Water Technology Research Group

Trinity College, University of Dublin, Dublin 2 Ireland

A SUBSTRATE CLASSIFICATION INDEX FOR THE VISUAL ASSESSMENT OF THE IMPACT OF ACID MINE DRAINAGE IN LOTIC SYSTEMS

N.F. Gray

Water Technology Research
Technical Report: 24
Tigroney Press

Acknowledgements:

This work was funded by EU Contract: EV5V-CT93-0248 *Bio-rehabilitation of the acid mine drainage phenomenon by accelerated bioleaching of mine waste*

Contact: tigroneypress@gmail.com

First published July, 1995 (ISBN 1-872220-25-8)

This e-version: Published by Tigroney Press on behalf of the Water Technology Research Group, Trinity College, University of Dublin.

August, 2017

ISBN 978-1-912290-16-1

Summary

The impact of acid mine drainage (AMD) on lotic receiving waters is complex and difficult to assess. While low pH, elevated sulphate and metals all characterize AMD these vary both spatially and temporally, with high river dilutions resulting in low absolute concentrations which are difficult to measure. From field observations the best indications of AMD contamination of lotic systems appear to be the brownish-yellow precipitates of iron (III) hydroxide, high densities of chironomids, and the absence of macrophytes. Using these observations a simple index based on the degree of deposition of ochre on the river substrate, and the level of floc formation, has been devised. The index is purely a descriptive one and is calculated rapidly using a visual inspection of individual sites. The derived index values are related to the biological impact that can be expected.

Introduction

Acid mine drainage (AMD) is a multi-factor pollutant which impacts on receiving waters in a complex manner. Four categories of pollution can be identified: (i) *salinization*; (ii) *metal toxicity* which affects the biota both directly, and indirectly through bioaccumulation and biomagnification; (iii) *acidity* and the destruction of the bicarbonate buffering system, and (iv) *sedimentation* which can be further separated into turbidity and deposition of iron (III) hydroxides. While the importance of each factor will vary both within and between affected lotic systems, visually it is the deposition of iron (III) hydroxides which is the most obvious impact on rivers. The major effects being the modification or destruction of the substrate and the elimination of macrophytes, resulting in a severe reduction in species diversity and population density. The effects of sedimentation processes associated with AMD on receiving waters is summarized in Fig. 1.

In lotic systems there are two basic types of substrate offering a wide range of habitats and niches for macroinvertebrates. These are stony substrates associated with fast flowing (erosional) rivers and silty or muddy substrates associated with slow flowing (depositional) rivers. Both have characteristic flora and fauna with the stony substrate having a more diverse fauna. Macrophytes offer another important source of niches for macroinvertebrates. A stony substrate offers a wide variety of niches which are exploited by specially adapted macroinvertebrates. The water does not only flow over the surface of the substrate, it also flows through it offering a rich habitat for a wide range of animals. Up to 70% of the total number of organisms in a river may be living in the interstices (crevices) of the substrate below the substrate-water interface (Bretscho, 1991). The macroinvertebrates are generally not active or efficient swimmers, and so rely totally on the substrate for anchorage and shelter. Fish in contrast are excellent swimmers and while they do not rely on the substrate for anchorage it is vital for shelter and food. Salmonids in particular rely on a well aerated gravel substrate for laying eggs, while healthy macrophytes are important to all fish for an abundant food supply, protection, and marking breeding territories. macrophytes also provide shelter and food for a wide range of macroinvertebrates as well as being used as breeding sites. Other important factors include the reduction of water turbulence, enhanced deposition of fine sediments and the production of oxygen (Carpenter and lodge, 1986). Substrate is the single most important factor controlling benthic macroinvertebrates (Hynes, 1970). However, the colonization and abundance of macroinvertebrate species varies with particle size of the substrate and more importantly the size of the interstices between the particles comprising the substrate.

The classic brownish-yellow hued flocs of iron (III) precipitate are commonly known as ochre or yellowboy and are comprised mainly of iron (III) hydroxide ($Fe(OH)_3$) although their exact chemistry is complex and variable. Iron is precipitated in a variety of forms, often in association with aluminium. The flocs form as AMD is neutralized, the critical pH threshold for iron (III) and aluminium being 4.3 and 5.2 respectively (Kelly, 1988). The iron (III) salts form either a suspension of colloids or fine suspended precipitates which flocculate to form discrete flocs which generally increase in size with distance from the original input of AMD. In suspension the floc reduces the vision of consumers, blocks gills and feeding mechanisms and is generally abrasive. Light penetration is also suppressed reducing primary productivity. When it settles out of suspension it encrusts rocks and stones, smothering and eliminating the benthic flora and fauna, filling the interstices of the substrate to give a deep layer of enveloping deposit (Hynes, 1960). Deposition is dependent on flow characteristics and shear forces, resulting in iron (III) deposits often being resuspended and carried further downstream to affect the biota outside the immediately impacted area.

This report describes a simple descriptive index to assess the impact of AMD on lotic systems by evaluating the degree of substrate modification by visual inspection.

The index

The index value is derived from Table 1 and can range from 0 (unaffected by AMD) to 10 (being very severely affected). So the index is directly related to AMD pollution. Using Table 1 the river is placed into a category (A to E) as outlined below. This is done by visually examining the substrate either from the bank or preferably from within the river. Once a category has been selected the effect of the floc formed within the river is used to help differentiate sites within a single category. This is done by selecting one of four options. If there is no floc visible either suspended in the water or settled on the substrate, then the lower value is selected. This base value increases if flocs are visible suspended in the water, and increases further if floc can be seen collecting on the surface of the substrate between larger stones within the river. If floc is seen collecting in areas of low flow only, for example in bank side puddles or areas where there is little or no flow, then this is considered to be of less significance due to other factors causing flocculation of iron (III) hydroxides.

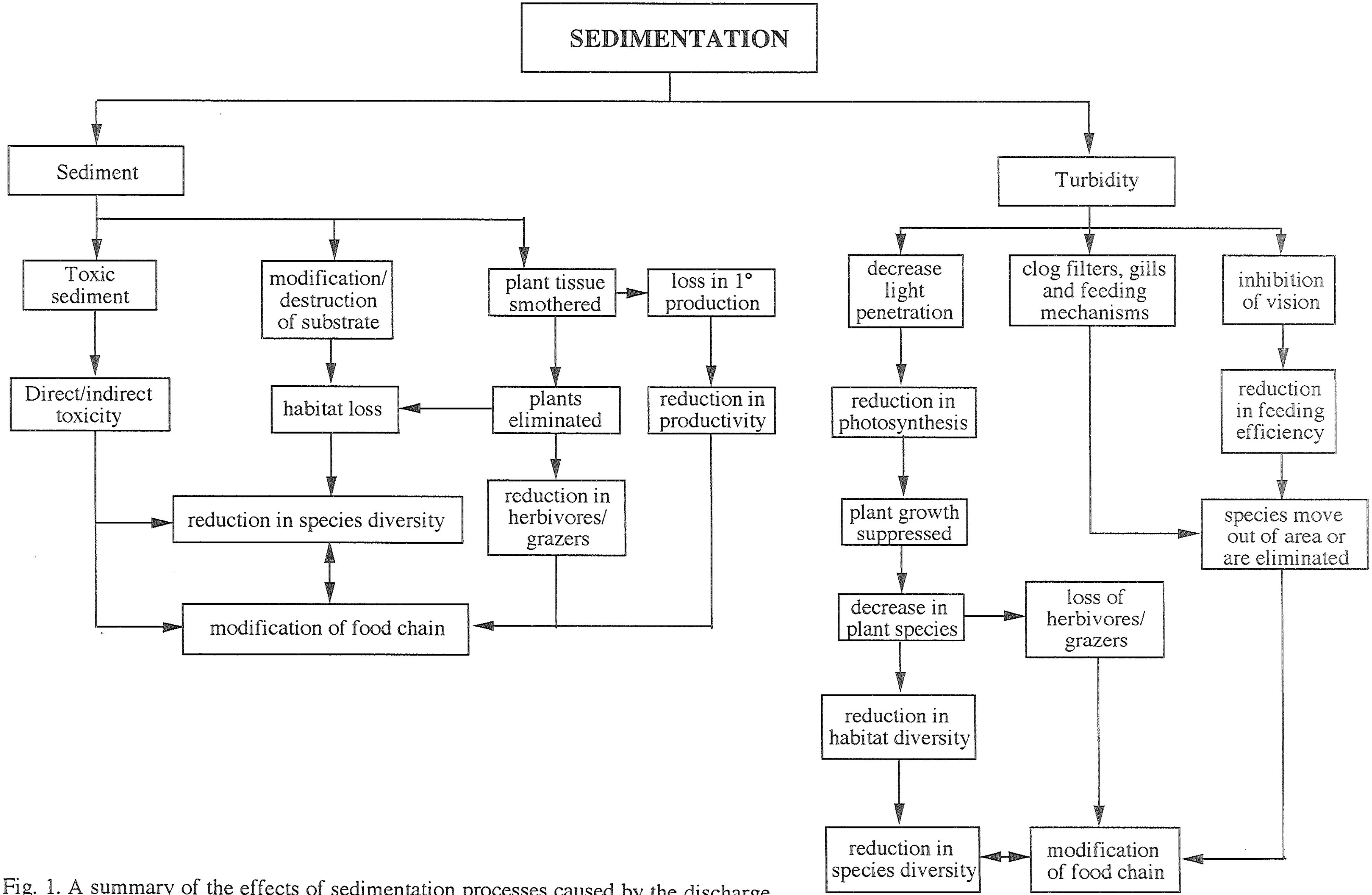


Fig. 1. A summary of the effects of sedimentation processes caused by the discharge of acid mine drainage on lotic communities.

Table 1. Index for the visual assessment of the impact of acid mine drainage on lotic systems.

	Rank			
Category	No floc	Floc in water	Floc collecting between large stones	Floc collecting in areas of low flow only
A	8	9	10	9
B	6	7	8	7
C	4	5	6	6
D	2	3	4	4
E	0	1	2	2

Substrate categories:

The substrate is grouped into five broad categories (A-E). These are summarized below and shown diagramatically in Fig. 2.

Category A The substrate is welded or cemented together with a thick smooth layer of iron (III) hydroxide. The material coats the entire bed so that the substrate is left as a smoothly irregular surface without any exposed areas of the substrate. Dull to bright brownish-yellow in colour, the crust can be prised off, although often very strong, to revel a thick crust of iron made up of many thin deposited layers. These tend to occur close to adit discharge points. Floc material can be deposited very rapidly at times of low flow, with a thin soft layer of ochre on the surface.

Category B A thick crust only forms on top of the large stones comprising the substrate and is not found on the smaller material between. The smaller substrate may be coloured brownish-yellow or covered with deposited floc but is still loose.

Category C The larger stones have a thin coating of material resulting in the surface being densely coloured brownish-yellow. The stones however do not have a thick or discernible crust formation. The smaller material between the larger stones may or may not be coloured to the same degree, and is still loose. Floc deposition may be occurring.

Category D The larger stones have a very thin coating of material resulting in the surface being only lightly coloured either fully or partially. The stones are distinctly different to either category B or C. The smaller material between the larger stones may or may not be coloured to the same degree, and is loose. Floc deposition may be occurring.

Category E The larger stones have no brownish-yellow coloration at all with all the material comprising the substrate free from coloration and loose. There may on occasions be deposited floc material either between stones or in areas of low flow.

Significance of index value:

A summary for the interpretation of the index values obtained is given in Table 2, while a fuller description is given below.

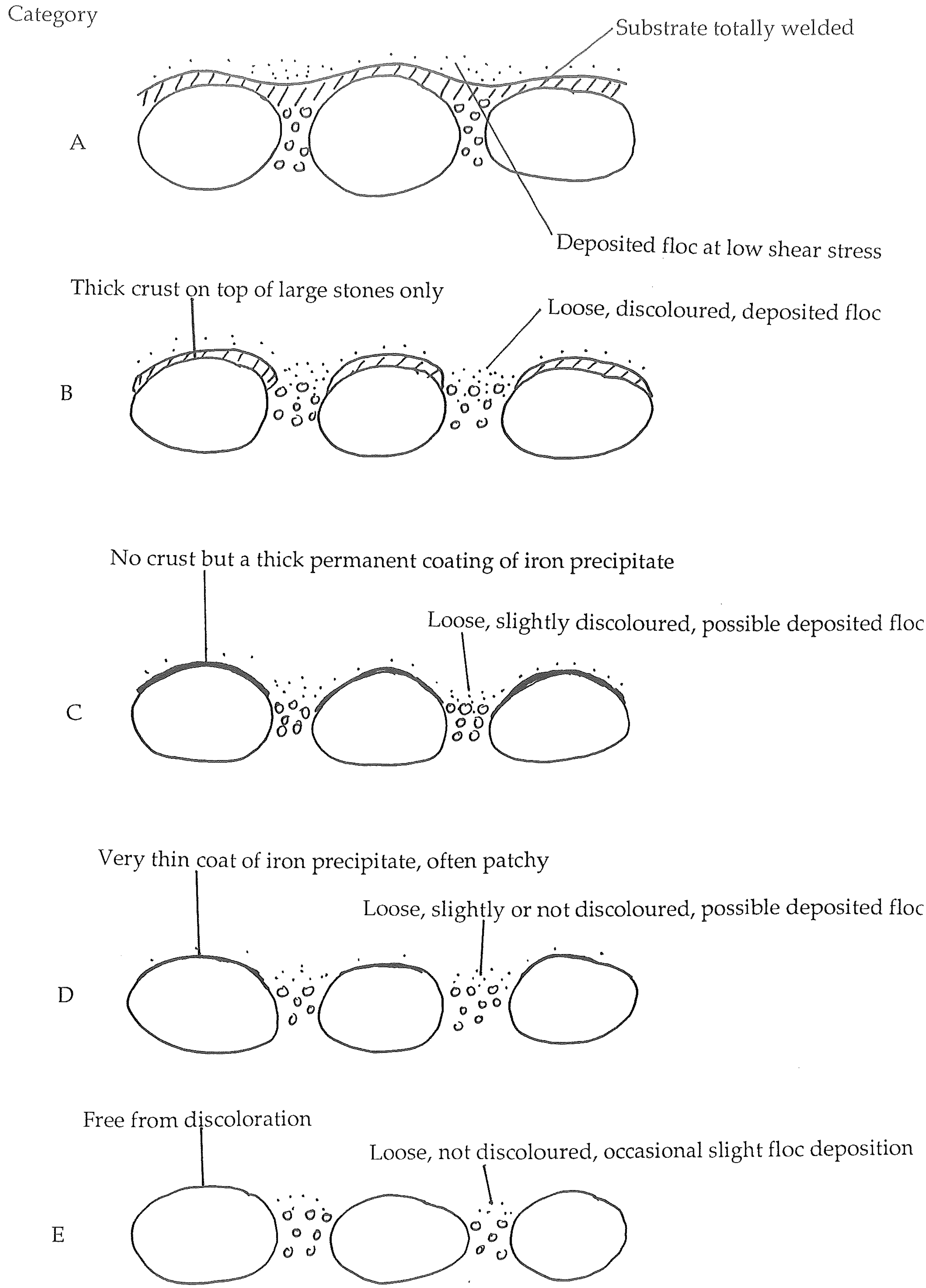
An index value of 8-10 indicates a very severely impacted river with the normal substrate destroyed, being replaced with a smooth cobbled surface, the stones welded together by a thick and very strong layer of iron (III) precipitate, offering no niches for either fauna or flora and offering very little resistance to flow. This type of substrate has no biota present at all, no macrophytes or fish. Migratory fish are also unlikely to be able to pass such areas due to the toxicity of the water. At certain times of the year a thin periphyton growth may develop on the surface of the substrate where shear forces permit. These growths are primarily iron bacteria. Where the index is between 6-7 the impact on the river is still severe but less devastating than before. The substrate is still highly modified but is not completely encrusted, with only the surface of the larger stones covered with a thick crust of deposited ochre material. The gaps between the

Table 2. Severity of AMD impact as assessed by visual index.

Index	Impact	Damage to substrate	Biota: Macroinvertebrate Abundance	Biota: Macroinvertebrate Diversity	Biota: Fish	Biota: Macrophytes
8-10	Very severe	++++	-	-	-	-
6-7	Severe	+++	+/-	+/-	-	-
4-5	Impacted	++	++	++	-	-
1-3	Affected	+	+++	+++	+	++
0	Unaffected	-	++++	++++	++++	++++

large stones contain loose smaller material which will be coloured brownish-yellow and usually covered with deposited floc. Tolerant macroinvertebrates invade these areas occasionally in very small numbers but are not found permanently. There are no fish or macrophytes. There may be restricted development of tolerant filamentous algae in the spring and autumn. This is the area of high floc formation with high deposition possible at period of low flow where the shear stress allows. So any algae present will be heavily coated with iron floc. However at higher flows the smaller substrate is agitated and the floc resuspended and washed downstream. Migratory fish will be able to pass such a zone during prolonged high flows. The periphyton is usually dominated by diatoms. At an index of 4-5 the impact of AMD is still obvious with the larger substrate having a dense brownish-yellow coloration. This coloration is not comprised of a thick layer of ochre and often may be comprised of fine precipitated material which can be easily wiped off. The smaller stones are loose and are often not coloured like the larger material comprising the substrate. Floc collects readily behind large stones and in all low flow areas. Some tolerant species are expected, especially dipterans such as chironomids, but oligochaetes may also be associated with the deposited material. There is however a very low species diversity with moderate abundance's. Macroinvertebrates will be present all the year around and the periphyton growth will be quite thick during the summer due to low grazing pressure. The periphyton will be much more complex than that found upstream with bacteria, diatoms, tolerant algae and protozoa present. Chironomid numbers will be higher where the periphyton is well developed. There are still no fish in this zone, nor macrophytes. An index of 1-3 confirms that the area is still affected by AMD, although the impact may be minimal. Typical areas would be the end of the recovery zone or past the mixing zone where there is a high dilution available of well buffered water. There is a slight ochre deposit/coloration on the larger stones with the smaller looser material free from coloration. The stones are covered with periphyton which does not normally have floc associated with it. However, during higher flows some floc can be transported into the area from more severely impacted areas. The species diversity and abundance of macroinvertebrates are high but clearly depressed compared to control (clean) sites. Chironomids (most tolerant to AMD) usually dominate along with other dipterans while Ephemeroptera (most sensitive) are generally absent. The species diversity will increase as the index falls. Fish are occasionally seen, especially eels (*Anguilla anguilla*), but remain uncommon even at an index value of 2. Macrophytes will be found sparsely at index value 3 rapidly increasing in diversity and cover as the index falls towards zero. At 0 the index is recording an unaffected river similar to that found upstream of the AMD input. Macrophytes will be common, fish abundant, and a high diversity of macro-invertebrates recorded. No floc is seen suspended in the water and in areas of low shear forces there is no brownish-yellow coloration or ochre deposits.

Fig. 2. Diagrammatic representation of the main substrate categories.



Discussion

There does not appear to be a wholly reliable method of identifying and monitoring AMD in lotic systems. While pH, sulphate and metals all chemically characterize AMD, pH and sulphate are probably the best chemical confirmation of AMD, although this depends on dilution and buffering capacity of the receiving water. However, in practice chemical parameters vary spatially and temporarily making assessment difficult. Tolerant algae such as *Euglena mutabilis* , which is typical of mine adits, are generally not present in rivers. The best indications appear to be the brownish-yellow-precipitates of iron (III) hydroxide, high densities of chironomids in the absence of known organic pollution, and the absence of macrophytes.

The most obvious effect of AMD is iron (III) deposition, causing ochre formation on the substrate. By careful examination of the degree of deposition a useful estimation of the severity of the impact of AMD can be made. The index described has been found to be an accurate method of assessing the impact of AMD on the substrate of rivers into which it has been discharged, leading to predictable alteration of the fauna and flora. It allows non-specialists to make a rapid in-situ assessment of the severity of the impact of AMD by visually assessing the degree of precipitation of iron (III) hydroxides on the substrate.

Acknowledgements

This work was funded by the European Union under EU Contract: EV5V CT93-0248 (Biorehabilitation of the acid mine drainage phenomenon by accelerated bioleaching of mine waste).

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