Summary and concluding remarks

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This meeting, entitled "Eutrophication: Research and Application to Water Supply", was the brainchild of Mr Jack Jeffery, the President of the FBA. The general feeling was that academic research on the process of eutrophication had progressed significantly over the past decade, but there had been little contact with the water managers, i.e. those whose work was at the sharp end of dealing with the associated problems. Uppermost in the minds of the organisers had been the problems related to the development of cyanobacterial (blue-green algal) blooms, but this work did not result in the exclusion of geochemical cycling, and other aspects which were relevant to reservoir management.

Mr Jeffery and I then met with Prof. Heinz Bernhardt and Mr Len Bays of IWSA, and it was clear from the outset that all agreed on the need for such a meeting. The programme was drawn up, admittedly at short notice, but we were convinced that we had achieved the correct balance, that each area of fundamental research covered would be followed by examples of application of the knowledge gained.

More than 100 delegates attended the two-day conference at the BAFTA Centre in London. One of the most gratifying aspects was the vigorous nature of the discussion which took place, not only during the formal sessions, but also during lunch breaks and the Conference Reception. This is, therefore, an entirely appropriate moment for the FBA and the IWSA to thank General Utilities for sponsoring this Reception. Although such events are seen as being, essentially, social in nature, they also provide the opportunity for the exchange of important information on the future management of our lakes and reservoirs.

Prof. Bernhardt chaired the first morning's session on the consequences of eutrophication – theory and practice. Dr Colin Reynolds (UK) gave his plenary lecture on eutrophication and the management of planktonic algae: what Vollenweider couldn't tell us. This was a detailed and critical account of the use and misuse of the "Vollenweider model" for lakes in northern temperate regions and their ability to support phytoplankton. Topics were framed and discussed in relation to the concept of phosphorus-loading and phosphorus-limitation. Dr Reynolds emphasised that we need to distinguish rate-limitation from capacity-limitation, and to understand which is more manageable and why. He also emphasised the importance of the mechanisms of internal cycling of phosphorus in lakes and reservoirs, and the need to appreciate the respective roles of physical and biotic components in the local control of algae, topics which were addressed in further detail by later speakers at the meeting.

Prof. Dieter Imboden (Switzerland) then discussed the impact of physical processes on algal growth, emphasising the effects of mixing and transport processes on the growth of algal populations in lakes. Rapid changes on time-scales of seconds, minutes and hours are particularly relevant for fast biological processes such as nutrient uptake and photosynthesis. Slower changes on time-scales of days to years are relevant for the less dynamic processes such as growth, respiration, mineralization and settling out of algal cells. Mathematical models were used to examine these points.

Prof. Gerrit van Straten (The Netherlands) dealt with the predicting power of models for eutrophication, and the problems of using mathematical models as management tools for

predicting chemical and biological changes in the aquatic environment. Uncertainty, variability and "educated speculation" are necessary when developing models which are to be used for predicting the effects of measures specifically designed to bring a system into an entirely different "operating point", as is typically the case when attempting to reverse eutrophication. The even more difficult problems associated with predicting the behaviour of complex non-linear systems, some of which exhibit chaotic and therefore fundamentally unpredictable behaviour, were also discussed.

Sven Jørgensen rounded off the first session with an account of structural dynamic models of seasonal succession in algal species and populations in lakes and reservoirs. A new generation of quantitative models is being developed. These attempt to translate some important biological properties of species (survival, variation, inheritance, reproductive rates and population growth) into predictions about the survival of the fittest, where "fitness" is measured or estimated in thermodynamic terms. For this the concept of "exergy" and its calculation was introduced and explored as a means of examining changes in species composition.

The afternoon session on remedial measures and their application was chaired by Mr Jack Jeffery (UK). Prof. Brian Moss (UK) began the session with an account of the scope for biomanipulation in improving water quality, illustrated by his own elegant work on the Norfolk Broads in south-east England but also including examples from North America and Europe, in a short but valuable review. Biomanipulation involves the managed use of grazing animals (especially zooplankton and some fishes) to control large populations of edible algae, the so-called "top–down" method of control via the food web. Prof. Moss discussed the options available and their advantages, disadvantages and limitations (e.g. inedible algae may thrive and become nuisance blooms), concluding that biomanipulation is not a palliative for solving eutrophication problems at minimal expense, nor is it recommended for use in large natural lakes which have a diverse fauna and flora. However, it is a potentially useful tool in artificial reservoirs where there is a high degree of existing intervention and where water retention times are low, although the complete removal of fish is a necessary prerequisite for success.

This theme was continued by Prof. Jürgen Benndorf (Germany) in his paper on the control of indirect effects of biomanipulation. He identified three types of indirect effects which are as important as direct effects are for achieving stable population control by biomanipulation. Behavioural changes, such as a shift in the daily pattern of vertical migration by zooplankters when their predators are removed or scarce, can alter the transport of phosphorus within a lake. So too can the development of anti-predator traits, including morphological changes like the growth of helmets and neck-teeth in *Daphnia*. The most important indirect effects, however, result from resource limitation and "bottom–up" control within the lower trophic levels of the food web. These effects have to be carefully managed in conjunction with control of the basic nutrient loadings into, and cycling within, the lake or reservoir.

The last point above was pursued further by Prof. Dietrich Uhlmann and Heidemarie Horn (Germany), who examined in detail the significance of sedimentation and sediments to phytoplankton growth in drinking-water reservoirs, comparing and contrasting the oligotrophic Neunzehnhain Reservoir with the nearby mesotrophic–eutrophic Saidenbach Reservoir, in Saxony. The second session was then brought to a close by Dr Helmut Klapper (Germany), with an account of his ingenious work on calcite covering of sediments as a possible way of curtailing blue-green algae. This involves pumping natural calcite from deeper sediments to seal the phosphorus-rich surface layer and promote the co-precipitation of phosphorus from the water column, thereby reducing its internal cycling and availability to algae.

The second day of the conference began with a short session on the role of sediments in eutrophication, chaired by Mme M. Boubigot (France). Dr Ivan Heaney, Julie Corry and Jean

Lishman described the changes in water quality and sediment phosphorus of a small productive lake following decreased phosphorus-loading. Removal of some 47-67% of the external phosphorus input to Esthwaite Water (English Lake District) in treated sewage effluent, has been monitored since 1986. The effects of this large reduction in the total input have yet to be realised. Internal release from a large store of phosphorus in the sediments apparently compensates for the reduced input from external sources, and the remaining high levels of phosphorus input (including that from caged trout grown in the lake), may prevent any major reduction in algal productivity. Dr Lars Kamp-Nielsen also examined the role of sediments as sinks and stores for nutrients, with particular emphasis on phosphorus and nitrogen, using simple models for predicting events in lakes following reductions in external nutrient inputs.

Eutrophication in rivers was the topic of the session after coffee, with papers by Dr J.-P. Descy (Belgium) on the River Meuse, and by Drs T. Vandevelde and V. Da Molo (France) on the River Oise. The latter, in the Paris area, is subject to seasonal blooms of algae which generate problems for the production of drinking-water from a treatment plant on the Oise. A mathematical model has been developed to simulate variation in water quality in a pre-treatment storage reservoir, and another model is being developed to simulate events in the main river. Integration of the two models should provide a management decision-aid for optimizing control of the treatment process for potable water.

Algal blooms have caused problems in the River Meuse since the early 1980s. Plankton algae appear to start developing large populations in the French section upstream, utilizing large inputs of phosphorus from some of the tributaries. Thus co-ordinated co-operation between France and Belgium is required to tackle the problem. A mathematical model has been applied to understand the main factors that control the algal growth: underwater light, temperature, discharge and grazing by zooplankton. This last is a major loss process in summer and may trigger a seasonal succession of algal species, leading to dominance by larger-sized taxa. After periods of large population growth, decomposing algae may adversely affect the oxygen budget of the river but, conversely, algal photosynthesis is the most important source of oxygen input at periods of low discharge. Thus a reduction in algal productivity may result in a dramatic decrease in the oxygen content of heavily polluted stretches of the river, causing problems that could be as severe as those resulting from algal blooms.

Two afternoon sessions, on the control of blue-green algae, and the active management of reservoirs, were chaired by Prof. Gwynfryn Jones (UK). Prof. Tony Walsby (UK) gave an account of the control of gas-vacuolate cyanobacteria, colonial forms of which frequently cause problems in water supply. They form noxious scums on the water surface during calm, warm periods, and the gas vacuoles may prevent the colonies from sedimenting in water-treatment plants. Methods of applying pressure to collapse the gas vacuoles were briefly reviewed, including that of using explosives – apparently this works! Dr Christian Steinberg and Elke Gruhl (Germany) also considered physical measures to inhibit planktonic cyanobacteria. They described experimental work in the Fischkaltersee, a hard-water lake in upper Bavaria, which receives substantial inputs of phosphorus. An air-compressor was used to artificially destratify the lake and maintain an aerobic sediment–water interface. For a complex set of reasons (including top–down grazing effects), the overall effect was to remove or prevent development of populations of cyanobacteria, and also other members of the phytoplankton. Intermittent destratification gave fast-working results in the lake, and is less risky and cheaper than artificial control by permanent destratification.

Drs John Hilton, Tony Irish and Colin Reynolds (UK) addressed the problem of active reservoir management, based on predictions from a functional model developed from Chew Valley Lake/Reservoir in the west midlands of England. The model predicts algal growth

capacity (maximum biomass) and seasonal succession of algal species. Model predictions were compared with observations in the reservoir, and model input variables were then modified to improve the predictive simulations. Good agreement was obtained by including pulsed inputs of phosphorus, derived from the sediments, at levels consistent with field observations. The uses of this particular model in several hypothetical operational scenarios were explored, and an example was given of an extension to the model which predicts chemical properties of abstracted and treated water.

Drs Gijsbert Oskam and Lambert van Breeman (The Netherlands) then described the management of Biesbosch Reservoirs for quality control with special reference to eutrophication. These are pumped-storage reservoirs fed with enriched water from the River Meuse, in which problems upstream in France and Belgium were described earlier in the day. Air injection is used to prevent stratification and further deterioration of water quality, and is an aid to controlling the algae, in conjunction with grazing zooplankton. Benthic *Oscillatoria* species are a special problem, producing toxic geosmin and growing on the inner embankments. Physical disturbance with a harrow is used to control them.

This was the first joint meeting between the FBA and the IWSA and, by all measures, it was a remarkable success. I would like to take this opportunity to thank the authors for their stimulating contributions and the IWSA for its collaboration.

The main aim of the meeting was to bring together those involved in research into aspects of the eutrophication of fresh water, and those with the responsibility of treating that water and providing a potable supply. It was clear, from the lively interchange of ideas and information, that we had succeeded in doing this.