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REVIEW OF UKTAG PROPOSED STANDARD FOR SUSPENDED SOLIDS

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EXECUTIVE SUMMARY

This report details information to assist WWF-UK and Wildlife Countryside Link partners in their response to the surface water UK environmental standards and conditions UKTAG technical report. The information presented consists of a literature review of evidence of the impact of solids on river ecological health, a critical review of the UKTAG proposed approach and proposals for possible alternatives and assessment techniques.

Evidence is provided from published literature highlighting the impacts observed and recorded on both fish and invertebrate individuals, species and communities from suspended and deposited solids. Impacts include physical, behavioural, reproductive and community impacts at varying levels depending upon concentrations, exposure periods and sediment types.

It is agreed that the current annual mean suspended solid standard of 25 mg/l is not currently sufficient and that an alternative must be considered. It is suggested that such a standard should be based upon individual catchment characteristics and the monitoring of damaging events. It is recommended that a single standard is replaced by a number of thresholds taking into consideration exposure length, return period and recovery time. Although it is recognised that the development of such standard thresholds requires further research and investigation it is considered that interim guidelines can currently be set based upon historical literature. At present the UKTAG standards only consider suspended solids, however, there is considerable scientific evidence to suggest deleterious impacts from deposited solids. Such impacts must therefore also be addressed. It is recommended that thresholds for deposited solids are also derived, dependent upon a number of characteristics including particle size, water velocity and the degree of turbulence.

The UKTAG proposals do not currently give any indication of assessment methods for the measurement of suspended or deposited solids. A number of techniques are briefly described including the continuous monitoring of turbidity through data loggers, the periodic assessment of the degree of extent of interstitial deposited solids and the determination of sediment provenance.

1 INTRODUCTION AND BACKGROUND

The UK Technical Advisory Group (UKTAG) on the Water Framework Directive are currently in the process of setting standards and conditions for implementation within the Directive. UKTAG released a technical report on UK Environmental Standards and Conditions in 2006 on which a number of stakeholders responded with comments and suggestions. Three further documents regarding environmental standards and conditions were released in June 2007 covering UK groundwater classification framework, specific pollutants and surface water standards and conditions.

The surface water standards and conditions report covers nitrogen in estuaries and coastal waters, phosphorus in lakes, temperature standards for lakes, rivers, estuaries and coastal waters, suspended solids management approach, standards and conditions for managed flows, standards and conditions for freshwater flow to estuaries, a system for assessing the structure and condition for the bottom and banks of lakes and a system for assessing the structure and condition of the beds/bottom and banks of transitional and coastal waterbodies.

This report has been commissioned by WWF-UK and Wildlife and Countryside Link partners to assist in their response to the surface water UK environmental standards and conditions technical report. This literature review, critical review of the UKTAG proposed approach and proposal of possible alternatives focuses, as requested, on aspects of sedimentation and turbidity in particular the management approach to incidents of sediment release.

2 REVIEW OF IMPACT OF TURBIDITY, SUSPENDED SOLIDS AND SEDIMENTATION ON RIVER ECOLOGICAL HEALTH

2.1 Fish

River and lake sediment loads both in suspension and deposited on the bed can impact upon fish species by affecting spawning site selection, intragravel survival, swim-up fry emergence and juvenile and adult survival. All species have the potential to be impacted by high suspended solid loads through physical and behavioural mechanisms including choking and feeding disruption. Those species at greatest risk from deposited fines include lithophilous spawners requiring clean spawning gravel and cryptic species such as bullhead and loaches residing within sediment spaces.

Physical impacts

Physical impacts on fish from increased suspended sediment concentrations may include clogging and abrasion of the gills, thickening and proliferation of the gill epithelium, reduced resistance to disease, reduced growth rate and in extreme cases death.

A number of studies have been undertaken on the survival of fish species at varying suspended sediment concentrations over differing time frames. Investigations on cyprinids among others identified that they could survive up to a maximum prolonged concentration (one week or more) of 100,000 mg/l although occasional exposures of concentrations up to 225,000 mg/l also exhibited some survival (Wallen, 1951). Rainbow trout were observed to survive concentrations of suspended solids of 80,000 mg/l over a one day period with concentrations having to be raised to 160,000 mg/l to induce mortality over the same time frame (Alabaster & Lloyd, 1980). It is therefore probable that suspended solid concentrations would need to exceed 100,000 mg/l to result in mortality over a short time frame (Alabaster & Lloyd, 1980). Such high concentrations are unlikely to be present within surface waters for a prolonged period and are likely to result from a sediment release incident over a limited time frame. Dependent largely upon the type of solid suspended, varying survival rates have been recorded for a wide range of fish species over extended time periods of up to 200 days. Mortality events have been observed in concentrations of between 200 and 4,250 mg/l in some cases whereas in others no deaths have been recorded in concentrations of between 200 and 1,000 mg/l (Alabaster & Lloyd, 1980).

Although fish may survive high concentrations of suspended solids often over prolonged periods they may subsequently suffer reduced fitness through damage of the gill epithelium through particle abrasion and clogging (Herbert & Merkens, 1961). In addition to gill damage, incidents of disease in fish, in particular ‘fin-rot’, have been reported to increase during events of high sediment load further reducing fitness (Herbert & Richards, 1963). Herbert and Richards (1963), additionally reported a reduction in growth rate of trout as suspended solid concentrations increased.

Behavioural impacts

Fish migrating through both freshwater and estuarine environments may frequently encounter high suspended sediment loads which do not appear to impede this behavioural activity. Atlantic salmon for example are known to pass through the Severn Estuary into the River Severn where sediment concentrations in suspension can reach into several thousand mg/l for periods (Gibson, 1933). Indeed salmonids are likely to have adapted physiologically to the turbid conditions that naturally occur within estuarine and harbour areas (Simenstad, 1988). For instance as salmonids enter estuarine waters changes can occur to their vision which is a direct adaptation to the light environment of estuarine waters (Simenstad and Nightingale, 2001). Moreover as identified by Newcombe & MacDonald (1991) it is not only the concentration of suspended sediment in the water column that is important but also the duration of that exposure (Fig. 1). Therefore aquatic biota respond to both the concentration of suspended solids and duration of exposure in much the same way as they do for any other environmental contaminants. In addition fish, like other animals, exhibit avoidance reactions and move away from the immediate vicinity of adverse conditions.

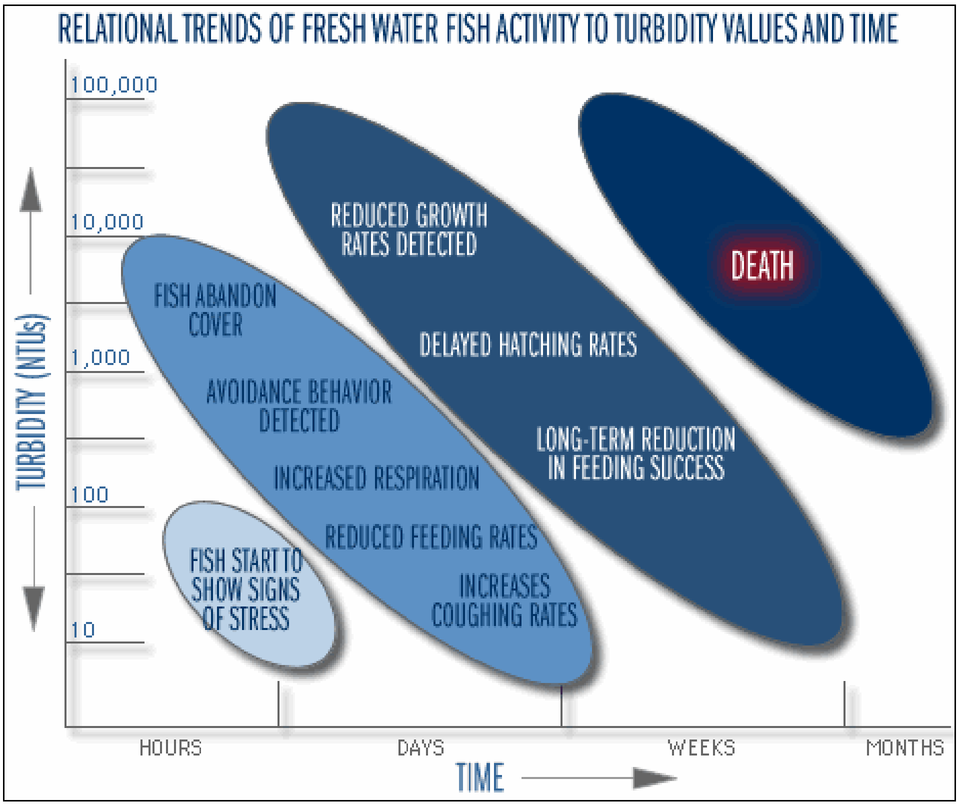

Fig. 1 The relational trends between freshwater fish activity and turbidity values over time

There may be impacts of varying intensity on other behavioural activities however, such as feeding including both impairment and assistance. The efficiency of catching prey may decrease during periods of high suspended sediment concentration although there have also been cases during extended periods of release, of fish using such conditions to their advantage. Accumulation at a turbid-clear water interface may assist in feeding behaviour through the provision of protection and concealment within the turbid water whilst allowing prey observation within upstream clearer waters (Scullion and Edwards, 1980).

Reproductive impacts

The behaviour of spawning salmonids in relation to physical cues usually results in redd placement in areas of high intragravel flow and low silt content (Hobbs, 1937; White, 1942; Stuart, 1953; cited in Crisp, 1996). Good intragravel flow is essential for survival of intragravel life stages both for a supply of oxygen and removal of waste products, such as ammonia. The availability of oxygen within spawning beds is critical with a deficiency resulting in lethal and sublethal effects including: reduced growth rate; reduced efficiency of yolk utilisation; premature hatching; reduced size at hatching and morphological changes. The deposition of fine silt particles on spawning gravels may reduce the suitability of spawning habitat and/or result in decreased survival of incubating eggs. Silt deposition results in both smothering of eggs and reduced intragravel flow and a corresponding reduction in oxygen availability through the occlusion of gravel pore spaces. Mortality figures of between 98 and 100% have been observed for salmonid eggs incubating within spawning gravels suffering from high siltation loads (Turnpenny & Williams, 1980). A number of studies summarised within Crisp (1996) on the incubation success of salmonid eggs and fry emergence suggest that substrata containing >15% of fines (<1.0 mm) are unsuitable for their successful survival. Percentages of 10% and below are considered ideal for survival success.

Other lithophilous species including bullhead, the three UK lamprey species and a number of cyprinid species including barbel, chub, gudgeon and dace all require similar spawning habitat characteristics to salmonids, in particular a good intragravel flow and oxygen supply. Salmonids are potentially the most susceptible to sediment release however, due to the prolonged period for which the eggs are present within the gravel pore spaces (up to 160 days and at a burial depth of up to 30 cm) in comparison to 6 to 8 days with egg deposition close to the surface of the spawning substrate for chub.

Studies undertaken by Petersen and Metcalfe (1981) showed decreased survival and reduced length and/or weight of emerging fry at increased percentages of sand within the spawning gravel mix. This was also correlated with premature emergence of swim-up fry at sites with an increased percentage of sand within the spawning medium. This investigation led to the derivation of the ‘sand index’ to enable the analysis of successful fry emergence in comparison to the fraction of sand within the spawning substrate matrix. The index is based upon the following equation:

$$\text{Sand Index} = S_c/16 + S_f/8$$

Where S_c is the coarse sand fraction (0.5-2.3 mm)
And S_f is the fine sand fraction (0.06-0.5 mm)

No decrease in the percentage emergence of fry is believed to occur at index outputs of 1 or less. It is suggested that a decreased emergence rate will be exhibited for outputs of between 1 and 1.5 and no emergence will be seen with outputs of above 1.5.

In addition to lithophilous species spawning on gravel beds, those depositing eggs on macrophytes such as perch and roach may also suffer from increased sediment loads within a watercourse. High suspended sediment concentrations during the incubation period of these species have been reported to result in high and total mortality events through the adherence of silt particles to the egg surface preventing sufficient oxygen and carbon dioxide exchange (Stuart, 1953).

Indirect impacts

Indirect impacts on fish populations consist primarily of effects of both suspended and deposited solids on their food supply including both macro-invertebrates and plants. Both smothering through deposition and abrasion, and reduced light availability through suspended solids may impact upon the health and abundance of aquatic macrophytes within a watercourse reducing their availability as a food source for fish populations.

In addition sedimentation has been observed to reduce both density and biomass of invertebrate populations as detailed below, resulting in both reduced ecological status and a reduced food source for fish.

2.2 Invertebrates

Numerous studies have been carried out to determine the potential implications of increased turbidity in freshwater ecosystems, the results of which included for example:

1. Sedimentation and turbidity have been found to be inversely related to invertebrate densities and biomass as well as autochthonous primary production (Tsui & McCart, 1981; Wagener & La Perriere, 1985; Rosenberg & Resh, 1993; Henley *et al*., 2000).

2. Fine sediment tolerant invertebrate genera were found to increase with increasing levels of suspended solids (Gammon, 1970).

3. Increased sediment loads may cause an increase in interstitial sediment that fills the spaces between gravels resulting in a reduction of available interstitial habitat and thus the overall abundance of invertebrates (Ryan, 1991).

4. Ecological effects of sediment increase also include reduced light penetration, smothering and abrasion which may subsequently result in decreased food availability for zooplankton, insects and fish which in turn results in reduced primary production (Henley *et al*., 2000).

Modifications of natural flow regimes of rivers can affect aquatic biota at the population and community levels (Schlosser, 1991; Marchetti & Moyle, 2001) and may cause changes to the natural river habitat. Osmundsen *et al.* (2002) carried out a study on the resulting effects from river regulation and subsequent fine sediment accumulation in gravel-cobble substrates, which revealed that the degree of this accumulation was very well described by the macroinvertebrate biomass and physical characteristics of the river bed. The modification of the natural habitat for invertebrate communities is of major concern as changes in the invertebrate composition may directly and/or indirectly affect the co-occurring fish communities. Habitat variables that drive the longitudinal and horizontal distribution of invertebrates in a system include the water depth, velocity, vegetation and substratum type and grain size (e.g. Jowett *et al*., 1991). The influx of fine solids at increased levels and subsequent alteration of the substrate composition may result in shifts in habitat and invertebrate distribution and/or reduced species diversity (see also Wood & Armitage, 1999).

Sediment deposition on respiration structures of invertebrates can cause a reduction in oxygen uptake (Waters, 1995) and affect feeding, particularly in filter-feeding invertebrates. Further problems arise when individuals are buried by fine sediments. Increasing sediment deposition and substrate instability following increased sedimentation may result in an increase in invertebrate drift (Rosenberg & Wiens, 1978; Wood & Armitage, 1997). The increased number of invertebrate specimens drifting also increases the potential for increased predation and burial (Wood *et al*., 2005). Caddisflies for example have been observed to be particularly prone to burial (Dobson *et al*., 2000; Wood *et al*., 2001) as their relatively heavy cases cause them to settle out of drift more quickly than non-case bearers. Moreover many species of Trichoptera, Ephemeroptera and others are unable to excavate themselves once buried by fine sediments (Wood *et al*., 2005). Investigations into the specific use of sedimented vs. non-sedimented water by aquatic invertebrates revealed that many stonefly, caddisfly and mayflies prefer to spend time in non-sedimented areas (Ryan, 1991).

The problem of sedimentation is compounded by its seasonal and temporal variability (Wright, 1992). Variable reproductive cycles of invertebrate taxa will be altered by the level of sedimentation.

The effect of water pollution, including suspended solids and deposited solids, was investigated by the working party of EIFAC (European Inland Fisheries Advisory Committee) during the development of Water Quality Criteria for European Freshwater Fish. The reports produced from the work undertaken by the working party have subsequently been summarised by Alabaster and Lloyd (1980). These summarise a number of studies including those on suspended and deposited solids undertaken on individual invertebrate species and communities. Critical concentrations of suspended solids determined within a laboratory for Cladocera and Copepoda for example were determined to be between 300 and 500 mg/l. The concentrations resulting in mortality however, appear to be largely dependent on the type of solid in suspension with the primary causes of mortality being clogging of the filter-feeding apparatus and digestive organs.

Data appear to be limited for the impacts of suspended solids however, with the majority of investigations involving their deposition. In terms of density of benthic invertebrates an example of the impact of solid deposition was shown in the Scott River. Within an area where siltation had occurred the density of organisms was around 300 organisms m^{-2} in comparison to 2000 m^{-2} within cleaner areas. Changes in community assemblage as a result of solid deposition were seen within a stream studied by Gammon (1970) where solid concentrations increased from 13-52 mg/l to 21-250 mg/l resulting in an increase in species preferring silt habitat such as Trichcorythoides and a decrease in other species such as *Cheumatopsyche*. A study undertaken by Ryder (1989, summarised in Ryan, 1991) found a 16-40% decrease in the total abundance of invertebrates with a 12-17% increase in interstitial fines and a 27-55% decrease in ephemeropteran *Deleatidium* abundance. Other examples include; the disappearance of populations of Trichoptera, Ephemeroptera, Crustacea and Mollusca upon the release and deposition of 19,750 mg/l of solids into a French trout stream, the disappearance of 'fish-food fauna' after the release of 250 mg/l from a quarry and the disappearance of invertebrate fauna on the release of 11,300 mg/l from a granite crushing mill. A study undertaken by Culp *et al*. (1986, summarised in Ryan, 1991) gives an indication of time response to solid deposition with a total benthic density reduction of over 50% in 24 hours although the solid concentration involved is not stated.

There appears to be little information regarding the recovery period of such losses or the period of exposure. It is therefore anticipated that the impact of both suspended and deposited solids on invertebrate communities and individual species mortalities is likely to be dependent upon both the type of solid and the period of exposure in addition to concentration.

2.3 Other aquatic considerations

In addition to fish and invertebrates there are likely to also be impacts upon other organisms such as macrophytes and diatoms from both suspended and deposited solids. Although out of the remit of this review the entire aquatic ecosystem should be taken into consideration on assessing the impact of solids release on good ecological status.

3 CRITICAL REVIEW OF UKTAG APPROACH TO SEDIMENTATION AND TURBIDITY

3.1 Overview of UKTAG proposals

The current UK environmental standard and condition followed for suspended solids is set by the Freshwater Fish Directive giving a guideline standard of an annual mean of 25 mg/l. Within the Directive it stipulates that member states must 'endeavour to respect' guideline standards whilst 'imperative standards' must be met. There are currently no imperative standards within the Directive dealing with suspended solids.

The proposal of the UKTAG is that this annual mean value of 25 mg/l should not be taken forward into the Water Framework Directive as a declaration of 'good ecological status'. The primary reason given for this is that the annual mean is more suited to dealing with the continuous, relatively steady discharge of suspended solids from industry as opposed to a measure of good watercourse ecology. It is suggested by UKTAG that this annual mean value continue to be used in the control of discharges from, for example, mines and quarries.

Under the WFD, where good ecological status is considered to be at risk on the basis of ecological data then the competent authority, the Environment Agency (EA) or Scottish Environment Protection Agency (SEPA) will investigate the cause of such a risk which may include levels of suspended solids. The UKTAG technical report currently states that 'there is no useful water quality standard by which to assess this in a reliable way'. The main reasoning for this statement is that 'an annual mean, is not appropriate for tackling occasional events such as run-off from land'. It is therefore recommended by UKTAG that a management approach be taken which should consider the 95th-percentile to take into account the rarer but potentially damaging events. If a correlation between failure of this percentile and damaging events was observed it would then be possible to manage future risks through land management for example.

In the event of a sediment flush from land as a result of heavy rainfall a management approach will be put in place for action following a defined checklist, summarised below:

- An assessment of the propensity for damage which may lead to targeted monitoring.
- Evidence from actual events including measurements, deaths and recovery time.
- Prediction of the probability of future damaging events.
- Compliance with any standards suggested for this purpose. This might be based upon results of samples taken during a damaging incident.

Based upon the evidence generated from the above checklist, UKTAG then recommend that pollution prevention measures be increased to minimise the risk of damaging events.

It is suggested that during the above management approach process, and through research, that numeric standards for sediment loads or concentrations might be defined, based upon catchment characteristics.

3.2 Review of UKTAG approach

Evidence from the literature review undertaken as part of this report, and the requirement for standards under the WFD, highlights that suspended and deposited solids have the potential to be a threat to the ecological status of water courses and the species residing within them. There is therefore a genuine and pressing requirement to address the issue of water quality standards, in particular for solids, both for use within the WFD and to protect riverine, lacustrine, estuarine and marine ecology.

It is considered by APEM that the current suspended solids standard, an annual mean of 25 mg/l, is not sufficient for the assessment of risk of damaging events which may substantially exceed this threshold during any given year but will not be considered as a failure as the waterbody may still attain the mean over the course of the year. It is agreed that an alternative must therefore be considered and that a more extreme value such as the 95th-percentile would be more appropriate. It is further agreed that standards based upon individual catchment characteristics would be a more robust protection measure than the current generic national standard. The sources of damaging events and the relative impact of such events will differ depending upon the characteristics of individual catchments and the position within catchments. The seasonality of a release event will also have significant implications on the extent of damage due to both the varying physical nature of the waterbodies and the biological risk periods of key species. The principle of assessing actual damaging events through physical measurements, observations of fish and invertebrate mortalities and assessing the probability of the occurrence of such damaging events are all useful tools. Putting into action pollution prevention measures based upon the event assessments will go some way to increasing ecological protection. The assessment of recovery time is briefly mentioned within the management approach, however, it is considered to be an essential part of the derivation of standards. It is recommended by APEM that more emphasis should be placed on this aspect of standard derivation to enable the definition of robust standards. Standards must be suitable for the period in which it would take for recovery from varying degrees of damaging events.

A more appropriate assessment process may therefore not be a single standard but rather a number of thresholds taking into consideration both exposure time, return period and recovery time. Fish will be better able to withstand a higher suspended solid concentration for a short period than they would be able to withstand over a prolonged period. This is supported by the evidence seen in trials and investigations as reported within the literature review above. It is therefore considered by APEM to be essential that standards take into consideration the likely exposure period and the population recovery time frame of any suspended solid concentration release.

In terms of the failure or risk of failure of good ecological status as indicated from ecological data, the EA will be required to assess the cause of such risk. It is however then stated ‘that high levels of suspended solids might be considered a reason, for example, that water quality is judged as insufficient for good ecological status. But the

UKTAG proposes that there is no useful water quality standard by which to assess this in a reliable way' (UKTAG). We do not agree with this statement and indeed appears to be contradicted within the document itself. Following sections discuss not only the use of a more extreme percentile as a possible standard but also the derivation of a standard through the investigation of specific damaging events and research. It is considered that a more appropriate statement may therefore be:

- the UKTAG proposes that at present there is not a useful water quality standard sufficient to assess individual catchments and events in a reliable way. It is therefore recommended that further investigation and research be undertaken through the assessment of actual damaging events to develop a more stringent standard or a series of catchment specific standards for use within the WFD.

It is considered however, that although this method would provide more stringent standards that the development of such values will require a protracted time scale. This delay in standard derivation may therefore result in the continuation of damaging events in the interim. It is therefore suggested that the setting of interim standards should be considered whilst formal standards are investigated and defined. Literature and guidance are currently available from which insight may be gained for setting these interim standards.

The working party of EIFAC (European Inland Fisheries Advisory Committee) investigated the effect of water pollution, including suspended solids, during the development of Water Quality Criteria for European Freshwater Fish. The studies used to determine the criteria have subsequently been summarised by Alabaster and Lloyd (1980) in which a series of tentative annual mean values for chemically inert solids in suspension were given for the maintenance of freshwater fisheries as follows:

- Less than 25 mg/l - no evidence of harmful effects on fisheries
- 25 – 80 mg/l – it should usually be possible to maintain good or moderate fisheries
- 80 – 400 mg/l – unlikely to support good freshwater fisheries
- Greater than 400 mg/l – only poor fisheries are likely to be found

These criteria were taken forward into England and Wales law in 1997 under the Surface Waters (Fishlife) (Classification) Regulations.

A further review in which the risk of suspended solids to fish habitat were assessed was regarding mining operations in the Yukon undertaken by the Canadian Department of Fisheries and Oceans (DFO, 2000). The levels of risk were very similar to those outlined by the EIFAC working party:

- 0 mg/l – no risk
- Less than 25 mg/l – very low risk
- 25 – 100 mg/l – low risk
- 100 – 200 mg/l – moderate risk
- 200 – 400 mg/l – high risk
- Greater than 400 mg/l – unacceptable risk

With reference to the values given within both of these reviews and other published literature it should be possible to set interim standards prior to the derivation of more stringent catchment specific standards. Such standards should be in the form of thresholds taking into consideration exposure periods and recovery times. On brief consideration of the literature data for example it could be argued that an interim imperative threshold could be set for salmonid rivers in the several thousand mg/l for exposure durations of one day or less but this may need to decrease for extended periods in the region of one week to 1,000 mg/l. The timing of such an event must however also be taken into consideration as a release during the spawning period for example would potentially have far greater implications than other lower risk periods. These values are given as a guide only and a further literature data assessment would be required to set exact values. Furthermore the return periods for such events would need to be considered, such that only a set number of events of a pre-determined magnitude were permitted within any given timeframe. To maintain a healthy freshwater fishery both the EIFAC and DFO reviews would indicate that for the remainder of the year concentrations must fall below 25 mg/l.

In addition to suspended solids there is a wealth of scientific evidence to suggest that deposited solids also have a deleterious impact upon fish and invertebrate communities. There are currently no standards by which this deposition is assessed as a risk to either fish or invertebrate populations. The inclusion of such standards are not currently referred to within the UKTAG report. Depending upon the size of solid particles, water velocity and the degree of turbulence, suspended solid standards in relation to risk from deposition may differ for individual catchments and indeed watercourses. The thresholds for deposited solid standards however, require careful consideration as the timing of events, for example, is likely to be a more important factor than event duration as even a short release period may result in the complete smothering and loss of incubating eggs.

Current water quality suspended solid standards have been made for fish species only, evidence has shown however, that impacts are also observed within invertebrate populations. The extent of damage to impact upon an invertebrate population may be the same or differ from those observed for fish. To ensure the monitoring of good ecological status it would therefore be beneficial to include an invertebrate suspended solid standard either as stand alone thresholds or encompassed within the fish standards. Again it may be possible to gain some insight from published literature for the setting of interim standards for invertebrates in isolation or for their inclusion within a fisheries standard. Data appears however, to be limited for invertebrates in particular in terms of varying exposure periods and contrary to fish concentrate on deposited solids opposed to suspended. For guidance however, a deposited solid value of 250 mg/l has been given within published literature briefly detailed above for both changes in community assemblage and complete disappearance of invertebrate fauna.

4 PROPOSALS OF SUSPENDED AND DEPOSITED SOLID ASSESSMENTS

The current proposals of UKTAG do not indicate the assessment methods to be employed to measure the concentration of suspended solids, in particular during incidents of high sediment release through for example run-off from heavy rainfall. Single measurements or monthly monitoring will not be sufficient to identify the frequency or extent of these potentially ecologically damaging events. It is recommended that to gather the data required to both identify the frequency of damaging events and the concentrations present during these events that where possible continuous monitoring of turbidity/suspended solids concentrations are undertaken. For these data to be used to the best capacity however, it will also be necessary to identify the presence and extent of any mortality events both in immediate and extended time frames as a result of any release. Damage and mortality will need to be assessed in terms of both suspended and deposited solids. As such the volume of deposited solids will also require monitoring on a regular basis and if possible post release events to determine extent of deposition and period of deposition. Details of proven techniques for such assessments are briefly defined below of which a number are detailed within the Life in UK; Siltation in Rivers Review of monitoring techniques (Naden *et al*., 2003).

There are ways in which turbidity can be monitored continuously through light scattering data loggers. Such data loggers can also trigger the automatic collection of water samples for suspended solid concentration analysis at pre-set turbidity values. This automatic collection process would enable the assessment of concentrations and release periods during potentially damaging events and the automatic data logger would alert staff to the event for on the ground analysis of mortality events. In addition to optical measures of turbidity and water sampling, sediment traps and acoustic scattering are also potential suspended solid concentration sampling techniques that could be employed.

In addition to the sampling of suspended solids, deposited solid sampling is also considered to be essential in the assessment of good ecological status. The extent and rate of solid deposition can be monitored and sampled using a variety of techniques including the assessment of scour and fill on riverbeds (cross sections and 3D channel bed characterisation), the collection of samples for analysis (bulk and freeze cores) and the deployment of sediment baskets and traps. In addition to assessing deposited solids it is also possible to measure DO (dissolved oxygen) and intragravel flow within the bed sediment through the use of, for example, a conductiometric standpipe. The impact of solid deposition upon egg incubation and fry emergence can also be monitored and assessed directly through egg planting and fry emergence traps.

To assist the statutory bodies in determining the cause of sediment release it is further possible to undertake sediment fingerprinting and provenance studies on solids both in suspension and deposited using the above collection techniques. Fingerprinting will enable the identification of spatial provenance and type of the solids to identify the principle sources and zones of release. Such identification will allow for the targeting of pollution prevention management and monitoring within areas of greatest release risk.

The continuous monitoring of suspended solids and regular assessment of deposited solids, in particular after damaging events alongside incidents of mortality on both short and long term time frames, would greatly assist in the definition of robust standards. The recording of damaging events and their frequency along with the identification of source of release through fingerprinting will enable the design of effective catchment specific pollution prevention management. Such detailed and specific standard derivation and pollution prevention management will be the most effective measures for the protection of good ecological status.

5 REFERENCES

Alabaster, J.S. and Lloyd, R. (1980). Water quality criteria for freshwater fish. Food and agriculture organization of the United Nations, Butterworths, London.

Crisp, D.T. (1996). Environmental requirements of common riverine European salmonid fish species in fresh water with particular reference to physical and chemical aspects. Hydrobiologia, 323: 201-221.

Extence, C., Balbi, D.M. & Chadd, R.P. (1999) River Flow indexing using British Benthic Macroinvertebrates: A Framework for setting hydroecological objectives. *Regulated Rivers Research & Management* **15**: 543-574.

Gammon, J.R. (1970) The effect of inorganic sediment on stream biota. *Water Pollution Control Research Series*. Report No. 18050 DWC 12/70, U. S. Environmental Protection Agency, Government Printing Office, Washington DC.

Gibson, A.M. (1933). Construction and operation of a tidal model of the Severn Estuary. London, H.M.S.O.

Harrison, E.T., Norris, R.H. & Wilkinson, S.N. (2007) The impact of fine sediment accumulation on benthic macroinvertebrates: implications for river management. *In* Proceedings of the 5th Australia Stream Management Conference. Australian Rivers: making a difference (Wilson, A.L., Dehaan, R.L., Watts, R.J., Page, K.J., Bowmer, K.H. & Curtis, A., eds.). Charles Sturt University, Thurgoona, New South Wales.

Henley *et al.* (2000) Effects of Sedimentation and Turbidity on Lotic Food Webs: A Concise Review for Natural Resource Managers, Reviews in Fisheries Science 8 (2):458-139.

Herbert, D.W.M. and Merkens, J.C. (1961). The effect of suspended mineral solids on the survival of trout. Int. J. Air Wat. Poll. 5, 46-55.

Herbert, D.W.M and Richards, J.M. (1963). The growth and survival of fish in some suspensions of solids of industrial origin. Int. J. Air Wat. Poll. 7, 297-302.

Jowett, I.G., Richardson, J., Biggs, B.J.F., Hickey, C.W. & Quinn, J.M. (1991) Microhabitat preferences of benthic invertebrates and the development of generalised Deleatidium spp. habitat suitability curves, applied to four New Zealand rivers. New Zealand *Journal of Marine and Freshwater Research* **25**:187-199.

Marchetti, M. P. & Moyle, P. B. (2001) Effects of flow regime on fish assemblages in a regulated California stream. *Ecological Applications* 11: 530-539.

Naden, P., Smith, B., Jarvie, H., Llewellyn, N., Matthiessen, P, Dawson, H., Scarlett, P. & Hornby, D. (2003). Siltation in Rivers. A review of monitoring techniques. Conserving Natura 2000 Rivers Conservation Techniques Series No. 6. English Nature, Peterborough.

Newcombe C.P. & MacDonald D.D. (1991). Effects of Suspended Sediments on Aquatic Ecosystems. North American Journal of Fisheries Management, 11, 72-82.

Osmundson, D.B., Ryel, R. J., Lamarra, V. L. & Pitlick, J. (2002) Flow-Sediment-Biota Relations: Implications for River Regulation Effects on Native Fish Abundance. Ecological Applications 12 (6): 1719-1739.

Petersen, R.H. and Metcalfe, J.L. (1981). Emergence of Atlantic salmon fry from gravels of varying composition; A laboratory study. Canadian Technical Report of Fisheries and Aquatic Science, Vol. 1020, pp 13.

Rosenberg, D. & Resh, V. (1993) Introduction to Freshwater Bio-monitoring and Benthic Macro-invertebrates in Freshwater Bio-monitoring and Benthic Macro-invertebrates. Chapman Hall, New York, 10: 488pp.

Rosenberg, D. M., & Wiens, A. P. (1978). Effects of sediment addition on macrobenthic invertebrates in a northern Canadian stream. Water Research 12: 753-763.

Ryan P. (1991) Environmental effects of sediment in New Zealand streams: a review. New Zealand Journal of Marine Freshwater Research 25: 207 - 221.

Schlosser, I. J. (1991) Stream fish ecology: a landscape perspective. BioScience 41: 704-712.

Scullion, J. and Edwards, R.W. (1980). The effects of coal industry pollutants on the macro-invertebrate fauna of a small river in the South Wales Coalfield. *Freshwater Biol.* **10**: 141-162.

Simenstad C.A. (1988). Effects of Dredging on Anadromous Pacific Coast Fishes. Summary and Conclusions from Workshop and Working Group Discussions.

Simenstad C.A. & Nightingale B. (2001). Dredging Activities: Marine Issues. White Paper. Research project T1803, Task 35. Washington State Transportation Centre.

Stuart, T.A. (1953). Spawning migration, reproduction and young stages of loch trout (*Salmo trutta*). Freshwat. Salm. Fish. Res. 5: 1-39.

Suren, A.M. & Jowett, I.G. (2006) Effects of floods versus low flows on invertebrates in a New Zealand gravel-bed river. Freshwater Biology 51: 2207-2227.

Tsui, P. and McCart, P. (1981) Effects of stream-crossing by a pipeline on the benthic macro-invertebrate communities of a small mountain stream. Hydrobiologia 79: 271 - 276.

Turnpenny, A.W.H. and Williams, R. (1982). A conductiometric technique for measuring the water velocity in salmonid spawning beds. Water Res. 16: 1383-1390.

Wagener, S. and La Perriere J. (1985). Effects of placer gold mining on primary production in subartic streams of Alaska. Water Research Bulletin 22: 91 - 99

Wallen, I.E. (1951). The direct effect of turbidity on fishes. Bull. Okla, agric. Mech.coll., (Biol.) 2, 48.

Wood, P.J. & Armitage, P.D. (1999). Sediment deposition in a small lowland stream - Management Implications. Regulated Rivers: Research & Management 15:199-210.

Wright, J.F. (1992). Spatial and temporal occurrence of invertebrates in a chalk stream, Berkshire, England', Hydrobiologia 248: 11–30.