'To Pump or Not to Pump'
Cost-Benefit Analysis of Future Environmental Management Options for the Abandoned Durham Coalfield

By P. L. YOUNGER, BSc, MS, PhD, FGS *(Member)** and K. J. HARBOURNE, BSc, MSc**

ABSTRACT

Deep mining activity has totally ceased in the Durham coalfield, and withdrawal of the regional dewatering scheme is being contemplated. Consequent groundwater rebound is expected to have severe and expensive environmental consequences, which could only be entirely avoided through indefinite pumping. However, continued pumping is expensive, at about £1 million/annum. The options of either abandoning or continuing pumping have differing time streams of future costs and, consequently, direct comparison of the expenditures involved is difficult. Both options are therefore analysed using economic evaluation criteria in order to determine the lowest cost alternative for the future. The overall outcome of the economic analysis, using both net present value and equivalent annual cost criteria, demonstrates that the option of continued pumping is less expensive than the option of abandoning pumping in all cases.

Key words: Cost-benefit; dewatering; economics; groundwater; mines; pollution; rivers; treatment; wetlands.

INTRODUCTION

During the last three centuries, the natural groundwater flow regime within the coal measures in County Durham has been extensively modified to expedite deep mining[1]. The current dewatering scheme involves pumping about 105 Ml/d from nine pumping stations in the exposed coalfield[1,2] (Figs. 1, 2, 3 and 4). Recharge to this area of the coalfield is approximately equal to the combined pumping rate of these nine stations[1], which therefore reduce easterly groundwater flow towards the last operational collieries (Easington and Vane Tempest) along the Durham coast[1]. Recent closure of these collieries has removed the need for continued dewatering. However, abandonment of the established pumping network will lead to the development of high acidity and high heavy metal loadings in the groundwater as the water table rises and oxidized remnants of pyrite are dissolved[3,4]. As previously reported[1], this process is expected to have a number of potentially serious environmental impacts, each requiring costly mitigation measures.

*Lecturer, Water Resources Group, University of Newcastle, Newcastle Upon Tyne, UK.
**Hydrologist, ENTEC Shrewsbury, Shropshire, UK.

The present debate on the future of the dewatering scheme therefore focuses on whether prevention of these environmental impacts (by continuing to pump indefinitely) is better than cure (dealing with adverse impacts as they rise)[5,6]. Central to resolving this debate is the question of cost. Combining latest modelling predictions of environmental impacts[3,7,8] with established economic discounting procedures, the paper attempts to prepare and compare costs for the two principal options (sustained pumping vs abandonment). As similar problems are being increasingly encountered elsewhere in the UK (e.g. South Wales[5,9], Yorkshire[10] and East Fife[11]), the methods may be of interest to water quality managers elsewhere.

DURHAM COALFIELD: ENVIRONMENTAL CONSEQUENCES OF ABANDONMENT

An initial conceptual model of the consequences of abandoning the Durham coalfield was prepared in 1992[12], and published in 1993[1]. Subsequent testing of the conceptual model for coalfield abandonment has been undertaken using both standard groundwater modelling techniques[7] and an innovative lumped-parameter approach[2,8], which utilizes the mining engineers' notion that groundwater in worked coal measures occurs in distinct 'ponds'. These different modelling approaches have yielded similar general predictions. It is anticipated that 60–100 Ml/d of polluting minewaters will emerge in the valley of the River Wear (with a small proportion emerging in the adjacent Team valley), with 30–40 years required before the maximum outflow rate is attained.

The quality of the future minewater discharges is expected to be very poor. Current uncontrolled minewater discharges in an already-abandoned area of the coalfield (beyond the outermost limits of the dewatering scheme) have recently been surveyed[3,4]. High iron, aluminium and sulphate loadings characterize these discharges, and the pH varies from 3.5 to 6.5. There is no reason to suspect that minewaters emerging in the central coalfield area after groundwater rebound will be of different quality[13,14]. Indeed, given the coincidence of the centre of the dewatered zone with maxima in sulphur contents of major coal seams[5], the quality of future discharges might even be worse.

Once the minewater begins to discharge at the surface, it is likely to be several decades before the

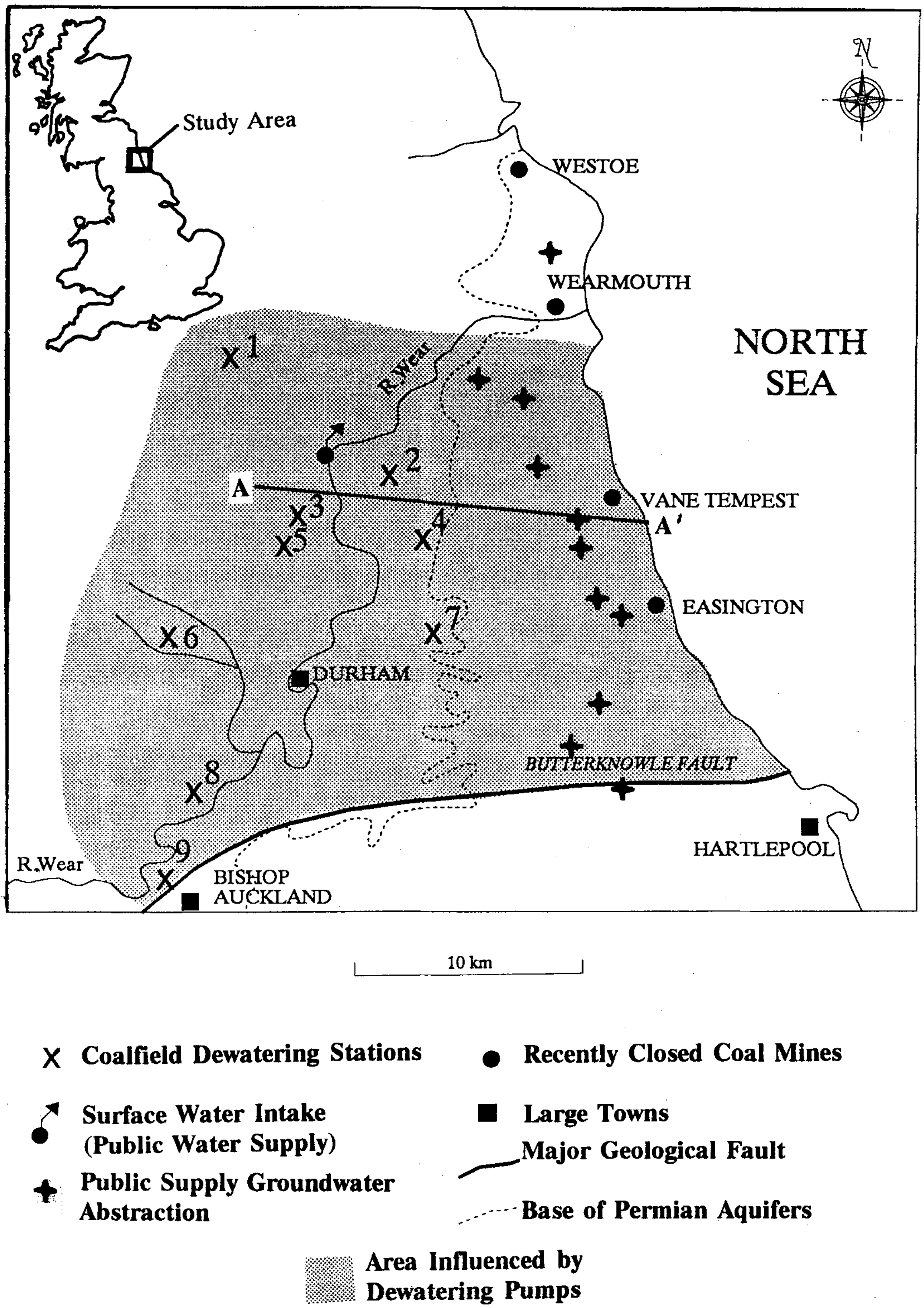

Fig. 1. Map of central part of Durham Coalfield showing positions of dewatering stations and public supply water intakes. (Line $A - A^1$ corresponds to hydrogeological cross-section in Fig. 2.) (Updated after Younger[1])

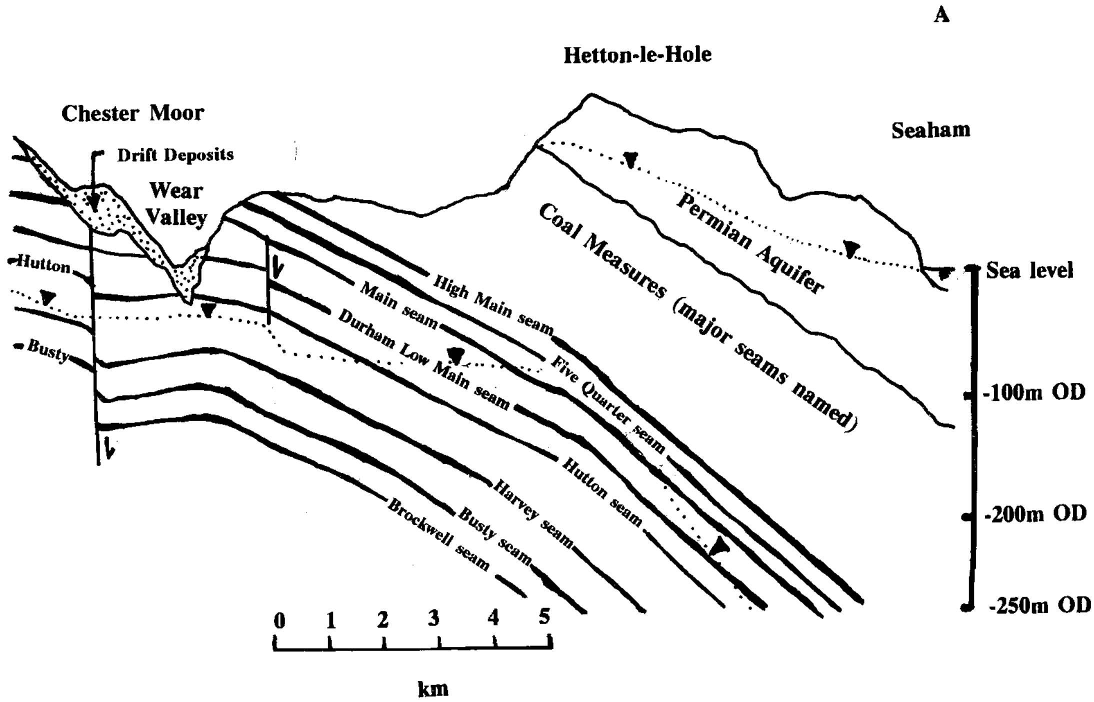

Fig. 2. Simplified hydrogeological cross-section (see Fig. 1 for orientation of section line A – A'). (Seam thicknesses are exaggerated.) Note positions of water tables (dotted lines with inverted triangles) in Permian aquifer (exploited for public supply) and in coal measures (affected by coalfield dewatering)

quality improves to an acceptable level. While an initially exponential decline is often observed after the water table stabilizes in abandoned workings[13], after a certain period of time the fall in pollutant concentrations appears to approach an asymptotic limit[15]. This apparently reflects seasonal oxidation of pyrites above the water table, followed by flushing into solution when the water table rises.

The question might be asked whether a partial reduction in pumping costs could be achieved by (a) reducing the total pumping rate (say, by removing some of the pumping stations), or (b) temporarily ceasing pumping to allow a partial recovery in groundwater levels, so that future pumping at the same rate (to balance recharge) could be against a lower head.

Evidence so far suggests that neither of these 'half-way house' scenarios would be likely to prove satisfactory. In the first case, given that the nine pumping stations approximately balance incoming recharge at present, any overall reduction in pumping rate would lead to a contraction of the cone of depression, and therefore to an increase in polluting surface discharges in the west of the coalfield. In the second case, the preceding discussion on the consequences of rebound makes it clear that any widespread recovery in groundwater levels can be expected to lead to a marked deterioration in water quality[14], so that when the pumps were switched on again they would be pumping poor quality water. This would probably require treatment before discharge to receiving waters if a deterioration in river quality was to be avoided (at present, water from the nine pumping stations is suitable for discharge without treatment). Furthermore, maintenance costs for the pumps might increase if they are dealing with more aggressive waters. In the analysis of options which follows, therefore, economic assessment has been restricted only to the two major options: to pump, or not to pump.

COSTS OF CONTINUED PUMPING

The costs of continued pumping in the Durham coalfield are often estimated at approximately £1M/annum[16], and for the purposes of the paper it proved desirable to check whether this figure was reasonable. The power consumed at each of the pumping stations, when delivering a specified discharge from a specified head[17], is given by the relationship:

$$P = \rho g Q H / \eta$$

Fig. 3. Kibblesworth Colliery coalfield dewatering station (No. 1 on Fig. 1), Gateshead. Old colliery engine house (to right); twin rising main (pumping 25.7 Ml/d) exiting mine shaft and entering header tank (centre of view)

where:

P = continuous power consumption (watts)
ρ = density of water (1000 kg/m^3)
g = gravitational acceleration (9.81 m/s^2)
Q = discharge rate (m^3/s)
H = pumping head (m)
η = combined pump/motor efficiency (here assumed to be 70% on the basis of discussions with pump manufacturers and users).

Values of pumping head, discharge rate and power consumption for all nine pumping stations (derived from published data[18]) are shown in Table I. The total continuous power consumption amounts to 1.716 MW (equivalent to 1.503×10^7 kWh over a year). Northern Electric plc suggest that, for a demand as large as 1.716 MW, contract prices of around 4.7 pence per kWh can reasonably be assumed. Hence annual electricity costs can be calculated as approximately £707 000. Further operational and maintenance requirements at each of the pumping stations can be assumed to bring the total annual costs of coalfield dewatering up to the £1M figure previously quoted; consequently, for the purposes of the economic analysis, this value will be used.

There is a possibility that the costs of long-term pumping could, in the correct financial circumstances, be offset by the production of geothermal energy[18,19]. Minewater temperatures at the nine current pumping stations vary from 12.6°C to 16.0°C[18]. Temperatures as high as these represent a large, low-temperature heat source, which could provide a heat source of up to 50 MW[19] but, if the water table is allowed to rebound, the geothermal potential of the groundwater will be lost as shallow groundwater temperatures in the coalfield (to the west of the dewatered zone) are significantly lower, at around 10.0°C[3]. However, due

TABLE I. Power Consumption at Nine Dewatering Stations in Durham Coalfield (Discharge and Head Values from Published Data[18])

Name of site	Discharge (m^3/s)	Head (m)	Power consumption (kW)
1. Kibblesworth	0.297	158.9	661.4
2. Lumley 6th	0.033	144.6	66.9
3. Chester Moor	0.099	105.5	147.1
4. Nicholsons	0.036	136.4	68.8
5. Kimblesworth	0.105	143.6	211.3
6. Ushaw Moor	0.089	97.0	121.0
7. Sherburn Hill	0.072	171.1	172.6
8. Page Bank	0.137	45.8	87.9
9. Vinovium	0.250	51.0	178.7

Numbers given with site names relate to station positions of Fig. 1.

Fig. 4. Outfall of Page Bank coalfield dewatering station (No. 8 on Fig. 1) which pumps about 12 Ml/d into River Wear

to the fact that the minewater is not used as a heat source at present, and that it may not be exploited in the future, the benefits which are likely to result from its use are not included in the present economic evaluation.

POTENTIAL COSTS OF ABANDONING PUMPING

Treatment Options and Costs

Abandonment of the dewatering scheme over the entire Durham coalfield will result in the generation of polluting discharges on a large scale[1,2,3,4,5]. Consequently, treatment of all minewater discharges as they occur will be extremely costly, and a method of minimizing these costs will be needed. Various studies[20,21] have addressed the issue of optimizing remediation of pollution from abandoned minewaters on the catchment scale by prioritizing discharges[9]. However, prediction of the exact locations of minewater emergence after abandonment is difficult[5,22], rendering prioritization of future discharges impossible. As a consequence, there is little hope that treatment facilities could be designed and installed for even the largest future discharges in the Durham coalfield before commencement of pollution. The first, and invariably worst, flush of minewater pollution would have to be endured before treatment could be installed.

Future treatment of minewaters is most likely to be undertaken using passive methods (constructed wetlands), since active treatment has much higher revenue costs. Passive treatment of coal-mine drainage is widely practised in North America[23], but has only recently been introduced to the UK[10]. In order to estimate the potential costs of passive treatment for future discharges in the Durham coalfield, costings have been obtained for pilot passive treatment schemes in the UK, using existing minewater discharges in western areas of the Durham coalfield as a guide to probable future classification of water quality.

At Wheal Jane, Cornwall, the combined total area of pilot passive treatment facilities completed in 1994 amounts to about 18 730 m^2, and construction has cost approximately £1 million. Therefore the average cost of wetland construction at Wheal Jane can be approximated as £53.4/m^2. In the River Pelenna catchment, South Wales, five key discharges are to be treated over the next four years[24]. When completed, a total of 19 800m^2 of wetland will have been constructed at a cost of £1 010 200, yielding an average cost of £51/m^2[25].

Application of these costs to the Durham situation is based upon a preliminary assessment of passive treatment options for four existing minewater discharges in the county[3], using design recommendations of the US

Bureau of Mines[23]. Table II indicates the areas of wetland required at each of the discharge sites to ensure that the discharges comply with all the relevant water quality standards. The 'compliance criterion' (CC) will result in large improvements in water quality consistent with stringent uniform emission standards, whereas the 'reasonable improvement criterion' (RIC) is less demanding, and is intended for situations where funding limitations or lack of land preclude comprehensive treatment (the RIC is a guide to the minimum wetland area necessary to make construction worthwhile).

TABLE II. WETLAND REQUIREMENTS FOR CURRENT MINEWATER DISCHARGES IN DURHAM[3]

Site	Discharge (Ml/d)	Classification	Wetland	Wetland area (m^2)	
				RIC	CC
Broken Banks	4.320	Net alkaline	Aerobic	390	780
Crook	0.168	Net acidic	Anaerobic	9100	18200
Quaking Houses	0.579	Net acidic	Anaerobic	9300	18520
Stoney Heap	2.210	Net alkaline	Aerobic	3000	5800

Assuming that future discharges will be of a similar quality to those currently occurring, the figures presented in Table II can be used to estimate the total potential costs of passive treatment for future minewater discharges in County Durham. Latest model predictions of the timing and magnitude of future minewater discharges are given in Table III. These estimates indicate that only a small fraction of the discharge will occur directly through the river bed as baseflow; most discharges are expected to occur as surface springs similar to the existing discharges in the west of the coalfield. From these results it is clear that, during the first 19 years after cessation of pumping, it would be necessary to provide an area of wetland which is capable of adequately treating 36.47 Ml/d of minewater discharges. The current uncontrolled discharges of minewater, outside the radius of influence of the dewatering scheme, amount to about 7.3 Ml/d. The estimated area of wetland which is required to adequately treat these discharges, according to the compliance criterion, totals 43 300 m^2 (Table II). Therefore, using simple arithmetic, it can be estimated that a total area of wetland of 217 006 m^2 would need to be constructed in the 19 years following abandonment of the dewatering scheme. The costs of providing this area can be calculated as £11.33 million using the average costs of wetland construction (£52.2/m^2) estimated from the projects at Wheal Jane and the Pelenna. In the same way it can be calculated that an additional 95 204 m^2 of passive treatment wetland would be required after 44 years at a cost of £4.97 million, and a further 118 113 m^2 after 53 years at a cost of £6.17 million. Estimates were also made using the reasonable improvement criterion.

In the absence of more detailed information concerning the timing and magnitude of future discharges, the costs of constructing the necessary passive wetland treatment systems have been divided evenly over the time periods referred to above. Therefore, for the purposes of economic analysis, the future costs of treatment can be presented, as shown in Table IV. Additionally, costs associated with the replacement of passive treatment wetlands will be incurred in the future. This is because the carbon sources needed for sulphate-reducing bacteria are expected to be depleted within 25 years of establishing anaerobic cells, and it is unlikely that the scope for freeboard available when designing an aerobic cell will last any longer[23]. Given that the polluting effect of minewater discharges is often sustained for periods considerably in excess of 25 years, it might be necessary to construct replacement wetland cells at discharge sites after this time to ensure continued treatment. Furthermore, there are likely to be basic maintenance requirements for the constructed wetlands; a conservative estimate from USA experience would be around 0.7 p/m^2 annum (equivalent to £3000/annum for all wetlands). Inclusion of all these effects yields the time stream of total future costs given in Table V.

TABLE III. TIMING AND MAGNITUDE OF FUTURE MINEWATER DISCHARGES PREDICTED USING PREVIOUSLY PUBLISHED MODELLING METHODS[8]

Location	Time (years)	Baseflow (Ml/d)	Surface flow (Ml/d)	Total discharge (Ml/d)
Southern pond (Bishop Auckland)	19	0.053	36.47	36.52
Central pond (Chester-le-Street)	44	0.02	16.00	16.02
Northern pond (Team valley)	53	0.041	19.85	19.89

It should be noted that the estimates used here err on the side of caution, and that if the higher estimates of eventual equilibrium minewater discharge rate were to

TABLE IV. POTENTIAL FUTURE COSTS OF PASSIVE TREATMENT IN COUNTY DURHAM

Timescale	RIC costs (£million/annum)	CC costs (£million/annum)
Years 1–19	0.300	0.596
Years 20–44	0.100	0.199
Years 45–53	0.345	0.686

TABLE V. TOTAL COSTS OF PASSIVE TREATMENT IN COUNTY DURHAM OVER 100 YEARS

Timescale (years)	RIC costs (£million/annum)	CC costs (£million/annum)
1–19	0.303	0.599
20–25	0.103	0.202
26–44	0.406	0.801
45–50	0.451	0.891
51–53	0.754	1.490
54–69	0.406	0.801
70–75	0.451	0.891
76–78	0.754	1.490
79–94	0.406	0.801
95–100	0.451	0.891

be used, predicted wetland requirements could be as high as 625 000 m^2, at a potential cost of £32.63 million.

Implications of Reduced Surface Flows if Pumping Ceases

Of the nine pumping stations currently operating in the exposed coalfield of County Durham (Table I), eight discharge into the River Wear and its tributaries, while one (Kibblesworth) (Fig. 3) discharges into the River Team. The instantaneous minimum prescribed flow for the River Wear at the Chester-le-Street gauging station is 2 m^3/s, which amounts to 173 Ml/d[26]. If the flow in the Wear falls below this value at any time during the day, a supplementary discharge must be provided (usually by a release from the Kielder aqueduct at Frosterley). The pumped minewaters currently help to limit the need for Kielder transfers by supplying an average flow of 0.82 m^3/s to the River Wear. An analysis of mean daily flow records for the Wear at Chester-le-Street for the period 1978–1993 (Table VI) shows that the mean discharge was less than 3 m^3/s on average 15.7 times per year. If it is assumed that the loss of 0.82 m^3/s of pumped coalfield water would have resulted in instantaneous flows of less than 2 m^3/s at some time during the day, this figure represents the mean number of days per year on which Kielder transfers would be necessary to compensate for the loss of pumped minewaters. As the cost of transferring 1 m^3/s to the River Wear has been estimated by the NRA to be £2000/day[26], the average costs involved in supplementing flows in the future can be estimated as £31 380/annum.

Abandonment of Lumley Water-Treatment Works

At present, the water-treatment plant at Lumley has the capacity to treat 68.3 Ml/d. If pollution of the River Wear occurred as a result of groundwater rebound, treatment processes would need to be extensively upgraded in order to provide water with a quality which is suitable for public supply. However, if the concentrations of pollutants were so high that specialist treatment proved infeasible or uneconomical, the Lumley water-treatment plant would have to be abandoned. This would necessitate the provision of alternative resources and treatment facilities, at considerable cost.

Current estimates by North East Water of the capital value of the Lumley plant fall in the range of £15–30 million, about a mean of approximately £24 million. In addition to capital costs, there are also likely to be increased distributional costs as a result of pipeline transfers of water from alternative areas of supply and treatment. However, these costs are difficult to estimate at present due to the uncertainty surrounding how and where the shortfall in resources will be met in the future.

Major minewater discharges into the River Wear are predicted to arise in the Bishop Auckland area within 19 years of a cessation of pumping (Table III). Considerable problems can be anticipated downstream at Lumley water-treatment works. As a result, it is estimated that the treatment plant will have to be abandoned 20 years after the dewatering scheme is stopped. The cost of abandonment for use in the economic analysis will be assumed to be £30 million, combining the £24 million element for the capital value of the works with a smaller element (conservatively assumed to be £6 million) to account for increased distributional costs.

TABLE VI. Frequency of Mean Daily Flows below 3 m^3/s (River Wear at Chester-le-Street)

Year	Frequency	Year	Frequency
1978	4	1986	0
1979	0	1987	0
1980	0	1988	0
1981	21	1989	53
1982	21	1990	44
1983	0	1991	44
1984	38	1992	26
1985	0	1993	0

Mean = 15.69

Pollution of Basal Permian Sands Aquifer

It is possible that minewaters may eventually pollute the Basal Permian Sands aquifer which overlies the coal measures, affecting several private borehole supplies and a network of public water supply wells belonging to North East Water[1]. At present, it is estimated that the boreholes provide about 10% of the water supply to the area[27]. Although North East Water intend to abandon these wells in the long term, regardless of whether or not pollution occurs, a short-term deficit might arise if closure is brought forward because of pollution. Costs of development of new water resources to meet this contingency have been estimated at £10–20 million.

Pollution of the Basal Permian Sands aquifer is most likely to occur after about 44 years, once the second pond (near Chester-le-Street) has rebounded to the surface. An analysis of the costs involved in abandonment and replacement of the borehole supply will therefore not be included until this point in the time stream.

Geotechnical Problems

Rising groundwater levels will result in a variety of geotechnical problems in County Durham and, although the nature of such problems is fairly certain, prediction of their precise location, timing, and magnitude is difficult.

The affected area is currently perceived to be the low-lying land in the valley of the Wear and its two principal tributaries, the Deerness and the Browney. As a working rule, it has been suggested that any land more than 30 m above river level or more than 1.5 km away from these rivers is unlikely to be affected[28]. Structures at risk therefore include all bridges crossing the rivers and all buildings or roads on the adjacent slopes. Near to the rivers, potential geotechnical problems are likely to include (a) increased subsidence risk from flooding of uncharted shallow workings, (b) attack of foundations by high-sulphate waters, (c) leaching from landfills, and (d) temporarily enhanced surface emission rates of carbon dioxide and methane[1,28].

Estimation of the costs associated with prevention or remediation of these various geotechnical effects is difficult, and is likely to be a significant source of uncertainty in cost estimates. Mitigation of such problems in relation to existing structures may be costly, and avoidance of similar problems in new structures requires new design regulations. Therefore all new structures in the affected zones must be designed to withstand the effects of a rising groundwater level, although if the costs of these measures for a particular structure are excessive, a decision will need to be made on a cost/risk basis[28]. Recommendations for all new works include designing foundations, piles, and retaining walls for worst-case conditions of total saturation. Concrete incorporated into structures, and which comes into contact with the ground, must conform to sulphate-resistance standards, and steel piles may need protective coatings to be able to withstand acidity to pH 4.5. Detailed geotechnical investigations must also be undertaken at new development sites to ascertain whether rising groundwater levels will result in slope instability or subsidence.

In order to estimate the potential costs associated with the mitigation and remediation of the various geotechnical effects, it is necessary to consider all the possible problems. No detailed investigations have been carried out, but Durham County Council have suggested (as a first approximation) that total costs involved in safeguarding existing structures and earthworks may amount to £10 million. Consideration of other problems, including emissions of methane gas and generation of landfill leachate, could result in overall mitigation and remediation costs being as high as £15 million. However, it must be stressed that precise determination of the problems and their associated costs is difficult and, as a result, only rough estimates can be provided. In the light of the uncertainty surrounding precisely where and when geotechnical problems will be encountered in the future, the costs required for mitigation and remediation of the various effects will be divided evenly over the time taken for total groundwater rebound. The northern pond in the Team valley will have rebounded fully after 53 years; therefore, over this timescale, average costs of £283 000/annum can be calculated.

Loss of Amenity Value and Threat to Tourism

Surface discharges of acidic and ferruginous minewaters to the River Wear and its tributaries in County Durham may result in severe visual pollution problems due to the deposition of both ferric and aluminium hydroxides on the beds and banks of the watercourses. The potential for a considerable loss of amenity should be readily apparent. Regional factsheets for 1992 estimated that visits to County Durham by UK residents produced a total revenue of £46 million, whilst visitors from overseas were responsible for the generation of £20 million[29]. The historic city of Durham and the scenic surrounding countryside contain a variety of riverside sites of interest, which attract millions of visitors each year. 70% of visitors cite Durham Cathedral, with its dramatic position above the Wear, as the prime motivation for their trip. Further attractions such as the castle, Finchale Priory, and the cricket ground at Chester-le-Street, also occupy riverside sites. At present, however, it is difficult to determine the precise extent of the area which will be affected by visual pollution, and it is therefore equally difficult to estimate the associated reduction of amenity value. Therefore it is only possible to include this impact qualitatively within the economic analysis.

Ecological Impacts

Surface water pollution arising from water-table rebound is expected to have a devastating effect on the local freshwater ecology. In order to assess these effects, studies have been made of two streams in County Durham which already receive minewater pollution[30]. Biological sampling of invertebrates at several sites along the lengths of each stream illustrated the considerable faunal impoverishment caused by the minewater pollution. If pumping is ceased and such pollution becomes more widespread, destruction of habitats for aquatic invertebrates will be compounded by severe impacts on fish populations. Nevertheless, there is considerable difficulty in placing monetary values on the disruption of natural habitats. Some initial estimates of the economic value of recreational and commercial salmon fisheries in the Northumbrian region have been provided in a study commissioned by the Ministry of Agriculture, Fisheries and Food[31]. While detailed figures for the River Wear were not derived, due to lack of data, it seems that the value of the Wear salmon fishery is about £1.5 million (at 1988 prices). In the light of such uncertainty, however, it is only reasonable to evaluate ecological factors in qualitative terms when discussing the formal economic analysis.

ECONOMIC ANALYSIS

Methodology

The purpose of economic analysis is to identify the benefits and costs of a particular project and hence to determine whether the project can be justified as the optimal or most cost-effective option for the future. One of the fundamental concepts to be considered in any economic analysis is the time value of money, since it is frequently necessary to evaluate options with differing economic lives and differing time streams of future benefit and costs. This concept of time value is best visualized by considering that individuals prefer to incur costs later rather than sooner, and gain benefits sooner rather than later. Standard techniques for making such comparisons involve the implicit weighting of the present over the future by the process of 'discounting'. In this study, two alternative discounting approaches have been used to compare the options for the coalfield; the present value approach and the equivalent annual cost approach. Full details of these approaches are readily available in standard texts[32,33], and will not be detailed here.

The values of discount rate to be included in the analysis must be chosen carefully, as they can have an important influence on the final economic evaluation. In general, high discount rates result in future costs having a smaller influence on the figure calculated for present value, whereas lower discount rates give much more weight to costs arising some distance into the future[32]. As a result, it is sensible to undertake a sensitivity analysis using several different discount rates to determine how the overall outcome is affected. For most applications in central government a real (i.e. net of inflation) discount rate of 6% is used[34]. In this analysis, discount rates of 4%, 6%, 8%, 10%, and 15% were tested.

The period of time chosen for the economic evaluation will also alter the present value of costs associated with a particular option, but only up to a certain point. For an given discount rate the present value of a series of costs will increase with increasing project life but beyond a certain time horizon and, especially at high discount rates, the present value of these costs becomes relatively insensitive to any further changes in project life[33].

The alternative options for the future of the dewatering scheme cannot be assigned definite values for the lengths of their respective lives. Abandonment of the pumping network will initiate the slow process of groundwater rebound, which will not be complete for many years and which will lead to the persistence of associated environmental problems for several decades[1,8]. The option of continued pumping has an even longer lifespan, consisting of an infinite time stream of future costs. However, as previously mentioned, the present value becomes insensitive to the length of project life beyond a certain time and will stabilize at a particular value. It has therefore been decided to consider the alternative options for the Durham coalfield over equal project lives of 100 years. After this time, any costs discounted to their present values would be so small as to have no significant impact on the economic evaluation.

The overall objective of the economic analysis is to determine whether it will be cheaper to maintain or abandon the current coalfield dewatering scheme. It is therefore necessary to take account of all costs likely to be incurred after the implementation of each option. The costs of continued pumping are relatively easy to define, but the potential costs associated with the remediation of various environmental impacts, following a cessation of dewatering, are much more uncertain. In an attempt to account for this degree of uncertainty, two alternative sets of costs for the option of abandoning pumping, representing low and high estimates, have been evaluated. The first stream of costs assumes that the polluting minewaters will be treated only according to the reasonable improvement criterion, and that transfers of water from Kielder reservoir will only be required until groundwater rebound in the northern pond (which is predicted to take 53 years) is complete. The second stream of costs is greater and assumes that the minewaters will be treated according to the compliance criterion, and that transfers of water from Kielder reservoir will be needed for some time after groundwater rebound is complete in order to provide dilution of minewater discharges. Additionally, the costs likely to be incurred as a result of pollution of the Basal Permian Sands aquifer are expressed as £10 million for the low-cost estimate and £20 million for the high-cost estimate. In both cases, however, the costs associated with the prevention of remediation of geotechnical effects and the abandonment of Lumley water-treatment works are assumed to be the same. The only impacts which could not be assigned monetary values were the consequences for the ecology of the Wear and the potential threat to tourism. It is important to consider these impacts qualitatively – even though they cannot be included in the quantitative analysis.

Results

The present values of costs associated with the alternative options for the Durham coalfield are presented graphically in Fig. 5, and equivalent annual costs for the three options are given in Table VII. The option of abandoning pumping using the high cost estimates has present values and equivalent annual costs which are considerably greater than those for continued pumping at all discount rates. Using the low cost estimates for abandoning pumping, the present values and equivalent annual costs are still greater than those for continued pumping at discount rates of 4%, 6%, 8% and 10%. Discounting by 15%, however, results in the present value and equivalent annual costs for abandoning pumping being slightly less than the value for continued pumping. However, such a high discount rate is unrealistic[34]. When the unquantified, but highly important, ecological and amenity value impacts of future minewater pollution are considered in tandem with these results, the option of continued pumping emerges as the most beneficial – irrespective of discount rate and choice of high or low cost estimates.

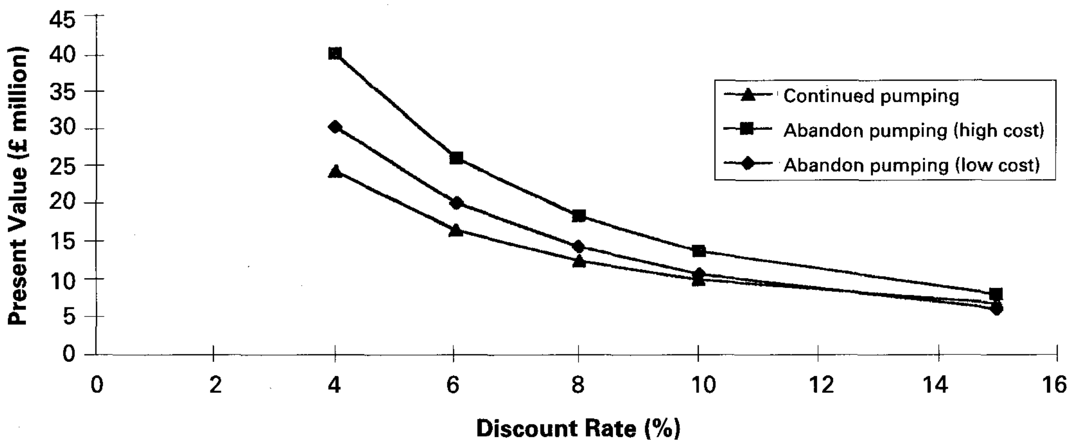

Fig. 5. Present value of costs associated with alternative options for Durham Coalfield

TABLE VII. Equivalent Annual Costs (£ Million) of Future Alternative Options

Option	Discount rate				
	4%	6%	8%	10%	15%
Continued pumping	1.000	1.000	1.000	1.000	1.000
Abandon pumping (low)	1.242	1.223	1.155	1.073	0.891
Abandon pumping (high)	1.640	1.575	1.478	1.380	1.185

CONCLUSIONS

1. It is considered that the cheaper option over a timescale of 100 years would be to maintain the current dewatering scheme. If pumping was abandoned, however, the worst effects of minewater pollution would eventually diminish in severity, and therefore the costs associated with their prevention or mitigation would also decrease. Hence, if a sufficiently long period of time was to be considered, the option of continued pumping would eventually prove to be more expensive than the option of abandonment.
2. At present it is impossible to predict the longevity of acid mine drainage: all that can be said with certainty is that the associated problems will persist over several decades, and perhaps centuries. Therefore it is currently not possible to determine the future time horizon beyond which continued pumping becomes more expensive than abandonment.
3. At present, the decision must be made whether eventual savings in pumping costs (in centuries to come) can be justified at the expense of the costs that will be incurred, and the ecological devastation that will be caused in the next 100 years, as inevitable consequences of a cessation of mine dewatering.
4. It is therefore proposed that the *status quo* should be maintained until such time as an acceptable decommissioning strategy for the coalfield can be developed. Such a strategy might demand technology beyond that which currently exists. Therefore a full re-appraisal of the costs and benefits of future options for the Durham coalfield might await unforeseen developments in groundwater engineering methods.

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