate intervention by man, by enhancing the spoil as a growth medium, can speed up the vegetation process which in turn helps to minimise the problems of instability and pollution.

Ideally, a strategy for reclamation of derelict sites will be incorporated in development plans. Disused mineral working of various kinds were recognised as having considerable nature conservation interest in the Nature Conservation Review carried out by the Nature Conservancy Council (Ratcliff 1977), and subsequently by Gemmell et al. (1983). To many, the recreational attraction of such sites is derived from the features such as vegetation, wildlife, topography, which together make up the quality of 'wilderness' or 'wildness'. That the public do desire wilderness recreation is shown by the popularity of National Parks and Country Parks. Derelict land with little or no potential for urban development could well prove a valuable resource in providing for this demand. The disappearance of wilderness, and low intensity agriculture and forestry, have had a profound effect on the wildlife which occupied those habitats. The use of derelict land for marginal forestry and wilderness recreation could perhaps go some way to reducing the pressure on wildlife populations. The present contribution of derelict land to nature conservation other than Sites of Special Scientific Interest (SSSI) in the UK has been widely reported (Usher 1976, Holliday & Johnson 1979). English Nature (previously the Nature Conservancy Council) has now recognised that derelict land, when recolonised naturally, may provide refuges for many wild species, albeit in man-made habitats.

Observation confirms that many derelict sites have some vegetation as a result of natural colonisation. Given sufficient time, these sites may develop into places acceptable to much of the public as semi-natural rather than derelict. Revegetation techniques could, therefore, make an ideal, low input means of stabilising spoil heaps, and an effective natural approach to addressing the problems of pollution and visual amenity.

CHAPTER THREE

3.0 A review of the case study sites

3.1 Introduction - derelict land in Lothian Region

Lothian Region, although one of the smallest regional authorities in Scotland, covering 1,723 km^2, suffers from having the highest density of dereliction of any Region (Couper 1991).

The dereliction takes many forms, from abandoned industrial buildings, harbours and railway routes to the more conspicuous shale and colliery bings. In 1988 the Scottish Derelict Land Survey indicated that Lothian contained as estimated 2041 ha. of derelict land, 16.4% of the national problem (Couper 1991). Although dereliction affects the entire region there are marked concentrations in the former mining areas and along the communication corridor between Glasgow and Edinburgh.

Following the enactment of the Scottish Development Agency Act in 1975 the Scottish Development Agency (SDA) was set up with the statutory function to develop Scotland's economy and improve its environment, this included addressing the problem of derelict, neglected and unsightly land.

Sections 7 and 8 of the Act enabled local authorities, to carry out remedial work on derelict land, with the result that in 1976 Lothian proposed a 10 year Structure Plan to rehabilitate 50 sites in Lothian equalling 1033 hectares. The required expertise was provided by the creation of the Derelict Land Rehabilitation Unit within the Regional Council.

Initially the priorities of implementation were influenced by the ease of acquisition, specific purposes or the need to abate a nuisance. However, as it became clear that central government funding would not enable the completion of the rehabilitation programme within the lifetime of the Structure Plan, expenditure was directed to areas where land rehabilitation would assist other social, economic and environmental initiatives (Couper 1991). The Bathgate area was one of the locations identified as a priority area for land rehabilitation within Lothian.

Over half the area of derelict land to be reclaimed during the first five years consisted of railway lines and washery lagoons as well as the highly visible, and sometimes smouldering bings.

In July, 1989, the Enterprise and New Towns (Scotland) Act 1990 superseded the Scottish Development Act 1975. From 1st April, 1991, Scottish Enterprise, has had the responsibility for environmental improvement, urban regeneration and land reclamation. Scottish Enterprise functions by having a network of local enterprise companies (LEC's) with the role of combining the functions of the Scottish Development Agency and the Training Agency. The enterprise company for Lothian Region is the Lothian and Edinburgh Enterprise Ltd.

Scottish Enterprise undertakes initiatives which promote the following strategic priorities:

i) improved human resources
ii) technology
iii) competitiveness
iv) internationalisation
v) access to capital resources
vi) product development
vii) environment

The significance of the environment being considered seventh on the list of priorities may be felt when, wherever possible, Scottish Enterprise must work under commercial disciplines and use resources to stimulate economic and environmental development.

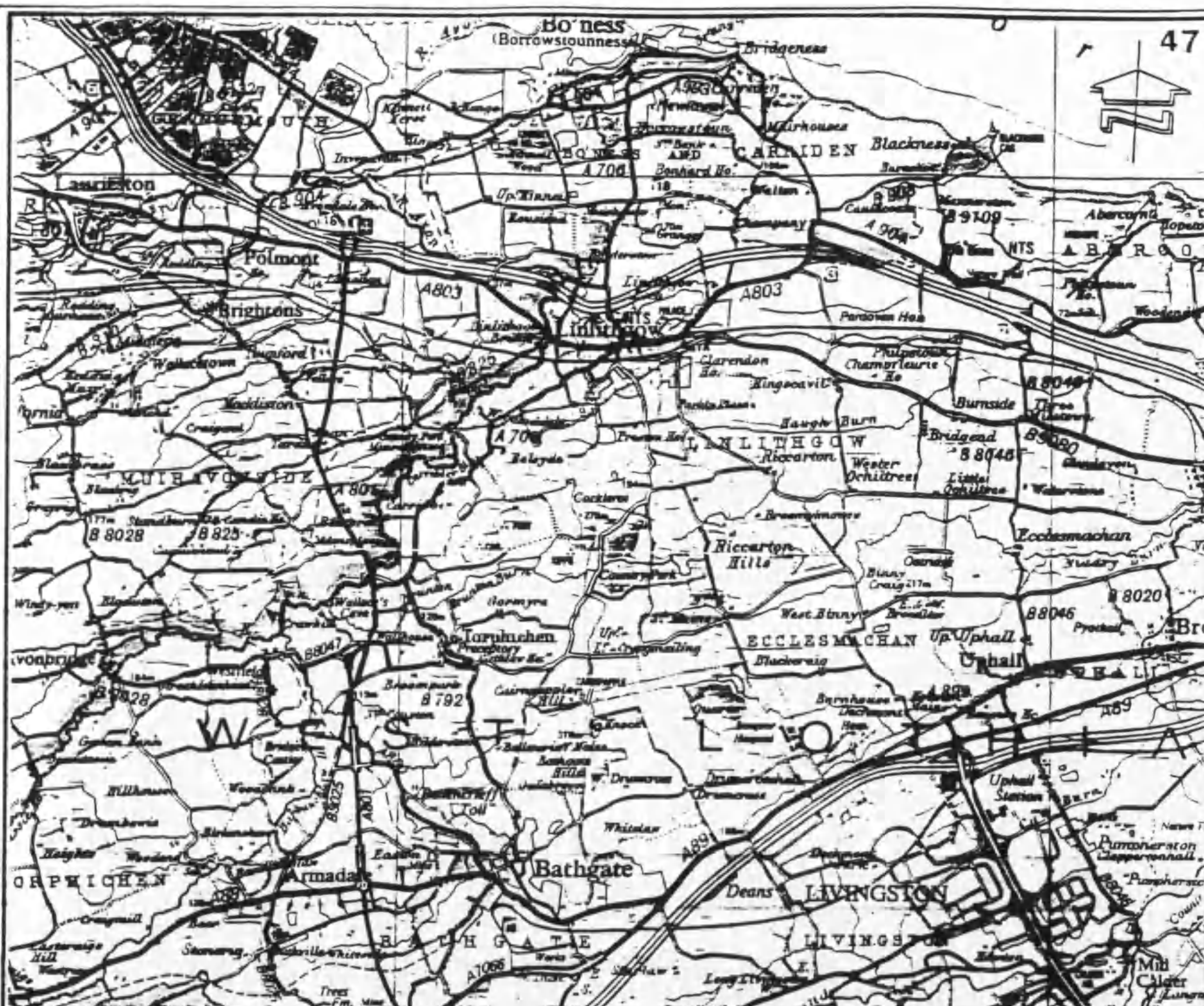
LEC's are awarded contracts based on agreed three year business plans with specific performance targets, for designing, developing and completing projects. Each company will be responsible for stimulating the growth of enterprise in its locality, with the ultimate objective being the creation of a self-sustaining local economy in which investment and training are private sector led and financed.

During the period 1976 to 1991, Lothian Regional Council rehabilitated 858 ha. of derelict land at a cost of £16.98 million, excluding infrastructure costs (Couper 1991). The information on site histories provided in this chapter has been taken from the Lothian Reclamation Unit working files on the sites concerned.

3.2 Foulshiels Colliery - site history

Grid reference NS977634
Foulshiels colliery was located on the periphery of the village of Stoneyburn in West Lothian. The coal waste on the site originates from two distinct periods of mining activity. During the period pre-1900 to 1958 a twin conical tip of approximately 870,000 tons of waste was tipped of which it was estimated 70% was run of mine waste and 30% washery discard (Kimber 1982). Between 1958-1962 a further 50,000 tons of waste, primarily washery discard, was dumped as a flat topped-tip (Kimber 1982), and a slurry lagoon retained the liquid fraction of the washery waste.

The resulting bings, were a visually dominant element



Site Location Of Foulshiels And Baads Collieries, Lothian	Date: September 1992
	Scale: 1/100,000
	Figure: 3.1

in the local landscape, considered by many of the local inhabitants as both recognisable and intrusive. Spontaneous combustion of bing material gave rise to atmospheric pollution in the form of sulphurous fumes with a high particulate content. Water pollution of both the Foulshiels Burn and the River Almond was associated with leaching and runoff from the large areas of colliery waste spread around the base of the bings and from gully and surface erosion of the otherwise relatively impermeable bing surface.

Effluent from the colliery site was first monitored by the Forth River Purification Board in 1958. At that time the main factor affecting water quality arose from the high concentrations of coal solids in the washery settling pond effluent. By 1961, water samples taken from the Bickerston and Foulshiels Burns indicated contamination from iron which gave rise to yellow-orange deposits on the stream bed. The problem was identified as being due to surface runoff from the bing material. During 1963 and early 1964 the National Coal Board made some attempt to alleviate the problem by covering some of the waste with soil, but the effect was negligible. Spontaneous combustion of the main bing in 1963 resulted in the spreading of the burning material to alleviate the problem; as a result burn water pollution increased. The condition of the water quality from closure of the mine and washery operations in 1963 to the commencement of the reclamation project was little changed, no biological life was found in either the Bickerston or Foulshiels burns before entry into the River Almond downstream of Blackburn.

During 1969, the County Planning Department put forward a proposal to rehabilitate the village of Stoneyburn with the intention of addressing the physical dereliction in the area and improving the local economy. After nationalisation of the coal industry in 1952, and closure of many of the coal mines in West Lothian, lack of alternative employment had produced social depravation commonly associated with a stagnating economy. The rehabilitation scheme included a project to reduce the impact of the old Foulshiels colliery on the village of Stoneyburn.

3.3 Reclamation proposals

To qualify for a 100% Scottish Development Department (SDD, operated the Derelict Land Grant system prior to the SDA) grant for the rehabilitation of the derelict Foulshiels Colliery site the project had to address reducing or eliminating atmospheric and water pollution as well as improving the landscape.

The SDD suggested that reclamation of the old colliery site should be carried out in stages, primarily to determine whether a waterproof membrane would be required to control pollution. The stages included:

a) removing the burning cap of the bing,
b) using well graded bing material to provide a blanket approximately one metre thick over the washery waste areas,
c) regrading of the bing to acceptable contours, compacting the graded material with the intention of reducing impregnation from water and thereby reducing leaching of pollutants,
d) vegetating the area to reduce visual intrusiveness.

The Lothian River Purification Board (LRPB) were not supportive of the proposal to regrade the bings. Although water pollution was still high during 1971, when the proposed work was to commence, it had shown signs of slowly decreasing since the closure of the mine. Plans to disturb the bing during the regrading process and expose fresh, unweathered material, would in the immediate instance increase pollution of the ground and surface waters. Spreading of the waste material, during regrading would also increase the amount of derelict land, at least in the short and medium term. The LRPB also pointed out that the burning had considerably diminished, if not ceased, with visible atmospheric pollution reduced to smoke and steam only after a period of rain. Their suggested approach to improving the area was:

a) not to disturb the bings in any way but to screen the village from the bings by planting groups of trees, between the site and the village,
b) to plant as much of the bings as possible by the addition of topsoil,
c) cover the coal waste at the base of the bings with top soil,
d) improve the drainage, and
e) return as much of the area as possible to agriculture.

Ultimately, the FRPB agreed to regrading of the waste tips on the basis that an efficient surface water drainage system was combined with establishment of vegetation. It was reasoned that by discharging rain water from the surface of the recontoured tip as rapidly as possible, infiltration of the rain water into the tip would be minimised, thereby reducing the potential for acid mine discharge.

Public access to the site was to be provided by the purchase, from the railway board, of the old railway line that had served the site during operation of the mine. As well as providing access to the site it would also serve as a link with other reclaimed mine sites in the area, notably Loganlea.

3.4 Site reclamation

In 1971 both waste tips were regraded to the present contours, a single large mound 25m high and a smaller side mound. Although no attempt to revegetate the waste was made at the time, natural colonisation of the more favourable areas occurred.

Regrading had proposed the removal of the top 60 feet of the main bing to reduce visual impact and a further 40 feet was then to be removed and spread over the washery area which was indentifed as the main source of surface water pollution. It was hoped that the fine particles from the waste material would bind the washery material and reduce the leaching of pollutants. The final stage was then to regrade the slopes of the bings to gradients of not more than 1 in 3. Problems encountered arose from burning material discovered some 80 feet down into the bing, and from the fact that much of the excavated material was coarser than envisaged and therefore not suitable for the washery or compaction. These problems resulted in considerable additional cost (£20-£30,000, 1971 figures) which included the importation of suitable material for covering the washery area and which, fortunately, the SDA agreed to meet. It was proposed that the problem of the burning material would be addressed by regrading the bings and letting the burning and hot material cool and eventually go out, forming a crust on the surface of the slope.

The slurry ponds were treated by covering with blaes, the red, burnt colliery spoil material, some of the area was then dressed with imported clean material but there was insufficient for the whole washery site. Over time, as the slurry ponds dried out and settled, deep ruts appeared as illustrated in Plate No. 12.

The engineering works were not carried out without difficulties, while moving the burning material an excavator caught fire and was totally destroyed, fortunately the operator escaped unhurt.

In May 1972 the surfaces of the regraded bings were prepared for sowing with a grass clover mix. Normal practice of improving subsurface drainage by routing was carried out to a limited extent to avoid the possibility of increasing water percolation and leaching of heavy metals present in the spoil material. Sewage sludge was spread over selected areas of the site to the depth of 100 mm and harrowed several times to a depth of 300 mm in contrast to 600 mm which would be considered normal practice to aid root development, improve aeration and provide reasonable drainage. Prior to the final harrowing, ground limestone was spread at a rate of 2 t ha^{-1} and the area seeded.

The second phase of the reclamation work started in May, 1979 with a site assessment and preparation of the tender documents. Site work commenced during 1980. The aims of phase two included; general visual improvement by fertilising, overseeding as necessary, planting of native tree species, improving the drainage system and maintaining the fencing and access ways. By 1979 the burning of the spoil had not ceased and it was proposed that some areas of the site would have to be opened up and the burning extinguished. However, the aspects of the site reclamation that caused most concern were the levels of stream pollution arising from acid mine discharge. It was hoped that these problems could be controlled by a further liming and fertilising regime that would address the problem of low pH while encouraging vegetation growth that would eventually reduce the problems of erosion and runoff. The south side of the site suffered particularly badly from leachate runoff, which had resulted in the formation of a large waterlogged area, devoid of vegetation. The problem was enhanced by the low-lying natural relief of the area and the compacted surface materials.

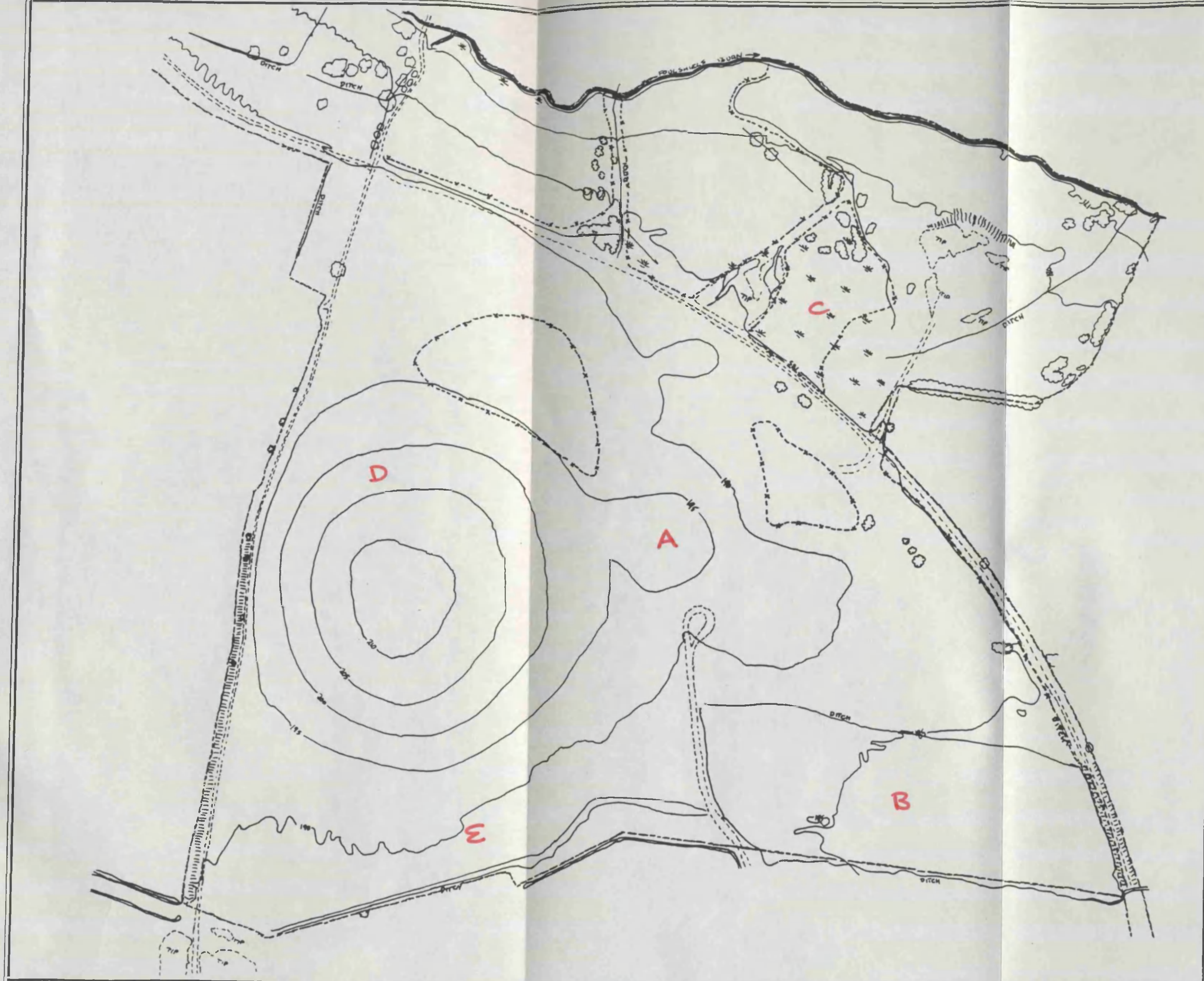
At this stage in the reclamation programme land on the north side of the site, which had suffered relatively low contamination from acid mine leachate was returned to agricultural use. Funding had been received from the Department of Agriculture and Fisheries for Scotland to stem the problem of acid mine leachate by drainage, liming and the application of fertiliser for sward and natural woodland improvement.

3.5 Reclamation assessment

Under the terms of the SDA reclamation grant, limited funding for five years post-reclamation management was provided by the SDA. This funding was intended to cover essential site management, such as weeding and selective fertiliser application.

After the final stage of reclamation in 1979, the lime and fertiliser requirements for the bing were determined by the Department of Agricultural Chemistry at the University of Glasgow. With the exception of the burning areas, surface spoil samples were collected over the site and analysed to determine pH, pyrite content and NPK status and requirements. During sample collection problem areas (Figure 3.2) were highlighted these included:

i) Area A: a small mound adjacent to the disused railway line on the east of the site, comprising of unburnt waste



Key

Site boundary

Temporary fencing

Foulshiels Reclamation Site

Date: September 1992

Scale: 1/2500

Figure: 3.2

supporting little vegetation,

ii) Area B: a rectangular area in the south east corner that had some covering by coarse grass but with extensive bare patches due to waterlogging and poor substrate structure,

iii) Area C: the site of the washeries, that supported no vegetation and was deeply gullied,

iv) Area D: a bare, unburnt area at the top of the largest mould on the north facing slope,

v) Area E: and the waterlogged area on the south side of the mounds, where patchy vegetation was present, but large areas were badly contaminated by the products of pyrite oxidation seen as precipitates of iron oxides (orange) and jarosite (yellow), particularly in the banks of the Foulshiels burn running along the southern boundary of the site. It was thought that the pollution was entering the area as leachate from the main mound.

Results of analysis indicated that pH and potential acidity for areas A, C and D could be controlled by suitable liming rates. Area C, demonstrated evidence of severe erosion due to the fine nature of material that had originated from the washery and it was anticipated that water penetration and erosion could present problems in the future.

Area B consisted of mainly poor quality soil. pH analysis indicated severe contamination due to runoff from the coal waste area, indicated by large quantities of iron-rich surface water flowing through the area. As the area was predominantly soil it was noted that there would be considerable buffering capacity of the soil pH and so control by liming would be more difficult.

Area E was noted to be frequently waterlogged. Pyrite was noted to be present in the fine surface material and recommendations were made that careful management would be necessary on draining the area, as the pyrite fraction could be expected to oxidised readily on aeration.

Recommendations for further lime application as a result of analysis were that most of the site including areas A, B and D should be limed at a rate of 20t ha^{-1}. In areas B and E a liming rate of 30t ha^{-1} was recommended with close monitoring of the surface pH at regular intervals to identify early changes in acidity status.

3.6 Baads - site history

Baads colliery comprised waste tips, a slurry pond, abandoned mine buildings and foundations and 1km of disused railway line. The spoil material covered approximately 14 hectares and was almost entirely unburnt.

Baads provided slightly different problems to Foulshiels for various reasons. Firstly, the site was jointly owned by three farmers, who, although sympathetic to the reclamation scheme, were not prepared to relinquish ownership and the site had to be leased to the LRU. Secondly the site was extremely acidic due to the high pyrite content of the spoil.

The aim of the reclamation project was to contribute to the Central Scotland Woodlands Project in conjunction with improvements to land drainage to curb the severe pollution problems in the local water courses arising from runoff from the site. An additional benefit was seen in the additional shelter the trees would add to the immediate area.

Some of the land involved in the regrading of the bing was returned to agriculture, and the mine buildings that were left standing after the pit closure were, and still are, used by a farmer for fodder storage.

3.7 Site reclamation

The lease on the colliery site commenced in January, 1978. Initial work involved improving the appearance and quality of the land involved. The bing was levelled out and spread as appropriate. As much land as possible was restored to agriculture and trees were planted along the ridge of the bing. The woodland was intended as long term with approximate maturity time of 70-100 years. The site of the old railway line was used as access to the site initially and on completion of the restoration work returned to agriculture.

Prior to reclamation the site had been progressively deteriorating the quality of the fields to the north of the bing, and the established tree shelter belt to the south. This deterioration had been linked to the increase in toxic run-off from the bing and its accumulation in these areas over the last 40-50 years.

Initial analysis of pH and pyrite content in the spoil was carried out by the Department of Agricultural Chemistry at Glasgow University, prior to remediation work. Analysis during 1978 indicated a mean pH of 3.2 with a range of 2.6 to 4.3. Percentage pyrite content was in the range of 0.7-1.48% FeS_2 and further pyrite analysis in 1980 was similar, with results of 0.11-1.26% FeS_2. The potential acidity could be assessed from the pyrite content as theoretically 1% pyrite produces acid requiring 40 tonnes lime (as $CaCO_3$) ha^{-1} to neutralise. The spoil material was also shown to have a high reserve acidity as a result of the buffering capacity associated with the high clay content of the spoil material.

Due to the high pyrite content of the spoil material, the University Chemistry Department recommended application of lime at rate of 50 t ha^{-1}. As the high lime input was likely to affect phosphate availability it was recommended that noted deficiencies should be addressed with an appropriate fertiliser.

The forestry compartment of the reclaimed site was 6.6 ha., initially the tree species suggested for the site were willow, alder, birch and rowan with blocks of pine interspersed between them. Prior to planting commencing the LRU were offered a large number of containerised lodgepole pine from the Forestry Commission at a very competitive price, and the majority of the bing area was planted with these trees with a strip along the roadside of the site planted with deciduous species. The trees were planted in two staggered rows per weeded strip, with a spacing of 1.4 m along the rows and 1 m between the rows to facilitate strip weeding. Fertiliser applied to the planted area was slow release NPK 15:10:10, although the rate of application is unknown.

It was interesting to note that the sub-contractor who planted the trees made the following comments to the main site contractor:

'....attention to ground conditions within existing vegetated areas. The roots of existing plants are bedded only in the top 50-75mm of the blaes material. ......the underlying material is unlikely to sustain the recently planted open rooted trees......'

The trees appeared to have survived well during the early years of reclamation, although growth rates may be considered rather slow in some areas, presumably due to exposure. Latterly wind-blow has become a feature of the site (Plate 23), the root structure of these blown trees has exposed and the effect of spoil compaction on root development. Exposed roots have a 'ball structure', resulting from the difficulty of penetrating the compacted spoil. This root poor development has resulted in increasing instability as the tree grows in height making them more susceptable to windblow than trees with normal root development.

3.8 CASE projects

Associated with this reclamation project was a CASE (Co-operative Awards in Science and Engineering) project grant. One of the projects aims was to examine the use of amendment additions, such as lime and organic matter in the reclamation of acidic colliery spoil from the Central Scotland Coalfields, for amenity and recreation purposes. Operated by the Department of Agricultural Chemistry, Glasgow University, the study involved an experimental trial in the forestry compartment of the site. The trial area was located in the NW corner of the site and designated Area B (Figure 3.3). The area comprised gently sloping unburnt spoil with a general S-SW aspect.

Within the amendment trial area four organic amendments were used; granulated spagham peat, sewage sludge (part dried from settlement beds), Alginure, a commercial seaweed base and chicken manure. In addition, the trial areas received ground limestone at varying rates and a pre-seed fertiliser of NPK prior to being sown with an agricultural pasture lay mix. Trial plots were 3x4 m with three replicates for each of the amendment trials.

The project was intended to monitor, over a three year period, changes in physical and chemical parameters of the spoil as a growth medium, such as structure and moisture retention, while also determining some of the reasons for poor grass sward establishment and recommendations for corrective measures.

3.9 Reclamation assessment

In August, 1980 the Department of Agricultural Chemistry carried out an assessment of the site. Spoil samples were collected in the bare and grasses areas in the location of the old slurry ponds. pH of the bare areas were recorded at 6.0 and the grassed areas 6.8. There was evidence of acid regeneration and the bare areas were heavily water logged, the spoil material being a heavy sticky silty clay. This substrate had prevented the germination of seed. In

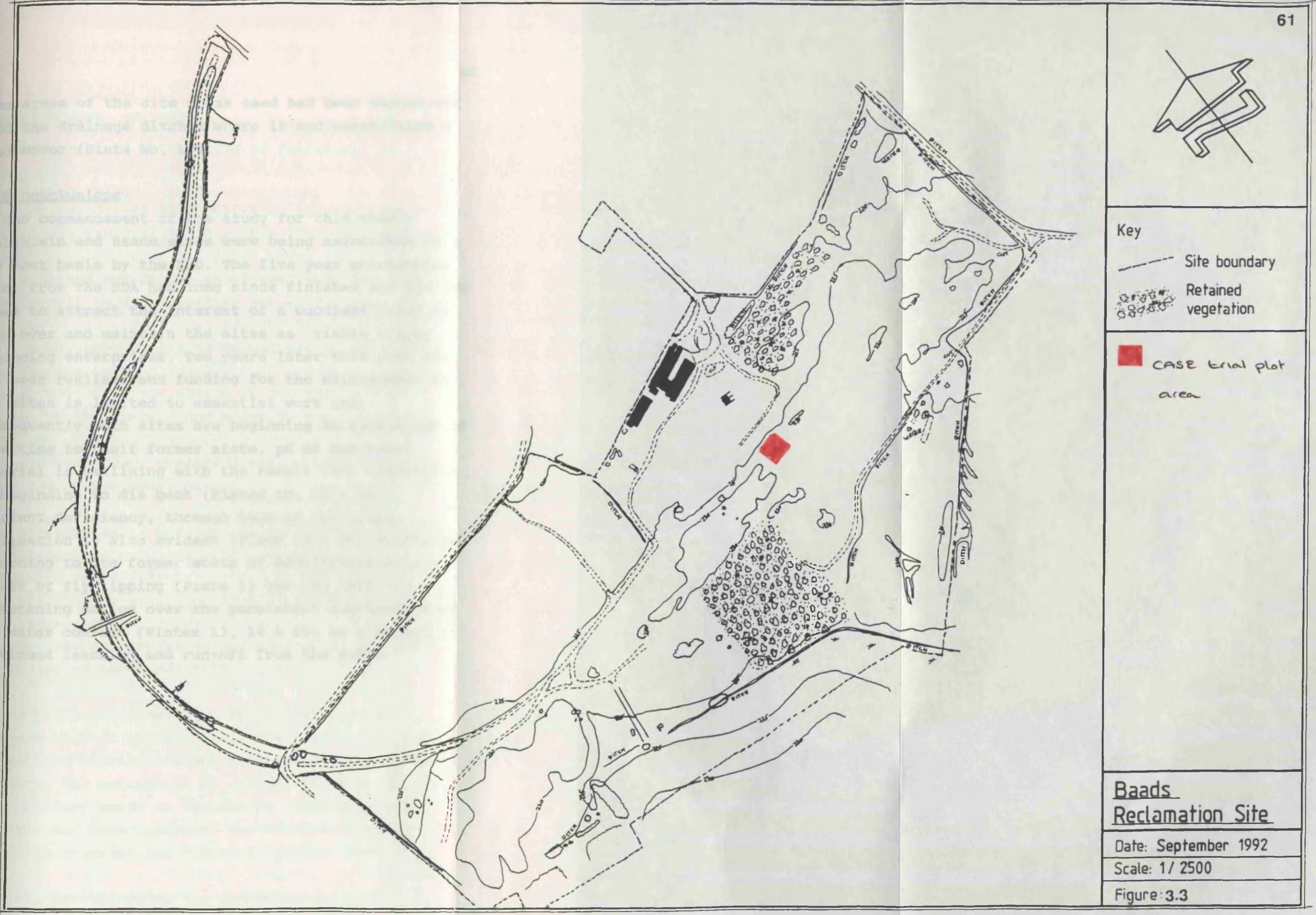

Key
Site boundary
Retained vegetation
CASE trial plot area
DITCH
Baads
Reclamation Site
Date: September 1992
Scale: 1/ 2500

Figure: 3.3

some areas of the site grass seed had been washed off into the drainage ditches where it had established a good cover (Plate No. 17).

3.10 Conclusions

At the commencement of the study for this thesis Foulshiels and Baads sites were being maintained on a low cost basis by the LRU. The five year maintenance grant from the SDA had long since finished and the LRU hoped to attract the interest of a woodland trust to take over and maintain the sites as viable timber producing enterprises. Two years later this plan has not been realised and funding for the maintenance of the sites is limited to essential work only. Subsequently both sites are beginning to show signs of reverting to their former state. pH of the spoil material is declining with the result that vegetation is beginning to die back (Plates 10, 16 & 18). Nutrient deficiency, through lack of fertiliser application is also evident (Plate 24). Foulshiels is returning to its former state of dereliction as a result of fly-tipping (Plate 1) and the LRPB are threatening action over the persistent degradation of the water courses (Plates 13, 14 & 15) as a result of continued leaching and run-off from the sites.

CHAPTER FOUR

4.0 Assessment of reclamation at Foulshiels Colliery

4.1 Introduction

The main sources of spoil material arising from mining of coal are the dirt bands within the coal seams, the cutting into the roof and floor above and below the coal seam and the formation of road ways for mine development. As mechanisation was introduced into the industry so more spoil was brought to the surface. Small coal, which prior to mechanisation would have been removed by hand below ground and used as back stowage was, with the advent of cutting machines brought to the surface and added to the volume of spoil for disposal above ground. Where collieries included washeries, washery discard could also be deposited on the spoil heaps.

Once waste material has been tipped the mineralogy of the material affects the rate and extent of weathering, particularly in relation to the clay minerals and the easily oxidised sulphides present. More widespread and dramatic changes can occur, however, where spontaneous combustion of coal waste gives rise to burnt and fused material.

Mining process wastes, vary very widely in their nutrient content as well as in their ability to hold and recycle essential plant nutrients. Past studies involving the extraction of some of these elements from colliery waste at Foulshiels (Kimber et al. 1978, Kimber 1982) have indicated the mineral composition of the waste material and potential problem areas.

This chapter addresses the effectiveness of the Foulshiels bing reclamation in relation to:

i) pollution control,
ii) the success of the spoil as a growth medium.

More specifically, an analytical programme was designed to:

i) measure changes of pH and plant available metals since the initial assessment in 1976,
ii) determine changes in water quality in the Foulshiels Burn, and
iii) relate these changes to reclamation effectiveness in achieving the objectives outlined in Chapter 3.

4.2 Experimental design and chemical analysis of spoil material for pH, conductivity and extractable metal concentrations

To enable the purpose of the study to be fulfilled it was important to design a sampling strategy that followed as closely as possible that used by Kimber in 1976. Reference was made to site plans used by Kimber for sample collection and sampling strategy.

Approximately 1 kg samples of spoil material were taken 0-10 cm below the ground surface within the vegetation rooting zone. Determination of burnt and unburnt material was made visually and all large stones were excluded from the samples collected. The samples were not collected on a strict grid pattern but were based the location of samples collected by Kimber.

Analytical methods also followed those used by Kimber, thus, pH was measured in a suspension of distilled water for comparison of data. However, as pH measured in a dilute electrolyte solution is considered to be more representative of an acidic soil's pH value (Wild 1988) additional analysis was carried out in a solution of 0.01 M $CaCl_2$.

Total metal content of several bings in Central Scotland have been analysed by MacDonald (1977). His results are summarised in Table 4.1.

Table 4.1
Total metal content of coal mine wastes of Central Scotland (after MacDonald 1977)

Metal	Concentration	
	Burnt waste	Unburnt waste
Aluminium (%)	7.9 - 13.8	6.1 - 19.8
Iron (%)	2.9 - 12.6	1.3 - 8.4
Chromium ($\mu g\ g^{-1}$)	233 - 559	150 - 531
Manganese ($\mu g\ g^{-1}$)	99 - 6263	10 - 8109
Nickel ($\mu g\ g^{-1}$)	138 - 515	89 - 470
Copper ($\mu g\ g^{-1}$)	20 - 535	29 - 491
Zinc ($\mu g\ g^{-1}$)	197 - 1794	38 - 2658
Lead ($\mu g\ g^{-1}$)	1.2 - 14.0	1.1 - 108.5

Although large quantities of some metals occur in coal waste material, only a certain proportion of these metals is in a form available to plants. To assess the importance of metal availability in relation to revegetation of colliery waste, methods for determining plant available quantities have been adopted, although not without considerable debate on both the methods and their suitability.

The various different reagents used for the extraction of plant available metals from colliery waste, have been based, or adapted from those used in soil metal extraction. Chadwick (1974) used a saturation paste extraction technique, preferring this to the more usual soil extracting reagents like ammonium acetate, of which he was critical. He found that with ammonium acetate the quantities of extracted cations greatly exceeded the measured cation exchange capacity of the wastes in some cases. Berg and Vogel (1973) used a water extract to assess manganese toxicity in acid coal mine wastes from eastern Kentucky.

In the present work 0.5 M acetic acid was used as the extracting reagent. It is a mild reagent which has the capacity to extract soil solution and readily exchangeable cations. It is a commonly used reagent which has the advantage of enabling comparison of results with other workers including Kimber (1982).

4.2.1 Measurement of pH and electrical conductivity

Method A 10.0 g sample of air dried spoil material <2 mm, was weighed into a shaking bottle to which was added 25 cm^3 of de-ionised water. The bottle was shaken for 10 minutes at room temperature, and the pH of the suspension measured.

pH was also measured in a solution of 0.01 M $CaCl_2$. For acid to neutral soils an electrolytic solution causes a depression in the pH by about 0.5 units compared to that of water. The lower pH is closer to the value of the spoil solution and therefore probably more representative of the spoil's pH value.

Electrical conductivity (EC) is a measure of soluble salt concentration. A pair of electrodes were placed in saturated samples of spoil material and the conductivity between the electrodes recorded as a measure of spoil salinity (Sm^{-1}).

4.2.2 Acetic acid extractable metals

Method Samples of spoil material were air dried and shaken through a 2 mm sieve. 5.0 g of the sieved material was weighed out into a shaking bottle and 50

cm^3 of 0.5 M acetic acid added. The bottle was shaken on an end-over-end shaker for 18 hours. The mixture was then filtered through a Whatman No.1 filter paper and the clear filtrate analysed for copper, zinc, manganese, iron, calcium and magnesium content by atomic absorption spectroscopy.

Atomic absorption spectroscopy is a routine and rapid method of analysis for a wide range of metals and is accurate to trace levels in many applications. To avoid the effects of inferences likely to occur with the determination of calcium and magnesium, 0.01 M strontium chloride was added to both the clear filtrate and calibration standards prior to analysis.

4.3 Results of analysis

4.3.1 pH and electrical conductivity

Table 4.2 gives the ranges, means and standard deviation of pH taken in 1976 and 1990-1 in a water suspension solution. Individual pH values, for water suspension solutions for samples taken in 1990-1 are presented in Appendix One, Table B. Individual pH values for $CaCl_2$ suspension solutions are presented in Appendix One, Table A.

Table 4.2
pH of coal mine waste at Foulshiels

Year	**1976**	**1990-1**
Range	2.95-5.62	3.0-6.4
Mean	4.43	3.94
Standard deviation	0.75	0.66

1976 n=45, 1990-1 n=72

Although spoil pH has no precise value it is useful in terms of understanding the chemical properties of the spoil material. The range of pH for the samples taken in 1990-1 have a wider range but a lower mean and standard deviation. Comparison of the two sets of data shows that the spoil analysed in 1990-1 was generally more acidic in nature, this is illustrated in Figures 4.1 and 4.2.

It should be noted that the sample size for the two periods are not identical and may influence comparison of the results. The larger the sampling size, the more representative the data should be of the field conditions.

pH of the burnt spoil material was generally not as acidic as the unburnt material, pH >4.0 rather than <4.0. This can be attributed to the change in chemical nature of the material by oxidation as a result of the spoil burning. Vegetation reflects the higher pH found in the waterlogged area of the site, not only in development and cover, but also with respect to species.

Electrical conductivity results are presented in Appendix One Table A. The highest conductivity values were obtained for the waterlogged area of the site. Here ion concentration would be enhanced by leachate from the bing and the clay content in the spoil in this area buffering the spoil solution. However, these results do not conclusively support findings by Doubleday (1971), (Figures 4.3 and 4.4), that high electrical conductivities in colliery spoil are often associated with high concentrations of calcium and magnesium (Section 2.2.2).

4.3.2 Acetic acid extractable metals

The concentrations of acetic acid extractable metals for all the samples of coal waste from Foulshiels are presented in Appendix One, Table A. For comparison with Kimber's data the results have been divided into unburnt and burnt spoil. The unburnt spoil has subsequently been subdivided to exclude samples taken from the waterlogged area. This area on the south side of the bing was not sampled by Kimber in 1976 as the spoil was permanently underwater until remedial drainage was carried out in 1979. The range, mean and standard deviation for both unburnt and burnt material are presented with the 1976 data set in Tables 4.3, 4.4 and 4.5. Unburnt spoil including samples from the waterlogged area of the site are found in Table 4.3, unburnt spoil excluding waterlogged samples in Table 4.4 and burnt spoil in Table 4.5.

In the unburnt material values obtained for manganese and iron in 1990-1 show an increase in availability, although the very low values for manganese noted in 1976 were not detected. Comparison of Table 4.3 with Table 4.4 indicates that the samples taken from the waterlogged area are considerably higher in available iron and manganese than unburnt material collected at other parts of the site, this may be attributed to:

a) the residue of past leaching activities prior to vegetation of the tip, and
b) the result of more recent leaching and translocation of ions as the spoil material becomes more acidic.

Manganese and iron are particularly mobile in their reduced state, the movement of iron down the surface of the bing is evident by the ochre discolouration of the spoil surface in the poorly drained areas and in

Table 4.3

Variations in acetic acid extractable metal concentrations, over time, in unburnt coal waste at Foulshiels

Year	Metal Concentration ($\mu g\ g^{-1}$)			
1976	Copper	Zinc	Manganese	Iron
Range	0.5-14.8	2.4-21.0	0.7-85.0	12.0-535.0
Mean	4.6	7.8	25.0	126.0
SD	2.6	3.7	20.0	123.1
1990-1				
Range	0.7-14.1	3.2-14.0	6.0-282.0	12.0-741.0
Mean	5.4	7.2	68.1	230.5
SD	2.9	3.0	60.4	171.0

1976	Calcium	Magnesium
Range	13.0-4680.0	8.0-360.0
Mean	584.0	109.0
SD	682.0	82.0
1990-1		
Range	32.0-1432.0	2.0-34.4
Mean	293.3	20.6
SD	359.9	10.1

(includes waterlogged samples)

1976 N = 45
1990-1 N = 33

Table 4.4

Variations in acetic acid extractable metal concentrations, over time, in unburnt coal waste at Foulshiels

Year	**Metal Concentration ($\mu g\ g^{-1}$)**			
1976	Copper	Zinc	Manganese	Iron
Range	0.5-14.8	2.4-21.0	0.7-85.0	12.0-535.0
Mean	4.6	7.8	25.0	126.0
SD	2.9	3.7	20.0	123.1
1990-1				
Range	0.7-9.3	3.2-14.0	6.0-121.0	12.0-550.0
Mean	4.7	7.6	51.2	190.2
SD	2.8	3.0	36.3	128.5

1976	Calcium	Magnesium
Range	13.0-4680.0	8.0-360.0
Mean	584.0	109.0
SD	682.0	82.0
1990-1		
Range	32.0-432.0	2.6-34.4
Mean	166.9	19.2
SD	94.7	9.9

(excludes waterlogged samples)

1976 N = 45
1990-1 N = 29

Table 4.5

Variations in acetic acid extractable metal concentrations, over time, in burnt coal waste at Foulshiels

Year	**Metal concentration ($\mu g\ g^{-1}$)**			
1976	Copper	Zinc	Manganese	Iron
Range	1.0-5.5	0.9-28.0	0.5-42.0	9.0-505.0
Mean	3.5	9.5	10.4	98.0
SD	1.5	7.6	11.7	132.1
1990-1				
Range	0.7-8.3	3.3-13.8	1.2-33.2	1.3-79.0
Mean	3.5	5.6	16.4	44.3
SD	2.3	3.1	9.8	24.3

1976	Calcium	Magnesium
Range	135.0-855.0	9.0-860.0
Mean	431.1	96.5
SD	169.8	241.4
1990-1		
Range	46.0-194.0	5.5-38.6
Mean	100.1	16.6
SD	43.8	10.7

1976 N = 12
1990-1 N = 12

Table 4.6

Results of T-tests carried out on analytes from 1976 and 1990-1 data

Unburnt material

Analyte	Probability
Magnesium	0.0000***
Calcium	0.038*
Manganese	0.0001***
Iron	0.017*
Copper	0.26
Zinc	0.48

Unburnt samples include waterlogged

Burnt material

Magnesium	0.28
Calcium	0.0000***
Manganese	0.19
Iron	0.19
Copper	0.92
Zinc	0.15

For the purposes of this study three levels of significance were used, 0.001, 0.01 and 0.05, these are indicated by ***, **, * respectively.

Unburnt material
1976 N = 45
1990-1 N = 33

Burnt material
1976 N = 12
1990-1 N = 12

the drainage network.

Berg and Vogel (1968, 1973) reported cases of manganese toxicity arising from coal spoil, and many of the results presented in Appendix One exceed the typical range of acetic extractable manganese in Scottish soils of 5-100 $\mu g\ g^{-1}$ (Mitchell 1964). Levels of acetic acid extractable iron in colliery spoil are also extremely high in some instances. Mitchell (1964) reported a normal topsoil acetic acid extractable iron range of 10-100 $\mu g\ g^{-1}$ in Scottish topsoils.

Calcium and magnesium have declined in availability in the unburnt material, although the decline with respect to calcium, is not as great in the waterlogged area and may be the result of translocation of calcium ions with leachate. Concentrations of calcium and magnesium in 1976 would have reflected recent applications of ground limestone, results obtained during 1990-1 indicate local deficiencies in some areas of the site.

At low pH magnesium and calcium present on cation exchange sites will be replaced by hydrogen and aluminium ions, resulting in rapid leaching of these ions and their subsequent unavailability to vegetation. These results support the findings for pH in Table 4.2. Decline in calcium and magnesium is associated with decrease in pH, which perpetuates the leaching and degradation of the spoil material as a growth medium.

Available copper and zinc in the unburnt material shows little variability between the two sampling periods, although copper would appear to be slightly more available in the waterlogged area. The levels of extractable copper determined exceed the range of <0.05-1.0 ug g^{-1} given by Mitchell (1964) for Scottish topsoils. The low levels of zinc determined in 1976 were not found and this is reflected in the lower standard deviation. Weathering of the spoil material to release copper and zinc ions has been balanced by leaching and plant uptake.

In the burnt spoil copper, zinc, manganese, iron, calcium and magnesium show a decline in availability from 1976 to 1990-1. The ranges for these metals, with the exception of copper, are lower and this is reflected in their standard deviation. Decline in these ions is probably due to weathering of the burnt material permitting leaching and plant uptake.

Table 4.6 presents the results of t-tests carried out on the analysis for the two sampling periods. The null hypothesis stated that there was no significant difference in plant available metals, over time, in both unburnt and burnt colliery spoil. Results for the unburnt material, including samples from the waterlogged area, show that for magnesium and manganese the null hypothesis can be rejected with a probability of >0.001, for calcium and iron the probability of rejecting the null hypothesis is 0.05, while the results indicate that there is no significant difference in plant available copper and zinc over the sampling period and therefore the null hypothesis must be accepted.

For the burnt material the null hypothesis can only be rejected for available calcium where the results of the t-test indicate that the probability of there being a significant difference in plant available calcium as being >0.001. For magnesium, manganese, iron, copper and zinc the null hypothesis must be accepted.

4.4 The relationship between pH and extractable metal levels over time

Statistical analysis using Pearson product moment correlation co-efficient, r, was applied to the study of the relationship between pH and the extractable metal levels found in the coal waste samples. The results are presented in Table 4.7 with those obtained by Kimber (1982) from his work at Foulshiels during 1976. Graphical representation of the 1990-1 results are given in Figures 4.1-4.6. In Figures 4.1-4.6 three of waterlogged samples are easily identifed as the cluster of results to the far right of each of the graphs. The fourth waterlogged result, with pH 5.0, lies between these three results and the majority of the results presented in the graphs.

No data analysis was performed on the burnt material, as the act of combustion oxidises the pyrite present thereby removing any potential acid production.

Table 4.7 shows the consistency of the relationship to pH to certain extractable metals between the two sampling periods. Correlation between pH and extractable iron is negative for both sets of results. This follows the behaviour of iron in soils. Plant available copper shows a slight negative correlation with pH in the 1990-1 results. This correlation was not apparent in 1976.

Magnesium, and to a lesser extent calcium give a positive correlation with pH, indicating that at higher pH larger amounts of plant available magnesium and calcium are present. A strong positive relationship between pH and manganese supports Kimber's (1982) findings, and contradicts the behaviour of this metal in soil.

The results presented in Table 4.7 indicate certain relationships between pH and plant available metal concentration. Although the relationship may not be causal in nature, it is accepted that pH has a direct influence on the mobility of trace metals.

Table 4.7

Correlation data: pH and acetic acid extractable metal concentrations in unburnt colliery waste, Foulshiels

	Correlation coefficient (r)	
	1976	1990-1
pH v copper	0.25	-0.40*
pH v zinc	-0.11	-0.23
pH v manganese	0.57***	0.59***
pH v iron	-0.48***	-0.57***
pH v calcium	0.28*	0.43*
pH v magnesium	0.38***	0.65***

***, **, * p = 0.001, 0.01, 0.05 respectively

1976 N = 45
1990-1 N = 29 (excludes waterlogged samples)

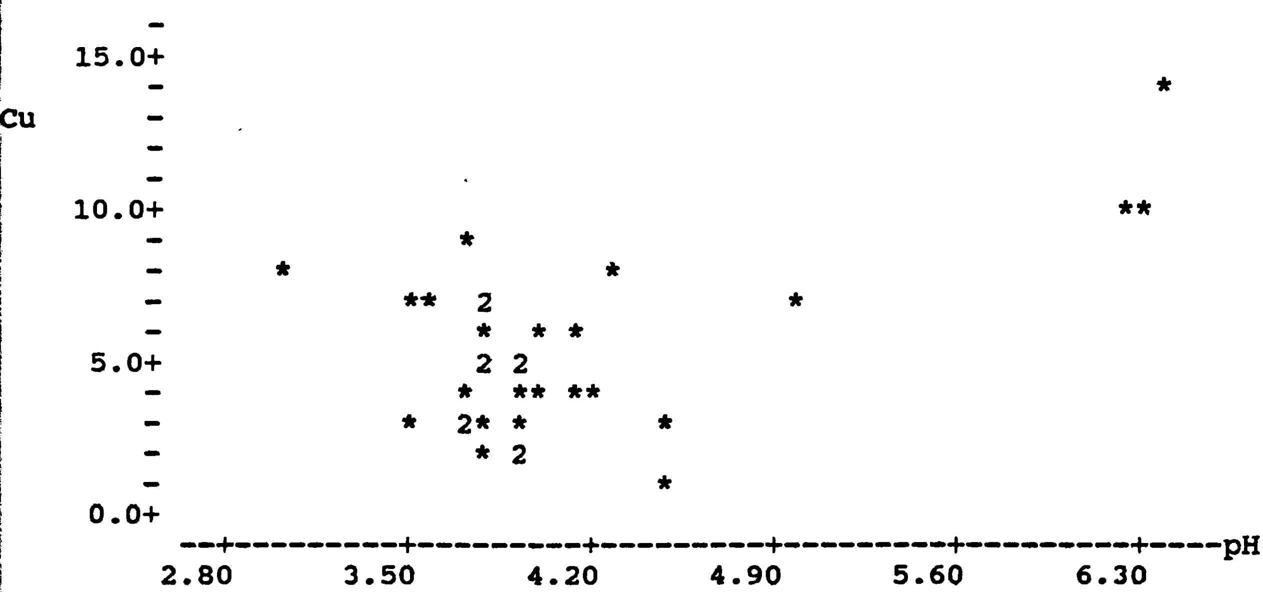


Figure 4.1 Relationship between pH and acetic acid extractable copper

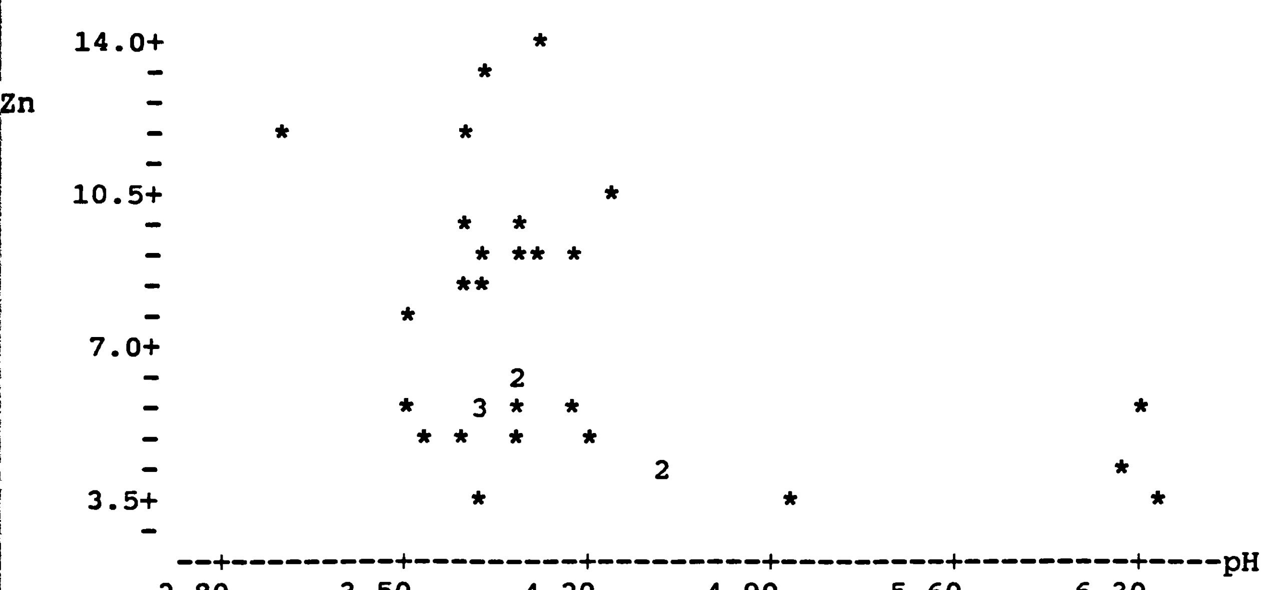


Figure 4.2 Relationship between pH and acetic acid extractable zinc

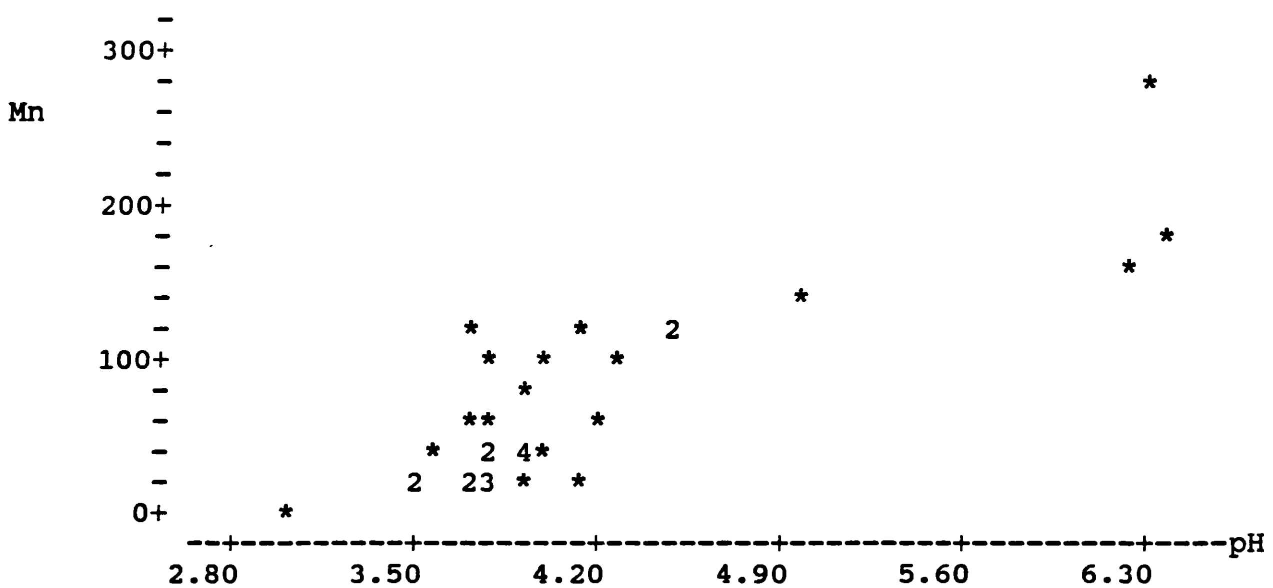


Figure 4.3 Relationship between pH and acetic acid extractable manganese

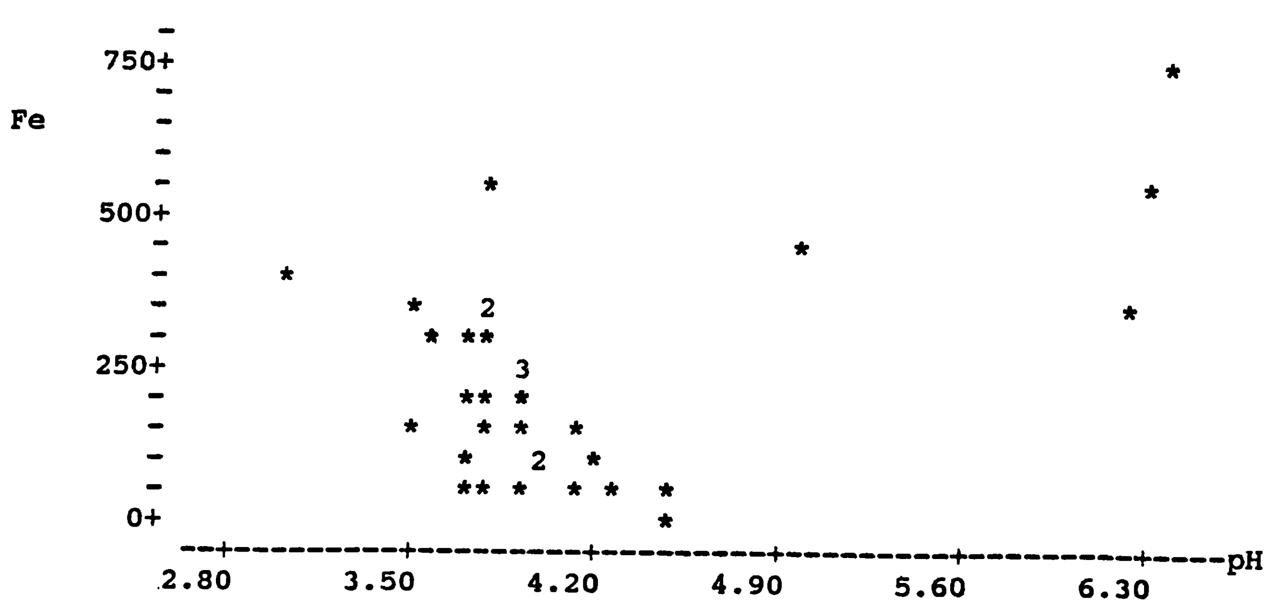


Figure 4.4 Relationship between pH and acetic acid extractable iron

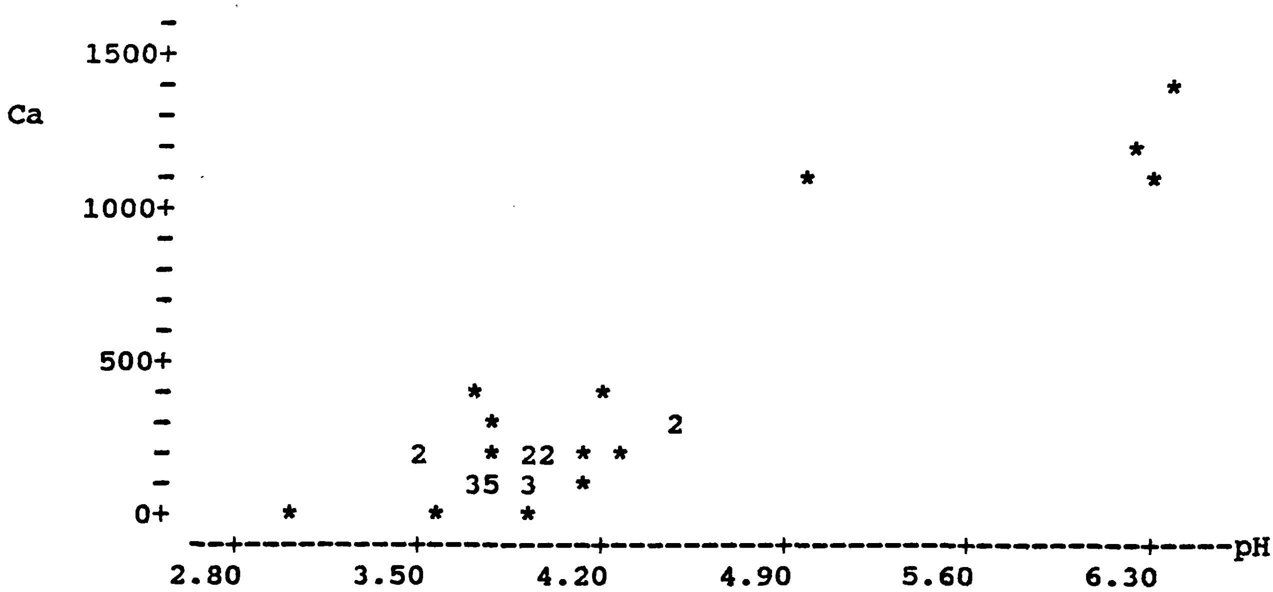


Figure 4.5 Relationship between pH and acetic acid extractable calcium

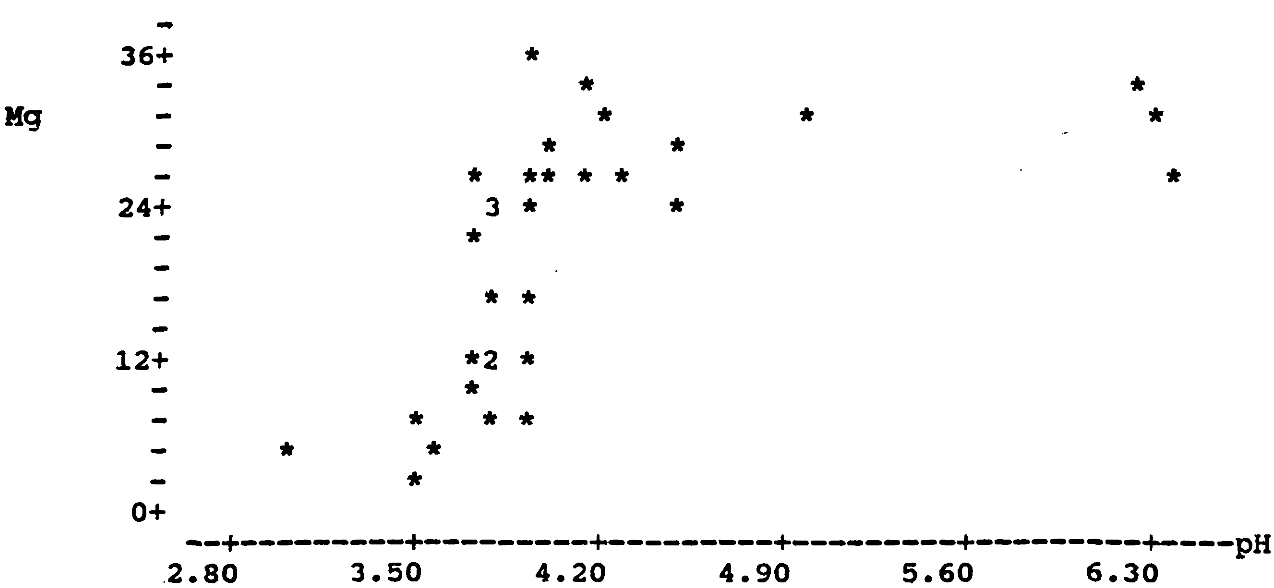


Figure 4.6 Relationship between pH and acetic acid extractable magnesium

4.5 Conclusions from pH, conductivity and extractable metal measurements

The results obtained from the experimental work carried out at Foulshiels during 1990-1 indicate that changes have taken place with regard to pH and plant available metal concentration since the initial assessment in 1976. These changes have direct significance on the reclamation project criteria with regard to pollution control and the success of the spoil as a growth medium; which in turn effect the social benefits of reclamation, particularly visual benefit and amenity use.

Saturated spoil and pH have a significant effect on the mobilisation of plant available ions in the spoil. Prior to the development of vegetation cover on the slopes of the bing, high rates of leaching and runoff would have occurred, particularly during the wetter months of the year. This runoff will have eventually found its way into the local watercourses and caused deterioration in water quality and hence effected aquatic life.

Calcium and magnesium have declined in concentration due to the increased acidity of the spoil material which has resulted in acid leaching of these ions. Similarly, manganese and iron concentrations have been affected by the acidity of the spoil and this is shown by their increased mobility and subsequent collection in the poorly drained areas of the site. Manganese and iron are particularly mobile in their reduced chemical state and their movement is indicated by the ochre discolouration of the spoil surface and ochre deposits in the drainage network.

Development of vegetation has improved the natural drainage by plant uptake of water and the provision of infiltration pathways, via root development, though the spoil. The presence of vegetation also provides organic matter in the form of dead leaves and roots. For this material to benefit the spoil as a growth medium it requires incorporation into the spoil by soil fauna. Spoil is naturally inhospitable to these organisms and there was little evidence of their presence during spoil sampling. As a result little organic matter is present in the upper spoil horizon and hence the spoil is lacking the benefit of improved soil structure and moisture retaining abilities that the presence of such material contribute to conventional soils. Organic matter is also known to chelate metals and thereby render them unavailable for plant uptake. Lack of chelation, as a result of poor 'soil condition', permits metals weathered from the spoil material to remain available for plants. This factor has contributed to relationship between pH and plant available metals remaining similar between the two sampling periods.

4.6 Analysis of water pollution in Foulshiels Burn

4.6.1 Introduction

Acid mine drainage (AMD) originates from the oxidation and leaching of sulphide minerals present in coal bearing strata. Acidity in mine drainages represents a major environmental problem in regions associated with the mining of high sulphur coal and sulphide minerals (Glover 1975).

In some coal mining regions the strata may not be acidic although the water soluble compounds of iron and manganese may still contaminate the drainage of the mine resulting in the deposition of the highly coloured pigment, ochre (hydrated ferric oxide). Where these discharges are non-acidic they are termed 'ferruginous'.

Ferruginous and acidic mine drainages may arise from a variety of coal mine related sources including coal spoil heaps. Drainages arise from the action of rainfall and may appear as surface runoff or as seepages from the toe, or from perched water tables within the spoil heap.

The effect of acidic and ferruginous mine discharges to surface waters depends on the drainage, the quality of the receiving waters and the relative dilution. The principal pollutants are suspensions of ferric oxide and dissolved iron, aluminium, manganese, calcium and magnesium sulphates. Low concentrations of heavy metal salts of copper, nickel and zinc may also be present (Glover 1975).

The adverse effects of acidity can result in loss of aquatic habitat, recreational values, contamination of groundwater, visual degradation.

4.6.2 Environmental effects of acidic and ferruginous mine discharge

The principal visual effect of acidic and ferruginous mine drainage on a surface water is the deposition of ochre. Chemically-deposited ochre is a pigment of considerable covering power, and as little as 1 mg l^{-1} (as Fe) in a stream will cause visible staining of the bed and the accumulation of opalescence in pools (WRc 1989).

Surface waters may be required for a wide variety of purposes including agriculture, industry and public supply, recreation and bathing. Acidic conditions in a surface water, as indicated by a low pH value, must be considered to reduce the value of the water for all these purposes.

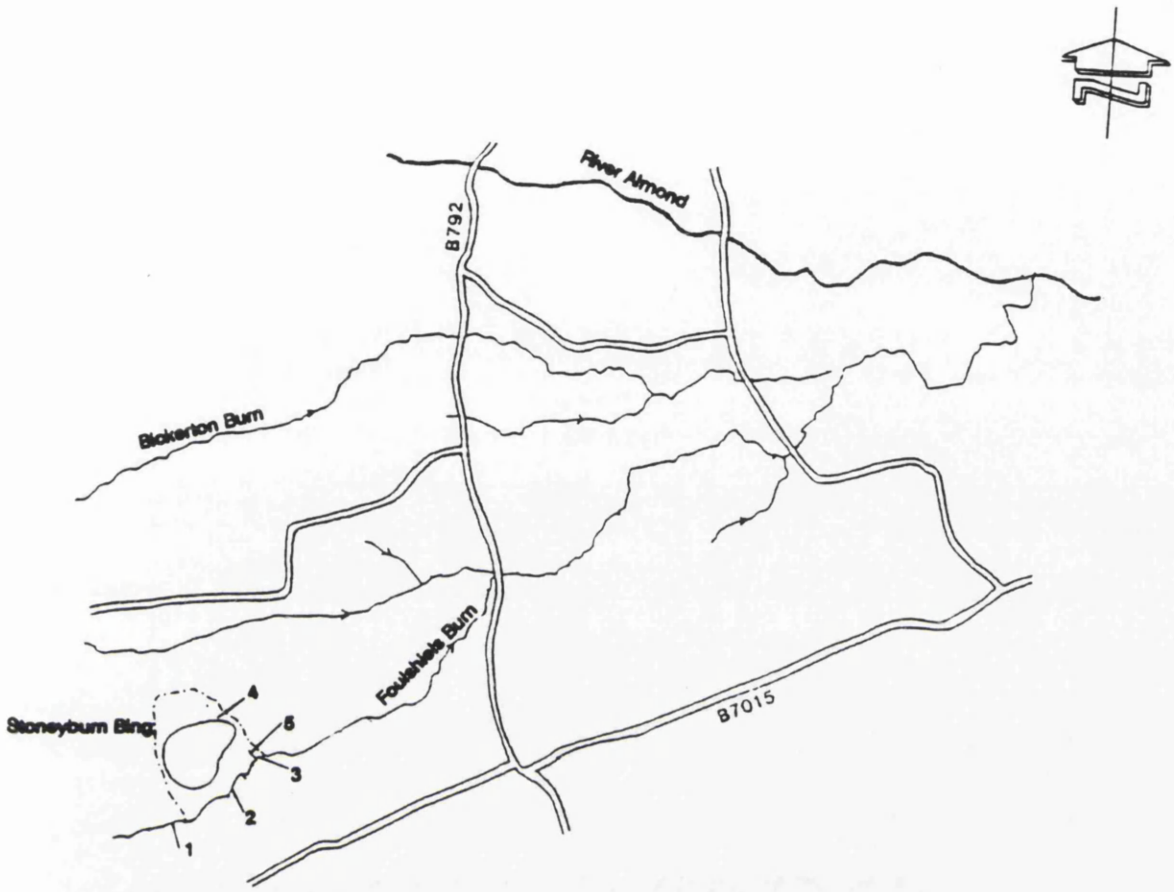
High concentrations of acidic drainages are toxic to all normal forms of surface water life, but in the absence of the mineral acid component, the other contaminants may have a less severe effect than the discolouration by ochre would suggest (Glover 1975).

4.7 Experimental design

During the winter and spring of 1976-7 Kimber (1982) carried out analysis of water pollution entering the Foulshiels Burn along a stretch of the burn adjacent to the bing. The location of the burn enabled samples of water to be collected upstream, adjacent to, and downstream of the bing and thereby provide an indication of the potential for pollution and the extent of the effect of this pollution as it was carried down stream. Figure 4.7 shows the course of the burn in relation to the bing and the sampling points used by Kimber and those during later sampling in the winter of 1991-2. At three of the sampling locations data was also obtained from analysis carried out by Forth River Purification Board (Table 4.10).

During the winter 1991-2 samples of water were collected for analysis every month from December, 1991 through to March, 1992. pH was measured and the sample filtered through a 0.45 um Whatman membrane filter prior analysis for iron, aluminium, manganese, lead, nickel, copper, zinc cadmium and chromium. Analysis to determine the levels of metals was carried out by Inductively Coupled Plasma Emission Spectrophotometry (ICP) capable of detection of a range of elements simultaneously, at parts per billion.

Water sampling locations are shown in Figure 4.7. Upstream of the bing the stream bed is primarily a dark muddy colour with no visible signs of pollution. As the stream follows the boundary of the bing, both the sides and the bed of the stream show heavy



Key

2	Sampling points
	Stream
	Road

The Course Of Foulshiels Burn
And Stream Sampling Points

Date: September 1992
Scale: 1/25,000
Figure: 4·7

Table 4.8

Chemical analysis of water samples taken from Foulshiels Burn December 1990 to March 1991

		Sample location				
		1	2	3	4	5
pH	Dec	6.0	6.4	6.0	6.1	nd
	Jan	7.1	6.8	5.6	nd	3.2
	Feb	7.0	6.8	6.8	6.0	3.1
	Mar	6.1	6.3	4.3	5.4	2.8
Fe	Dec	405	1560	371	2420	nd
	Jan	682	1570	390	nd	6170
	Feb	513	1220	1220	15820	45500
	Mar	1360	2670	1920	23320	128000
Al	Dec	262	681	287	815	nd
	Jan	344	1090	846	nd	13550
	Feb	143	701	380	1040	1460
	Mar	353	372	2970	1720	19940
Mn	Dec	48	1540	1640	6040	nd
	Jan	53	1130	1280	nd	506
	Feb	80	479	743	5980	2960
	Mar	110	4500	4760	6740	10130
Pb	Dec	bdl	37.0	37.6	44.1	97.9
	Jan	bdl	44.3	47.5	nd	66.0
	Feb	nd	nd	nd	nd	nd
	Mar	nd	nd	nd	nd	nd

All results in $\mu g\ l^{-1}$ except pH
bdl - below detectable limits   bdl - Pb = 1.0 $\mu g\ l^{-1}$
nd - not determined

Sample 1 - up stream of the bing
Sample 2 - the middle entrance culvert
Sample 3 - down stream of the bing
Sample 4 - back ditch
Sample 5 - tributary entering stream prior to sample 3 location

Weather

December - fine
January - fine
February - prolonged rain
March - prolonged rain

Table 4.8 continued.

Chemical analysis of water samples taken from Foulshiels burn December 1990 to March 1991

		Sample location				
		1	2	3	4	5
Ni	Dec	20.7	41.2	47.0	90.7	nd
	Jan	7.7	35.7	56.3	nd	23.9
	Feb	nd	nd	nd	nd	nd
	Mar	bdl	25.2	62.7	56.4	317.0
Cu	Dec	6.1	41.8	58.8	94.6	nd
	Jan	bdl	34.4	51.4	nd	373.8
	Feb	nd	nd	nd	nd	nd
	Mar	bdl	19.0	21.9	57.3	190.1
Zn	Dec	6.5	51.0	66.4	194.0	nd
	Jan	4.7	64.6	96.3	nd	377.9
	Feb	nd	nd	nd	nd	nd
	Mar	6.3	89.6	131.5	128.0	1397.0
Cd	Dec	bdl	bdl	bdl	<0.2	nd
	Jan	bdl	bdl	bdl	nd	1.7
	Feb	nd	nd	nd	nd	nd
	Mar	bdl	<0.4	<0.4	0.5	<0.4
Cr	Dec	bdl	bdl	bdl	25.2	nd
	Jan	bdl	bdl	bdl	nd	25.0
	Feb	nd	nd	nd	nd	nd
	Mar	bdl	<15.0	<15.0	<15.0	56.4

All results in $\mu g\ l^{-1}$ except pH
bdl - below detectable limits
nd - not determined

bdl Ni = 1.0 $\mu g\ l^{-1}$
Cu = 1.0 $\mu g\ l^{-1}$
Cd = 0.1 $\mu g\ l^{-1}$
Cr = 1.0 $\mu g\ l^{-1}$

Sample 1 - up stream of the bing
Sample 2 - the middle entrance culvert
Sample 3 - down stream of the bing
Sample 4 - back ditch
Sample 5 - tributary entering stream prior to sample 3 location

Weather

December - fine
January - fine
February - prolonged rain
March - prolonged rain

Table 4.9
Chemical analysis of stream water from Foulshiels Burn comparison of 1976-7 and 1991-2 data

	Sample Location				
Analytes	1	2	3	4	5
pH	6.55 (6.7)	6.58 (4.3)	5.68 (5.9)	5.83 (nd)	3.03 (nd)
Aluminium	27.5 (800)	71.2 (15600)	112 (16800)	119 (nd)	1165 (nd)
Iron	740 (500)	1755 (960)	975 (8000)	13853 (nd)	59890 (nd)
Manganese	72.8 (500)	1912 (22400)	2105 (20800)	6253 (nd)	3399 (nd)
Lead	bdl (nd)	40.7 (nd)	42.5 (nd)	44.1 (nd)	82.0 (nd)
Nickel	9.5 (<10.0)	34.1 (350)	55.3 (450)	73.6 (nd)	170 (nd)
Copper	2.0 (20.0)	31.7 (40.0)	44.0 (50.0)	123 (nd)	282 (nd)
Zinc	5.8 (20.0)	68.4 (850)	98.1 (1100)	258 (nd)	887 (nd)
Cadmium	bdl (nd)	<0.4 (nd)	<0.4 (nd)	<0.2 (nd)	<1.1 (nd)
Chromium	bdl (nd)	<5.0 (nd)	<5.0 (nd)	<20.1 (nd)	40.7 (nd)

All results in $\mu g\ l^{-1}$ except pH
Figures in brackets represent the mean of Kimber's results taken in November 1976 and May 1977

bdl - below detectable limits
nd - not determined

bdl Pb = 1.0 $\mu g\ l^{-1}$
Cd = 0.1 $\mu g\ l^{-1}$
Cr = 1.0 $\mu g\ l^{-1}$

Sample 1 up stream of the bing
Sample 2 at the culvert at the site's centre entrance
Sample 3 down stream of the bing
Sample 4 back ditch
Sample 5 tributary entering stream prior to sample 3 location

Table 4.10

Comparison of pH and iron content with Forth River Purification Board, 1974 and Kimber's data 1976-7 data for Foulshiels Burn

Sample location	pH	Iron
Upstream of bing		
1974	6.9	1.3
1976-7	6.7	0.5
1991-2	6.55	0.74
Adjacent to bing		
1974	4.9	11.3
1976-7	4.3	0.96
1991-2	6.58	1.75
Down stream of bing		
1974	4.0	40.3
1976-7	5.9	8.0
1991-2	5.68	0.97

Results for iron in mg l^{-1}

staining with iron oxides (Plates 13 and 14). Sample 1, taken upstream of the bing, enables comparison to be made with those samples contaminated by leachate arising from the coal waste material.

Table 4.10 gives the results of pH and iron analysis in the Foulshiels Burn from 1974, three years after the regrading had been completed, prior to the revegetation programme, 1976-7, to its current status in 1991-2.

4.8 Results and discussion

Table 4.8 presents the results for pH, iron, aluminium, manganese, lead, nickel, copper, zinc, cadmium and chromium for the four month monitoring period. Prior to collection of the first two month's samples the weather was predominantly dry, the third and fourth samples were collected after prolonged periods of rain. The effect of the weather on sample analysis can be seen in the results. The fourth sampling period in March took place after nearly two months of continuous rain. For the first sampling point, upstream of the bing, the highest values for iron, aluminium and manganese where recorded in this month. Nickel and copper showed a decline in soluble concentration over the same period, while zinc, cadmium and chromium seemed unaffected by the increased volume of groundwater and stream throughflow as a result of the rain.

At sample location 2, adjacent to the bing, soluble iron, manganese, zinc increased in concentration with the increase in rainfall. This trend is also evident for water soluble cadmium and chromium although the concentrations of these two metals are still comparatively low. Nickel and copper declined in concentration with the increase in rain over time.

Sample location 3, the furthest point downstream of the bing showed increases in water soluble iron, aluminium, manganese, lead, nickel, zinc, cadmium and chromium with continued rainfall. Copper decreased in concentration over the same period. pH at sample location 3 also decreased significantly over the four month period.

Sample 4 was collected from a ditch that drains the acid area on the smaller mound to the east of the site. Results from this sampling point show an increase in soluble iron, aluminium, manganese and cadmium, while nickel, copper, zinc and chromium declined in concentration during the sampling period. Soluble lead was determined only during December from this sampling point, therefore no inferences can be made as to the effects of the weather on its solubility.

Sample 5 was collected from a small tributary just before it joined the Foulshiels Burn. The course of this tributary ran alongside the smaller acidic mound of colliery spoil on the reclaimed site, and the results obtained from this sampling point reflect this. The pH of water sampled at this location was the most acidic of all the sampling locations. From January, when sampling at this point commenced, through to March the water became progressively more acidic (pH 3.2 to 2.8). Water soluble iron and manganese increased in concentration throughout this period, nickel, zinc and chromium would also appear to have increased in concentration over this period, although analysis for these metals was not carried out in February. Copper and cadmium declined in concentration from January to March.

Table 4.9 gives the averages of the results for the selected analytes obtained over the four month monitoring period and compares these results with the average of results taken in December and May 1976-7 by Kimber (1982). The results show that water pollution caused by the leaching of metals from the spoil material has generally decreased in concentration over the intervening fifteen year period. The results obtained up stream of the bing indicate an improvement in the background levels of these metals in the burn. This may be attributed to a decline in upstream sources of pollutants. pH has improved in time particularly at sampling location 2. Unfortunately Kimber's data does not permit any direct comparison with sampling locations 4 and 5, where this study indicates the primary source of pollution at present.

The results show that soluble iron, aluminium, manganese, lead, nickel, copper, zinc, cadmium and chromium increase in concentration as the course of the burn passes the reclaimed site. It can, therefore, be concluded that the spoil material is continuing to pollute the Foulshiels Burn.

The location of the source of greatest pollution entering Foulshiels Burn would appear to be the tributary entering Foulshiels Burn prior to sample location 3. This tributary collects runoff from the acid area of the site. There is no record of drainage in this area having been improved and it is possible that the high levels of contamination present are due to the longer retention time of rainfall on this area of the site. In comparision, drainage improvements, made to the waterlogged area boardering Foulshiels Burn, have improved collection and removal of runoff, reducing the contact of the water with the spoil material. These drainage improvements are reflected in the reduced level of contamination of the Foulshiels Burn in 1991-2 compared to results obtained in 1976-7, which show greater similarity with results obtained at sample locations 4 and 5 during 1991-2.

CHAPTER FIVE

5.0 Assessment of reclamation at Baads Bing

5.1 Introduction

The aim of any reclamation scheme involving the establishment of vegetation must be to create a naturally sustainable nutrient cycle within the substrate. Under natural conditions this cycle builds up over decades with new species becoming established as nutrient levels rise. Attempts to shortcut this natural process have been the focus of reclamation techniques.

The spoil material should be regarded as a parent material from which a soil will develop. Natural soil forming processes should be identified and encouraged with the aim of producing a series of climax vegetation covers that both fits the substrate as it develops into a soil and the topography.

Many initially successful reclamation schemes have regressed to become sites of secondary dereliction through lack of adequate management and nutrient inputs. Waste organic materials such as animal manures, sewage sludge, spent mushroom compost and municipal refuse have been advocated as a means of supplying longer term slow release nutrients that will help avoid such deficiencies (Bradshaw and Chadwick 1980). Bulky organic wastes can also be used to ameliorate many of the physical problems associated with derelict ground, particularly porosity, aggregate stability, water availability and generally improve conditions for root penetration and plant growth.

This chapter reviews the application of different types of amendments used in colliery waste reclamation. The success of the CASE project amendment trials established at Baads Bing in 1978 is assessed with respect to the nutrient status of the spoil in relation to the treatments applied.

5.2 Organic fertilisers

These take the form of various types of organic matter, which may be bulky, giving physical properties to the substrate as well as nutrients, or may of low bulk but provide a more limited range of concentrated nutrients.

Some types of organic matter have the added advantage of including micro-flora and fauna to initiate soil forming processes. The importance of this factor has been underestimated in the past, but an active soil microbial community is essential for the successful reclamation of derelict land (Wigfull and Birch 1988).

High bulk substances, such as straw and bark, are often of high carbon:nitrogen ratio but are slow to decompose locking up nitrogen in the meanwhile. Low bulk substances of low organic matter and high nitrogen, potassium and phosphorus should be used sparingly as they will be toxic in high concentrations. These include poultry manures and pig slurries which are important slow release fertilisers.

Sewage sludge has been used as an economic organic fertiliser in land reclamation for many years where its nitrogen, phosphorus and organic matter content has been found to be an effective means of overcoming the nutrient and physical soil deficiencies common to a wide variety of waste material, including colliery spoil.

Other well balanced organic nutrient sources include screened domestic waste. Application rates for these ameliorants will vary with site characteristics such as drainage, acidity and microbial population. However, Bradshaw (1983) calculated the rate of application required had to be sufficient to enable 1600 Kg/N to be present in the soil before cycling can effectively provide enough nitrogen without yearly additions.

Hall et al. (1986) showed that sewage sludge can reduce the requirement for fertiliser. Rates of application need to be higher than for agriculture in order to achieve the desired substantial and long term effect but, at a preferential rate of 100 tds/ha, this need not exceed maximum soil limits for heavy metals. Whilst accepting the need to protect the environment, it is argued that where the proposed land end-use is non-agricultural the agricultural limits for zootoxic elements in particular may be inappropriate.

Although organic matter does not directly counteract acidity as lime does, it modifies many of the nutrient availability problems of acid substrates by augmenting slow release nutrient levels and by acting as a buffer.

Chicken manure is richer in nitrogen than most of the other bulky organic materials and for this reason it is useful for colliery spoil amendment. The manure provides an immediate supply of nitrogen as well as providing a source over time, as the material breaks down. Bradshaw et al. (1973) found that the addition of poultry manure at a rate of 12.5 t ha^{-1} to colliery spoil in South Wales was an effective means of reducing the cost of fertiliser additions.

5.3 Application of lime

Lime is essential for vegetation establishment on colliery spoils in Scotland due to their inherent acidity. Lime requirement is calculated by equilibrium of spoil with calcium hydroxide solutions to determine the amount of lime required to raise the pH to 6.2, the optimum for pasture growth.

The chemical effects of liming include raising the spoil pH, reducing the levels of plant available metals, and increasing the availability of phosphate. Nitrogen availability is also enhanced as lime encourages the growth of leguminous species.

In addition to the amount of lime required to address the active acidity/potential acidity due to the oxidation of pyrite must also be taken into consideration. An additional application of 40 t ha^{-1} $CaCO_3$ should be made for each 1% of FeS_2 in the spoil (Costigan et al. 1981), with application rates of up to 50 t ha^{-1} not uncommon in pyritic spoil (Bradshaw and Chadwick 1980).

Insufficient application of lime may result in acid regeneration causing die back of the plant cover, Bloomfield et al. (1982) state that surface applications of lime to re-establish spoil pH at depth, after die back has occurred, are ineffective due to the slow rate of percolation. Instead, the more effective method of ploughing in any vegetation cover with incorporation of lime is suggested. This has the added advantage of increasing the organic matter content of the spoil material. Areas of reclaimed sites requiring further applications of lime are not uncommon due to the heterogeneous nature of spoil material (Plates 10, 16 and 18).

5.4 Inorganic fertilisers

An obvious and frequently used answer to low nutrient levels is to add inorganic fertilisers to provide nutrients direct to the growing vegetation in a utilisable form. This will allow rapid shoot growth, and root growth to reach deep into the spoil to extract moisture and nutrients from below the surface and to add organic matter as the plants die and decay, thus providing longterm substrate improvement. Deeper rooting also encourages granulation of loose textured spoils and breakup of the heavier spoils.

Fertiliser addition is usually in a single dose of a compound inorganic fertiliser, in most cases 20:10:10 or 20:15:15, with additional phosphate applied as required. Bradshaw et al. (1973) found that the addition of 20:15:15 at a rate of 626 kg ha^{-1} was sufficient to establish a plant cover on a number of sites, but in order to maintain growth, additions of a further 376 kg ha^{-1} in the second year and even third year were necessary. Bloomfield (1982) reported similar findings. Nutrient losses occur through leaching and soluble phosphorus is also made unavailable by fixation with the spoil. A continuous monitoring strategy is therefore required to assess the nutrient status and compensate for losses.

Inorganic fertilisers are considerably more expensive than their organic counterparts, and because of the need for further applications over time, they tend to used sparingly during vegetation establishment. As spoil has few of the characteristics of soil, other problems with the application of inorganic fertilisers have been noted. Established plants will die as fertiliser levels fall, and many years of growth and fertiliser input will be necessary before the substrate can support a cycle of nutrients to sustain vegetation without maintenance. The place of inorganic fertilisers must be as a supplement to other methods which aim to accelerate rather than substitute for natural processes and which regard the untreated substrate as a parent material to be developed as a soil.

5.5 CASE amendment application rates

Four primary organic amendments were applied at Baads; granulated sphagnum peat, weathered chicken litter with a woodshaving base, sewage sludge (part dried from settlement beds) and Alginure a commercial seaweed based soil conditioner with gypsum.

The sphagnum peat and sewage sludge was applied at rates of 5, 10 and 20 tonnes per hectare, chicken manure at 1, 2 and 4 tonnes per hectare, and the Alginure at rates of 2.4, 5.2 and 10.4 tonnes per hectare. Control plots which received no organic amendments were included and received lime rates of nil, 10 and 25 tonnes per hectare.

In addition to the trial amendments and lime applications all the trial areas were treated with a pre-seed fertiliser, inorganic granular compound NPK 15:10:10 which was applied at a rate of 300 kg ha^{-1}. The trial areas were sown with an agricultural mix containing:

Perennial rye grass I/L
Perennial rye grass E
Red or creeping fescue
Timothy E/L
Timothy I
Cocksfoot E/I
White clover or Kent Wild White

Over the first two years of the study the chicken manure and sewage sludge treatments were recorded as having resulted in better vegetation cover than the other treatments.

5.6 Experimental design and chemical analysis of spoil material for pH, conductivity and extractable metal concentrations

The study at Baads had two purposes; to determine the nutrient status of spoil on the main site with respect to its ability to support vegetation, and to determine the long term effect of a variety of amendments applied under the CASE project in 1978. To achieve these aims the following site sampling regime was applied.

A total of sixteen spoil samples were collected randomly over the site with the exception of the CASE trial areas. Further samples of spoil were taken from four trial plots, each of which had been treated with different amendments. All samples were analysed to determine any variation to pH and plant available copper, zinc, manganese, iron, calcium and magnesium. In addition further field pH measurements of a further eleven trial plots were made and the results compared with the amendments applied.

Measurement of pH and electrical conductivity was carried out as described in section 4.2.1, measurement of acetic acid extractable metals was carried out as described in section 4.2.2.

5.7 Results of analysis for pH, conductivity and extractable metal concentrations from spoil material taken from the main site

Results of analysis of the spoil material from the main site are presented in Appendix Two, Table A. The range, mean and standard deviation of the results for each analyte are presented in Table 5.1.

Table 5.1
Results of pH and acetic acid extractable metal concentrations in spoil material from the main site at Baads

	pH	Copper	Zinc	Manganese	Iron
Range	2.8-6.2	0.3-1.8	0.2-4.1	0.5-55.0	48.0-207.0
Mean	3.5	0.73	1.16	13.24	110.9
SD	0.9	0.4	1.1	17.7	46.3

	Calcium	Magnesium
Range	54.0-832.0	5.8-41.0
Mean	182.5	16.5
SD	189.6	10.2

N=16

Results presented in $\mu g\ g^{-1}$ with the exception of pH pH of the spoil samples taken from the main site indicate a broad range of results, however, it can be seen from the mean and standard deviation that the majority of the samples were very acid, this is shown in Table 5.1.

Results of acetic acid extractable metals show that copper and zinc occur in low concentrations in the spoil with little variability in the range of results. Manganese and iron show more variability in the available concentrations of these ions, as do calcium and magnesium. The mean values for calcium and magnesium indicate that there is generally a low concentration of these acid neutralising ions in the spoil and this is reflected in the pH.

The relationships between pH and each of the metals extracted is shown in Figures 5.1 to 5.6. Statistical analysis using Pearson product moment correlation co-efficient, r, was applied to the study of the relationship between pH and the extractable metal levels found in the spoil material from the main site at Baads. The results are presented in Table 5.2.

The correlation of pH and manganese, pH and magnesium and pH and calcium support the positive correlation of pH with the availability of these ions at the Foulshiels site. However, the correlation between pH and calcium is more significant at Baads, and that between pH and magnesium less so.

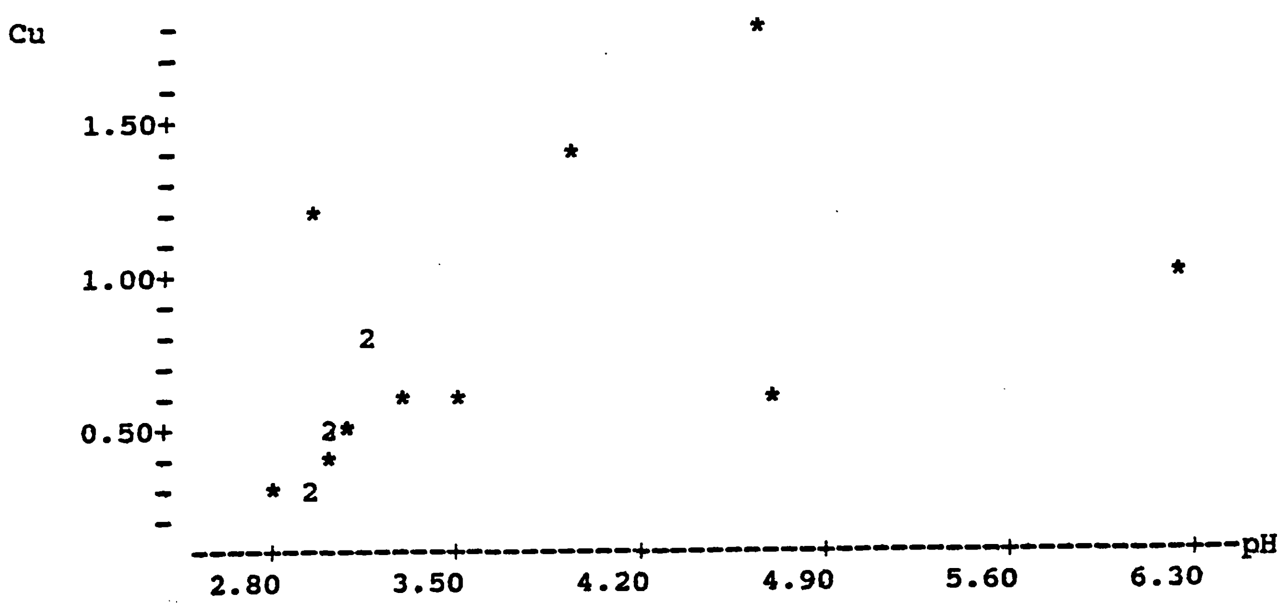


Figure 5.1 Relationship between pH and acetic acid extractable copper

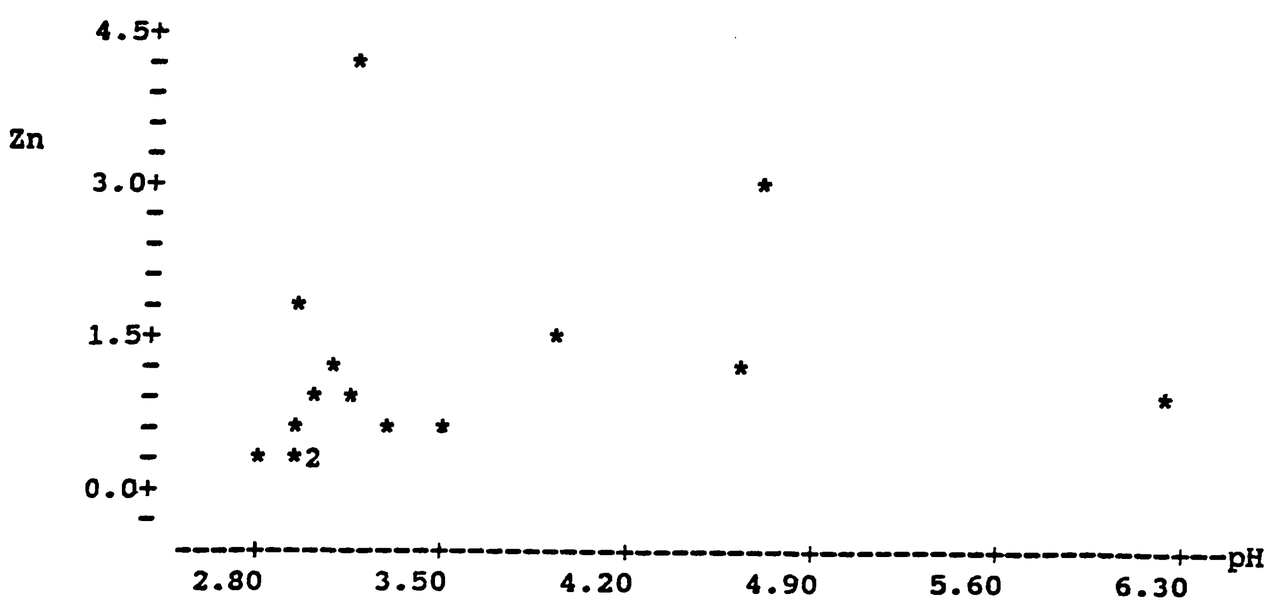


Figure 5.2 Relationship between pH and acetic acid extractable zinc

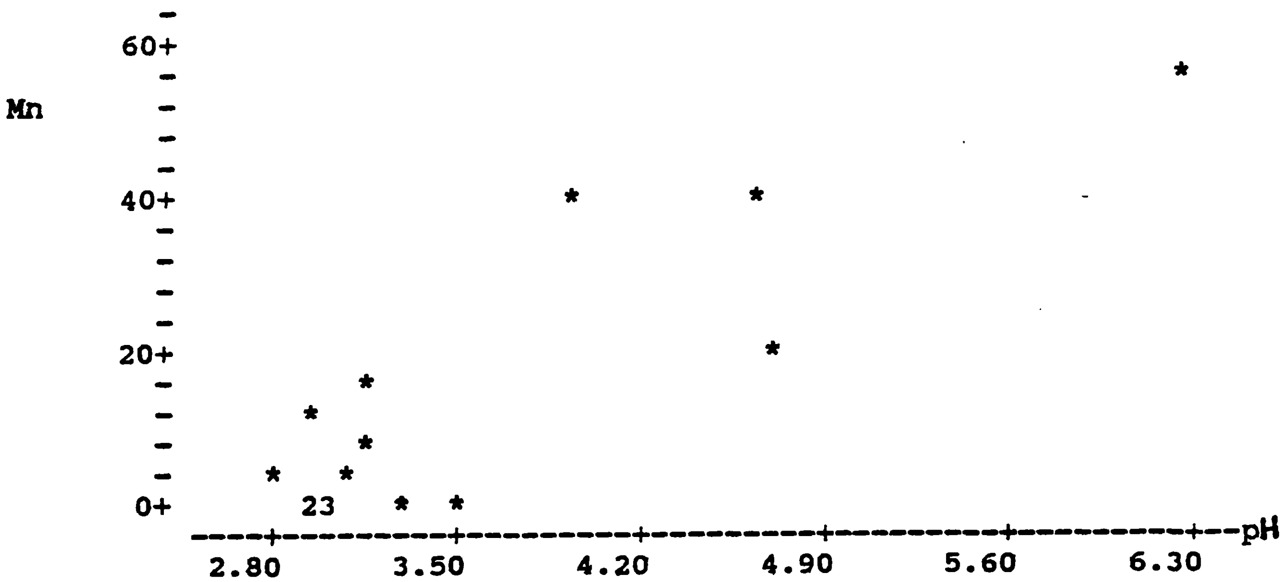


Figure 5.3 Relationship between pH and acetic acid extractable manganese

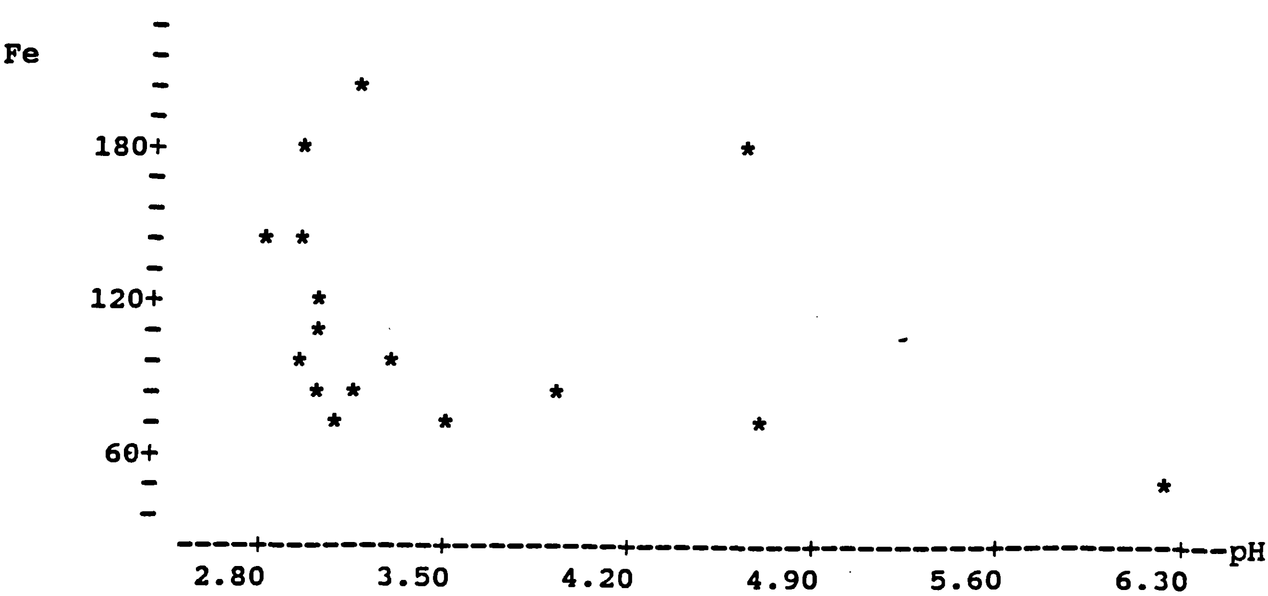


Figure 5.4 Relationship between pH and acetic acid extractable iron

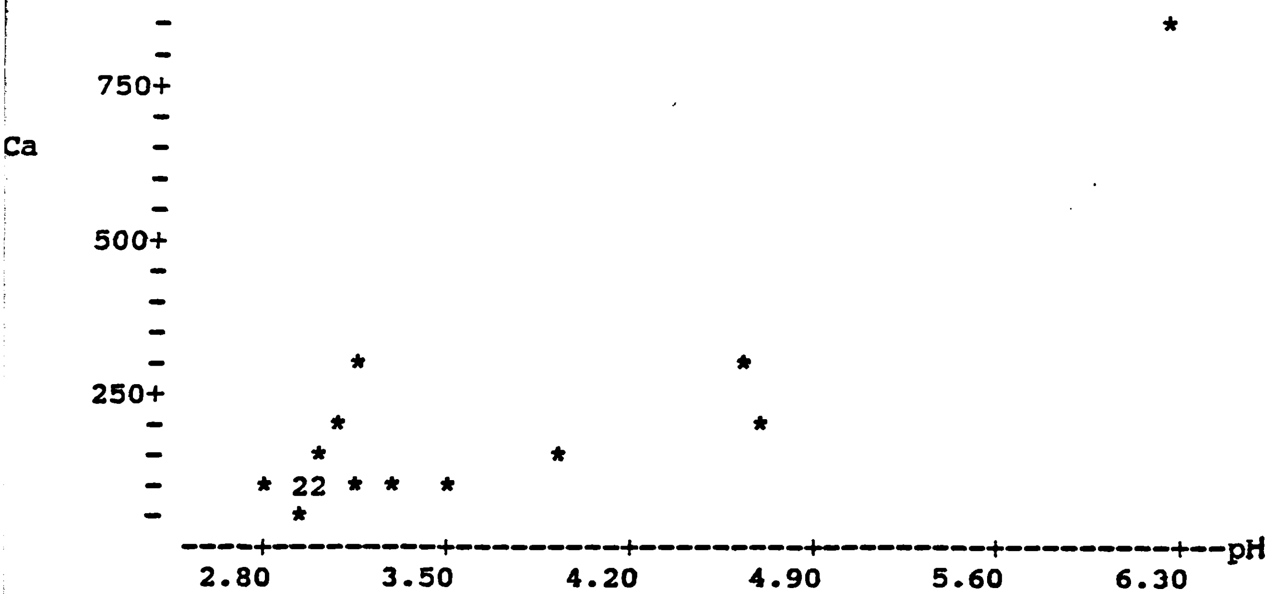


Figure 5.5 Relationship between pH and acetic acid extractable calcium

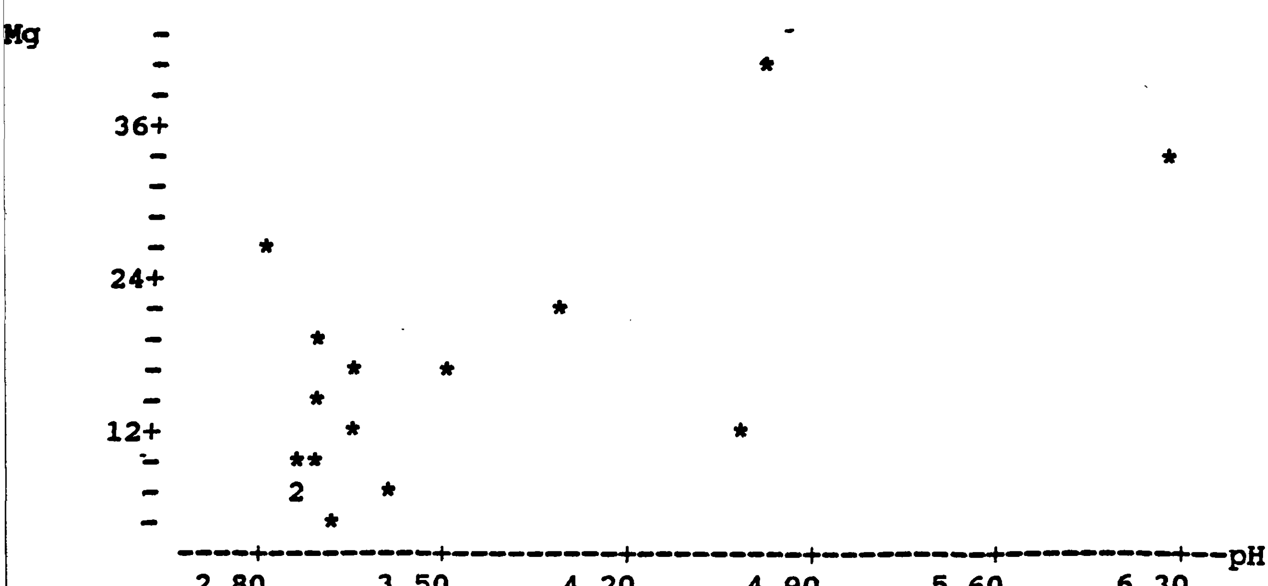


Figure 5.6 Relationship between pH and acetic acid extractable magnesium

Table 5.2
Correlation data: pH and acetic acid extractable metal concentrations in spoil material from the main site at Baads

	Correlation coefficient (r)
pH v copper	0.509*
pH v zinc	0.197
pH v manganese	0.868***
pH v iron	-0.346
pH v calcium	0.870***
pH v magnesium	0.662**

***, **,* p = 0.001, 0.01, 0.05 respectively

The correlation between pH and copper at the Baads main site is slightly positive, whereas pH and zinc show no correlation. Although the relationship between pH and iron was negative, as determined at the Foulshiels site, it was not significant.

Electrical conductivity measured in the spoil from the main site showed a variable range in concentration (Table A, Appendix Two).

5.8 Conclusions from pH and extractable metal measurements

Baads bing is known to contain highly pyritic spoil and the results presented in this study emphasise the problems of pyritic weathering with respect to spoil acidity and the mobilisation of ions. Although the site received high applications of lime during the reclamation period most of this has now been either leached away or utilised by the site vegetation.

Evidence of pyritic weathering over the site is common place, particularly in the area of the washery. The acidic leachate moves down slope, killing all vegetation in its path. If this secondary degradation of the site is permitted to continue the site will return to its former barren state.

With the acidity, ions are more mobile and the comparatively low levels of copper, zinc, manganese and iron found in the spoil at Baads is the result of leaching. The site has an exposed location subject to quite high rainfall. This, combined with the recontouring of the site, results in rapid runoff and preventing areas of waterlogging from occurring as in the case of Foulshiels.

5.9 Results and discussion of analysis from the CASE trial plots

Results of analysis for pH and acetic acid extractable metal concentrations for samples taken from specific CASE trial plots and details of the amendments applied are presented in Table 5.3.

Plot A25 had a surprisingly low pH in relation to the lime application received and the level of calcium determined in the spoil. Plots A26 and A29, received the same application rate of lime and both had higher pH values, but differing extractable calcium values, whereas A33 which received no lime or amendments has the lowest pH and a high extractable iron value, both probably as a result of pyrite weathering.

The variability between plots A25, A26 and A29 in relation to pH and extractable calcium levels may be attributed to the different application of amendments to each of the plots received. A25 received 10 t ha^{-1} sewage sludge, plot A26 received no amendments while plot A29 received 1 t ha^{-1} of chicken manure. It is possible that the application of organic matter to plots A25 and A29 could have contributed to the better retention of available metals as the results indicate that both these plots have generally higher available metal concentrations than plot A26 which only received lime.

Table 5.3

pH and acetic acid extractable metals from amendment plots at Baads

Plot Ref.	Amendment applied	pH	Cu	Zn	Mn	Fe	Ca	Mg
A25	lime 50 t ha^{-1} sewage sludge 10 t ha^{-1}	2.9	1.9	4.1	69.0	232	795	28
A26	lime 50 t ha^{-1} no amendments	5.7	2.8	4.9	6.5	115	75	77
A29	lime 50 t ha^{-1} chicken manure 1 t ha^{-1}	5.0	2.2	4.8	78.0	226	288	50
A33	no lime no amendments	2.5	1.2	2.5	30.0	300	56	41

All results in $\mu g\ g^{-1}$ with the exception of pH

Unfortunately analysis of the sewage sludge prior to application was not made, therefore, its significance to the levels of metals sampled in the spoil to which it was applied cannot be determined.

A factor that may have influenced the results of the trial plot analysis could be the aspect of the plots, which gently sloped south, and the location of the sampled plots to others, excluded from the study. For example, plot A25 was located directly down slope of a plot that received no lime and the equivalent of 20 t ha^{-1} sewage sludge. The lack of lime application to this plot may have resulted in high acidity of the spoil material and the leaching of this acidity down

Table 5.4

pH of Baads trial plots treated with different amendments

Plot Ref.	pH	Amendment applied (t ha^{-1} equivalent) L	P	SS	CM	A
A20	2.88	-	-	-	-	.3
A21	2.41	-	-	20	-	-
A24	3.00	-	5	-	-	-
A25	3.50	50	-	10	-	-
A26	6.00	50	-	-	-	-
A27	6.60	50	-	-	-	1.2
A28	6.35	50	5	-	-	-
A29	5.30	50	-	-	1	-
A30	3.10	-	-	-	4	-
A31	3.00	-	20	-	-	-
A33	2.88	-	-	-	-	-
A34	5.12	50	-	-	4	-
A35	2.50	-	-	5	-	-
A36	3.35	25	-	10	-	-
A39	6.30	50	-	20	-	-

L - lime, P - peat, SS - sewage sludge,
CM - chicken manure, A - Alginure

the slope to plot A25.

Variation in pH in relation to the different plot amendments is shown in Table 5.5. The effect of high applications of lime (50 t ha^{-1}) is easily demonstrated. With the exception of A25 all the plots that received lime at 50 t ha^{-1} had a pH of 5.12 or greater after the initial application of lime 10 years previously.

Amendment plots that recieved high applications of lime in conjuction with organic amendments appeared, in some instances, to illustrate the benefits of the addition of the organic matter in sward development. Whereas plots that recieved only organic amendments demonstrate little change in pH in relation to the control (Plot A33) and were generally devoid of vegetation.

Although the results for CASE trial plots recorded here would indicate that lime is the most effective means of combating colliery spoil acidity the period of time that has passed since the amendment applications were made, makes conclusions as to the effectiveness of the different types of amendment in relation to one another difficult to determine.

The properties of organic amendments which make them useful as a soil conditioner and their ability to chelate metals, thereby making the metals unavailable for plant uptake can be of particular benefit in relation to the vegetation of spoil material. However, organic amendments breakdown quickly, hence their re-application on a set timescale is required for longterm benefit.

CHAPTER SIX

6.0 The social benefits derived from the reclamation of Foulshiels as perceived by the local community

6.1 Introduction

Reclamation of derelict and contaminated land enables an important resource to be re-utilised to the benefit of the environment and society. Former industrial sites reclaimed to soft end uses enable the value of the reclamation project to be assessed on the basis of environmental quality and amenity provision for those that use the site, or live in its vicinity.

Although nature conservation will normally only be appropriate where derelict land sites have been naturally colonised by vegetation, or where habitat recreation has taken place, the conservation of wildlife for amenity and educational value may be appropriate on a much wider range of sites. The ability of derelict land to provide facilities for informal interests, such as walking and picnicing, undertaken by a large proportion of the population, has considerable benefit. Use of reclaimed land for recreational pursuits helps to mitigate the pressure of demand, and ease the competition with, the more traditional industries of agriculture and forestry for countryside resources.

Informal recreation is the most widespread use of derelict land. Almost any type of site will be used by local people, most commonly for walking but also for such activities as motorbike scrambling, riding and play areas. Reclamation and management of these areas, thereby enhancing their value to the local community, is an important aspect of derelict land reclamation. To promote the use of reclaimed derelict land for recreation and amenity, sites must meet certain criteria. Potential users must be aware and knowledgeable of accessible areas, the site must provide conditions attractive to the user and conflicts between different types of recreational activity must be reconciled. Some activities, such as motorbike scrambling, are spatially exclusive and hard to reconcile to other informal and unstructured activities. High levels of use may be concentrated to restricted areas. These areas, if used for recreation may have low ecological resistance and recreational carrying capacity. Reclamation design must, therefore, take into consideration the types of use the site may be required to for fill, and may require that the site is designed to be less attractive to those uses considered inappropriate.

By definition derelict land illustrates aspects of industrial history which are no longer part of everyday life and can be used to describe how or why these land uses developed and declined. Some sites are more evocative than others and particularly valuable features are remains of buildings or other infrastructures associated with former use.

Reclamation of derelict land has a social benefit through improving the visual quality of the area. Past coal mining areas are often characterised by numerous large spoil heaps that encroach on the landscape and result in visual blight. Landscape design, as part of a reclamation project, should be regarded as a non-utilitarian resource with social and aesthetic value of greater importance than its purely practical values. Reclamation projects should reflect this by interpreting the future role and consequent landscape character of an area.

Social structure and functional characteristics can differentiate communities formally associated with mining with those coming into the area for other reasons. This may reflect the attitudes and usage of the area by the local community. Deep mining frequently leads to the establishment of a community based on mineral extraction, closure of pits in traditional mining areas has lead to outward population migration, while increasing affluence and mobility of society in general, has enabled a change in the population mix of the countryside. With these changes in country population have come changes in attitude and perception of local people to the environment and their surroundings.

This chapter assesses the social benefits of Foulshiels reclamation in relation to the amenity and visual benefits to the residents in Stoneyburn. By means of survey, incorporating interview and questionnaire, opinions on the benefits gained from the reclamation of the former colliery site were obtained. Analysis of the survey data was then used to evaluate environmental perceptions in relation to various respondent variables such as age and length of residence in the village.

6.2 Experimental design

A questionnaire was designed to obtain information from the residents of Stoneyburn, on their opinion's with regard to the reclamation project, particularly with respect to the visual and amenity benefits the reclamation of the site provided. Age and length of residence in Stoneyburn were considered important factors influencing the responses obtained from individuals, therefore, a section of the questionnaire was devoted to obtaining data from respondents with respect to these criteria.

The format of the questionnaire was strictly followed during each interview. The questionnaire contained both open and closed questions. Open questions invited responses that permitted the use of descriptive summaries in the analysis, while closed questions, involved the respondent making a choice between a set of answers with the potential to use non-parametric statistical analysis.

The survey was carried out in the east side of the village. This part of the village is within the zone of visual influence, the area around Foulshiels from which the site is visible. Respondents were selected from every twelfth house in the survey area. Where occupiers were not interested in participating, their immediate neighbours were approached. A total of thirty three questionnaires were successfully completed.

6.3 Questionnaire results

In the appraisal of environmental quality using social survey techniques subjectivity plays and important role. As a result of the small sample size used in the survey, which never the less was a significant sample proportion, it was decided that descriptive statistics should be used to evaluate all the data.

6.3.1 Respondent data

Age structure of the respondents was bimodal in distribution. The respondents in the survey were either long-term residents in the village (longer than 35 years) or had been resident less than 10 years. When considering that the mine at Foulshiels closed in 1958 and the washery in 1963 the number of respondents that are likely to have remembered either of these events will have been resident in Stoneyburn or the locality a minimum of 26 years (washery) and 31 years (mine) allowing for the respondent to be able to recall events as a two year old. It is likely, therefore, that no more than 16 (48%) respondents remember the mine working. Reclamation of the site commenced in 1971. Nineteen (57%) of the respondents in the survey remembered the first and subsequent stages of the reclamation project.

Twenty five of the respondents (75%) were 36 years and older. Of these 25, 16 (64%) had been resident in Stoneyburn for more than 36 years, of which five had been resident all their lives. Respondents resident in Stoneyburn for less than 10 years did not fall into a particular age grouping and their reasons for moving into the area varied from a location to retire, a rural home from which the respondent commuted to work or the offer of council housing. Whilst the first two reasons for locating in the area are by freedom of choice, the third reason may have been the result of necessity, as in the only offer of housing available.

6.2.2 Visual benefit

When asked 'how appropriate the reclamation of the site has been in relation to the other land uses in the vicinity?' twenty six respondents (79%) felt that the reclamation was appropriate. Of these, one respondent (3%) felt that the reclamation was appropriate because it was important to plant trees, another 9 (27%) felt that there was little point in returning the site to agriculture because of current over production of agricultural produce, while two ex-miners (6%) from the former Foulshiels Colliery felt that the site provided a nostalgic reminder of their past livelihood. A further 4 respondents (12%) felt that the site was not sufficiently close to the village to be of direct benefit to the residents but that the reclamation was not necessarily inappropriate in relation to other land uses in the area. The remaining 10 respondents (30%) felt the site was fine as it was with no further suggestions for alternative usage.

Seven respondents (21%) felt that the site could have been more appropriately reclaimed. Three would have preferred the site to have been returned to agriculture. Their reasoning for this was shared, in that they felt the site attracted fly-tipping in its present use. The remaining four respondents felt there was little visual benefit from the site but were unable to suggest an alternative form of reclamation.

When asked how the respondents rated the visual quality of the site one respondent (3%) felt the site was very poor, 9 respondents (27%) felt it was fair, 14 respondents (42%) felt the visual quality was good while 9 respondents (27%) felt it was excellent. Of the 33 respondents questioned 20 (60%) felt that the visual quality of the site from the village was good, while some of those that were more familiar with the site through use (14 (40%)) felt that lack of maintenance detracted from the visual quality. Specific aspects of the site mentioned were; fly-tipping at the centre entrance to the site, litter strewn in some areas of the site, and the health of some of the trees, particularly those growing on the small side mound. These trees growing in particularly acid substrate and the quality of their foliage and the stunted growth of some, particularly oak, reflect the quality of the growth medium.

Respondents were asked what improvements they would like to see made to improve the visual quality of the site. The prevention of fly-tipping and litter collection were considered priority by thirteen (39%) of the respondents.

6.3.3 Amenity value

When asked what functions the respondents thought the reclamation of the site was intended to perform 23 (70%) replied 'to make the area more attractive'. Seven (21%) of the longer term residents added that it was to address the problems with the burning material and the resulting smell and dirt this caused. These 21% were also aware that the reclamation of the bing had been linked with other proposed environmental improvements in the village during the late 1960's early 1970's. Only two respondents (6%) were aware of the water pollution caused by the colliery waste, and that the reclamation was intended to address this, amongst other problems. One of these respondents had worked on neighbouring land.

Five respondents (15%) felt that the functions the reclamation of the site had intended to achieve had been addressed fairly well. Nineteen respondents (58%) felt the functions had been achieved well and 7 (21%) excellently. Two respondents (6%) had no idea whether the reclamation had for filled its proposed functions, as they had never visited the site and had no knowledge of it.

How well the site was maintained for its intended functions brought a wide range of response. Three respondents (9%) had no idea, either because they had not used the site or because their last visit was a considerable time ago. Five respondents (15%) thought the site was poorly maintained, while thirteen (40%) thought the site was fairly well maintained. 10 respondents (30%) felt the site well maintained, and two (6%) thought the site was excellently maintained although neither had visited the it for at least three years.

The sample size precluded any firm conclusion to be drawn between site usage and age dependence. The younger respondents used the site primarily at the weekend and women were the primary users during the week. Although, this trend would seem more related to employment characteristics than age, the survey did reveal that men between the ages of 20 and 36 were less likely to use the site. Retired respondents who used the site, did so equally during the week and at weekends. Two respondents who used the site commented that it provided a circular walk of suitable length that had the advantage of not having to retrace one's steps. These same respondents felt the site was sufficiently large to permit a variety of route variations which enhanced the benefits of the site and therefore increased their usage. One of the older respondents stated that he would use the site more frequently if there was seating provided at regular locations to enable him to take rests during his walks. The two respondents under 20 used the site for push-bike and motorbike scrambling with their friends and '...to keep out of their parents way..'. This latter comment was understood to include taking part in activities their parents disapproved of, such as smoking.

When asked whether the respondents used other reclaimed sites in the locality besides Foulshiels, 19 (58%) responded yes. Use of reclaimed sites included the former mineral railway, which links a number of old colliery sites in the area. The majority of the railway now links in with a network of footpaths, one of which runs alongside Foulshiels, and another passes through a previously derelict area of land between

Stoneyburn and the neighbouring village of Loganlea. Eleven respondents (33%) replied that they only used Foulshiels and three respondents (9%), who were relatively new to the village were unaware of the areas of reclaimed land in the locality and felt unable to comment.

Asked 'what aspect of the site did they find most or least attractive?' respondents were asked to award points to specific criteria on a scale of 1 to 5, 1 representing the least attractive and 5 the most attractive. Appearance of the site gained the highest score. The respondents that gave attractiveness a score of 5 or 4 where those that remembered the site pre-reclamation when the effects of atmospheric pollution on the village were quite acute. Those that considered the moderately attractive (score 3) were familiar with the site, either as regular or occasional users, while those that thought the attractiveness of the site poor (score 2 or 1) were either unfamiliar with the site, or felt that the problems with fly-tipping and the effects of poor maintenance in relation to litter and vegetation appearance, detracted significantly from the general appearance. The respondents that felt that the site would have been better returned to agriculture also considered the attractiveness of the site poor.

The second highest scores were attained for remoteness, interpreted as quietness and seclusion, and the wildlife/nature interest the site provided. It was apparent that those respondents that considered the quietness of the site most attractive enjoyed the benefits of exercising their dogs off the lead or remaining out of sight of parents! While those that appreciated the wildlife/nature interest of the site took pleasure in the broad range of flowering plants that had become established on the spoil.

Proximity and accessibility of the site to the respondent rated equal third. Respondents that used the site regularly felt that these criteria were important to their usage. The three access points from the village were considered a benefit by six of the respondents. Six of those that used the site regularly considered accessibility an important aspect of the site. These six respondents also mentioned the benefits of the site with respect to the good walking surface that the colliery waste provided, although 9 respondents felt that some areas of the site collected more water on paths during the winter than they would have liked. Five respondents felt that the accessibility of the site was too good and therefore detrimental as it attracted fly-tipping and encouraged motorbike scramblers. Those that used the site for motorbike scrambling commented on the benefits of the surface, particularly with respect to the good road holding characteristics! Only two respondents that were not in favour of the scramblers, primarily because of the noise the motorbikes created, not because they saw a conflict in use of the site. Those that felt that fly-tipping was encouraged through easy access were in favour of access to the site via styles or wishing gates.

Two aspects of the site that some respondents found attractive but were not listed in the questionnaire were, the nostalgic value of the site and the view provided from the summit of the larger bing.
The three respondents that considered nostalgia an important site attraction had strong links with the working colliery, either as ex-miners or their immediate family. One ex-miner commented that prior to poor health, he would take his grandchildren over to

the site and explain to them how the mine worked. All three respondents associated the site with a way of life that was much harsher and less forgiving than the lifestyles available to most people today. Although none were prepared to return to life in a mining community, they all commented on the friendliness and helpfulness of neighbours to one another compared to the what they saw as lack of involvement in present day communities.

The view provided from the summit of the largest bing was considered an important aspect of the site by four respondents. As the surrounding area of Bathgate is quite flat, on a fine day the bing provides an excellent vantage point for some miles around.

When asked whether respondents thought the site reclamation worthwhile or whether they would have preferred the Local Authority to invest in other aspects of the community a range of responses were obtained. The two respondents under the age of 20 and four of the respondents within the 21-35 year age grouping would have preferred better entertainment facilities. The general complaint was that there was little for the younger people of the village to do unless they had the means to travel into town. Five of the respondents between the ages of 36-65 years commented that they would have preferred better public transport facilities for the village. Whether these comments would have been valid at the time of reclamation, or whether recent deterioration in public transport influenced this opinion was difficult to determine. Four other respondents felt that the Council should have spent more money on general improvements in the village rather than the colliery site.

6.4 Summary and discussion

Evaluation of the results obtained from the survey indicate that two-thirds of the respondents use Foulshiels for informal recreational activities. Although some of these activities would appear to be conflicting, for example, the use of the site for walking and motorbike scrambling, the user:carrying capacity ratio appears to mitigate any potential confrontation between these activities. As a result both are able to be accommodated simultaneously. The hard-wearing nature of the colliery spoil has particular advantages for motorbike scrambling. Spoil is more resistant to erosional damage than soil surfaces and this helps to prevent deterioration of paths and saves maintenance.

Although respondents that use the site may be accept the varied activities the site supports they appear less tolerant to the wanton degradation of the site by such activities as fly-tipping and litter. This change in attitude may reflect the change in interest in the environment, away from the strictly economic view of what the environment offers, towards a more overtly moral or aesthetic concern for the present and future environment.

The visual benefits of the site were appreciated by the majority of the respondents, and particularly those that remembered the site prior to reclamation. Most of the respondents understood the importance of continual site maintenance if the area is to avoid degradation and loss of amenity. The majority of the respondents perceived that many of the problems associated with the site, such as the poor quality of some of the vegetation, and surface water on the site during the wetter months were a product of insufficient maintenance.

However, with all studies that attempt to interpret human perceptions there are a number of factors that influence the responses. Possibly the most significant is the socio-economic level of the respondents. Those respondents that have moved to Stoneyburn by choice are more likely to respond to their environment positively than those that have been forced into the area, for example, because it is the only source of available housing. Education is also an important factor which has significant bearing on an individual's perception and subjective judgement.

CHAPTER SEVEN

7.0 Reclamation objectives and aftercare management of former colliery sites

7.1 Introduction - approaches to successful reclamation

The legacy of derelict and contaminated land in the UK is increasing despite the reclamation and restoration effort. The problem of much of the derelict land in Britain is that it frequently occurs on the edge of communities, often by housing areas. Children are at risk when playing near abandoned buildings and other structures such as shafts. Contaminated land presents problems with pica, may inhibit establishment and growth of vegetation and pollute groundwater.

Dereliction encourages fly-tipping and litter which blights whole neighbourhoods. The degraded and neglected atmosphere of an area can cause loss of self respect by those living in the area and lead to further deterioration. Derelict land can drive inhabitants and established industries away to more attractive locations and discourage new industries from locating in the area.

The removal of hazards or the creation of valuable land for buildings and industry justify the considerable expense involved in reclamation of derelict and contaminated sites. However, this expenditure is harder to justify when the creation of public amenity is the product of remedial work to control pollution and treat dereliction. Low cost techniques of land reclamation widen the scope of returning such sites to community use, and provide a potentially valuable asset to the community.

The after uses of a site may provide important functions in the provision for needs of recreation, education or landscape, improving the environment and providing opportunities for local people to use the open space. Although more remote sites will have a low level of active use, they are still a value to the landscape and the ecology of the area, particularly in intensively farmed areas. The proximity of much derelict land to communities makes it well positioned to serve the demands of local people. It can provide a buffer between housing and farmland, absorbing the pressures of the demand for public open space and provides a pleasant contrast with surrounding farmland and housing areas.

The ecological value of such sites, although not specifically addressed in this study, is of primary importance to reclamation projects. Over recent years there has been increased interest in nature conservation and the creation and supplementation of some of the lost and degraded habitats. Surplus agricultural land has been seen as an opportunity to rectify habitat loss and the reclamation of derelict land can provide similar opportunities rather than add to unwanted farmland. This suggestion is strengthened by the nature of many derelict sites, which are well suited to development of their ecological value due to low fertility, and in some instances long abandonment.

Nature and time have combined to produce vegetation cover on some derelict sites, and these sites are frequently used by local people for recreation. Vegetation types and species that naturally invade derelict and contaminated sites are those best suited to the harsh conditions. By working with these species the amount of amelioration required for the growing medium is reduced, yet revegetation with these slow growing species still enables complete cover to be achieved. Long term maintenance requirements will also be reduced since the objective will be to maintain a semi-natural state, not an artificial one.

The poor substrate created by colliery spoil, when treated with lime and other amendments to improve the chemical and physical quality of the growth medium, makes these sites ideally suited to slow growing, acid tolerant, native grass species. The imbalance of plant nutrients inhibits invasion and domination of rigorous ruderals to the exclusion of native species. These less demanding species are then able to co-exist and provide greater value to wildlife. In contrast to plantation style reclamation, natural woodland shrub land has a varied structure and is unevenly distributed over an area. This increases the variety of micro habitats available. Non-native trees create a micro climate unsupportive of much of the flora and fauna of the Scottish countryside.

Derelict land should be regarded as having existing and potential benefits for local wildlife, which could be maximised by reclamation. Mature vegetation and rare species should be protected. Emphasis should be on the development of existing vegetation, this will also help the reduction in costs. Vegetation should be designed to make the most of views. Habitat creation should be incorporated into some sites, with areas of grass land, wetland, heathland, trees and scrubs. Site reclamation should be designed to relate and interact with adjacent land uses. Landscape has a high visual importance and the reclaimed site should enhance rather than detract from the landscape in the area.

Topography of sites need not always be reformed. Naturally revegetated bings show how vegetation can mask the steep sides and plant establishment is often achieved in a much shorter time than if the site has been subjected to spoil movement. The advantages of leaving the spoil material in situ are both economic with respect to the cost of engineering works but also relate to environmental cost. Exposing unweathered colliery waste during earth moving processes has been shown to result in increased environmental pollution and can add to the problems of vegetation establishment. This work has shown that the elevated levels of some of the pollutants associated with former colliery sites present a problem with respect to longterm vegetation establishment and environmental degradation of water courses for some considerable time after the initial reclamation works. Topography may also be turned to the site's advantage, providing viewpoints, segregating areas of the site for different uses, for example, motorbike scrambling, walking, ponds and wetlands and providing secluded and more open areas.

Derelict land lends itself for used by educational groups for site and field studies. A naturally revegetated site provides these facilities and so serves a constructive role in the community. Rehabilitation of sites should, when possible, capitalise on this, retaining relevant features and building further features into revegetation design to consolidate and encourage educational use. There are two main strategies that may be relevant to nature conservation. The first is protection and conservation of wildlife and the second, conservation of wildlife as an amenity and educational resource. Nature conservation in the strict sense will normally be appropriate only where sites have been naturally colonised by vegetation of a high conservation value, for example the conservation of disused lime quarries. The conservation of wildlife for amenity and educational value may be appropriate on a much wider range of sites and habitats may be specifically designed and constructed for the purpose. However the two strategies are not mutually exclusive.

Low cost revegetation of derelict land is carried out by fitting the choice of vegetation to the substrate to develop an ecosystem. The design of vegetation must be naturalistic, fitting the limitations of the site regarding both substrate and topography. It must also be suitable for the intended afteruses of the site, particularly with respect to density and cover. Learning from natural processes, reclamation may improve upon the design of the site in the composition of vegetation, creating a more functional and attractive landscape whilst providing a more varied and unusual habitat for wildlife.

Natural wetlands are not uncommon on derelict mining sites due to irregular topography and drainage. When reclaiming former colliery sites, it may reduce costs considerably to retain, modify or create wetlands in preference to creating a well drained substrate or dry land habitats. However, naturally developed wetlands on very poor substrates such as colliery spoil do not support much vegetation and where the substrate is toxic leachate will concentrate in wet areas and will prevent vegetation development. Increasing the fertility of wetlands on poor substrates is based on a build up of organic matter on and around the wetland area to establish nutrient levels and a sustainable cycle of vegetation. Where the inflow of water is from a nutrient poor, derelict area, or collects on derelict land substrates, it will be necessary to import organic matter to the wetland.

Wetlands have been used successfully to remove toxic leachate from an opencast colliery site at Cupar in Fife. Similarly, Lothian Regional Council's Derelict

Land Rehabilitation Unit has recently established a wetland at Gilmerton colliery tip in consultation with the Forth River Purification Board and the Water Research Council.

A vital consideration to be incorporated into the design of all reclamation schemes is maintenance, to ensure that the features of the site are either self-maintaining or require acceptable commitment and resources. For example, pyritic spoil material requires regular treatment with lime beyond the five year maintenance programmed provided for in the Derelict Land Grant, to prevent deterioration of the spoil as a growth medium.

7.2 A summary of the management objectives for reclaimed colliery sites

Management of land restored to soft end uses is essential. Maintenance requirements are normally greatest in the early years immediately after reclamation as vegetation is being established but management at a level appropriate to the use of the site is required in perpetuity.

A recent study evaluated Derelict Land Grant (DLG) schemes between April, 1982 and September 1985 (Roger Tym & Partners and Land Use Consultants 1987). Of the 931 DLG aided schemes completed in this period 64% were restored to soft end uses. For the efficiency of derelict land grant aided reclamation projects to soft end uses to be maximised, it is essential that the effectiveness of management is understood.

Management must develop understanding of, and techniques for aftercare, of naturalistic vegetation. This means retaining naturally developed vegetation even though it may look 'untidy'. Early management of trees and shrubs will entail weeding, applying lime, amendments and sometimes fertiliser, thinning, staking, tying and beating up. However, carefully designed vegetation establishment, based on ecological principles, should enable the longterm maintenance costs to be controlled. Aspects of general site maintenance, required in perpetuity, involve the checking and clearing ditches, path maintenance, litter and flytipping control.

Management commitment is vitally important if the sites are not to degrade either to their former barren substrate or become so overgrown that their amenity value is lost. If sensitively managed nature conservation sites have wider benefits for recreation, amenity and education.

In summary reclamation of derelict and contaminated land provides opportunities for conservation and creation of restored habitats as an amenity and educational resource while addressing the problems of safety and pollution that these sites can present. Reclamation design should be based on an hostilic approach and viewed as a valuable opportunity, rather than a problem to be solved with heavy financial demands. Although techniques for developing derelict and contaminated sites for wildlife use are not as developed as restoring land to agriculture, many of the techniques are adaptable to naturalistic reclamation. What is required is a change in attitudes rather than a revolution in reclamation techniques.

APPENDIX ONE

TABLE A

Results of chemical analysis of samples collected from Foulshiels 1990-1

Sample Id.	pH	EC	Cu	Zn	Mn	Fe	Ca	Mg
1	3.7	0.8	2.9	8.3	28.3	98	149	24.4
2	4.0	0.6	3.5	9.3	33.0	114	165	28.8
3	3.9	0.8	1.8	9.1	39.0	126	45	6.7
4	3.8	0.5	2.1	5.9	20.0	334	110	24.0
5	3.8	0.5	4.8	13.1	42.1	281	121	24.1
6	3.8	0.5	3.1	8.2	53.4	550	128	25.0
7	3.8	1.4	6.8	8.9	41.0	41	145	6.3
8	3.7	1.4	9.3	10.1	57.0	50	141	9.2
9	4.1	0.6	6.1	9.4	110.0	52	144	25.3
10	4.3	0.5	7.9	10.7	108.0	49	165	26.7

Results are presented in ug g^{-1} with the exception of pH and conductivity which is measured in Sm^{-1}

All sample results are the mean of duplicate extractions
Supporting solution for pH is $CaCl_2$

TABLE A contd.

Results of chemical analysis of samples collected from Foulshiels 1990-1

Sample Id.	pH	EC	Cu	Zn	Mn	Fe	Ca	Mg
11	3.9	0.7	5.1	10.0	76.0	73	160	36.4
12	4.0	0.2	6.2	14.0	92.0	101	173	27.0
13	3.7	0.3	4.1	12.1	121.0	283	432	12.6
14	3.8	0.3	4.9	3.2	99.0	151	191	16.0
15	3.0	0.7	8.3	11.7	6.0	383	32	3.9
16	3.9	0.8	3.1	6.1	31.0	219	65	17.5
17	3.9	0.8	2.1	5.2	11.0	274	210	26.1
18	4.5	1.0	0.7	4.3	113.8	53	312	28.4
19	4.1	6.2	3.7	5.9	24.0	151	205	33.9
20	4.2	0.5	4.0	5.1	54.6	87	359	31.7
21	3.8	4.4	5.9	5.5	15.4	215	300	11.5

Results are presented in ug g^{-1} with the exception of pH and conductivity which is measured in Sm^{-1}
All sample results are the mean of duplicate extractions
Supporting solution for pH is $CaCl_2$

TABLE A contd.

Results of chemical analysis of samples collected from Foulshiels 1990-1

Sample Id.	pH	EC	Cu	Zn	Mn	Fe	Ca	Mg
22	3.7	0.3	3.1	4.9	21.3	192	126	21.0
23	3.5	0.3	7.1	7.7	28.6	157	177	2.6
24	3.5	0.4	3.2	5.3	22.9	349	183	7.6
25	3.6	0.8	7.4	5.0	31.0	294	44	3.7
26	4.5	0.6	2.5	4.1	116.5	12	286	24.8
27	3.8	0.4	6.7	5.3	19.0	332	73	11.6
28	3.9	0.4	5.2	5.5	33.0	229	103	24.9
29	3.9	0.4	4.4	6.2	37.0	267	98	13.2
30*	5.0	2.4	7.3	3.2	139.0	431	1073	30.5
31*	6.3	2.0	10.1	5.5	282.0	560	1132	30.8

Results are presented in ug g^{-1} with the exception of pH and conductivity which is measured in Sm^{-1}
All sample results are the mean of duplicate extractions
supporting solution for pH is $CaCl_2$
* samples taken from a waterlogged area

TABLE A contd.

Results of chemical analysis of samples collected from Foulshiels 1990-1

Sample Id.	pH	EC	Cu	Zn	Mn	Fe	Ca	Mg
32*	6.2	1.6	10.3	4.3	167.0	359	1201	34.7
33*	6.4	1.2	14.1	3.8	173.0	741	1432	27.2
34+	4.4	0.9	2.3	6.3	33.2	41	134	27.0
35+	4.3	0.5	3.0	9.7	7.1	58	194	8.6
36+	4.1	0.5	3.9	5.7	32.0	75	60	38.6
37+	4.1	0.2	5.0	3.3	14.0	61	76	18.7
38+	4.2	0.7	6.5	13.8	10.9	1.3	108	10.6
39+	4.2	0.4	2.8	4.7	16.0	36	107	12.7
40+	3.6	1.0	1.7	4.7	15.9	16	46	5.5

Results are presented in ug g^{-1} with the exception of pH and conductivity which is measured in Sm^{-1}
All sample results are the mean of duplicate extractions
Supporting solution for pH is $CaCl_2$
* samples taken from a waterlogged area
+ samples containing predominantly burnt material

TABLE A contd.

Results of chemical analysis of samples collected from Foulshiels 1990-1

Sample Id.	pH	EC	Cu	Zn	Mn	Fe	Ca	Mg
41+	3.4	0.4	8.3	7.7	27.3	22	52	6.4
42+	3.6	0.5	2.4	3.6	17.1	67	98	11.2
43+	4.2	0.1	1.0	3.9	12.0	41	87	24.0
44+	5.1	0.2	4.0	4.7	10.4	79	156	28.5
45+	4.3	0.2	0.7	3.3	1.2	34	83	7.3

Results are presented in ug g^{-1} with the exception of pH and conductivity which is measured in Sm^{-1}

All sample results are the mean of duplicate extractions
Supporting solution for pH is $CaCl_2$

+ samples containing predominantly burnt material

Table B

Results of pH from Foulshiels taken in 1990

3.7	4.0	3.9	3.8	3.8	3.8	3.8	3.7	4.1	4.3	3.9
4.0	5.0	6.3	3.7	3.8	3.0	3.9	3.9	4.5	4.1	4.2
3.8	3.7	3.5	3.5	3.6	4.5	3.8	3.9	3.9	6.2	6.4
4.4	4.3	4.1	4.2	4.2	3.6	3.4	3.6	4.2	5.1	4.3
3.1	3.6	3.5	3.2	4.1	5.0	3.0	3.3	3.6	4.0	4.3
3.6	3.5	3.3	4.2	3.0	3.3	3.4	3.4	3.5	4.5	4.1
3.9	3.7	3.6	3.2	4.0	3.8					

(H_2O supporting solution)

n = 72
mean = 3.94
median = 3.8
SD = 0.66
min = 3.0
max = 6.4
Q1 = 3.6
Q3 = 4.2

Table C

Species identified at Foulshiels

Achillea millefolium (Yarrow)

Aegopodium podagraria (Ground Elder)

Agrostis tenuis (Common Bent)

Alnus glutinosa (Common Alder)

Betula pendula (Silver Birch)

Calluna vulgaris (Ling)

Cerastium vulgatum (Common Mouse-ear Chickweed)

Cirsium vulgare (Spear Thistle)

Cirsium Tussilago farfara (Creeping Thistle)

Corylus avellana (Common Hazel)

Deschampsia caespitosa (Tufted Hair-grass)

Euphrasia officinalis agg. (Eyebright)

Heracleum sphondylium (Hogweed)

Holcus lanatus (Yorkshire Fog)

Juncus spp. (Rush)

Lathyrus pratensis (Meadow Vetchling)

Lupinus spp. (Lupin)

Lotus corniculatus (Birdsfoot-trefoil)

Matricaria inodora (Scentless Mayweed)

Orchis fuchsii (Common Spotted Orchis)

Orchis strictifolia (Marsh Orchis)

Pinus contorta (Lodgepole Pine)

Plantago lanceolata (Ribwort Plantain)

Quercus spp. (Oak)

Ranunculus acris (Meadow Buttercup)

Rosa canina (Dog Rose)

Rubus fruticosus (Bramble)

Rumex spp. (Sorrell)

Salix spp. (Willow)

Sambucus nigra (Common Alder)

Sarothamnus scoparius (Broom)

Senecio aquaticus (Marsh Ragwort)

Sorbus aucuparia (Rowan)

Succisa pratensis (Devil's-bit Scabicus)

Trifolium pratense (Red Clover)

Trifolium repens (White Clover)

Tussilago farfara (Coltsfoot)

Ulex europaeus (Gorse)

Vaccinium myrtillus (Blaeberry)

Vicia spp. (Tufted Vetch)

APPENDIX TWO

Table A

Results of chemical analysis from samples collected from Baads (main site) 1991

Sample Id.	pH	EC	Cu	Zn	Mn	Fe	Ca	Mg
1	6.2	1.0	1.0	0.9	5.0	48	832	34.3
2	4.6	1.8	1.8	1.3	41.0	177	321	12.6
3	3.1	4.1	0.8	4.1	1.5	81	302	17.9
4	3.1	2.3	0.5	1.2	2.8	70	176	5.8
5	3.0	6.2	1.2	1.9	11.2	178	75	7.9
6	4.7	2.1	0.6	3.0	1.5	67	210	41.0
7	2.8	2.0	0.3	0.3	3.5	139	102	26.7
8	2.9	2.6	0.3	0.6	0.9	146	89	9.8

All results are in ug g^{-1} with the exception of pH and conductivity which is measured in Sm^{-1}
The results presented are the mean of duplicate extractions
The supporting solution for pH is H_2O

Table A contd.

Results of chemical analysis from samples collected from Baads (main site) 1991

Sample Id.	pH	EC	Cu	Zn	Mn	Fe	Ca	Mg
9	3.1	21.0	0.8	0.9	51.9	207	107	12.5
10	3.3	4.8	0.6	0.5	0.9	92	98	7.1
11	3.5	1.4	0.6	0.6	1.6	69	116	15.8
12	3.0	1.2	0.4	0.2	0.5	88	127	19.0
13	4.0	0.8	1.4	1.6	4.9	88	130	22.6
14	3.0	1.6	0.5	1.0	1.3	120	93	13.8
15	2.9	1.5	0.3	0.2	1.7	94	54	6.8
16	3.0	2.5	0.5	0.3	0.8	110	88	10.2

All results are in ug g^{-1} with the exception of pH and conductivity which is measured in Sm^{-1}
The results presented are the mean of duplicate extractions
The supporting solution for pH is H_2O

APPENDIX THREE

QUESTIONNAIRE

Respondent data

1) Length of residence in Stoneyburn

   Less than 10 years
   11 - 25 years
   26 - 35 years
   36 - 45 years
   Greater than 46 years

2) Age grouping

   Under 20 years
   21 - 35 years
   36 - 50 years
   51 - 65 years
   Greater than 65 years

Visual benefit

3) How appropriate has the reclamation of the site been in relation to the other land uses in the vicinity?

   very poor (1)
   poor (2)
   fair (3)
   good (4)
   excellent (5)

   Would an alternative form of reclamation been better, for example, to flatten the area and return to agricultural use?

4) How would you rate the visual quality of the site?

   very poor (1)
   poor (2)
   fair (3)
   good (4)
   excellent (5)

5) What improvements, if any, would you like to see made to increase the visual quality of the site?

Amenity value

6) What functions do you think the reclamation of the site is intended to perform?

How well are these functions achieved?

very poorly (1)
poorly (2)
fairly well (3)
well (4)
excellently (5)

7) How well is the site maintained for these functions?

very poorly (1)
poorly (2)
fairly well (3)
well (4)
excellently (5)

8) How frequently do you use the site?

daily
more than once a week
once a week
once a month
occasionally

9) Do you only use this reclaimed colliery site, or do you also use other sites in the locality?

Yes No

10) What aspect of the site do you find most attractive/least attractive? (number 1 to 5)

appearance
remoteness
proximity
accessibility
wildlife/nature interest
other (specify)

11) In your opinion was the reclamation worthwhile or would you have preferred the Local Authority to have invested in other aspects of the community? (detail)

APPENDIX FOUR

Plate 1 Foulshiels: one of the access routes to the Site illustrating the problem with fly-tipping.

Plate 2 Foulshiels: at the peak of the summer shallow rooted grasses die back due to lack of moisture in the spoil material.

Plate 3 Foulshiels: Lodgepole Pine on the north west face showing a slight tendancy to crooked growth as a result of the prevailing wind.

Plate 4 Foulshiels: The main path up the bing on the south side of the site.

Plate 5 Foulshiels: the site supports a large rabbit population, although the spoil material is not ideal for burrows as the lack of spoil structure leads to frequent collapse.

Plate 6 Foulshiels: compaction of the spoil material makes root penetration very difficult and trees are subject to wind-blow.

Plate 7 Foulshiels: Lupins are established in a variety of places at the base of the bing.

Plate 8 Foulshiels: a pathway up the bing

Plate 9 Foulshiels: variations in plant growth indicate changes in spoil characteristics.

Plate 10 Foulshiels: the tell tale sign of vegetation dieback.

Plate 11 Foulshiels: at the boundaries of the site, where site conditions are less harsh, vegetation grows profusely.

Plate 12 Foulshiels: the site of the old washery lagoons. The unlevel surface is the result of the material drying out.

Plates 13 and 14
Foulshiels: ditches
indicate the problems
of water pollution

Plate 15 Foulshiels: cattle grazing adjacent to the site drink from Foulshiels Burn.

Plate 16 Baads: acidic spoil causes dieback and stunts the growth of containerised trees.

Plate 17 Baads: lime washed off the site into the ditches supports plant growth.

Plate 18 Baads: pyrite oxidation and vegetation dieback at the site of the washery.

Plate 19 Baads: the old colliery buildings are now used by a neighbouring farmer.

Plate 20 Baads: the amendment trial plots, the plot in the centre of the photograph is a control.

Plates 21 and 22 Baads: an area of the amendment trial plots, indicating acidity problems but also the colonising of the site with orchids.

Plate 23 Baads: poor roots development makes the trees far more suceptable to windblow.

Plate 24 Baads: a tree showing signs of nutrient deficiency.

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