FRESHWATER BIOLOGICAL ASSOCIATION

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WHITACRE-SHUSTOKE RESERVOIR IMPROVEMENTS

Water-Quality Aspects

- a preliminary assessment

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To Messrs Alexander Gibb and Partners,

The following report is submitted in furtherance of your request for specialist advice on water quality aspects of the proposed improvements at the Whitacre and Shustoke Reservoirs of Severn Trent Water Authority. In accordance with your expressed wishes, the report is an initial assessment of the problems presented and is intended to offer indications of the possible approaches to their solution. The opinions offered are founded upon our experience and judgement alone; no detailed analyses have been undertaken. Although every care has been taken to ensure that the advice is the best that can be offered at this stage, its preliminary nature is emphasized: no final decisions about the relative merits of different approaches should be solely founded on the findings of this report.

For and on behalf of the Association

C.S. Reynolds August 1989

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1. Introduction

The purpose of this report is threefold: first, it provides a statement of the relations between water quality difficulties, caused by algal growth in the Whitacre/Shustoke Reservoir system, and the current installations and operational practices; second, it suggests the available approaches to their solution, bearing in mind the opportunities provided in the main project to introduce structural or operational features as part of the general improvements at Whitacre and Shustoke; third, it indicates the further studies that would be required to establish their comparative merits.

2. Algal Growth in the Whitacre-Shustoke Reservoir System: general appraisal of the problems

2.1 Algal growth in standing waters

From the time of their original commissioning in 1883, the precise uses to which the Shustoke Reservoirs, together with the Whitacre Works, have been put have been changed several times, as have the districts supplied therefrom; there have also been changes in the treatment process, as technologies and demands have developed. However, the traditional functions of reservoirs, especially those (such as Shustoke) proximal to distribution systems, have altered little. Besides the maintenance of a strategic reserve capable of balancing the variability in supply against continual customer demand, the lowland reservoir has also served a purification function in allowing water to clarify by depositing its suspensoids during the period of storage. The ideal period for storage has scarcely been defined - it would, in any case, depend upon the type of suspensoid and the hydraulic conditions in the impoundment; instead, it has usually been a fortuitous quotient of the storage volume and the throughput rate. Again, tradition has tended towards "the longer the retention time, the better".

The negative aspect of long storage times is that they permit biological changes, consequential upon the change from flowing to standing conditions, to become manifest. From the water-quality point of view, the most important of these is the flourishing of the planktonic community of plants and animals. This is represented in most fluvial sources, though the populations are usually reckoned to be sparse. In the altered conditions of a standing water mass, subject to variable levels of wind mixing but without aggressive, turbulent downstream removal, the introduced organisms are able to increase in concentration.

The rate and extent of the increase in the planktonic plant component (or phytoplankton) is often dependent upon the amounts and balance of essential attainment are raised. This is precisely the experience throughout the populous temperate regions of the world, where lakes and reservoirs in receipt of increasing loads of phosphorus have come to support larger average biomasses of planktonic algae. This cultural eutrophication sullies the appearance of waters; it may injure other aspects of the lake's ecology; and makes reservoir waters more difficult and more costly to treat to meet acceptable standards of potability. Moreover, these problems may be compounded by the need to take greater volumes of water through treatment plants, and they may well be prejudicial to secondary uses of the reservoir (fisheries, recreation).

Besides supporting increased quantities of algae, nutrient enrichment may lead indirectly to significant shifts in the species composition of planktonic communities, the most notable including the replacement of chrysophyte-desmid dominated phytoplankton by "blue-green algae" (or, correctly, cyanobacteria), and the shift from algae-invertebrate-salmonid food chains to ones perhaps restricted to algae and bacteria. These shifts are ultimately determined by complex interactions at the primary-producer level, involving interactions between light, temperature and hydraulic stability. For a given water body, however, it can be stated that whilst the dependence upon nutrient supply remains critical, its planktonic ecology will be regulated most by the supply of that nutrient; the more that nutrient stress is relieved and supplanted by the light/stability property, the less is the relevance of the actual nutrient supply and the more is the behaviour governed by short-term hydraulic variability.

2.2 <u>The present condition of the Whitacre-Shustoke system</u>

It is, of course, very easy to account for the behaviour of a system with the benefit of hindsight. Yet, even without any significantly documented history to hand, the present condition of the Shustoke system would appear to have evolved along classic lines. Historically, the two proximal water sources, the rivers Blythe and Bourne, have been introduced through, respectively, the small Whiteacre (147 Ml) and Upper Shustoke (92 Ml) Reservoirs and mixed together in the much larger (191 Ml) Lower Shustoke Reservoir, which then constitutes the flow to the works. From early times, when the reservoirs supplied Birmingham, to the anticipated supply capacity to the Nuneaton and Coventry areas (~90 Ml/d), there has never been a period of normal operation when the retention time in the Lower Shustoke reservoir has fallen below 20 d and will generally have been > 30 d. Against the rates of growth of planktonic algae attainable under ideal field conditions (the order of one doubling every 1-3 days), the potential biomass attainment by an inoculum of river algae, doubling itself 7 to 30 times over is clearly a daunting prospect. Nearly a century of satisfactory operation without the implicit algal problems suggests that the proximal water sources carried neither the scale of abundance to furnish the inoculum of algae nor the nutrient capacity to support its biomass potential. On the other hand recent chemical analyses of the proximal, fluvial water sources suggest a nutrient-saturated capacity now exists throughout the year (Table 1).

TABLE 1. Concentration of main plant nutrients in river waters potentially or actually supplied to the Lower Shustoke Reservoir during the period Spring 1988 to Spring 1989. (Source: STWA, unpublished data).

	Blythe	Bourne
Nitrate-N	> 5.5 mg N l^{-1}	> 10.0 mg N l^{-1}
Phosphate-P	> 600 µg P l^{-1}	> 230 µg P l^{-1}
Reactive-Si (as SiO_2)	> 3.2 mg SiO_2 l^{-1}	> 5.6 mg SiO_2 l^{-1}

Given that the phytoplankton in either river or within the L. Shustoke Reservoir had long surpassed the point when its abundance was controlled primarily by the chemistry of the water, physical conditions would already have become the leading environmental constraint upon plankton production ecology. In this way, the ascendancy and dominance of *Oscillatoria* species in the plankton of Lower Shustoke through the period 1985-88, a period marked by cool, disturbed summers, can be readily appreciated: it is the anticipated dominant organism of turbid, well-mixed water columns. There is a positive feed-back in very enriched waters in that the biomass that may be ultimately supported itself contributes the turbidity which gives *Oscillatoria* a competitive advantage.

Cyanobacteria have a deserved reputation in water supply for being difficult to treat. There are several contributory factors and they are not the same for all species. They are somewhat resistant to flocculation, resulting in significant penetration of rapid gravity filter beds (such as those operated at Whitacre WTW) and the carry over of residual flocculant. Penetration would have been less over the slow sand filters in use at Whitacre until 1977 but the problem of short filter runs between blockages would have been correspondingly prevalent.

Given the opportunity provided by sustained river flows, the expedient of feeding directly Blythe and Bourne water through the Whitacre and Upper Shustoke reservoirs, respectively, and by-passing Lower Shustoke was a reasonable one for the Authority to have adopted, particularly as this would also allow the isolated Lower Shustoke Reservoir to "run down" its algal content and the sustaining phosphorus concentrations. This does not constitute a long-term operational strategy and, as events of 1989 have demonstrated, the central requirement of a standing reserve of treatable water when low river flows obtain is unchanged. The key problem at Lower Shustoke is whether it is possible to operate a long-retention reservoir to yield a consistently low algal content or to provide a standing reserve of similar quality.

3. Alternative approaches to future operations

Three general approaches to operating the Whitacre-Shustoke with minimum interference from algal growth are available. One is through control of the physical environment; another is by controlling the chemical support; the third involves a fundamental re-engineering of the reservoir construction. Each carries high cost implications; none is guaranteed to be successful.

3.1 Physical control

Provided a reservoir is deep enough to become thermally stratified, the possibility of regulating its growth potential and biassing its dominant species by artificial destratification techniques may be considered: Thames Water has managed its major Thames Valley reservoirs in this way for many years. By keeping the supply reservoirs continuously mixed, diatom populations are maintained rather than the nuisance bloom-forming blue-green algae. The planktonic biomass is actually not greatly reduced but it remains dominated by species considered to be 'easy to treat'.

Because the physical environment is so strongly selective, another approach is to adopt intermittent destratification : by alternating between growth conditions required by (say) diatoms and those for bloom-forming blue-greens, neither group is allowed sufficient time to develop large populations before the other is selected. In this way, a low average biomass can be maintained throughout the main growing season.

This method has been tested experimentally and its applicability to stored water-quality has been evaluated (Reynolds et al., 1984; Reynolds & Reynolds, 1985), but its usefulness as a deliberate operational strategy has no precedent (though it has been used to control the distribution of blue-green algae in Ardleigh Reservoir with astonishing success: personal communication from the reservoir manager). Its potential applicability to Lower Shustoke is rendered less attractive owing to its depth: though clearly deep enough to stratify at times, the probable summer behaviour is that no stable thermocline forms at a depth of less than 5 m or so (no data are at hand but it would be relatively simple to model the stratification behaviour using a combination of the Monin-Obukhov and Wedderburn determinations). This is insufficiently different from the reservoir mean depth to ensure either that episodes of full-mixing would sufficiently alter the growth conditions or that cessation would result in a sufficiently stable environment to bring about the change. Indeed, the risk is that in a cool summer, conditions would remain generally similar throughout the year, giving an extended growth period rather than an intermittently truncated one. Given that these are the conditions favoured by Oscillatoria (ultimately replacing the diatom species initially favoured but quite unlike the preferences of other blue-greens), it is apparent that, far from improving stored water quality, the approach could lead to renewed problems entirely analogous with those currently experienced at Whitacre.

3.2 Chemical Control

Chemical methods directed against algae in reservoirs include the use of algicides such as copper sulphate or proprietary herbicides. Not only are these exclusively short-term agents and even then sometimes apparently ineffective, the wisdom of adding acknowledged toxic substances to water destined for consumption should be seriously questioned on every occasion it is contemplated and, owing to the risk of contaminant accumulation in the Reservoir sediment, repetitive usage should certainly be rejected.

Chemical modification of the raw water to reduce its algal growth capacity, however, is a safe and well-tested approach. In theory, the reduction of say one of the essential nutrients to the level of scarcity in the abstracted water could be expected to bring about an appropriate reduction in fertility. In practical terms, however, only reduction of the phosphorus load is realistic: in water, the element has only one source; the requirement is universal; and its chemistry is such that its removal by precipitation is effective and irreversible. The technology of "phosphorus-stripping" is also well-developed: it can be as sophisticated as the superb installations at the Wahnbach Talsperre, supplying Bonn and Köln in West Germany, or as relatively simple as the contact tanks introduced by Anglia Water at selected reservoirs. The chemistry is almost identical, ferric salts (chloride or sulphate) being dosed to precipitate ferric phosphate.

The effectiveness of the method against algal growth is conditioned by two main factors. One is the extent of removal of the phosphate, which is always liable to be incomplete without the most stringent quality control: it would be necessary to reduce the total phosphorus content of a standing water to less than 100 µg P l^{-1} before the standing crop supported could be usefully restricted. In an operational reservoir, the target concentration of the incoming water would need to be below 5 µg P l^{-1} to ensure that algal growth remained P-limited. With indigenous supplies from even the Bourne approaching 800 µg P l^{-1} at times, we are talking in terms of > 99% removal of P.

The second conditioning factor is that the concentration gradient between P-stripped water in store and the (presumably) P-rich sediments accumulated over many years will sustain internal P-loading for an unspecified period of time. Again, experiences elsewhere indicate a qualitatively predictable behaviour - a new equilibrium, pitched at a low average P concentration in both the water and the superficial sediments is eventually struck - but the timescales cannot be guessed without quantitative measurements of sediment- and interstitial-P concentrations, estimates of gradient and frequency of water renewal. These would need to be established at Shustoke.

Further questions require to be addressed: how would the P-stripped water be best used and, as a colollary, where in the system should the stripping take place? It would not, for instance, be necessary to remove phosphorus from all water delivered to the treatment plant, when algal growth only becomes a problem during long term storage. Moreover, it is strongly desirable to install only one stripping plant, which has to be upstream of Lower Shustoke Reservoir. In turn this might require the laying of one or more large capacity pipes to bring Blythe Water to the contact plant and would presumably require some pumping.

A preferable strategy might be to continue to operate the WTW on Blythe and Bourne water whenever available and, as at present, by-passing the Lower Shustoke Reservoir. At the same time, available capacity on the Bourne flow should be used to make up the standing reserve in Lower Shustoke. This water, alone, would be P-stripped so that the water in store is held, relatively alga-free, and is therefore available as a high-quality source water whenever the Blythe/Bourne supply fails. Because the Upper Shustoke Reservoir fulfils the required short-term storage function on Bourne water, P-stripping would be located between the two Reservoirs. The contact-zone might be usefully located in a small, segregated area at the head of Lower Shustoke Reservoir.

3.3 Engineering opportunities

The main contract provides for an examination of opportunities to reconstruct parts of the reservoir system at Whitacre if these will improve efficiency and effectiveness of the water treatment. The analysis of the present operations shows that whereas the retention times of the two small reservoirs are sufficiently short to avoid large increases in planktonic algae, that of the main Lower Shustoke reservoir is long enough to almost guarantee that the otherwise untreated reservoir will be subject to heavy growths. Subdivision of this reservoir into smaller units would increase the flexibility of the system as a whole and, provided that normally abstracted water from the Bourne was fed through one or two sub-divisions ('X', 'Y') Lower Shustoke, could be kept 'sweet', with a low algal concentration, provided the retention time was still kept down to 3-4 days. The remainder of the erstwhile main reservoir could be also subdivided into two or more standing reserves, preferably enclosing the deepest water in the present reservoir. These would, of course, be prone to algal growth in the non-flowing, untreated water, in the same way the main reservoir is now but they would offer a choice as to which was the best quality at the time the store is required. Say that 'A' was considered better than 'B', this water would be run through the smaller subdivisions, 'X' or 'Y' or both, and onto the works. 'A' would be refilled with river water at the earliest opportunity, in the full expectation that it would support a large algal growth soon after re-isolation. Meanwhile, 'B' will have 'run-down' and represent the better quality water when next the store is required. A scheme could be developed where two or more sub-reservoirs could be used in rotation to counter the problems of excessive growth in storage. This would aim at securing flexibility of operation but the best combination of large (A, B....... and small subreservoirs (X, Y......., if any) would need to be carefully formulated.

This approach - towards an operational strategy - is admittedly better suited to an existing system of small and interlinked reservoirs, where the object is to make the best use of the available facilities. Apart from Lund's (1975) prognosis, based on field experiments with water less enriched than that of either the Bourne of Blythe, it has never been advocated *de novo*. Besides being relatively capital-intensive to devise (though cheap to operate), it is clearly cumbersome and still carries an unacceptably high failure risk. What if A, B.... were simultaneously subject to *Oscillatoria* growth? On the other hand, if reconstruction of Lower Shustoke reservoir is contemplated for other operational considerations, the question of the number and size of the subdivisions warrants more detailed examination. If considered in conjunction with P-stripping or physical mixing techniques, the 'risks' would be greatly reduced; however, P-stripping at source would render the subdivision of the reservoir, on water-quality grounds at least, largely unnecessary.

4. Summary

The report reviews qualitatively the causes and controls on algal growth in reservoir, with particular reference to increased fertility of lowland source waters and with particular reference to the experiences with the Lower Shustoke Reservoir.

Three approaches to maintaining a high quality of stored water at Shustoke are identified. Physical mixing seems unpromising in that the reservoir is insufficiently deep for mixing to effect a significant difference in the growth conditions. Constructional works could be biassed towards an improvement in stored-water quality, though these do not appear to be justified on water-quality grounds alone. The third alternative, phosphate-stripping at source, appears to offer the most reliable way of overcoming algal growth in the reservoirs but to be fully cost-effective, it should be applied only to water intended to be held in reserve in Lower Shustoke; it is also recognised that internal P-loading from the reservoir sediment represents a drawback of uncertain magnitude and duration.

Further studies to gain enhanced, quantitative evaluations of one or other of these approaches can be readily undertaken in later phase, should these be required.

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