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Combining biology and hydrology—questions from an integrated study of chalk streams

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Abstract Combining biology and hydrology has allowed us to investigate the effects of plants and animals on the transport of sediments in chalk streams. In developing our integrated study we needed to understand the different use of terms and approaches used by the two disciplines. We present some of the questions that have arisen and that have wider application in all studies linking biology and hydrology, a process we must encourage if we are to understand the functioning of flowing water systems.

Key words aggregates; biology; chalk streams; end users; flocs; hydrology; integrated studies; microbiology; models; particles

INTRODUCTION

Chalk streams drain from aquifers and are characterized by water rich in calcium ions and by modulated temperature and rate of change of flow. They are usually shallow (most are wadeable along much of their length) and have substrata of cobbles and gravel with some finer mineral particles. Organic matter is also abundant and forms noticeable deposits along parts of the stream margins and elsewhere on the bed. Organic and mineral substrata allow rooted plants to develop and these also invade the marginal deposits. The plants act as particle traps and also engineer flow (Wharton *et al.*, 2006), creating fast-flowing channels where they extend to the surface, a growth habit typical of the dominant water crowfoot (*Ranunculus* spp.). The stream becomes shaded where the riparian zone consists of overhanging trees and this reduces in-stream macrophyte vegetation considerably, often resulting in an exposed gravel/cobble bed. At a microscopic scale there are abundant attached algae, and microbial biofilms are found on all surfaces.

INTERDISCIPLINARY STUDIES—OUR PROJECT AND IDEAS ON WIDER SCALES

Interdisciplinary studies are essential if we are to understand complex systems such as chalk streams. We are co-PIs on a project investigating the role of rooted macrophytes on the modification of flow patterns and in the retention of organic matter. This has parallels with studies in seagrass communities in shallow marine habitats where water ebbs and flows. Some of the organic matter in chalk streams, as in the sea, has undergone transformation by suspension-feeding invertebrates. These animals trap fine particulate and dissolved organic matter and convert it into much larger, compacted faecal pellets that are bound throughout with exopolymer collected from the water column or exuded by micro-organisms within the gut contents (Wotton & Malmqvist, 2001). Faecal pellets sink readily through the water column and become an important component of the organic matter present on the substratum (Wotton *et al.*, 1998). We have thus combined biology and hydrology and have a clearer picture of the processes that occur under, and around, macrophyte stands (Cotton *et al.* 2006). We also have information on processes at the reach scale.

Our project fits within the central part of a continuum of increasing scale of study (Fig. 1) made by scientists with a range of expertise (Fig. 2). At higher scales we have catchment and land-use studies that are best monitored using satellite imagery to feed information to models. At smaller scales come investigations into microbiology and in the molecular genetics of variation within populations. It is likely that these higher and smaller scales are based on a more deterministic approach than our project, as the influence of plants on hydrology, and the growth and responses of plants to changing conditions, are rather more stochastic. This division into stochastic and deterministic is important for modellers who need to build some idea of chaos into predictive models that are based on living organisms.

Increasing scales studied

Organic colloids
Clays
Sand grains
Other individual small particles
Flocs
Other aggregates
Biofilm matrices
Cobbles and boulders
Branches and submerged wood
Macrophyte beds
Sediment and sand banks
Reaches
Catchments

Fig. 1 Increasing scales studied when examining the functioning of flowing water systems.

Expertise needed for understanding

Molecular biologists/geneticists
Microbiologists
Plant biologists/ecologists
Invertebrate biologists/ecologists
Fish biologists/ecologists
Geomorphologists
Hydrologists
Sedimentologists
Environmental chemists
GIS analysts

Fig. 2 The range of expertise needed for studies in the functioning of flowing water systems (environmental chemists have been included at one point but their contributions are essential elsewhere).

Ideally, all levels need to be studied together. At the smallest scale, measures of stream respiration show microbial metabolism to be the most important producer of carbon dioxide, with microbial respiration maybe more than a hundred times greater than the respiration of other consumers (Allan, 1995). Although little known to non-biologists, the by-products of minute algae and micro-organisms are also essential in many stream processes. This is an area of "education" that biologists have brought to interdisciplinary studies and it is going to be of increasing importance as we delve further into the real drivers of the system. On larger scales, it is clear that many variations in the hydrology of chalk streams result from climate and, possibly, climate change if we project into the near future. On this large scale we also need to be able to model the influence of water abstraction, chalk aquifers producing water of high quality that requires little treatment before being passed to the domestic supply system. Remote monitoring of river systems is now common practice and this, together with satellite imagery, provides us with very large data sets. The combination of miniaturization in electronic engineering, and the advent of powerful computers, have made important inroads into monitoring short-term and long-term change and have informed many studies and more detailed scales. One of the advantages of the interdisciplinary approach is that it forces component groups to communicate with each other. This is educational but it also highlights differences in approaches and terminology.

COMMUNICATION TO END-USERS AND BETWEEN DISCIPLINES

End-users need information for planning and conservation, good science being the foundation for effective management. The most useful information is in the form of models into which variables are entered to provide management tools. Such models are relatively easy to construct but, of course, are only effective if the information they contain is accurate. It is accepted that all natural systems have stochastic components and the predictions of models are likely to fail badly on occasions, but this does not deflect from their usefulness. So, how to get across the idea of the changing nature of chalk streams so that end-users can use models as guides?

We held meetings with several local, end-user agencies and they were very receptive to the science in our collaborative programme. One of the responsibilities of researchers is to communicate and this begins with the exchange of ideas between individuals from different disciplines within the group. Not only did we need to educate each other about aspects of biology and hydrology, but we also had to overcome problems with terms. For example, biologists are unclear about the term "suspended sediments" and hydrologists do not commonly use the term "seston". We all have difficulties in using the term "fine material" as it may mean that which is <1 mm in diameter, <63 µm in diameter, or of some other dimension. Another key difference is the use of "substrate" by hydrologists, when biologists refer to "substratum", a substrate being the medium used for growth by micro-organisms. We also have different approaches to particles and to the interaction of water and the substratum. This aspect throws up an important series of questions and we would like to pose these now: "What is a particle?"; "What is the importance of water column processes for sediments?" and "What is the importance of sediment microbiology?".

WHAT IS A PARTICLE?

At its simplest this question is easy to answer. The size and density of a clean grain of sand can be measured, its content analysed. Fall velocity of the sand grain can be recorded and so can the likelihood of resuspension once the particle has reached the substratum, the time and distance being calculated readily from known equations. Sand grains are likely to be washed into the stream during times of high flow and they will also move over the substratum when current velocity is high. But how typical are clean sand grains of the particles present in the water of chalk streams and on the substratum?

Particles in water bear charges and the net effect of particle charge is to repel materials of like charge and attract those of opposite charge. This can lead to coagulation (Fig. 3), whereby two particles become loosely joined to one another, or very small particles become attached to a larger one. Among very small particles will be bacteria and other micro-organisms that attach more firmly to surfaces by exuding exopolymers (EPS) to form a link which can develop into a biofilm, with cells embedded in a polymeric matrix. When particles with EPS coatings come into contact they will stick and this process is best referred to as flocculation, flocs also attracting motile cells or being impacted by other cells, which become attached to the biofilm or accumulated EPS from the water column. Such flocs can be large (centimetres across, Neu, 2000) although most are much smaller. Their content varies with the amount of mineral particles in suspension, divalent cation composition and many other factors (Droppo *et al.* 1997; Droppo, 2003).

Has sufficient attention been paid to the material in suspended flocs? When we measure particles, do we use samples where flocs have been disaggregated and no longer represent their original state? Do we measure the diagrammatic floc in Fig. 3 as one, two or more particles? Have we taken into account the biological nature of all particles and aggregates, given that they have biogenic materials associated with their surface? To a large extent, these remain open questions. Also, what of aggregates that begin with impaction of colloids? Such micro-aggregates are well known from marine environments but how common are they in fresh waters? Are they as important to nutrient dynamics as they appear to be from studies on ocean waters? We do not know.

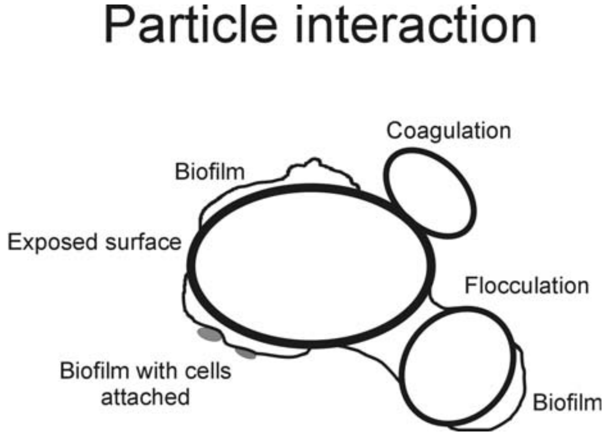

Fig. 3 Interactions between particles forming aggregates.

WHAT IS THE IMPORTANCE OF WATER COLUMN PROCESSES FOR SEDIMENTS?

Flocs resulting from coagulation and flocculation (and the terms are often used loosely and interchangeably) sink through the water column to the substratum (Fig. 4). In doing so, they bring materials, integral with the floc, that would otherwise remain in suspension until impaction. Pelletization of organic and inorganic matter also occurs (Fig. 4). Most prominent are the faecal pellets of invertebrates, especially those produced by suspension feeders. These are tightly-packed aggregates bound with membranes or with constituent EPS and they may be very abundant, making up a substantial fraction of the total seston (Malmqvist *et al.*, 2001). As we have discovered, they are important features of chalk streams although their role has been little investigated prior to our study. Ladle *et al.* (1987) have done much to characterize their nature.

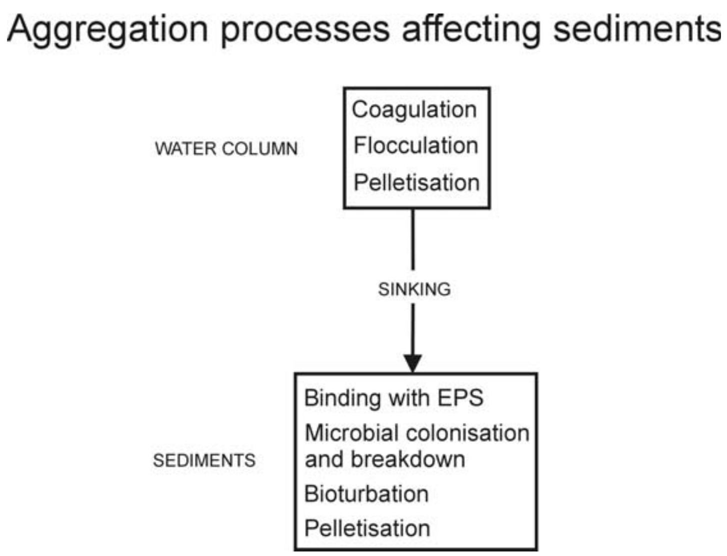

Fig. 4 Aggregation processes in the water column and in the sediments.

We know that faecal pellets sink though the water column (Fig. 4) and their rate of sinking depends both on their size and on the materials that they contain (Malmqvist *et al.*, 2001). We also know that pellets collect on the substratum and that other animals utilize these pellets as food and transform them (Wotton & Hirabayashi, 1999). Observations of organic sediments show them frequently to be pelletized—evidence of turnover and egestion by a wide range of animals. How significant are these processes for stream metabolism and how much do we take these processes into account when studying movement and retention of organic matter in streams and rivers? How important are these aggregates in mobilizing or storing contaminants? How important is pelletization for the retention or movement of elevated levels of fine sediment that are of concern in chalk streams? How important is bioturbation (disturbance of sediment layers by animals)? We hope to answer some of these questions in future research projects.

WHAT IS THE IMPORTANCE OF SEDIMENT MICROBIOLOGY?

If we focus on mineral particles and their sedimentation we miss many important interactions that affect retention and turnover. There is no such thing as a purely mineral substratum, as colonization by micro-organisms, or impaction of EPS, occurs rapidly. Interstitial spaces between grains can also fill with exuded polymers (Lock, 1994) and this adds to the stability of deposits, much greater force then being needed for the movement of individual particles. In estuaries, the colonization of the surface of muddy sediments by diatoms and other algae leads to the formation of a near impenetrable matrix that can be cut out with a razor blade and peeled back to reveal a poorly-oxygenated substratum below. Similar processes must occur in streams and rivers and the presence of downwellings and upwellings into, and from, the substratum are common features that can be compromised by the development of microbial communities. We are interested in hyporheic flows and the exchange of nutrients between the substratum and overlying water, but how much are these processes considered in models and how do they change with time and with unpredictable flooding events or drought?

FUTURE PROSPECTS

If we are to find out more about rivers we need to integrate more thoroughly at several scales. The most effective way of doing this is to link "macro" hydrological studies with those of organisms such as rooted plants, and studies at this intermediate scale with "micro" studies on EPS and other materials resulting from the abundant micro-organisms. Do we need these levels of investigation to make effective decisions? Many would argue that we do not. Do we need this approach for understanding? Emphatically, yes. Is understanding a system important for effective planning and management? We all have our own views.

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