Symposium on Maintenance of Water Quality

The Institution of Water Engineers and Scientists

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THE INSTITUTION OF
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Symposium on
Maintenance of Water Quality

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PREFACE

THE REPORT (1973) of the Department of the Environment and The Welsh Office entitled "A background to water reorganization in England and Wales" set out the Government's objectives in determining its policy for the reorganization of the water services. The first of those objectives was to secure an amply supply of water of appropriate quality to meet the growing demands of the people, industry, and agriculture. Other objectives included the provision of adequate sewerage and sewage disposal facilities and the achievement of a massive clean-up of the country's rivers and estuaries by the early 1980s.

Concurrently, the Councils of The Institution of Water Engineers and The Society for Water Treatment and Examination put to their respective members proposals for the amalgamation of these two professional bodies. The case for amalgamation included the following:—

> "Although the circumstances are not the same in all parts of the United Kingdom, there will in general be an increasing need for re-use of water and thus increased emphasis on the water cycle as a whole and on quality as well as on quantity of water for public supply".

Since then the members of both bodies agreed to amalgamate. The Institution of Water Engineers changed its name, on 2nd January 1975, to The Institution of Water Engineers and Scientists, and members of The Society for Water Treatment and Examination became members of the new Institution on 1st September 1975. This Symposium was thus the first national event of the new Institution after amalgamation.

In the context both of the national need and the objectives of the new Institution, the subject of the Symposium was particularly appropriate.

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Paper No. 8—*continued*

1. PROTECTIVE MEASURES—IMPOUNDING RESERVOIR SOURCES

By A. B. Baldwin, MEng, FICE (*Fellow*)*

CONTENTS

INTRODUCTION

Commonly the tradition of water undertakers who derive their supplies from impounding reservoirs has embraced the simple policy that "prevention is better than cure". For reservoirs in mountainous areas, prevention of pollution was virtually complete. Impounding reservoirs on lower levels, e.g. the Midlands, have perforce had to be content with more modest protection. In the light of the success achieved in direct abstraction and supply from grossly contaminated sources the traditional attitude is now thought by many to be a policy of perfection. This realization has brought the very basis of the traditional attitude into question. There is a point of view that the available cure is adequate and prevention may therefore be relaxed—even to the point of extinction.

THE PAST

A century ago water-borne disease was an ever-present threat to life. Source protective measures were required for little, if anything, more than a safeguard against bacteriological contamination. Since any single line of defence may fail, undertakers adopted as many lines of defence as were open to them. They were and are:—

(1) Control of gathering grounds to ensure satisfactory sanitary conditions.

(2) Storage in reservoirs isolated from contamination.

(3) Filtration and other treatment.

(4) Sterilization by chlorine (available only during this century).

Though any one line could and did fail, in combination this practice created a record second to none.

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THE PRESENT

To-day impounding reservoirs are no longer protected by remoteness. The population of these islands is crowded and uses its new found mobility to search for space and freedom. Furthermore, significant numbers originate from or have travelled in lands where typhoid and cholera are endemic and an increase in the prevalence of carriers can be assumed. Reorganization of local government and the water services created a situation which was judged by some to be an appropriate time to deprive water undertakers of their ownership of lands within catchment areas. Maintenance of sanitary standards on gathering grounds backed only by persuasion and appeals to public-spiritedness meets with decreasing success from both resident and visitor. The present, therefore, may well mark the moment when it is no longer prudent to rely on care of gathering grounds as an important line of defence against contamination.

Gathering grounds are now exposed to the hazards of dangerous or undesirable chemicals in a manner not previously known. These substances are transported by road and rail and may gain access to feeder streams through accidental spillage. Some are used in agriculture. Irresponsible dumping constitutes an ever present danger. Monitoring raw water is a practical safeguard against chemical contamination known to be a possibility, but is impractical as a universal searcher. Oil and gas pipelines crossing gathering grounds can suffer spillages, leaks, and bursts. Effective warning measures against these new risks have been devised based on reliable communication arrangements and organized collection of information. Even with timely warning it can prove to be impossible to prevent the ingress of contaminants and the affected source may have to be taken out of supply.

After decades of isolation many impounding reservoirs and their surroundings have acquired an appearance attractive to the city dweller in search of the countryside. It is therefore natural that there is an increased demand for water-based recreation centres on such places rather than on less salubrious waters.

After a reservoir has been opened for recreation, with lavatory boxes at intervals around the periphery and toilets in the club houses, it is interesting to note how some visitors prefer to use the nearest tree. At least one sailor cheerfully admits that his normal practice is to moor the safety boat to a buoy for the night and then to swim ashore because he enjoys the swim. Experience would seem to indicate that it is impractical to sustain stringent control over the behaviour of visitors to reservoirs over long periods of time. If visitors are to be allowed they should be accepted with full awareness of human frailty.

The summer storm is to be seen descending into the depleted reservoir and streamlining to the draw-off tower. Failure of storage as a safeguard is more readily tolerated, while contamination from gathering grounds remains minimal. Such failure takes on a new significance when the gathering grounds are likely to be subject to continuous pollution. It is therefore important and urgent to investigate whether an impounding reservoir frequented by the public is equally effective as a source protective measure as one which is isolated.

THE FUTURE

Foretelling the future is a hazardous occupation in any sphere—more so than most where policy is involved. Rather than try to read a crystal ball let us set down steps which have been taken and incidents which have actually happened at one time or another to the gathering grounds and the isolation of one or another impounding reservoir. The list may then be read as a pointer to the future, as it may please the reader.

(1) Bird-watching under permit: Such activity is no more harmful than the presence of the reservoir keeper.

(2) Nature study under permit: Increased numbers involved are not materially different from birdwatching.

(3) Trout fly fishing by season ticket: Isolation is still virtually intact—each fisherman is almost an unpaid watchman—water is not contaminated by bait.

(4) Bait fishing for trout: It is undesirable to make distinctions between types of trout fishermen.

(5) Coarse fishing by day ticket: The reservoir is available for several months for coarse fishing during the trout close season. It is undesirable to make distinctions between types of fishermen. All are ratepayers and bait is already allowed in the water. Day tickets are preferred for a casual day's fishing

(6) Dinghy sailing: Since the reservoir is populated with fishermen there can be no objection to a small increase in numbers—especially as the club-house has a toilet.

(7) Canoeing, rowing, skin-diving, sea cadets, etc: Each has its special needs for shore-based facilities and buildings. By arrangement all these activities can take place without detriment to existing recreation.

(8) One visitor with each fisherman: Dinghy sailors and others can be accompanied by the whole family and it is not unreasonable for wives, for example, to sit alongside their fishermen husbands.

(9) Visitors to walk around casually: Anything less would be unreasonable and impossible to control.

(10) Unlimited unrestricted access to the general public: It is impossible to distinguish between visitors with, and without, accompanying fishermen.

(11) Since so many recreationalists are affected by water levels, operate reservoir having regard to users and visitors at the reservoir.

(12) Transfer gathering grounds to local authority: The local authority has the task of improving the quality of life in the broadest sense so they can make good use of land with high amenity value.

(13) Transfer reservoir and environs to the parks department: The reservoir could then be used by the general public as a public park.

(14) Residential development in attractive areas: Risk of faulty drains can be judged intolerable, abandon water rights and search for a less contaminated source.

CONCLUSION

All the population need pure water at any price. The layman, and some who ought to know better, place an unwarranted faith in the efficiency of chlorination and can believe it is a complete defence in itself. Such a view discounts protection afforded by care of gathering grounds and by storage. Put simply, constant reliance upon chlorination depends upon the unfailing vigilance of a man and the un-erring operation of a machine. Both have been known to fail at the same time.

The rare occasion does arise when the only practical course of action is to bypass filters, treatment and chlorination and to pass raw water into the distribution system. Such experiences help to evaluate the practices of good housekeeping in the gathering grounds and prevention of pollution of impounded water.

Any provisions which attract our young people and divert them from drug taking is worth having at any price. Part of that price may be sought from consumers of impounded water in the form of lower standards of security. Should recreation on reservoirs, and other present-day pressures, turn gathering grounds and storage into ineffectual barriers the choice for the water consumer is either the acceptance of higher risk or the provision, at a cost, of new barriers to replace the loss.

DISCUSSION

Author's Introduction

Mr. A. B. Baldwin, in a written introduction of the paper, explained that he had been unable to present the paper in person at the Symposium. He had arranged that Mr. A. I. Ward would introduce the paper on his behalf.

Verbal Discussion

Mr. K. J. H. Saxton (Welsh National Water Development Authority), in opening the discussion, stressed the author's warnings; the layman did think erroneously that chlorination was the be all and end all of water treatment. Fly-tipping was taking place in reservoir gathering grounds and events last July had resulted in the North West Water Authority taking Cown reservoir out of supply. These warnings could not be ignored, but as one who for ten years had encouraged greater amenity and recreational use of reservoirs and gathering grounds, it was not surprising that he disagreed with much else that the author had said.

In looking to the future the author had not differentiated between elderly impounding reservoirs and new schemes specifically designed with recreation in mind; between supplies receiving minimal chlorination and those with full chemical treatment; and he had not separated water-based sports from fringe-area activities. Different attitudes were also relevant when considering large storage volumes as compared with small reservoirs. We could not be as dogmatic as the paper inferred; it was easy to generalize, but we should and could not ignore individual circumstances.

He himself would never suggest that prevention of pollution be relaxed to extinction, but he would question whether increased recreational use of some of our larger lakes in the last ten years had resulted in any significant increase in the pollution in them. He had repeatedly asked for such evidence but none had been produced.

Referring to vandalism, again there were differences of degree. In Wales this summer an old 12 mg reservoir in a pretty location on the outskirts of a new town, the supplies from which received minimal treatment, had had to be taken out of supply because, irresponsibly, the public had (during hot weather) insisted on swimming there and had even threatened physical violence to the reservoir keeper when he had tried to stop them. This was one side of the coin. On the other side, he was convinced that if in areas where the public were deliberately encouraged to go structures and facilities of high quality were provided and were well maintained, there was a good chance they would not be vandalized.

On the subject of control, many water authorities did not own all their gathering grounds but it was essential they remained in ultimate control of activities on their reservoirs and the lands immediately surrounding them. In the past at most reservoirs one person had been responsible for activities on and around the water, for operation of the treatment works, and for the water supplied from it. He carried the "can" in all three respects and conducted his affairs accordingly. We must ensure that if in the regional water authorities the functions were separated, those responsible were kept in close contact.

In conclusion, and reverting to the subject of amenity use, the Institution published in 1972 its booklet on Recreation on Reservoirs and Rivers. As one who had helped to prepare the report, he still thought its advice made sense!

Mr. C. A. Serpell (Sunderland and South Shields Water Company) referred to the principles which had been applied to the recreational use of a large direct supply reservoir with which he had been concerned. The overriding consideration had been that the organic load in the water reaching the treatment works from the reservoir should not be allowed to increase. To this end all sewage plants discharging into the reservoir, or into the main stream feeding the reservoir, had been brought up to a high standard of efficiency. Apart from these discharges, no new discharges into the reservoir had been permitted and at all recreational premises the sewage was stored and at suitable intervals conveyed out of the catchment area by road tanker.

Subject to these restrictions, it was believed with confidence that algal growths would remain suppressed and would not become a treatment problem. With nine years' operational experience, he did not anticipate that well-organized recreational activity would have any significantly adverse effect on the water leaving the reservoir.

Mr. B. H. Rofe (Rofe Kennard and Lapworth, consulting engineers), asked whether it was really necessary to give way to anarchy in such situations as had been described by a previous speaker. It was to be regretted that it was no longer customary for water authorities to employ reservoir keepers but it must be accepted that it was no longer economic to employ one man with sole responsibility for a small reservoir. In any case, such men were now very hard to find. Nevertheless, where one man had been made responsible for the upkeep and maintenance of the reservoir it provided a continuity of observation and a pride in service which was not maintained by occasional visits by a maintenance team from the authority.

The recent Reservoirs Act had recognized this to some extent by the inclusion of a new statutory post called a supervising engineer. This man would be responsible for a reservoir or group of reservoirs and would be obliged to inspect and report on them regularly. Some of the larger divisions, like the Metropolitan Division of the Thames Water Authority, had maintained such a system for many years and had thus been able to prevent to a large extent the onset of pollution and vandalism in their reservoirs, whilst at the same time maintaining a constant watch on their safety.

Dr. R. F. Packham (Water Research Centre, Medmenham Laboratory) said that a number of water authorities appeared to be giving consideration to the possibility of permitting power boating and water ski-ing on reservoirs. The WRC had always advised caution in relation to these activities because of the possible contamination of water sources with petroleum products by spillage. He asked if any of the participants had experience of these activities on water supply reservoirs.

Mr. L. R. Bays (Bristol Waterworks Company) agreed with Mr. Saxton that there was no evidence that recreational use of reservoirs had been responsible for pollution. Indeed, there was one reservoir in the North of England which for many years had suffered from high levels of bacterial pollution caused by roosting seagulls. When fishing was introduced to the reservoir the presence of fishermen acted as a deterrent, and the gulls went to another catchment (presumably in a neighbouring undertaking!) and there was a marked improvement in the water quality.

If reservoirs were used for certain selected activities (bird-watching, sailing, fishing, etc.) then there were many advantages. The people using the facilities could be the best unpaid bailiffs, and there was the added bonus that you could always resist requests for more undesirable activities, such as water ski-ing or power boating, simply on the grounds that the waters were already being fully utilized.

Concerning the reference on p. 2 to the sailing club member who freely admitted to swimming ashore from the safety boat, he suggested that he should be expelled for irresponsibility.

Mr. D. N. Rainbow (Northumbrian Water Authority) reinforced Mr. Saxton's comments that recreational considerations should be planned from the outset, and that the activities should be controlled directly by the water authorities. In this way any potential risk of pollution could be minimized.

The use of regulating reservoirs for recreation provided some degree of flexibility in detecting and dealing with any pollution, should it arise.

Concerning Dr. Packham's comments on likely problems associated with water ski-ing, his own Authority had a water ski club based at one of its reservoirs, which was the upper one of a group of three in a valley. The club was now in its second year of activity and to date there had been no specific problems. The club had responded responsibly to the controls imposed. Recently an exercise had been carried out jointly with the Water Research Centre to examine samples taken from the reservoir before, during, and after ski-ing, and also from a control reservoir where no recreation was allowed. More information on this experiment was given by Mr. Ravenscroft (p. 7).

Mr. H. Speight (Southern Water Authority) referred to Dr. Packham's request for information on the attitude of individual RWAs to water ski-ing, insofar as his own Authority were shortly to have a demonstration of ski-ing activity on one of its existing direct supply reservoirs. This situation had arisen because of strong pressures to accommodate ski-ing on two new reservoirs in the Authority's area. One of these was nearing completion and would, at a future date, have a direct supply element; the other was about to enter the promotional stage, and would be entirely direct supply.

The demonstration was directed not so much at ascertaining whether ski-ing was detrimental to water quality, but rather to enabling members of the Authority and representatives of a number of District Councils to form their own assessment as to whether or not the sport was detrimental to the quality of the environment generally.

Reference had been made earlier to the I.W.E.S. three R's report. At the time that document was prepared grant was not directly available to a water authority in regard to recreational activity on a new reservoir. At that time grant was made directly to the potential participants but the situation had changed under the 1973 Act and RWAs were able to receive grant themselves as they discharged their statutory duty to encourage recreational use, wherever practicable. The suggestion had been made to his own Authority, and he stressed that it was no more than a suggestion, that grant would not be given in respect of either of the new reservoirs to which he referred unless water ski-ing were permitted on each of them. He found this situation rather disquieting and it would be interesting to know whether other authorities had met with this kind of suggestion.

Written Discussion

Mr. B. D. Ravenscroft (Northumbrian Water Authority) wrote concerning Dr. Packham's reference to water ski-ing and Mr. Rainbow's contribution (p. 6) on the joint monitoring exercise carried out recently by his own Authority and the Water Research Centre. The reservoir in question was remote from any treatment works and was used primarily as a regulating reservoir for others further down the system. The principle objectives of the exercise were:

(1) To establish background levels of polynuclear aromatic hydrocarbons (PAH) in the peaty waters of the remote upland reservoir where water ski-ing took place, and on a similar reservoir in the same area where no power boating activity was permitted.
(2) To determine to what degree normal water ski-ing activities affected these levels.
(3) To attempt an assessment of the overall risk to potential potable supply water inherent in the situation where water ski-ing was permitted on a reservoir.

This last item was of particular importance to the Authority since consideration was being given to a scheme which would permit such activities on a reservoir which was very much smaller in size than that mentioned above and from which water was taken directly via an adjacent treatment works to supply.

The findings in respect of (1) and (2) were that background levels of PAH in the reservoirs were low, and furthermore were not materially increased by normal water ski-ing activities.

It was considered that a more significant introduction of PAH and substances likely to give rise to taste and odour problems in subsequently treated water could arise from fuel spillages due to accidents on the reservoir or on the shore, and from fuelling activities themselves.

His personal view was that whilst such risks might be accepted and tolerated on regulating reservoirs remote from any treatment works, they represented too great a hazard when considering reservoirs associated directly with treatment units, and that in these latter circumstances water ski-ing or any other form of power boating should not be permitted.

Author's Reply to Discussion

Mr. A. B. Baldwin, replying to the discussion, wrote that his brief paper suffered the shortcomings of all generalizations. Naturally, individual circumstances had to be taken into account when making decisions affecting a particular reservoir. Proposed new reservoirs did consitute a special class for a firm promise of recreational facilities as the price extracted by interested parties to buy off opposition.

Consideration had been given to the possibility of increase in risk rather than the question of whether evidence existed or otherwise. The note asked the question, "were we right not to be worried on account of increased risk?" It might be that complaints of taste or an outbreak of water-borne disease would be the first irrefutable evidence of an increase in pollution and this seemed to be somewhat late in the day.

There was a view that there were water sports which "we didn't mind". Sports of that kind might attract others that we did "mind" about, e.g. swimming, and it was parties of trespassers turned swimmers, amongst others, who threatened physical violence on reservoir keepers with increasing frequency.

It was accepted that we must live with recreation but it was not an unmixed blessing to have sportsmen as unpaid bailiffs. Unpaid bailiffs must urinate and observations suggested that the nearest wall or tree was more acceptable for the purpose than lavatory boxes, however closely sited on reservoir perimeters. The practice of carting night soil from a catchment area was begun by water engineers long since dead and they would approve of its continuance as a pollution prevention activity.

In learning to live with recreation it must be remembered that the lesson had to be learned not only by the responsible authority—consumers also must learn to live with their water sources being used for recreation. In justice to themselves water authorities should ensure that consumers knew plainly that allowing recreation on water was a deliberate policy of accepting whatever increase in risk there might be to consumers.

2. PROTECTIVE MEASURES—RIVER SOURCES

BY C. A. KENNETT, FRIC (*Professional Associate*)*

CONTENTS

INTRODUCTION

RIVER SOURCES DIFFER fundamentally from the other two types of water source which are being considered in this Symposium. With underground and upland sources the problem is to avoid, so far as is practicable, pollution of a relatively pure source. In the case of most rivers used as a source for potable supplies, one has to accept that a measure of pollution is inevitable. Protective measures can, therefore, only be directed towards excluding the most objectionable and dangerous forms of pollution and ensuring that the methods of treatment installed are adequate to deal with such pollution as is not excluded by the preventive measures. The degree to which this can be achieved and the extent to which it is necessary are inextricably linked with the whole problem of river basin management, the policy which is being adopted with regard to source development, and the magnitude and the complexity of the treatment works installed.

A fair amount has been written on these and allied topics but mainly in general terms or in relation to experimental and theoretical investigations.

In this contribution to the Symposium an effort is made to relate these general considerations to the practical problems of river abstraction, taking as an example a particularly difficult and vulnerable river source.

STRATEGIC SITING OF INTAKE

The positioning of the intake and its relation to the physical and artificial features of the catchment is fundamental to this whole consideration. From the outset two diametrically opposed policies may be feasible:—

(1) The avoidance of serious pollution by siting the intake high in the river catchment so that it is upstream of most known sewage effluents, trade effluents, etc.

(2) Adoption of the principle of re-use of water by siting the intake low in the catchment and well below effluent discharges to allow for maximum self-purification, but accepting the consequent pollution load.

Generally, alternative (1) sacrifices quantity in the interest of quality and alternative (2) accepts poor quality for the sake of quantity. Between these two extremes the range of possibilities is infinite.

Historically, the first alternative was regarded as normal practice until the 1950s and 1960s when confidence in methods of treatment available, together with the increasing

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difficulty in meeting the rising trends of consumption, caused the re-use theory to be more generally accepted. At that time the doctrine of placing at least one intake as far down the river as possible came to be regarded, by water resource authorities, as positively desirable since it permitted the resources of the catchment to be maximized, particularly when combined with regulating reservoirs near the source and intermediate intakes and water reclamation plants in the middle reaches. This policy was assured of some popular support or, at least, minimal public opposition, since the avoidance of intakes high in the river basin eliminated objection from the defenders of amenities and recreational uses of the river, among whom fishing interests were usually the most prominent.

Moreover, the development of an intake initially in the lower reaches usually permitted a postponement of the construction of regulating reservoirs in that particular catchment. Since such reservoirs would commonly be sited in areas of high amenity value and the lower reach intakes tended to be in areas of relatively low amenity value, public opposition could be circumvented at the cost of higher pollution acceptance by the promoting water authority.

In this period intakes were constructed on two tributaries of the river Trent, namely, the rivers Dove and Derwent and in both instances the intakes were sited near to the confluence of the rivers to the Trent. The second of these intakes accepted a high pollution load from domestic sewage effluents and industrial discharges.

More recently there has been a distinct reaction against the foregoing policies, particularly if the river concerned is polluted with industrial effluents. Prominent among the reasons for this change of attitude are fears concerning the long-term effects of complex organic compounds which have reduced the confidence of water authorities in the capability of most established forms of treatment to provide a complete answer to all pollution problems.

Current thinking on this subject can perhaps be summarized by stating that wherever other factors (such as the geographical location of the area to be served by the source) permit, the intake should be placed as far down the river catchment as practicable, provided that this does not mean accepting pollution or a high risk of pollution in any of the following forms:—

(*a*) Toxic or radioactive waste.
(*b*) Industrial wastes with high organic content.
(*c*) Petroleum products.
(*d*) High metallic residuals.
(*e*) High nitrates.
(*f*) High chlorides.

The above represent the most pernicious forms of pollution. In some cases pollution limits are set in the recommendations of the World Health Organization, which are increasingly being adopted as general guidelines in ascertaining the suitability of raw water for development for public water supply.

Furthermore, the positioning of a water intake on a low reach rather than nearer the headwaters greatly increases the statistical probability of accidental pollutions, many of a dangerous nature, which are discussed later in this paper.

The above generalized principle is subject to many qualifications based upon the optimum balance for any river catchment between costs of reclamation and costs of raw water treatment. Clearly, the whole policy is also influenced by the relative difficulties in obtaining water sources in any given region. Increasingly, cost benefit studies such as those carried out in the River Trent Study will become essential to river source development on any scale but—as in the River Trent Study—the final overriding consideration must always be the feasibility of ensuring final water safety to consumers.

It is self-evident that the nature and extent of the treatment plant installed for dealing with the raw water from any finally chosen abstraction point must be adequate to produce a potable water from raw water of the quality to be anticipated at that point on the river. Indeed, the costs of various levels of treatment will have been taken into account in the cost-benefit studies referred to above and may have played an important part in producing the optimum solution. In this connexion a summary of advanced water treatment levels and associated costs is given in a paper by Miller and Short.

It is, however, more difficult to define the margin which should be provided in any treatment process to cover accidental and unforeseen pollution levels. The provision of such margin must clearly be related to the likely incidence of such accidental pollution having regard to the existence or otherwise of potential sources of accidents and to the extent to which other protective measures (such as storage) are provided. It may, however, sometimes be possible to provide treatment margins against accident without great increase in cost. Thus, for example, if carbon filters are provided the life of a carbon filter bed may be reduced by a sudden accidental increase in pollution load but it may not be necessary to consider increasing the initially designed size of the bed to guard against such accident.

One further factor to be taken into consideration when carrying out feasibility studies for a river source is the possibility of diverting effluent discharges from above to below any proposed intake point. Engineering economics will usually be the deciding factor in resolving such questions but also the loss of re-usable quantity may have to be balanced against the added protection achieved.

TACTICAL SITING OF THE INTAKE

The general location of an intake having been decided, it is often possible to improve the quality of the water abstracted by careful siting of the intake with regard to the pattern of river flow in the area. Thus, a study of the flow patterns in the river under varying conditions will reveal the existence of eddies, back waters, etc., which if not avoided can be the cause of considerable nuisance in inducing floating debris and suspended silt into the intake. In addition to taking advantage of natural configurations, artificial improvements can sometimes be achieved at relatively small cost. Studies of the actual river supplemented by model tests will often repay the time and money expended by saving a series of difficulties with which the abstractor will be faced if such factors are neglected.

PROTECTION OF INTAKE

Planned protection

The source position having been selected, and the treatment processes, etc., having been designed taking into account the anticipated pollution levels, planned protection consists of measures taken to ensure that no additional source of pollution becomes established upstream of the intake or that none of the existing pollutants is permitted to change or worsen the pollution produced.

The legal and administrative background to such protection in this country has been improved considerably with the Water Act 1973 and more recently the Control of Pollution Act 1974. The first of these Acts gives water authorities direct control over the sewage effluents, the rivers and the public water supply abstraction points and also responsibility for controlling the nature of the discharges by other polluters to the rivers.

The Control of Pollution Act gives water authorities wide powers to influence or eliminate actions which, if not controlled, might cause pollution of rivers used for waterworks purposes.

Even with these provisions there are two possible weaknesses against which safeguards are necessary:—

(1) The possibility that the conditions under which an industrial effluent is discharged may be inadequately stringent and be governed by inadequate pollution parameters. Thus, the parameters used in the past by river authorities, namely BOD and suspended solids, may have little relevance to the problems of high organics, offensive smells, and perhaps more significantly the possible biosynthesis or biodegradation of organic compounds to harmful material not originally discharged. It is to be hoped that a greater awareness of the nature of these problems, together with the combined responsibility of the new water authorities for control of pollution and for producing potable water will all have the effect of tightening the controls on polluters discharging to rivers used as potable water sources.

(2) Inadequate liaison between neighbouring authorities or neighbouring divisions of the same authority.

In countries where this type of legislation does not apply, a strong liaison link is clearly necessary between the authorities responsible for the water intake and the authorities responsible for control of pollution of the river.

Protection against accidents

Accidental pollutions of a river source may occur in the following ways:—

(*a*) By accidental deterioration of established effluents.

(*b*) By accidental spillage from road tankers, etc., with subsequent drainage into water courses.

(*c*) As a result of fire or explosion.

(*d*) As a consequence of industrial action.

It is probable that in this country to-day the above factors represent the most serious and potentially dangerous causes of pollution of a river source. Known pollutions will have been taken into account in siting the intake and in the treatment processes to be applied. Existing legislation gives a high measure of protection against the introduction of new pollutants where these are planned in advance. Nevertheless, the risks of accidental pollution from all the causes listed above have increased rather than decreased in recent years. It is therefore increasingly necessary for the water authority to have regard to these potential hazards and to seek to reduce to minimal proportions the possibility of such accidental pollutions resulting in contamination of the water leaving the treatment works.

The following measures are suggested towards this end:—

(1) A permanent liaison arrangement with the persons responsible for river management and those responsible for the river intake works. The precise details of this liaison will clearly have to be varied according to circumstances, but permanent manning of a control room either centrally or at the works concerned is usually essential.

(2) A system of liaison with the police authority covering the catchment area so that immediate warning of road accidents leading to dangerous spillage can be obtained.

(3) Compilation of a list, if it is practicable to do so, of chemical substances customarily carried by road in the catchment area could be extremely useful.

(4) Monitoring of the actual raw water quality by automatic monitors or by fish tanks.

(5) Provision of adequate raw water storage.

Reviewing the above precautions, it will be perceived that items (1) and (2) are subject to human error in transmission and also to the limitation that neither police nor river management can be alert to all pollution all the time.

Item (3) is an aid to protection rather than a complete safeguard.

Item (4)—continuous monitors can only be installed to detect a limited range of pollutants. Fish tanks, although sensitive to a wide range of pollutants, are subject to human error and cannot readily be linked to an automatic alarm or shut down system.

Item (5)—The question of the provision or otherwise of raw water storage for river sources has generated much heated discussion. The first annual report of the D.O.E. Steering Committee on Water Quality recommended that storage equivalent to at least seven days' water usage should be provided. It would appear that the figure of seven days' was arrived at as being a compromise between the requirement to safeguard the supply against accidental pollution and the desirability of avoiding plant growth which might result from longer-term storage. Whilst in the happy circumstances of relatively unpolluted rivers remote from industrial activities the latter consideration may well outweigh the former, there is no doubt in the mind of the author that in the type of circumstance generally described in this paper, i.e. polluted rivers in industrial areas, the importance of the former consideration is overwhelming, the latter can virtually be ignored. Problems arising from accidental pollution are liable to be very serious and may be beyond the capacity of the treatment plant; problems arising from plant growth can usually be allowed for in design and dealt with as they arise. This much being said it is far from easy to be dogmatic concerning the volume of storage which is necessary.

The first annual report of the D.O.E. Steering Committee to which reference has already been made states that the purposes of the storage are:—

(*a*) To permit closing of the intake during the period of exceptional pollution of the source.

(*b*) To provide dilution of heavy pollution and balance out variations in raw water quality.

(*c*) To allow self-purification to take place.

It is evident that (*a*) above presupposes knowledge of the occurrence of excess pollution in the river. If one could rely on an adequate warning system then the time of travel of possible pollution from a high point in the catchment to a point below the intake provides a possible design figure for the number of days storage to be provided. Under such circumstances it is probable that seven days would be adequate in the majority of instances.

However (*b*) above evidently presupposes inadequate warning so that some pollution enters the storage. The degree of dilution then required to ensure a treatable water clearly depends so much on the concentration and nature of the pollutant and the reserve capacity in the treatment plant that it is not possible to state any general rules.

In dealing with a low reach intake on a potentially heavily polluted river, experience shows that reliance on (*a*) is unsound and that considerably more than seven days storage is necessary as a safeguard.

Having regard to (*c*), it seems likely that about 14 days' storage might be a minimum figure in the circumstances envisaged. Moreover, this quantity is for quality control only and should be extra over any volume required for flow balancing.

Later in this paper some examples are given of recent pollutions experienced on the river Derwent and the action taken as a consequence. The invaluable defence offered by the storage reservoir in these instances is self-evident.

From this discussion it is clear that no one safeguard or indeed a combination of more than one can give 100 per cent protection, but a high order of protection can be afforded by an intelligent combination of several safeguards taking into account particular circumstances within the catchment.

PHYSICAL PROTECTION

By physical protection is meant means adopted to prevent certain forms of pollution from actually entering the intake. Two measures have become fairly standard practice:—

(a) *Floating booms.*—These are intended to exclude floating debris but they are not always effective and they are very prone to vandalism and storm damage.

(b) *Screening.*—It is common practice to include band screens or cup screens in river intakes for the exclusion of vegetable or mineral silts. It is generally agreed that band screens require more maintenance than cup screens, although since they are more compact the associated building and civil engineering costs are lower. The mesh sizes adopted vary considerably from one installation to another and clearly the effectiveness of the screen varies greatly with the mesh size. It is considered that there is a strong case for excluding organic silts from the water abstracted since, although in itself the material is fairly innocuous, it may form deposits in a storage reservoir which provide nutrients for algae resulting in tastes and odour troubles.

At the Church Wilne intake on the river Derwent cup screens with mesh size of 1,600 meshes per sq in are operated. It is found that the percentage of silt excluded by these screens can be as high as 77 per cent, but this figure varies down to almost zero depending upon river conditions.

Generally, the high silt removal is achieved when the river is carrying a high load of suspended solids, usually after heavy rain. Under such circumstances, much of the silt load consists of fibrous matter of organic origin and it is this type of silt which is removed by the screens.

At the opposite extreme when the river carries a low suspended solids load, this consists almost entirely of finely divided inorganic material which the screens do not exclude.

It follows that, although the figures for silt removal in percentage terms may sometimes be disappointingly low, in fact considering the performance of the screens in total they carry out a valuable operation of excluding organic silt which is the more immediately potentially troublesome material in the storage reservoir. The inorganic silt represents, of course, a nuisance requiring clearing from time to time due to possible adverse affect on quality should stratification and de-oxygenation result in re-solution of metal deposits.

EXAMPLES OF RIVER POLLUTION INCIDENTS

The following examples of accidental pollution or potential danger of pollution of a river source are based on experience at the Church Wilne intake on the river Derwent, in Derbyshire:—

Discharge of Benzene.—An industrial installation upstream of the intake discharged Benzene into the river for a period of 8 hr causing a heavy fish mortality. As it happened, at the time when this occurred, water was not being abstracted from the river. No prior warning from the polluter, the police, or the river management division was received before the pollution reached the intake and the first indication that something was amiss came from a member of the waterworks staff paying a routine visit to the intake and noting the number of dead fish floating on the river. The source of the pollution having been identified with the aid of the river management division, no abstraction took place until the pollution had cleared.

This incident is of particular interest since it illustrates how serious accidental pollution can take place unknown to the polluter, to the river management, or any other body who might be expected to give warning to water undertakings. It emphasizes how necessary it is to have a last line of defence solely in the hands of the persons responsible for the water abstraction. It is profitable to speculate how the various safeguards ennumerated earlier in this paper would have protected the source output in this instance.

The author's conclusion with regard to the Church Wilne works was that only the availability of substantial storage would have provided a safeguard had abstraction from the river been taking place at the time of this pollution. Systems having no storage or storage approaching a minimum of seven days' capacity would have been at serious risk.

Fire at Industrial Premises.—A large industrial plant utilizing a variety of chemical substances suffered a severe outbreak of fire. The consequent hosing of the works to extinguish the conflagration presented a serious potential pollution hazard which on this occasion was contained, no discharge to the river taking place. It is considered that potential danger existed because the pre-occupation of the firm concerned and the firemen with their own problems might well have resulted in the consequences of their actions being overlooked or going unnoticed.

High Organic Discharges.—From time to time and sometimes for fairly prolonged periods the river has been polluted with industrial wastes having a high organic content associated with an unpleasant smell. The source, i.e. the factory, was identified but the reason for the trouble was never disclosed by the firm concerned. This was an instance where the type of pollution produced did not actually infringe the consent conditions imposed by the river authority. Although the firm concerned took action to improve their effluent, the fact that it was not, under the legislation existing at that time, an infringement of consent conditions distinctly handicapped the authority in dealing with the problem.

Generally, the pollution was too heavy to permit the river being used even when allowance had been made for the effects of dilution in the storage. Consequently, the output from the work was entirely dependent on the storage for the period of bad effluent.

Discharges of Untreated Sewage.—These have occurred from time to time due to plant breakdowns or strike action. On some occasions no warning has been received, on other occasions liaison has been good. Generally, abstraction has ceased during the period of pollution but it is possible that the dilution in the reservoir would have been adequate to render this degree of pollution treatable. Without such dilution, however, there would have been prolems with the final water.

Discharge of Toluene.—A discharge of Toluene by an industrial establishment was notified to the river management division and subsequently to the water supply division. Abstraction ceased until the river had cleared.

CONCLUSIONS

Reviewing the material of this paper one is driven to the conclusion that it is virtually impossible to prevent occasional pollution of a river source occurring from time to time, even though the conditions and legislation now applicable in this country probably give as much chance of avoiding or gaining warning on pollution as one can hope to have.

In the ultimate the authority responsible for operating the intake must rely on its own protective measures, of which continuous monitoring and storage are the most effective. Of these, storage remains the most essential provision on a potentially polluted river, but if the source is in a particularly vulnerable position at the lower end of a catchment then monitoring, storage, and a good liaison system are all essential if serious deterioration of the output from the works is to be avoided.

ACKNOWLEDGMENTS

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DISCUSSION

AUTHOR'S INTRODUCTION

Mr. C. A. Kennett, in his introduction, said that the paper had been required in general terms, but at times it had seemed like another paper on the river Derwent scheme. Of necessity continual reference had been made, for comparison, to experience with, and outlook on, the Derwent. To augment those views, the discharges immediately prior to abstraction, and their effects, were illustrated.

Source protection would vary with each scheme and one could not be dogmatic. Ideal protection would be the ultimate, but would rarely be obtained or be necessary.

After investigations of a river source, the treatment to be adopted would affect one's outlook on source protection, and the limits to which one had to go, or indeed needed to go. After all, any water-bearing liquid could be treated to potable standards, at a cost. The decision had to be taken whether to invest in complex protective measures and monitoring, with only basic treatment, or to accept, within reason, what came down the river and budget for complex treatment to deal with possible troubles. A point illustrated was that on the Derwent scheme the versatility of carbon filters was opted for to deal with lower grade waters rather than to build immediately the second scheduled reservoir, and prolong selective abstraction.

On direct abstraction schemes, one's entire effort had to go into monitoring and protecting the river, because of the immediate effect of contamination on treatment. If the D.O.E. recommendation on storage was accepted, then a dual aspect could arise. The stored water technically became the source, and this had to be protected in the light of retention time and the expected natural purification, and this could mean an acceptance of lower river quality standards compared to direct abstraction. One of the subsections of source (reservoir) protection, albeit a large subsection, would be river protection to minimize the entry of undesirable water. This outlook had been adopted on the Derwent and it was thought, amply illustrated in the paper, that much of the absolute urgency of river protection had been taken out, when considering, as stated dilution and retention factors.

Tolerance was requested on a minor digression in order to make a point, in that much discussion and controversy could still occur over what was the desirable length of storage, quantity considerations apart. He personally was a member of the "old school" who believed in letting a reservoir run riot, biologically speaking, particularly in view of the known concentration of some organics by plant and animal life. The former M.W.B. had a policy of not fighting algal blooms, but learning to live with them.

This digression was introduced because organic residues in rivers were an unknown hazard, and as indicated were relevant to the Derwent. These residues were known to change regularly and with some 200 new ones coming on the market each year, it seemed fortuitous that one had not yet arrived that completely defied conventional trreatment. The odiferous nature of the Derwent made the problem self evident, but TOC apart many were not detectable by the normal accepted parameters of water quality assessment, and it became a difficult aspect of source protection.

Finally, he tendered a personal view on monitoring with reference to the Derwent, in that continuous quality monitoring had not been in operation to date. The point indicated how far one needed to go, and was based on assessment of the scheme as a whole, namely:

(1) During initial stages with plant under capacity very selective abstraction could be practised, with laboratory checks prior to and during pumping.
(2) The benefit of more than seven years analytical data gave an equally detailed pattern of river behaviour, such that it was known that apart from accident, cyanide, phenols, and toxic metals were not a hazard.
(3) An excellent warning system had been instigated, such that on two occasions the intake works knew of problems hours before the relevant operational staff.
(4) With dilution of a near full reservoir, if all other systems failed, 3–4 hr of pumping of bad water could still be tolerated, and be within acceptable limits for treatment.

Verbal Discussion

Mr. H. Speight (Southern Water Authority), in opening the discussion, complimented the author on the detail which the paper contained and in relation to the risk to which the author had exposed himself insofar as speakers might well challenge the basic philosophy which was to be found on p. 10. Largely because of the intensity of the opposition to new reservoir projects during the 1960s it had appeared attractive to advocate an increasing resort to abstractions made from the lower reaches of river systems in order to ensure that the necessary quantities of water could be made available with the minimum of promotional difficulties. As the author stated there was now a growing realization that this philosophy produced its own crop of operational difficulties and it no longer seemed that reliance on treatment after abstraction was the universal answer to the problems which it professed to solve. Nevertheless, the situation had to be appreciated that there were many parts of the British Isles where the provision of direct supplies from upland impounding reservoirs was quite impracticable economically and, indeed, considerable areas of the country had long been dependent on lowland river supplies.

The outlook, however, was not entirely depressing insofar as the integration of responsibility for management of the water cycle within the RWAs now presented an opportunity for assessing the extent to which expenditure and expertise could most effectively be applied either to sewage disposal arrangements or to the provision of sophisticated methods of water treatment prior to supply. He was aware of one situation in south-eastern England where the policy adopted by the previously fragmented authorities had led to an intake being sited some 2 km below an effluent discharge of some 20 Ml/d. The need of the water undertaker concerned to have an assured source within a reasonable period of time precluded entering upon the protracted negotiations which would have ensued had a separate attempt been made to reverse the relative locations and, without going into detail, the early months of operation of the plant concerned had been bedevilled by problems directly attributable to the nature of the effluent itself.

On p. 11 the author referred to the tactical siting of an intake and he himself supported the plea that thought, possibly allied to model experiments, should be given to the detailed arrangements for siting. He quoted an instance where the turbulence created by a series of sluices effectively mixed in oil floating on the surface of an otherwise clean river with the river water itself and ensured that the water undertaker concerned then had to face the attendant taste problems. The re-siting of this particular intake upstream of the sluices (a distance of less than 100 m) would have eliminated the problem completely.

On p. 12 the author referred to the accidental pollution of river sources and mentioned the possible consequences of industrial action. He himself thought that, much as the situation was to be deplored, it was no longer possible to rely upon the devotion of water service employees to the extent which was common in earlier years and there was a very real risk that industrial action within the industry itself could lead to pollution problems. He, personally, was more concerned however about the potential effects of an increasing volume of trade effluents being directed to works under the control of the RWAs. The situation could well arise where it appeared attractive to maximize income by bringing as much effluent as possible to such works, but there was an attendant risk that any effluent which put a works out of action biologically would have very much the same effect as the kind of industrial action which had just been considered. Discharges of the offending trade effluents direct to a river system would still cause pollution but they would not have the effect of also producing a deterioration in the quality of what would, otherwise, have been a satisfactory discharge. This was a problem which would increasingly have to receive detailed attention in the RWAs in relation to rivers being used for water supply abstractions.

Finally, the author had made reference to the provision of raw water storage as an insurance against various unwelcome events, but it appeared that he was advocating substantially more storage than the minimum of seven days which had been recommended by the Steering Committee on Water Quality. He hoped that the author would comment on this situation as he himself was in the position of having to consider whether it would be prudent resource planning to advance the introduction of pumped storage capacity in the lower reaches of at least two rivers on the basis that more than seven days' storage would be justified as a kind of insurance policy.

Mr. J. G. Flint (Central Water Planning Unit) said that when the D.O.E. Steering Committee on Water Quality recommended a minimum storage capacity of seven days' abstraction, the statement was qualified by adding (in para. 25): "Because of the risk of accidental pollution from existing and potential transport, agricultural, mineral and land use activities, we believe storage should be provided for all river water abstraction schemes irrespective of their location".

The provision of longer storage was left open, presumably so as not to add limitations upon particular schemes. The mention of possible plant growth should not be taken as more than an indication of one of the unfavourable factors.

The author of the present paper had clearly weighed this particular disadvantage against the benefits of long storage at Church Wilne, where he had demonstrated such a high degree of risk for fairly prolonged periods. However, he had not put a case for longer storage so much as one for improved effluent control. Reorganization must have completed the liaison with the sewage treatment plants and he would be interested to hear whether it had similarly assisted water treatment plant operators with the problems created by industrial sources.

Apart from yielding a reserve supply when the intake was closed, storage was said to possess advantages of dilution and self-purification, but these did not necessarily support long-term storage where the risk of contamination by hazardous chemicals was high. In such a case, 28 days' storage would dilute the average concentration by only four times and if the substance was extremely harmful and not bio-degradeable, or had to await the reproduction of sufficient numbers of organisms, then the consequent embarrassment of such a volume of polluted water would be of an appropriate magnitude.

Mr. P. Whatmough (North West Water Authority) said that in any situation involving pollution, whether of a river abstraction or of a reservoir, time was the vital factor. Time was needed to get facts on which to base decisions, and it was most important to get early warning. In many such instances the situation had not been fully appreciated until the contaminant had reached the consumers' taps, by which time both the service reservoir and the distribution system were full of tainted water.

In the case of spillage from a road tanker, we should probably have early warning and, not least, would know the nature of the contaminant, but in other cases we would be dependent on our own organization for the discovery and identification of the pollution. Our efforts should (ideally) be concentrated at the point of abstraction, or (second-best) at the treatment plant.

The time taken for a contaminant to pass through the plant and service reservoir might be 12 hr, so that even if the service reservoir became contaminated, it should be possible to keep spoiled water out of the distribution system. Often it would be possible to feed the distribution system from another source, and a disaster situation could be avoided. An hourly taste of the finished water leaving the plant would be of great value, since often an unusual taste would be the first indication that something was amiss.

Continuous monitoring of a few selected chemical parameters was of limited value in an industrial society that used and discarded thousands of substances ranging from merely undesirable to downright poisonous, and in an emergency a meaningful chemical analysis would take far too long. Biological methods seemed to offer better prospects for monitoring a wide spectrum of potential pollutants. Probably the most interesting developments in this field were gross pollution detectors described by Holland, *et al**. Had the author considered the use of such detectors at his intakes? While the response times of Hollands' devices were rather long (from 0·5 to 6 hr), in this context they could be adequate to gain vital time.

Mr. D. C Sims (Severn-Trent Water Authority), referred to Mr. Whatmough's comment that time was nearly always the critical factor when dealing with the pollution of river sources. His own experience was limited to nine direct river abstraction works in Oxfordshire and Warwickshire of varying capacities up to 12 mgd, three of which were equipped with bankside storage. The operation of those works with storage was through the storage in order to benefit from the improvement in quality. Those reservoirs, like most in this country, were constructed to maintain quantity not quality. They were all much larger than seven days' storage and were therefore not quite the same as quality bankside storage now under consideration.

How did one set about designing bankside storage for the "quality "function it had to perform? The design was against pollution which should be considered as these types:

(1) *Notified pollution*—taking place from established discharge points. This category included sewage works, industrial discharges, and notified road accidents. The pollutant would be known, also the time of occurence and period of pollution. In these cases you knew "what" you were up against and "when".
(2) *Un-notified, obvious pollution*—taking place from any source established or otherwise. This group included pollutions causing fish deaths, oil on surface, or other visible evidence. The pollutant would be unknown, but might be established from analysis before reaching the point of abstraction. Times might be estimated or unknown. In those cases you might know "what", and you might know "when".
(3) *Un-notified, undetected pollution*—taking place from unknown source by unknown pollutant.
This group included taste and odour producers and things that generally produced unpalatable results, e.g. silage liquor. In those cases you did not know "what" or "when".

Trying to analyse this factor "what" further, could it be reduced to time? How long did it take to identify "what" after (*a*) notification of fish deaths; (*b*) observation of surface

* Holland, G. J., and Green, A. 1975 *Water Treatment and Examination*, vol. 24, pt. 2, p. 81, "Development of a gross pollution detector".

"oil"; (*c*) some other observation? He suggested the answer was about two days. The other relevant time factors were: When would it start?, and when would it stop? These would depend on the distances of the pollution to the abstraction point, river flow at the time, and the "retention" characteristics of the river. This retention time would be known from experience, e.g. how long did oil remain in the river after pollution had ceased.

The design of the storage therefore was to provide *time* to analyse the pollutant, and to provide effective treatment. A suggested basic design was that the storage should be divided into at least four compartments; there was thus a choice of five abstraction points instead of one. They should be capable of:

(i) being used to produce a time retention of 2, 4, 6, or 8 days;
(ii) being emptied individually back to the river;
(iii) being drawn from individually to the treatment works; and
(iv) being easily de-silted (this might not be necessary).

The normal operation against pollution incidents would be through one compartment. If this became polluted there were three others to draw from or say six days' time to analyse pollutant, and provide effective treatment, or inform consumers. Was this long enough?

Mr. D. H. A. Price (Department of the Environment) said that the recommendation of the D.O.E. committee on storage was advisory and not mandatory. The retention time to be provided, the possible division of storage capacity, and the general arrangements, including by-passes, were matters to be decided by the water undertaking according to local circumstances including the nature and the extent of existing and of potential hazards. The recommendation was asserting the fundamental importance of storage as a means of protecting the supply.

Mr. H. F. Kaltenbrunner (N.V. Waterwinningbedrijf Brabantse Biesbosch, Rotterdam) said that it was wrong to give a universally applicable recommendation for the best storage time in raw water reservoirs for river sources, or to discuss whether the ideal storage time was seven or 14 days. The necessary retention time in a raw water reservoir depended mainly on its functions. For deciding on a certain retention time one should therefore consider what the functions of a particular reservoir were and how these functions—together with some determining factors—influenced the choice of the retention time.

The possible functions of a reservoir and the determining factors which influenced the necessary retention time could be summarized as follows:

(1) *Quantity storage* (*flow balancing*).—The determining factors for the retention time were:
(*a*) water demand, and
(*b*) hydrological characteristics of the river catchment (flow).

(2) *Provision of optimum water quality* (*quality balancing*).—Provision of optimum water quality did not only mean delivery of the best possible water at any given moment but equalization of the water quality over a longer period.
The determining factors for the retention time were:
(*a*) water demand,
(*b*) expected variations in river water quality, and
(*c*) allowed variations in raw water quality delivered to the treatment plant.

(3) *Self-purification of the river water*.—The determining factors for the retention time were:
(*a*) amount and kind of pollution,
(*b*) hydrological characteristics of the river catchment (dilution), and
(*c*) desired degree of self-purification.

(4) *Protection of the waterworks against accidental pollution.*—The determining factors for the retention time were:
(*a*) possible variations in water demand,
(*b*) amount, kind, and duration of pollution that could possibly occur,
(*c*) hydrological characteristics of the river catchment (flow), and
(*d*) water treatment processes.

Each of these functions of a reservoir necessitated a certain minimum retention time which varied strongly according to the different determining factors. There were, of course, various interrelations between the different functions of a reservoir and the determining factors for the retention time which had to be considered separately from case to case.

Finally, it was a question of the definition of priorities in the planning stage of the functions of a reservoir and/or which set of determining factors decided the choice of the retention time in a raw water storage reservoir.

Mr. D. D. Young (Severn-Trent Water Authority) said that the author was a little sweeping in his statement that parameters used by river authorities had little relevance to the problems associated with water supply. Sewage works had always been designed to produce effluents assessed in terms of suspended solids, BOD and, perhaps, ammoniacal nitrogen, and the emphasis on the parameters resulted to a considerable extent from this fact. In many areas inadequate consideration would have been given to raw water quality requirements in the past, but this was one of the many short comings of the past which the new structure was designed to remedy.

This criticism would not be justified in the case of the control of the discharge of industrial cooling water above Church Wilne. An exceptional degree of protection was provided in this case, by the installation of total organic analysers linked to an emergency system at each outfall and measuring the TOC at 15 min intervals.

The potential benefit of monitoring raw water quality by automatic systems was referred to in passing by the author. It would be most valuable to the symposium to hear his views as to the parameters which should be monitored and whether monitors were best placed at the intake, some distance up stream, or perhaps even in the vicinity of major hazards.

Written Discussion

Mr. N. S. Thom (Central Water Planning Unit) wrote that the author's suggested measures to protect river sources (p 12) were excellent. However, the third measure did not guard against accidental discharges to sewage works or to effluent treatment plants of substances that might reach the river, either because they were untreatable or discharged in too high a quantity or too suddenly for the treatment works to cope. Compilation in advance of a list of such potentially hazardous substances together with data on the expected hazards would help to mitigate harm. Such a list could, in certain circumstances, be confidential to the water authority.

It was perhaps hardly necessary to add that there were many substances* which even prolonged storage would not remove. Perhaps means should be available for returning the stored water to the river at a rate that could be controlled so as not to harm the river life.

Author's Reply to Discussion

Mr. C. A. Kennett, replying to the discussion, wrote that he was pleased that Mr. Speight seconded the suggestion of more thought on intake siting, as experience showed that this avoided many operational difficulties.

* Thom, N. S., and Agg, A. R. 1975 *Proc. R. Soc. B.*, vol. 189, p. 347.

It was also pointed out that the D.O.E. seven-day recommendation was just that, and that the length of storage was a personal choice based on river quality and how one accepted the possible side problems of prolonged storage. In the case of the Derwent, where some form of quality deterioration was frequent and the river in summer was often below abstractable limits, the designed 30-day storage not only acted as a pollution buffer and gave more scope for selective abstraction, but the overall quality improvement made it justifiable.

Much of the reply to Mr. Speight also referred to the remarks of Mr. Flint, on the D.O.E. recommendation. Of course, it was agreed that a case could be made for improved effluent control, but the problem had to be looked at realistically. The Derwent scheme had been designed and built during the period of diverse interests, and although discharges had complied, within reason, to consents, the overall quality was not geared to future use for water abstraction, and one could not immediately impose a new set of conditions. He agreed that reorganization had improved matters regarding information as to what occurred, and early warnings, but again, ideals would not be achieved overnight. Priorities were being given now where effluents affected potable abstractions.

He still thought that the dilution factor was important, as a subsection of protection, taken in context with quality checks or monitoring. For maximum abstraction of the Derwent the 4-hr flow between checks would yield about 12 mg, and with reservoir levels maintained, when possible, 75–100 per cent, gave a 30-1/50-1 dilution, assuming even mixing.

In reply to Mr. Whatmough, he could not agree that, with storage, monitoring at the treatment works became second best, and in fact this had been the policy on the Derwent. After all, within reason, the starting product was immaterial if plant was available to produce water of the required standard. As mentioned in the paper it depended upon where the money was spent—detailed monitoring or complex treatment.

He agreed that a blanket monitor such as the gross pollution detector was going in the right direction, but also iterated that knowing one's own river pattern, fluctuations of certain minor parameters (Cl, NH_3, COD), could indicate that a more detailed check was required. An indication of this system had been given since the Symposium in that a discharge of acetaldehyde had denuded the river of oxygen, and at the same time reduced the free ammonia by complex synthesis. Such a sharp change made investigation imperative and indicated industrial rather than sewage discharge.

Apologies were made to Mr. Young, as statements were not meant to be critical. In fact, the work of the Trent River Authority had been acknowledged in an earlier paper on the Derwent Scheme*. Nevertheless, it remained that parameters measured, mainly for biological aspects of the river, did not account for other more important factors of quality for water supply. Certainly reorganization had improved matters, particularly in quality assessment of raw waters.

Regarding monitoring, the author's preference would be at the intake. It would be useful but expensive to monitor and signal possible individual hazards, and cynical as it sounded would not be 100 per cent effective under the control of the dischargers.

Mr. Thom's comments on toxics upsetting reclamation works were relevant in that the Derwent had suffered a deterioration, due to a chromate discharge destroying the biology of the sewage works. Any such incident would be part of the early warning system from the works concerned, but the event had in fact led to a compilation of toxic chemicals and volumes stored by industry discharging to sewers.

Finally, he felt that the contribution from Mr. Kaltenbrunner, regarding assessment of length of storage, had stated exactly the thinking on this matter.

*Adams, R. W., Robinson, R. D., and Kennett, C. A. 1973. *Journ. I.W.E.*, vol. 27, p. 15, "The river Derwent scheme of the Nottingham Corporation".

3. PROTECTIVE MEASURES—GROUNDWATER SOURCES

BY R. J. SLATER, BSC, FICE (*Fellow*)*

CONTENTS

INTRODUCTION

"PREVENTION IS BETTER THAN CURE"—surely no statement of policy is more apt when considering the pollution of groundwater sources of supply.

As time passes, so the objective of providing a sufficient and wholesome supply of water becomes more difficult to achieve. Water undertakers, to-day, face economic and technical problems of a far greater magnitude than those which their predecessors, at any time, had to solve. The advance of civilization has brought in its train a number of related but nevertheless undesirable by-products, including a shortage of wholesome water supplies and an ever-increasing risk of serious pollution.

This paper endeavours to review the elements and factors which account for any social or industrial activity being regarded as a risk and the means at our disposal for minimizing the effect on sources of supply.

THE NATURE OF POLLUTION

Pollution can be divided into two main categories—bacterial and chemical. Before the recognition of bacteria and viruses the physical nature of water, together with its basic chemical characteristics, were the only means of judging quality. Appearance, taste, and smell are, of course, still important, but groundwater, unlike surface water, is unlikely to be affected to any marked extent.

There are a number of inorganic pollutants, such as nitrates, phosphates, fluorides, chlorides, sulphates, iron and other heavy metals, all of which can occur naturally, or the normal stable balance could be disturbed by man's actions. Organic pollutants are not normally present in groundwater, but those that could be introduced as a result of some deliberate or unintentional action are many.

Broadly, these chemicals would fall into three main categories:—

(1) those used in agriculture;
(2) waste products of industrial processes;
(3) those in store or transit.

The particular chemicals which have been shown to be the cause of pollution include nitrates, hydrocarbons, phenols, dichlorophenols, and organic acids.

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Enteric diseases, such as typhoid, dysentry and Cholera are all carried in the alimentary tract of humans and some animals, so that the presence of *E. Coli* (a typical intestinal organism) in any sample of water must be accepted as an indication of pollution and hence possible danger. There are comparatively few examples of microbiological pollution that did not occur as a result of the disposal or, more precisely, the lack of proper means of disposal of sewage or animal excrement of some sort.

As our knowledge of virology increases, so we can evaluate more exactly the role of water as a possible vehicle for viruses such as the causative organisms of infectious hepatitis, poliomyelitis, and epidemic summer diarrhoea.

The extent to which a disease might be transmitted if present in groundwater depends on a number of factors, such as the ability of the causative organisms to survive within the varying conditions of the aquifer, the virulence of the organisms, and the susceptibility of the individual to that particular pathogen. The size of dose necessary to cause infection varies greatly with different organisms, so that any degree of risk should be avoided as far as possible.

As to treatment of pollution at source, it is in some ways ironic that the chemistry of the majority of inorganic pollutants mentioned earlier is such that removal at the point of abstraction is complex and expensive.

All the common water-bourne pathogens of temperate climates are inactivated by normal treatment by chlorine and, so far as we know, by ozone. Ova of parasitic worms and cysts of Entrioeba histolytica are resistant and require removal by filtration, but these are not endemic in this country.

HYDROGEOLOGICAL FACTORS

Having defined pollutants, we must now consider how aquifers affect their transmission and survival. The characteristics of aquifers occurring in this country vary from fine sands, which result in low velocities and natural filtration and possibly change, to fissured rocks which permit comparatively free flow.

The greatest change is likely to occur during the initial phase of infiltration when the pollutants, which contaminate the surface, are passing vertically downwards through the zone where aerobic conditions exist and most purification takes place. Once the saturated zone, or water table, is reached, little further change occurs. At this stage the flow becomes horizontal and velocity and hence survival or stability in relation to time and environment become relevant.

Research and experience indicates that the upper metre or so of the unsaturated zone of a uniformly fine-grained aquifer provides the best possible conditions for the removal of bacteria and viruses. At the other end of the scale there is relatively no change within fissures. Furthermore, bacteria and viruses in general have the longest survival time in comparatively unpolluted sources at low temperature, but this factor can vary greatly with different pathogens.

THE LAW IN RELATION TO POLLUTION

Before dealing in detail with the practical problems of the situation, it is necessary to consider briefly the legal position in the U.K. to-day. Whilst both Common Law and Statute Law are relevant to the subject, the process of development and amendment of legislation has created a situation where the powers that exist are of little help to water undertakers in a policy of prevention. Furthermore, although most of the existing statutory provisions will be superseded by the Control of Pollution Act 1974, when that is brought into effect (sometime between the late Autumn of 1975 and the middle of 1976), the principal machinery for preventing pollution will continue to be the informal consultation procedures established over the last 15 years or so, as the result of guidance from the Department of the Environment and their predecessors, between the predecessors of water authorities and local planning authorities. These consultation procedures give water authorities and their agents the opportunity of commenting on or objecting to any proposals for development which they consider may conflict with any of their interests, including protection of the purity of groundwater supplies.

Under Section 11 of the Water Act 1973, water authorities are required to provide a sufficient and wholesome supply of water and local authorities are given power ". . . to take steps from time to time as may be necessary for ascertaining the sufficiency and wholesomeness of water supplies within their area. . .". The Act, however, does not define "wholesomeness" and the quality of water supplied, even within the U.K., varies considerably. To a certain extent standards are set by common acceptance, but observations on the draft E.E.C. standards have been invited and it could be that these will form the basis of future legislation. In the meantime, the recommendations of the W.H.O. European Drinking Water Standards (2nd Edition) are probably the most widely accepted guide.

Pollution in the legal sense at Common Law means the addition or doing of something to water which changes its natural quality. To ascertain whether water has been polluted, any polluting matter already present in the water must be disregarded. What really counts is whether what is added would cause appreciable pollution if the water was otherwise pure.

Whilst no action lies at Common Law for the abstraction or diversion of underground water which percolates in no defined or known channel through the soil, a landowner, including a water undertaker, has a right of action against anybody who pollutes water percolating through adjoining land so that the water reaches his land in a polluted condition. Where the landowner proves that his rights to pure underground water have been injured by pollution, the Courts will award compensation or grant an injunction to stop the pollution from continuing. If a sufficiently strong case can be proved, an injunction will be granted restraining a proposed use of adjoining land which would have caused an imminent risk of serious pollution.

The law under which pollution may be controlled is being changed and the following statutory provisions will be repealed as from the dates when the corresponding provisions of the Control of Pollution Act 1974 are brought into full effect:—

Water Act 1945, *Section* 18.—Power for statutory water undertakers to make byelaws in order to restrict activity within defined areas around their sources.

Water Act 1963, *Sections* 72 *to* 75 *Inclusive*.—These provisions contain a code enabling water authorities to control the discharge of any trade effluent or sewage effluent or any other poisonous, noxious, or polluted matter into underground strata by means of a well, borehole, or pipe.

Deposit of Poisonous Waste Act 1972.—This Act contains a licensing code controlling the deposit, on land (including land covered by water), of any poisonous, noxious, or polluting waste in circumstances in which the waste could give rise to an environmental hazard.

The following statutory provisions, however, are not to be repealed by the Control of Pollution Act 1974:—

Water Act 1945, *Section* 21.—This provision makes it an offence for a person to pollute or to do anything which is likely to cause pollution of any spring, well, borehole or adit, the water from which is used or likely to be used for human consumption. Whilst the provision has been on the Statute Book for nearly 30 years, and during that time there have been numerous cases of groundwater pollution, the difficulties of obtaining sufficient evidence to satisfy the Court that an offence has been committed have been sufficient to deter any water undertaker from attempting to prosecute under the provision.

Public Health Act 1936, *Section* 50.—This provision gives local authorities the power to require cesspools and septic tanks to be maintained in good order. Hitherto little use has been made of the provision specifically for the purpose of the prevention of pollution of groundwater. The Water Act 1973 has extended similar power to water authorities and it is hoped that these bodies will now use it to good effect.

The Building Regulations 1972, *Reg. No. N.*17—*Cesspools, Septic Tanks and Similar Structures.*—This regulation provides that cesspools, etc., are to be so sited as not to render liable to pollution any spring, stream, well, adit or other source of water which is used or is likely to be used for drinking or domestic purposes. Although the regulation has been in operation for some considerable period (there was a corresponding regulation before the 1972 Regulations were introduced) some local authorities clearly did not appreciate the wider implications of the provision and permitted a number of badly sited units to be constructed.

The main objective for water authorities in the future should be to develop and extend the present system of informal consultations with local planning authorities and authorities responsible for the enforcement of building regulations. In the longer term thought should be given to the provision of a clear framework of administrative law which requires developers and users of land to take all necessary measures to the satisfaction of water authorities so as to minimize risks of pollution to all sources of potable water.

SOURCES

Groundwater is abstracted from springs, wells, and possibly adits and boreholes.

Spring water is usually collected in a pond or chamber from which porous pipes may radiate to pick up as much groundwater as possible and as such they present a considerable risk from local pollution. It is desirable, therefore, to determine the catchment area and to acquire or adequately control as much of this land as possible, having regard to the yield and possible uncontrolled use of the area concerned. Farming, subject possibly to restrictions, can usually be allowed.

Shallow wells, which are usually brick-lined with open joints, have for many centuries provided what has previously been regarded as a satisfactory source of drinking water. Visitors, who did not enjoy the same immunity as the locals and thereby suffered some minor discomfort, had good reason to say "it must be the water". Although the number of properties not on mains supplies is reducing annually, there still remain many local small sources of supply which are subject to occasional pollution.

Wells and boreholes are lined with concrete or solid metal tubes backed with grout to prevent the inflow of surface and subsoil water. They are expensive, so that the length usually employed these days is the minimum considered necessary to prevent possible pollution within the immediate vicinity of the borehole. The actual lengths of solid lining varies from about 15 to 35 m in depth. For the yields normally obtained from a granular aquifer, this depth is more than adequate, but with fissured materials this is only a gesture unless the grouting up is extended well beyond the drilling diameter.

In confined aquifers, the length of the lining is determined by the depth to the bottom of the confining layer. It is important, if any of the strata above the aquifer contains water, to ensure that the seal, which is formed at the bottom of the tubes, is good. This is often done by drilling a short distance into the aquifer and landing the lining tubes in a concrete plug. If the aquifer is known to support a high flow in the upper layers of the stratum, then a good seal may be achieved at the expense of the yield.

One rarely finds two wells or boreholes to the same design. It is, however, important that the well top incorporates the following features:—

(1) well lining or bore pipe should be 0·5 m or so above the highest known flood level,
(2) any pipes and cables should enter the well top through a watertight gland, and
(3) any pit should have a watertight cover to direct surface water away from the well.

The general arrangement should include an area of hard standing to facilitate the maintenance of pumping plant and provide means of minimizing the risk of liquid, tools, and workmen from falling into the hole.

"Once commissioned best forgotten about" is a short-sighted policy for wells. There is a tendancy to rely implicitly on the accuracy of water level gauges and equipment from one year to the next, but an inspection should be carried out regularly to check:—

(*a*) the accuracy of the water level gauges,
(*b*) the condition of the linings, pumping plant, and the rising main for visible signs of leakage,
(*c*) the level of the gravel pack, if any, and
(*d*) to report on the general cleanliness of the well top and cover.

The inspection of adits is a more complicated procedure and requires skilled and proper equipment. The former Metropolitan Water Board was the only undertaking with a direct labour gang able to carry out this type of work. It is possible that the establishment of the Regional Water Authorities will rejuvenate this dying breed. The precautions to be adopted in order to safeguard both the man and the purity of the supply are set out in the handbook "Safety in wells and boreholes", published by the Institution of Civil Engineers.

Whereas wells and boreholes were, until the late 1930s, contained within a pumphouse, the tendency now is to leave them out in the open. Whatever the arrangement, there will be buildings and pumping plant; the two principal hazards at any well pumping station are soil drains and, if Diesel engines are installed, gas oil.

Soil drains should be laid in iron on a firm bed with watertight manholes and covers. In the absence of main drainage, domestic sewage should be taken to a watertight cesspool (which should be emptied regularly), sited as far from the point of abstraction as possible. The soil drainage system should also be tested regularly and the number of cesspool emptyings checked against water consumption on the station.

All oil should be stored above ground within a bunded area of a volume in excess of the capacity of the tanks when filled. All vent pipes and filling connexions should be located within the bunded area. Experience shows that the source is at greatest risk during bunkering and ideally there should be a hard standing adjacent to the filling point which would direct oil, if spilled, away from the well. If there is a spillage, then the contaminated subsoil should be removed by excavator rather than trying to disperse it. Roof and surface water can usually be taken to soakaways, via oil inceptors where appropriate.

PREVENTION OF POLLUTION

Whilst the risk of pollution can be minimized, complete success cannot be guaranteed, nor can one be sure that unforeseen circumstances or accidents will not occur.

The risk will vary according to the type of aquifer, but it is accepted practice that all groundwater abstracted for public supply be disinfected, probably by the addition of chlorine or ozone, and that an increase in pollution to the extent that a satisfactory standard of treated water is not being achieved results in a shutdown of the source.

Although this might be regarded as being a second line of defence, pollution prevention should be approached as if this did not exist.

Sources of pollution resulting from social activities can be grouped into several categories:—

(1) *Disposal of sewage:—*
- (*a*) domestic unit
- (*b*) community.

(2) *Disposal of surface water:—*
- (*a*) urban areas
- (*b*) traffic routes.

(3) *Industry:—*
- (*a*) storage of materials
  - (i) surface
  - (ii) underground
- (*b*) bulk transfer of materials
  - (i) by road
  - (ii) pipelines
- (*c*) disposal of wastes (see also (4) (*c*)).

(4) *Mineral excavations, including mining:—*
- (*a*) working, including disposal of water
- (*b*) disused
- (*c*) restoration, including disposal of household and factory wastes.

(5) *Farming:—*
- (*a*) application of fertilizers
- (*b*) disposal of wastes
- (*c*) use of pesticides, herbicides, etc.

There are also others which result from the development of groundwater, such as:—

(6) *Well development and maintenance.*

(7) *Overpumping of aquifers.*

(8) *Artificial recharge.*

The possible effect of these activities and means of control are discussed under these headings.

Disposal of Sewage

Domestic.—The recent court decision following the Government's proposal to allow 50 per cent. rebate on the general services charge will, no doubt, reveal, for the first time, the number of domestic properties not on main drainage.

In accepting the presence of *E. Coli* as an indication of potentially dangerous pollution, we are setting the highest realistic standards which can be achieved and which are vastly more reliable than those likely to result from following recommendations as to minimum distances between wells and sewage disposal units given in various building regulations particularly abroad.

The two main types of domestic disposal unit are:—

(*a*) Cesspool

(*b*) Septic tank.

The distinction between (*a*) and (*b*) may be quite fine, in that many cesspools have been so adapted after inspection so as to behave as a soakaway, and effluent from a septic tank is often disposed of in the same way. There are many areas where this may not matter, but generally supervision and enforcement of regulations are such that a cesspool these days, bar structural failure, is watertight.

Discussion on the merits of the two systems continues, but again in general, a watertight cesspool with no provision for overflow and regularly emptied and maintained, is to be preferred on all fissured aquifers and septic tanks with bacterial filters and sub soil irrigation can have merits elsewhere.

Control of new disposal units can be achieved by consultation with local authorities under Town and Country Planning Acts and Building Regulations, but each case should be considered on its merits, having regard to the type of aquifer, the distance and direction of any sources, additional pollution load, and whether acceptance of a unit at this particular location would encourage applications for planning permission on adjacent sites or create a precedent elsewhere.

Supervision of many of the existing units, however, is more difficult and one can only resort to powers under Section 21 of the Water Act 1945 or Section 50 of the Public Health Acts 1936, if pollution is suspected. If this produces no response and the unit is definitely defective, then it is often expedient for the water undertaking to contribute towards the construction of a new unit to an approved design.

Community.—Units dealing with a group of properties are commonplace. Many have, in the past, lacked attention and, therefore, their efficiency and hence the quality of effluent, is poor. It is possible that under the new arrangements the situation will improve. Indeed, if any such unit is situated in close proximity to a source, then it is essential that it is well maintained. The siting of these units will in future be determined by the water authorities so that no problems should occur provided that any potential resources are recognized as such at the time.

A number of feasibility studies have been undertaken in connexion with the piping of sewage effluent across country to the sea. The risk of leakage is presumably similar to that for other cross-country pipelines, but in this case, water authorities will be more aware of the location of any abstraction points *en route*.

Disposal of Surface Water

Urban Areas.—The return of water from roofs and paved areas of catchments is to be encouraged. On one hand it is essential that the aquifer in the immediate vicinity of the soakaway can absorb the quantities that would be received but, on the other, their siting on extensively fissured areas should be discouraged. On balance, a large number of small soakaways is less likely to cause serious pollution.

Traffic Routes.—The reduction in replenishment of an aquifer caused by a motorway with its adjacent hard shoulders and cuttings is often more than appears at first sight. Surface water should be disposed of via soakaways with interceptors where any road drainage is included. Here again, a number of small excavations is to be preferred to a few large ones. Large soakaways sited near to abstraction points can result in noticeable increases in chlorides due to applications of salt to motorways in winter.

Evidence of the potential hazard from motorway drainage is now available from a number of investigations carried out, both in this country and abroad, during and after construction, but if any doubt exists as to the relationship of the proposed route and the existing source, then more information should be obtained by experiment, using tracers.

Another aspect of the disposal of both sewage effluents and surface run-off into water courses, streams, and rivers, which needs to be considered, is the possibility of natural replenishment of an aquifer through the bed of a river.

INDUSTRY

Storage of Materials.—The numbers of raw manufacturing and processing materials stored and used in certain locations and circumstances, which could cause pollution of groundwater, are large. The risk to groundwater is, however, lower than for surface water. Particular attention should be directed to fuel oils and any hydrocarbons and to any toxic materials in the broadest sense of the word. Storage above ground presents few problems, provided that the area is adequately paved and, if large quantities are involved, bunded to prevent access to the sub soil.

Storage underground presents a more difficult condition and close attention to the structure and the arrangements for refilling is worthwhile. In several European countries the accidental seepage of fuel and heating fuels has led to the prohibition of underground storage tanks on certain catchment areas.

Bulk Transfer of Materials. The two means of transportation which could have some adverse affect on groundwater are pipeline and road. Considerable lengths of pressure pipeline have been laid to convey gas and oil across country but, to date, there have been comparatively few incidents. Notification of proposed routes is now obligatory, but on past record there would be little ground for objection unless the proposed pipeline was particularly close to a major abstraction point.

Equally, the movement of fuel oils and chemicals by road tanker should present no problem, but accidents can occur anywhere. Therefore, any highway of sufficient width to accommodate such a vehicle is a potential risk. A number of these lorries have overturned and the spontaneous reaction of those called to deal with the accident seems to be to wash the offending liquid from the surface of the carriageway as quickly as possible. In a number of instances this would not be in the best interests of the water undertaking and this situation requires further consideration.

It is suggested that police and fire brigades be advised of the limits of catchments within their areas of operation and that all vehicles carrying liquids which could pollute water supplies should bear some means of identification, such as a removable name board with instructions as how best to deal with any spillage that might occur.

A more drastic protection method would be to prohibit access to vehicles carrying specified loads on roads within a certain distance of the abstraction point.

Disposal of Wastes.—Prior to the Disposal of Wastes Act 1972 and the Water Resources Act 1973, few questions were asked about the disposal of industrial wastes, other than to the main sewers. Disused boreholes and mineral workings provided an easy access to fissured strata and unless there was some obvious effect within a reasonable distance, the practice was allowed to continue. Few containers of materials used in industrial processes bear large distinguishing marks and those that do wear rapidly in exposed conditions. Flooded gravel pits provide an all too easy opportunity for instant disposal and have as a consequence produced some classic examples of this type of pollution.

MINERAL EXCAVATIONS

Working.—Prior to 1947, the winning of materials by open excavation or shaft was largely uncontrolled. With the introduction of the Town and Country Planning Act, so procedures for consultation with local authorities and water undertakers were established and general conditions relating to the working of pits within catchment areas and their subsequent reinstatement were imposed, so as to reduce the risk of pollution. Conditions varied according to circumstances, but in Kent, where large deposits of gravel overlie the Chalk, operators were required to leave a depth of sand and gravel on top of the Chalk to act as a filter.

Under the Water Act 1945 and the Water Resources Act 1963, a licence is not required to extract water in order to excavate minerals. The quantity of water likely to be pumped from a well of gravel pit dimensions is by water supply standards, quite large. Such pumping could alter the whole pattern of groundwater flow with attendant problems, such as saline infiltration.

Much publicity has been given to the damage caused by the continuing discharge of ferruginous and saline water from disused mines. In Kent, the discharges from two collieries were allowed to infiltrate into the Chalk and although these have now ceased it is likely that the saline contamination will take many years to clear.

Disused.—As excavations closer to large urban areas have been refilled, so the pressure on those on the perimeter increases. Unauthorized tipping, whilst still practised, is not so prevalent and it should be a condition that the perimeter fencing of any worked-out pit should be maintained. Any excavation, either wet or dry, within a catchment area, should be regarded as a potential hazard.

A number of groundwater sources have been polluted by the tipping of industrial wastes either alone or in combination with other waste, not necessarily deliberately, but in ignorance of the consequences. Times have changed, legislation has been introduced to deal with the future, but we are left with what has happened in the past.

Restoration.—Experiments carried out in 1961 in connexion with the preparation of a Report on Pollution of Water by Tipped Refuse, indicated that although the percolate from both dry and wet pits was potentially polluting, natural purification did take place and there was no reason why this means of disposal should not continue, subject to selection of sites.

A number of methods of reducing the effect of pollution by sealing the bottom of the excavation by an impervious membrane, ranging from natural clay to plastic sheeting, or by sealing the top immediately tipping had been completed have been suggested. Another suggestion involves the laying of underdrains.

More recently, an interim paper on the results of a survey of existing sites undertaken by the Institute of Geological Sciences for the Department of the Environment, indicates that although a number of potentially hazardous sites are in use, few incidents of pollution of groundwater sources have actually occurred. The survey is not yet complete and in the meantime guidelines on the selection of new sites are given.

FARMING

Application of Fertilizers.—There is no denying that the campaign initiated by the Ministry of Agriculture, Fisheries and Food during the Second World War to increase the production of crops by the application of nitrogenous fertilizers, has been most successful. Due to the change in relationship between the cost of fertilizers and the value of various crops, including grass for grazing, it is difficult to know whether optimum conditions have ever been reached. Although views have been expressed that the use of such fertilizers have not had a deleterious effect on groundwater, the figures tend to speak for themselves.

Nitrates occur naturally in low concentrations in all groundwaters. In recent years these levels have risen as have the quantities of nitrogenous fertilizers being applied to land. Levels appear to be continuing to rise, except where undertakers owning areas of land in the immediate vicinity of the spring or well have been able, by restrictive covenant or other form of agreement, to control the rate of application. In these instances, the trend has been reversed, or at least the position is not getting any worse.

Farming records, other than in educational or research establishments, seldom match those of the water laboratories. In any event, apart from the rate of application, many factors, such as soil condition and weather both immediately before and after application come into play. Levels have tended to increase during the past few years when the winter rainfall has been significantly less than average. This is not what one would expect, unless the quantity of water available as a solvent is a controlling factor. All water undertakers are conscious of this growing problem and investigation work is being undertaken by the Water Research Centre in conjunction with the Department of the Environment. It is hoped that this will yield sufficient information for the trend to be arrested and possibly cured. In the meantime, it is recommended that application of nitrogenous fertilizers on catchment areas of groundwater sources should be limited and that the single massive dressing should be discouraged.

Disposal of Wastes.—The other main source of nitrogen from farming activities is from the disposal of manure. The dispersion and sparodic application caused by grazing is unlikely to cause any problem, and here again it is as a result of intensive activity that problems can occur. This technique involves the herding of animals in a relatively small area, hence comparatively large quantities of waste are accumulated at one point. Although it is desirable that these waste products should be returned to the land, it may not be possible under all conditions. However, recommended quantities which are related to the type of crop have been suggested.

Intensive cattle farming, therefore, should not be located near to or within reasonable distance of an abstraction point. If allowed, then sufficient hardstandings should be provided and watertight lagoons should be constructed to contain the anticipated waste during the most adverse of weather conditions. The effect of this type of activity requires further study and assessment.

Use of Pesticides, Herbicides, etc.—The quantities of pesticides and herbicides being used have increased significantly. Many of these are persistent chemicals with a high potential for pollution of groundwater. The risk arises mainly from incorrect use, the disposal of unused chemicals, used containers and the industrial effluents arising from the manufacture of these chemicals. Further investigation work is necessary, but the siting of manufacturing plant and distribution depots needs careful consideration.

Well Development and Maintenance

In recent years, considerable success has been achieved by the use of two chemicals, namely hydrochloric acid and Calgon, in the development and maintenance of boreholes. Injection of either of these chemicals into the borehole is followed by swabbing, jetting, backwashing or surge pumping, during which period the byproducts of the treatment are effectively removed. Such operations, either on public or private sources, are within the control of the water authority so that no risk should obtain. Any problems usually stem from the disposal of the water pumped immediately after treatment.

Overpumping of Aquifers

The general effect of overpumping is to allow the ingress of water from an adjacent aquifer, assuming there is some connexion, or the sea. As to whether this is of any consequence or constitutes a pollution hazard depends on the quality of water which is allowed to flow in.

The two main aquifers where saline intrusion exists are the Chalk and the Triassic Sandstones. The inflow of mineralized groundwater from adjacent aquifers has also affected the latter, and the Permian Limestones and the Jurassic Limestones are at risk.

The obvious method of protection is to reduce or otherwise control pumping, for example, on a seasonal basis so that a positive hydraulic gradient is maintained. Other techniques which have proved to be successful in Holland and the U.S.A. include the maintenance of a fresh water ridge or extraction barrier, and artificial recharge.

Serious consideration is now being given in various parts of the country to the conjunctive use of ground and surface water, involving the overpumping of an aquifer temporarily during a period of drought in order to augment or regulate river flows. This could result in the natural flow of groundwater to the river ceasing and if good hydraulic continuity exists, it is possible that the flow pattern may be reversed. This in itself may limit the usefulness of this operation and consideration should be given to the possible deterioration in quality of the groundwater, if also being used for supply, arising from recirculation.

Artificial Recharge

The final report of the Water Resources Board on the Water Resources in England and Wales suggests that up to one-quarter of the additional supplies required between now and the end of the century might be obtained by artificial recharge, particularly of the Chalk, Triassic Sands, and Jurassic Limestones.

Although this technique was suggested as a means of steadying the falling water levels in the London basin in the early 1900s, little work was done until 1959, when filtered water was introduced during the winter into the Chalk via disused wells and adits in the Lee Valley and a substantial proportion recovered during the summer. Since then the operation has been extended to two other wells. No problems have been experienced in regard to quality, except that the hardness of water being abstracted from private wells in the area where water levels had risen, has increased. Other aquifers which have been recharged using treated water include the Bunter Sandstone, Folkstone Beds, and the Ashdown Sands.

Investigations carried out by the Water Research Centre on recharge basins indicate that changes in quality of the recharge water occur not only as a result of infiltration but also on the micro-organisms present, the population of which depend on the organic load and oxygen available. It appears desirable, therefore, to determine, if possible, or predict the changes likely to occur having regard to the water quality and the characteristics of the sub soil in the base of the lagoon.

If water is introduced into the aquifer via a well or borehole, there is no filtering action, but experience has shown that the water should be compatible with the natural water otherwise chemical and bacteriological reactions can lead to a physical clogging of the borehole, which not only reduces the rate of recharge, but also the yield of the boreholes being used as a summer abstraction point.

DETECTION OF GROUNDWATER POLLUTION

If a deterioration in water quality occurs, then it is essential that the source of pollution is located as quickly as possible.

This deterioration can take the form of a small departure in character from the normal to gross pollution, which is beyond the capacity of the installed treatment plant and which would require the source to be taken out of supply. Gross pollution, although obvious, is rarely instantaneous; therefore, any change in the character of the water being abstracted should be regarded as suspicious. It is essential to have good base records and a system of sampling for both chemical analysis and bacteriological examination.

A good knowledge of the catchment area is desirable, but the officer responsible for quality control is not necessarily the best person to go looking for pollution. Assuming the recommendations contained in the "Safeguards to be adopted in the operation and management of waterworks" pamphlet have been followed and catchment maps on which all sewers, sewage treatment works, disposal units, cesspools and any other potential sources of pollution have been marked, then the severity and nature of the pollution will provide a good idea as to the area that needs to be considered.

All water undertakings employ inspectors for inspection and prevention of waste and many incorporate these duties with their distribution activities within a particular area. These men should in time acquire an extremely good working knowledge of the districts and with appropriate training in the possible causes of pollution and its control can become in this sense multifunctional.

If pollution is suspected and positive proof of this is required, then there are a number of techniques involving tracers which can be used to indicate whether or not the location in question is in hydraulic continuity with the point of abstraction.

A popular chemical for this purpose is the very distinctive yellow/green dye Fluorescein, which has a high colouring power and hence can be detected in concentrations as low as 1 in 2000 million, is relatively harmless, and is little affected by passing through soils. It is best applied in an alkaline solution but care should be taken if water is being abstracted for supply as the colour, if a good communication is found to exist, can persist for hours or even days. Rodamine B is a relatively more expensive red dye which has been used in the past in certain circumstances, such as turbid waters. It may however provide a health hazard and is best avoided. Other chemicals which have been used include common salt (which is still relatively cheap even though several tons would be required to be washed in to the point under scrutiny), lithium salts, and sodium phosphate.

All these chemicals are carried in solution so that their application to the movement of bacteria is limited. Several specimens of bacteria have been used successfully, especially Serriatia marcescens, which is reputed to be non pathegenic, produces red colonies and survives well to the extent that experiments need careful control.

Radio isotopes provide an additional method of tracing the movement of groundwater and pollutants. Tritium, which is not subject to absorption or other chemical loss, is used as a radioactively labelled compound or is an indicator in the assessment of the age of the water. Emission of beta particles is low and samples must be taken and analysed in the laboratory. Several other isotopes have been considered.

CHECK LIST FOR PREVENTION OF POLLUTION OF GROUND-WATER SOURCES

(1) Prepare a catchment map indicating:—

limits of areas of main drainage, including trunk sewers;
sewage disposal units, sewage treatment works, septic tanks, cesspools;
major roads and service areas;
industrial premises involving use, storage or disposal of pollutants;
pipelines;
mineral excavations and mines;
intensive farming units, especially manure heaps and effluent lagoons;
disused pits, quarries, shafts, wells and boreholes.

Indicate sites where applications have been submitted for planning permission involving a risk of pollution. This information to be updated from time to time.
(2) Prepare a schedule of inspection of danger points. Update from time to time.
(3) Prepare map showing location of wells and boreholes where regular observations of the water table may be taken. Take levels and prepare revised map at six-monthly intervals or thereabouts to indicate maximum and minimum water-table conditions.
(4) Prepare schedule of sampling for:—

(*a*) bacteriological examination,
(*b*) chemical analysis.

Determine average and range of results for (*b*).
(5) Prepare schedule of inspections of wells and boreholes:—

(*a*) check watertightness of well top and cover,
(*b*) inspect lining and rising main by hand lamp or wander lead for signs of leakage,
(*c*) check water level gauge,
(*d*) check level of filter pack, if any, and
(*e*) check depth to bottom of well.

(6) Inspect drainage of station at regular intervals and test for watertightness if in doubt.
(7) When working in a well check:—

(*a*) medical history of workmen,
(*b*) provision of protective clothing, boots, and disinfectant.

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World Health Organization, Geneva. 1970 "European standards for drinking water", 2nd ed., available from HMSO.

DISCUSSION

AUTHOR'S INTRODUCTION

Mr. R. J. Slater, in introducing the paper, referred to previous papers on the subject and in particular the Groundwater Pollution Symposium arranged by the Water Research Association in 1972.

Since 1973 the National Water Council and the Water Research Centre, through their respective publications, had kept the industry informed on any published work in this field and the progress on relevant legislation. Not being an expert in any particular field he felt justified in trying to deal with the subject as a whole by reviewing the factors involved and the social activities which, in certain circumstances, might be regarded as potentially polluting. He hoped the check list given at the end of the paper would be of benefit to those concerned with preventing pollution.

In retrospect he regretted condensing the section on hydrological factors. Hydrogeology was extremely important in assessing the extent to which pollution was likely to occur and also in determining the cause.

The state of the law at present in relation to pollution was very unsatisfactory and the judgements given on cases on appeal had been of little help. We had been promised the Control of Pollution Act 1974, but it had yet to come into effect. Society had advanced more quickly than laws could be made to control the consequences of the changes that had occurred.

He then showed a number of slides (not reproduced) illustrating changes in behaviour; the increase in the level of lead following the advent of the internal combustion engine; the usage of phosphorous as a result of the marketing of soapless detergents; the increase in the number of items thrown away after use; and the reliance placed on other people to clear up the mess and the effects of this when the system broke down.

Slides were also used to illustrate the hazards arising from the use of road transport and the considerable dangers arising from the disposal of industrial and domestic wastes of all kinds and changes in farming practices, particularly from the use of nitrogenous fertilizers. Typical sources of groundwater were illustrated and the need for effectively controlling the risk of pollution in the immediate vicinity of these sites was stressed.

Verbal Discussion

Mr. J. Jeffery (North Surrey Water Company), in opening the discussion, said that the importance of prevention rather than cure in groundwater pollution stemmed from the retention time of water in an aquifer. Thus, even after a source of pollution had been removed, years could pass before the pollution appeared in abstracted water and many more could elapse before it disappeared altogether.

When the Control of Pollution Act 1974 came into full effect, Section 18 of the Water Act 1945 would be repealed. Would this mean that byelaws made under that Section ceased to have legal force? If so, how would such byelaws be replaced?

Provisions not to be repealed under the Control of Pollution Act included Section 21 of the Water Act 1945. The author seemed to imply that the Section had no value because no water undertaker had attempted to prosecute under the Section. Whilst accepting the difficulties of satisfying a Court that a pollution hazard existed, the Section had often been used successfully in an indirect way.

In discussing tipping in disused mineral workings, the author said that legislation dealt with the future, but made no reference to control problems. Applications for tipping authority were often vaguely worded, and were made by contractors who did not fully understand what they were handling. Great expansion of inspection and supervision would be needed before there could be confidence in the law.

In the farming section of the paper, he strongly supported the recommendation that application of nitrogenous fertilizers on catchment areas of groundwater sources should be limited and the single massive dressing discouraged. The paper might have mentioned disposal of sewage sludges. Fish* gave five sources of increasing nitrate concentration

* Fish, H. 1974, *Civil Engineering*, December, p. 31, "Nitrate and London's public water supply".

in surface and groundwaters. The first of these included increasing disposal of sewage sludge on land. Two years ago, sewage sludge was applied in September to a farm over a chalk aquifer at a rate equivalent to 600 units of nitrogen per acre. This was a much higher rate than would normally be considered good husbandry, especially in the autumn. Accepting that some nitrogen was not easily converted to nitrate, the example showed that the implications of sewage sludge disposal were not always fully considered.

Finally, he would have liked to see mention in the paper of the memorandum "Safeguards to be adopted in the operation and management of waterworks". The section on blood testing of employees seemed particularly important when considering groundwater sources.

Dr. W. B. Wilkinson (Water Research Centre) said that the paper had one shortcoming in that it barely recognized the need for a sound knowledge of the hydrogeological properties of the water-bearing and adjacent strata. Such an understanding was essential if protective measures were to be effective and if *predictions* as to the rate of spread of pollutants and their effect on adjacent groundwater sources were to be made.

The need to understand fully the aquifer system was best illustrated (Fig. 1*a*) by considering one simple situation that might face the water engineer. Area X represented an existing or proposed source of pollution, for example a landfill site or an effluent discharge, circle Y represented an abstraction well, and Z was a river. The principal questions to be answered were:

(1) Would the resulting pollution from X enter Y?
(2) In what concentrations?
(3) At what rate would the pollution move? and
(4) What protective measures could be taken?

The answer to these questions depended particuarly on a knowledge of the:

(*a*) geology of the area,
(*b*) transmissivity, storage coefficient, coefficient of dispersivity and other hydrogeological properties of the aquifer,
(*c*) meterological conditions and infiltration,
(*d*) groundwater levels and flow pattern,
(*e*) current and future abstraction rate from the well, and
(*f*) permeability of the river bed.

A range of typical situations that could occur, depending on the hydrogeological conditions, were shown diagramatically in Fig. 1 (*b*), (*c*), and (*d*). In Fig. 1*b* pollution of the well resulted possibly from both the effluent source and the river, if it was also polluted, but if the movement of groundwater was slow it might be several years before pollution of the well occurred. In Fig. 1*c* the abstraction rate from the well was relatively small so that no contamination entered the well but pollution of the river might result. In Fig 1*d* no contamination entered the well, even though the groundwater contours were similar to those in Fig 1*b*, because the aquifer was effectively sealed by an upper clay layer.

In order to make a major step forward in protecting groundwater sources from pollution it was necessary to attempt to quantify the problem. To do this the W.R.C. were studying a number of groundwater pollution situations by firstly gathering the necessary data, secondly measuring the appropriate aquifer properties, and thirdly using numerical models to predict the extent and rate at which a pollutant might spread. It might be that this approach was outside the range of experience of the staff of some of the divisions of the water authorities or water companies who had to take decisions on the protective measures to be adopted. If this was the case it would be necessary for the division or company to seek external advice, but with time they should attempt to establish their own expertise.

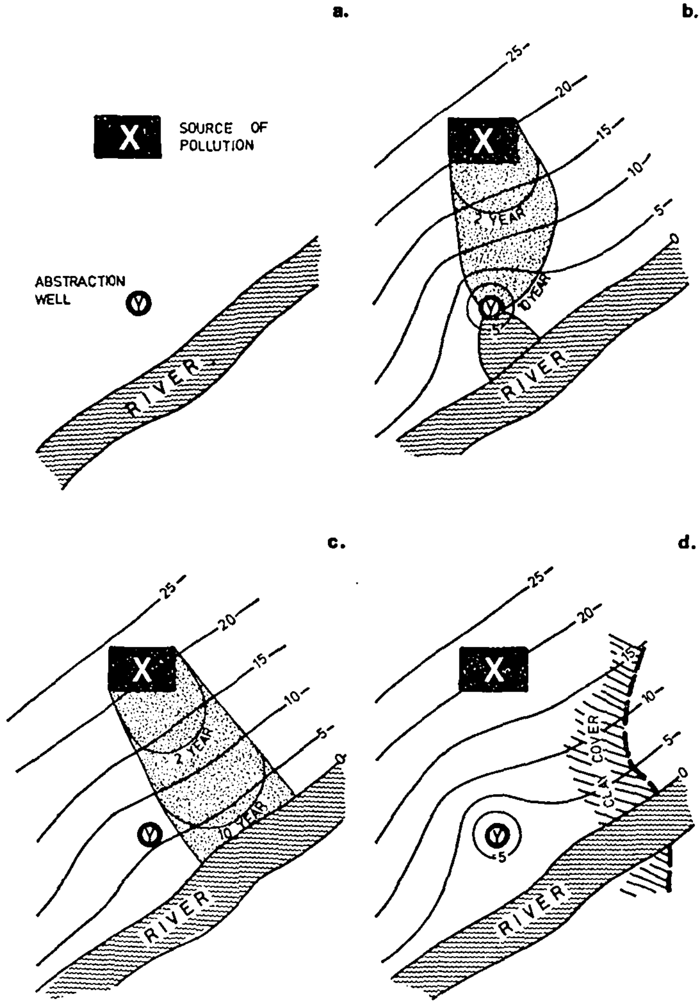

Fig. 1. Diagrammatic representation of a potential groundwater pollution situation

The author suggested that it was desirable to "determine the catchment area of a groundwater source and actively control as much of this land as possible", but how was this catchment defined. For many groundwater sources, both spring and boreholes, the catchment area varied with infiltration, river flow, and the rate and duration of abstraction from the groundwater source under consideration and adjacent sources. If the catchment was to be defined it might be necessary to sink additional observation boreholes. In the case of regional groundwater schemes a very large area of an aquifer might be developed and it would be out of the question to acquire this land.

The author also suggested that tracers should be used to give "positive proof" of the source of pollution. In some circumstances, particularly fissured limestone, they had

had some success but it should be remembered that the rate of groundwater movement might be very slow and it could take many years for a tracer to move from the source of pollution to the abstraction point. An experiment in this case would thus yield little or no information.

In order to establish preventive measures he suggested that a water engineer should certainly follow the useful check list given by the author, but he should also ensure that:—

(1) The hydrogeology of the area was understood in detail.
(2) Measurements were made of the relevant aquifer properties.
(3) Monitoring observation wells be installed to give prior warning of all changes in groundwater quality.
(4) An attempt was made to estimate the rate of movement of pollutants through the aquifer, possibly using models.

Mr. B. H. Rofe (Rofe, Kennard and Lapworth, Consulting Engineers) congratulated the author for suggesting a clear line of action for prevention of pollution which all those concerned with management of groundwater sources should adopt as a matter of urgency.

He referred to two aspects of the disposal of sewage and surface water and noted that these aspects had on many occasions over the last few years been included by planning authorities in reasons for refusal of development. In his experience the lack of disposal facilities for sewage or surface water seldom stood up to expert scrutiny, and it was not satisfactory for a water authority to refuse permission merely because it happened to be inconvenient to progress a particular section of sewerage or disposal works at that time.

He suggested that the author's statement (p.29) "Control of new disposal units . . ., and whether acceptance of a unit at this particular location would encourage applications for planning permission on adjacent sites or create a precedent elsewhere", could be open to misinterpretation. An engineer should give a fair and unbiased appraisal of the technical problem before considering whether the answer might create an undesirable precedent for other reasons.

Concerning surface water disposal, he fully agreed to the proposal to support the provision of local soakaways for roof drainage and road drainage. Many water authorities tended to disallow this on a conservative safety-first basis, which thus increased surface water disposal works required and decreased the recharge to the aquifer. Considered on a countrywide basis, about 800 hectares of impermeable area was created by housing development each year; if the run-off from this area was all to be diverted to watercourses it would involve additional drainage capacity to accommodate storm run-off of about 10 cumec or the provision of about 1000 km of surface water sewers of a diameter 100 mm greater than before which might cost of the order of £5 million per year. In addition, the local aquifers would be deprived of recharge of an aggregate quantity of some 2000 megalitres. In view of the very substantial benefit to the economy and the negligible risk of pollution from the sources, it was suggested that soakaways should be adopted wherever the local strata permitted.

Mr. R. G. Toms (Wessex Water Authority) was concerned with the suggestion (p.31) that the problem of pollution from tipped refuse was not serious. Such drainage was, in his experience, extremely difficult to treat by natural purification; because it soaked away and was not obvious, it could not be assumed that it was satisfactory.

In the past, refuse pits had usually been sited well away from major aquifers. Now, with the increasing demand for refuse sites as well as the greater use of groundwater, the two would inevitably come closer together. The increasing size of some of the sites would also result in drainage becoming more important.

There was at present an increasing pressure to use any convenient site for refuse disposal in order to keep costs down. This was a short sited policy, as in attempting to overcome short-term economic difficulties it could lead to long-term problems of water quality deterioration.

Written Discussion

Mr. S. S. D. Foster (Institute of Geological Sciences) wrote that in his introduction the author had acknowledged that the paper did not consider in depth hydrogeological factors. Whilst congratulating him on the readily implementable and practical nature of his check list for pollution protection, he himself did not believe that the subject of maintenance of groundwater quality could be effectively discussed without detailed consideration of such factors. It was only through appreciation of the hydrogeology that the implications for water quality management of the important differences between surface water and groundwater systems would themselves be fully appreciated.

Dr. Wilkinson (p.37) had already dealt with certain hydrogeological considerations. He himself would like to add two further topics to the discussion—the rôle of the unsaturated zone and the problem of groundwater sampling.

In the case of almost all aquifers except karstic limestones, it was unquestionable that the unsaturated zone played a major rôle in intercepting, diluting, or delaying the penetration of pollution originating at the land surface. At the same time, it was potentially capable of storing-up water quality problems for the future. Yet comparatively little was known about the various physical, chemical, and biological processes involved*. It was likely that very high concentrations of certain water pollutants occurred in many parts of the unsaturated zone of the important British aquifers—nitrate was a particular case in point.** Yet in no area had there been a detailed survey of the distribution of pollutants in the unsaturated zone nor did we know if they were, in fact, moving down to the water-table. Investigation was expensive, involving of necessity a large amount of drilling, but it was hoped that the current IGS and WRC research programmes, relating primarily to groundwater nitrates, would answer some of the most pressing questions.

It was important to realize that, as a result of such factors as frequent gross heterogeneity in permeability distribution in aquifers (especially fissure-flow formations) and their variable hydraulic boundary conditions, pumped samples of groundwater frequently had complex origins.* Studies to detect and evaluate pollution incidents needed a more controlled basis for sampling. Depth samples would be preferable in many cases and purpose-drilled investigation boreholes would often be required. Use of temperature and conductivity logging techniques and borehole flow measurements‡ could elucidate the levels of groundwater flow and the origins of the borehole column, thus providing a rational basis for depth sampling.

It was worth noting that in the field of groundwater quality studies, a detailed understanding of the hydraulics of the groundwater system was an essential prerequisite to any chemical work. This was quite distinct from the situation in studies of river pollution.

Author's Reply to Discussion

Mr. R. J. Slater, in reply to the discussion, wrote concerning Mr. Jeffery's contribution, that he understood that very few (possibly four or five) sets of byelaws, made under Section 18 of the Water Act 1945, remained in existence and that these could not be extended when they ceased to have effect at the end of the ten-year period commencing

*Foster, S. S. D. In press. Ministry of Agriculture, Fisheries and Food, Bulletin 32, paper 3, "The vulnerability of British groundwater resources to pollution by agricultural leachates".

**Foster, S. S. D., and Crease, R. I. 1974. *Journ. I.W.E.*, vol. 28, p. 178, "Nitrate pollution of Chalk groundwater in East Yorkshire—a hydrogeological appraisal".

‡Tate, T. K., Robertson, A. S., and Gray, D. A. 1970. *Quart. Journ. Eng. Geol.*, vol. 2, p. 195, "The hydrogeological investigation of fissure-flow by borehole logging techniques".

from the date on which they were made. However, under Section 31, Control of Pollution Act 1974, it was an offence to allow any polluting water to enter any "specified underground water" other than that which was authorized by a disposal licence or was in accordance with good agricultural practice. But under Sub-Section (5) the Secretary of State might make regulations which restricted the carrying out of activities likely to result in pollution in certain areas. Just how this would operate remained to be seen, but similar powers appeared to be available.

The maintenance of Section 21 of the Water Act 1945 on the Statue Book would seem to inspire confidence in what was a very wide power, in that it needed only be shown that pollution was likely. He certainly did not underrate its value as a deterrent.

He accepted Mr. Jeffrey's suggestion that problems could arise from tipping in disused mineral workings. Success depended largely on control and at the present time water undertakers must accept some responsibility for inspection.

Control of farming activities was not so easy and undertakers should endeavour to foster a relationship with those farmers working in the catchment areas that really mattered. Disposal of sewage sludge should not be the problem that it was in the past, now that this was under the control of the same authority. It did, however, afford the opportunity for controlled experiments.

Brief reference was made to the Memorandum "Safeguards to be adopted in the operation and maintenance of waterworks", which contained much good advice. There was some dissention amongst pathologists as to the value of blood tests and a further official view might be helpful.

Mr. Rofe criticised the ethics in dealing with domestic sewage disposal units and whilst he himself accepted that the risk from one unit, in a particular location, might be very small, it would be a brave engineer who, at a planning appeal, would say that the sixth, or seventh, or should it have been the fifth, unit in the vicinity was likely to create an unacceptable risk. There was, unfortunately, no way of being sure that a disposal unit in this or that position would pollute and one could not resort to trial and error.

He was grateful to Mr. Rofe for putting a price tag on the cost of not accepting surface water drainage. This should be encouraged, subject to the provisos on size and pollution from oil.

He accepted Dr. Wilkinson's criticism on the apparent lack of recognition in the paper of the hydrological aspects. He did refer, in the introduction, to the 1972 Conference organized by the Water Research Association, which contained Hunter Blair's paper. He was grateful to Dr. Wilkinson for setting out in his example the primary factors that needed to be considered.

The majority of water engineers of the past concerned with groundwater sources of supply acquired a knowledge of these factors by experience and by and large they were, in a limited way, successful in solving the problems. Today, as competition for water increased and resources reached their limit, so these factors assumed greater importance. So did the rôle of the hydrogeologist as a member of a divisional or regional team with a water authority, or as an expert with the Water Research Centre, who were presently taking on so much useful research work.

Whilst he accepted that a catchment area might be difficult to define precisely, any such variations that did occur were at the boundary where they were of least consequence. Catchment areas could be defined in so many ways and knowledge accumulated over the period of time. Each case should be considered on its merits having regard to the basic hydrogeological factors and to the degree or possiblity of pollution. Furthermore, it was not necessary to acquire in order to control.

Although he had used the word "positive" in relation to tracers, the fact that no connexion was proved was in many ways much preferred to a definite result.

As the checklist inferred, the more knowledge one could acquire about the catchment the better. The systemmatic collection and evaluation of data on basic properties by personnel experienced in relating these to the operational effects was of considerable benefit and he supported wholeheartedly Dr. Wilkinson's approach.

Mr. Toms drew attention to the potential risks from tipping domestic refuse into disused pits. He agreed that the selection of sites was most important, having regard to the hydrogeological factors. Research into the nature and effect of the percolate was continuing and it was hoped that this would be completed before the pressures to which Mr. Toms referred became too great.

Mr. Foster dealt with two other important hydrological aspects and it was interesting to hear of the current research, including that in the biological and chemical fields.

The real significance of the accumulation of pollutants with time had yet to emerge, and the expense of experimental work into this specific problem was appreciated. Publication of results would no doubt create an awareness and possibly a response of information. One was bound to ask whether we were making the best use of information which was, or could be made, readily available.

4. CONTROL OF EFFLUENTS

BY R. G. TOMS, BSC, FRIC*

CONTENTS

INTRODUCTION

THE CONTROL OF EFFLUENTS cannot be properly considered without giving an outline of the relevant legislation. However, as other papers[1,2,**] are available giving detailed information about this, it is not proposed here to go beyond mentioning the bare requirements of the law. Broadly, there is already available sufficient legislation to enable a general control of most effluents; when the Control of Pollution Act 1974 becomes operative, any additional legislation will need to be aimed at the processes producing polluting matter rather than at the discharge itself. Most of this paper will consider how the technical control of effluents may have to vary in order to cope with future problems that seem to be developing.

LEGISLATION FOR CONTROLLING EFFLUENT DISCHARGES

Although the Salmon and Freshwater Fisheries Act 1923 did enable some control to be exercised over effluent quality, the first legislation to have a major impact on the quality of effluents entering a watercourse was the Rivers (Prevention of Pollution) Act 1951. The 1951 Act was originally operated by River Boards, and its main effect was to control the quality of new discharges to inland waters. This reduced the rate of deterioration of river quality, although it did little to improve it. The Clean Rivers (Estuaries and Tidal Waters) Act 1960 extended the control to new discharges to estuaries, and the Rivers (Prevention of Pollution) Act 1961 gave powers for fairly comprehensive control of all discharges to inland waters. As a result the stage was set for a major improvement in the condition of polluted rivers but as the plans for undertaking this exercise were gradually being applied, so economic conditions turned against the successful operation of the Act. This has reduced the rate of improvement to negligible proportions and may, for a temporary period in the future, make it necessary to accept a limited deterioration in the quality of certain rivers. The present difficult situation is not, however, a complete tragedy as it should only be temporary and it does enable us, in slowing down the rapid rise in expenditure on waste purification, to pause and question whether the direction we were accelerating in was the correct one. It is this point which is now examined in more detail.

* Chief Scientific Officer, Wessex Water Authority.
** A numerical list of references is given on p. 53.

There had been a great danger that lack of expenditure on effluent treatment during and immediately after the Second World War, together with the growing volume of trade waste resulting from increased industrial output, would lead to the loss of many water resources through deterioration in water quality. The upsurge in the provision of piped water supply in rural areas after the war, which occurred without the corresponding increase in the improvement of sewage works, meant that many of the existing sewage plants rapidly became overloaded. An example of the problem was the River Lee in Hertfordshire, which for centuries had provided London with an important part of its water supply. At a meeting held in the 1950s between the then Metropolitan Water Board and the Ministry of Housing and Local Government, it was suggested that the river would have to be "written off" as having no future use because sewage effluent from the new town developments such as Hatfield, Stevenage, and Harlow, which would drain into the river, would make the water quality unsatisfactory for supply. The new legislation, however, was effective in ensuring that existing effluent discharges to the river were improved and that new effluents could be controlled so that far from the river deteriorating, there was a significant improvement in its general quality.

Even though the general quality of the Lee has improved, other problems of newer recognition have developed, such as the use of detergents and the growing concentration of nitrates[3]. These indicate the way the control of discharges to rivers and of river quality has had to alter over recent years and will need to alter in the future. It places great importance on the monitoring of waters in order to determine trends that may lead to problems, and so indicate what effluent controls are necessary. It also emphasizes the need to control development that can lead to such problems.

Since 1961 there has been considerable interest in an improved environment and both the Royal Commission on the Environment[4] in its reports and the Jeger Committee[5] dealing with the disposal of sewage have pointed out the many limitations that exist in control over discharges. These reports were partly responsible for the introduction of the Protection of the Environment Bill 1973, by the Conservative Government, which was eventually approved in an only slightly changed form by the Labour Government as the Control of Pollution Act 1974. This Act came into force towards the end of 1974, although due to the difficult financial situation much of the Act is unlikely to come into operation until late 1975 or 1976.

This Act, while giving greater control to certain discharges entering sewers, has probably its major impact on effluents by requiring that all discharges to estuaries and the sea shall require consent. The problems of determining consent conditions for such discharges are more complex than those for discharges to inland waters as the effect of tides, currents, and silt in suspension are all of considerable significance and yet difficult to predict. Another difficulty is that of survey work, because instead of sampling from a convenient bridge, it may be necessary to use a sea-going vessel designed to withstand adverse conditions of weather and sea. The problems involved in such survey work are, however, too complex to consider here and consequently the paper will deal in more detail with the control of discharges to inland waters.

The Control of Pollution Act will enable more comprehensive conditions to be applied in consents for discharges, including the possibility of requiring continuous monitoring equipment to be installed on outfalls. The consent conditions will receive greater publicity than was previously possible, and the implementation of the legal control implicit in the consent conditions will not be limited to water authorities but will be available to anybody who wishes to use it if discharges are unsatisfactory.

The Act also provides greater control over effluents or solid wastes that are put onto or into land, and which give rise to groundwater pollution or contaminated run-off.

EFFLUENT STANDARDS

When managing the quality of effluents entering controlled waters it is first necessary to understand why there is the need to control such discharges. For many years such control has been dominated by the thinking of the Royal Commission on Sewage Disposal[6], which promulgated the standards considered necessary in 1912. Even to this day many writers out of touch with practical progress still consider that these are the standards that are automatically granted for any discharges.

The Royal Commission standards (i.e. the Biochemical Oxygen Demand (BOD) shall not exceed 20 mg/l and the suspended solid content shall not exceed 30 mg/l provided that there is an eight times dilution with clean river water), had great merit and is presumably the reason for their long existence. However, conditions have changed considerably, and effluent discharges now form a much higher proportion of river flow than was imaginable when the Commission formulated its recommendations. Also, there has been a vast development of industries manufacturing and using synthetic chemicals, whose waste products affect water quality. Methods of deciding standards must therefore be reconsidered, if there is to be any progress in improving the quality of water resources.

The new thinking in production of standards gained considerable impetus from the Department of the Environment's publication "The control of sewage effluents to standards higher than that of the Royal Commission"[7]. This publication, in recognizing the need to improve effluent standards, put the onus on the River Authorities to make the case *if such higher standards were necessary. It went further in stating that the mere absence* of dilution water was not in itself a sound reason for imposing high conditions.

Although the report included some rather dubious statistics regarding the evidence about the effect of an effluent of Royal Commission Standard on a river with less than eight times dilution, it nevertheless heralded the move from earlier rule-of-thumb river quality control to the introduction of the mathematical approach to quality determination and hence the use of mathematical modelling techniques.

Much sound work on mathematical modelling was undertaken by the Water Pollution Research Laboratory, at Stevenage. In the United States, where the use of effluent standards is of much more recent origin, the enormous upsurge in recent years in expenditure on water quality research and the implementation of the Federal Water Pollution Control Act Amendments 1972, together with the injection of large Federal Government funds, has led to a different approach to the problem. Instead of the gradual development based on experience, as has occurred in this country, the United States has suddenly surged forward with advanced modelling procedures, frequently employing sophisticated mathematical techniques. Although these sometimes appear to be in advance of the accuracy of the practical knowledge of what occurs in the aquatic environment, nevertheless this has forged ahead the boundaries of understanding in the field of water quality problems. Much of this original work could be of value in studying the effect of discharges on UK rivers. Mention must also be made of the considerable amount of work undertaken in the Trent Study[8,9,10], which included an investigation as to how variations in effluent standards would affect the quality of the Trent.

The report of the Trent Research Programme includes the following:—

> "The research programme has confirmed that water treatment, effluent treatment, river water quality and river flow cannot be dealt with independently. It has emphasized that the efficient use of water resources requires sewage works to be operated with regard to both the quality of water in the river and the requirements of potential abstractors downstream. The creation of multipurpose authorities will provide the machinery to achieve this. But the research programme has made clear that there are serious gaps in technical knowledge of what is required to bring the factors together so as to produce efficient and economic management of the river system".

The report also went on to say in its conclusion:—

"In part the difficulty arises from the lack of any definition of what constitutes a 'wholesome' water for the purposes of the Water Acts. This is a problem to which the Department of the Environment should direct its attention without delay if the maximum use is to be made of rivers as sources of water supply. But there is also a need for further research leading to the establishment of the effluent and water treatment processes necessary to achieve specified standards of water quality".

RATIONAL DETERMINATION OF STANDARDS

The logical approach in deciding upon consent conditions for any discharge will normally include the following steps:—

(1) To determine the objectives, i.e. what is the present and future use of the water, whether it be for supply, industry, recreations, amenity, navigation, etc.
(2) To determine the quality of the water that is necessary to meet these objectives.
(3) To determine the quality of the proposed discharge in conjunction with other and possibly future discharges that will result in the watercourse complying with the quality standards determined in step (2).

This last step is not a straightforward mathematical deduction from step (2), as it is in this step that for an accurate deduction it is necessary to resort to complex mathematical modelling techniques which at present take us to the limit of knowledge concerning water quality. Thus, the very common requirement for the calculation of oxygen uptake by an effluent entering a watercourse requires a variety of factors to be taken into account. These may include:—

(*a*) The biochemical oxygen uptake of materials in solution.
(*b*) The oxygen uptake of suspended solids which are in suspension at a particular point along the river.
(*c*) The oxygen uptake by suspended solids that have settled on the river bed at that point.
(*d*) The oxygen uptake by fauna present in the river. These may be highly concentrated if there are appreciable deposits of sludge.
(*e*) Respiration of flora including plants and any algae that may develop.
(*f*) The photosynthetic production of oxygen (which itself depends on the amount of sunshine, shade, and the turbidity of the water).
(*g*) Temperature.
(*h*) The oxygen already present in the effluent and the river (the latter and possibly both being subject to diurnal variation).
(*i*) The river flow and effluent flow.

Even when the items have been listed that have to be taken into account in determining oxygen removal, the relationship of each with the change in oxygen is not a simple one. It is still not possible to calculate accurately what will happen in any particular situation. It is necessary, therefore, to supplement the calculations that are at present feasible with the expert knowledge of experienced staff. In particularly complex situations such as a heavily industrialized river or an industrial estuary, the problem is frequently beyond the ability of staff to solve without resorting completely to mathematical techniques.[11,12]

The standards included in consent conditions have normally been those required to keep the river in a healthy condition, for example limits on BOD to retain dissolved oxygen and limits on suspended solids to ensure good appearance and non siltation. Limits on a relatively few toxic materials such as heavy metals have sometimes been incorporated in order to ensure that fisheries are not affected. Rarely have any conditions been incorporated purely to safeguard the water abstractor, an exception being the ammonia limitation found in some sewage effluents so that the ammonia present in the abstracted water does not interfere with chlorination. The ammonia limitation also helps to protect fish life and restricts the oxygen removal by oxidation of ammonia in the river.

The recent reorganization in the water industry has brought together all direct interests in water, so the person setting effluent standards now has much more direct involvement in the use of the water. This is likely to have an effect in two complementary directions.

Firstly, the growing interest in the quality of water abstracted for supply and the increasing complexity of effluents will require that consent conditions take greater account of materials that may be discharged in trace amounts or those that are non-biodegradable.

Secondly, the consent conditions, instead of being a set of rules laying down a set of arbitrary standards which say what is right and what is wrong, can now be used as a tool for management of resources. Thus, in a river system there is the capacity at times for a river to absorb an increased amount of impurity than at other times. Similarly, there is as little relevance in insisting on a Royal Commission effluent for a baseline condition as there is in saying that consent conditions for an effluent should not be any more stringent. With the development of knowledge in the field of water pollution, so it should be possible to be more precise in setting discharge standards than has been possible in the past. Nevertheless, such determination will have to make allowance for a safety margin and this will to some extent include a factor which covers the part of the calculation where we still do not have a full understanding of the natural processes involved.

There has been criticism in the past that the allocation of consent limits which lay down a maximum concentration of impurity discharged at any particular time do not give a good indication of the effect of a discharge on a watercourse, as it is the total load of impurity and not its concentration that requires consideration. There is considerable truth in this, although the maximum concentration is also of importance. The difficulty in laying down a total loading condition in consents has been because some effluents, particularly those from industry, vary considerably over any 24 hr period. A discharge of sewage effluent usually varies much more slowly, although there can again be a significant variation over 24 hr, as the flow and strength of sewage entering the works changes according to the activity or lack of activity of the sewered population.

As sewage effluent frequently forms the largest proportion of the discharges entering a watercourse, its control by a water authority has to be such that even at the time of maximum loading, the effluent must not result in adverse water conditions. The flow leaving a sewage works usually varies from a rate of $0{\cdot}5 \times$ DWF during the night to $2 \times$ DWF during the day. Not only does the sewage works have to cope with this wide variation in loading, but so also does the river as the volume of effluent changes. It seems logical therefore to suggest that an improvement in river conditions and also a significant increase in treatment capacity at any sewage works, would result if the flows reaching a sewage works were balanced so that the works was operated at maximum efficiency over the whole day.

At present the quality of a river downstream of an effluent discharge can show considerable variation over 24 hr as the strength and volume of the effluent varies. An example of this was on the river Lee below Luton sewage works, where the reduced flow of sewage entering the sewage works overnight prevented the biological filters being properly dosed. As a result, during the night the effluent often had a high ammonia content, which was not present during the day.

ORGANIC RESIDUES

While the previous paragraphs refer in essence to a reduced degree of treatment or to a more economic method of treatment, to a large extent this concerns easily biodegradable matter. Present treatment of effluent can produce an effluent which causes problems in water supply because of the residue of organic matter which is difficult to degrade biologically. Residues of organic matter in the river water after abstraction can result in problems, such as the development of tastes and odours once the water is in the supply mains[13]. It is therefore necessary to decide on the maximum organic loading in a river which is acceptable for use as a raw water source for public supply without resulting in supply problems. Thus the concentrations of organic materials in effluents entering the river will need limiting to achieve this. The BOD test, while being an excellent indicator of the potential for oxygen uptake by an effluent, gives no indication of the non-biodegradable organic matter present and is of little value for solving this problem. There is likely in future to be a much greater move to control the total organic content of effluents. This may be indicated by the chemical oxygen demand (COD) test, but is better indicated by the total organic carbon test (TOC). There are problems at present in applying such a standard, but it is likely that as suitable equipment becomes available so there will be a move to include TOC standards in consent conditions.

This is a problem which will require more emphasis to be given in effluent treatment to reducing this residual core of organic material. Considerable research into the purification of organic wastes has gone into the methods of reducing easily oxidizable organic matter, and it is suggested that the basics for the process are now so well known that present investigations are giving little return for the work undertaken. It would seem more essential for the future that the investigation work should be redirected to removing the non-degradable matter.

TABLE I
(Results in mg/l)

	TOC	PV (4 hr)	BOD	COD
Sewage effluent				
Saltford	10·5	8·6	28·0	62·0
Winsley	15·0	19·1	44·0	—
Freshford	13·0	10·0	25·0	—
River water				
Avon at Staverton	6·0	7·6	3·8	—
Avon at Bradford	8·0	2·8	2·8	—
Wellow Brook at Wellow	7·0	3·3	3·2	—
Avon at Bathford	4·5	2·6	4·6	—
Raw supply water				
Newton Meadows	4·5	0·36	—	—
Batheaston West	4·0	0·32	—	—
„ East	4·0	0·20	—	—
Monkswood—Small	3·5	0·20	—	—
„ Large	3·5	0·20	—	—
Oakford	4·0	0·20	—	—

Table I indicates the relationships between the various measurements used to determine oxidizable matter present in sewage effluent, lowland rivers, and raw water for supply. In general, the results indicate little correlation between the various determinations but the analysis of the raw water supplies suggests that, although the Permanganate Value (PV) would indicate it to be much lower than found in the nearby lowland river, there is still an appreciable residue of organic matter present that is resistant to oxidation.

AQUATIC HERBICIDES

The problem of dissolved oxygen in a river system has been with us for many years. There are, however, many other factors to be taken into account in controlling impurities entering surface water. One field in which there has been rapid development and where

TABLE II. AQUATIC HERBICIDES

Name	Period of use	Use	Chemical name	Comments
2·4 D. amine	May–September. More effective if used earlier rather than later	Control of broad-leaved emergent plants	2,4-dichloro-phenoxyacetic acid	Can cause tainting of water used for supply
Dalapon	Summer	Control of reeds and other grass—like emergent plants	2,2-dichloropro-pionic acid	Slow die-back of reeds. Only limited amount of deoxygenation
Chlorthiamid	Early spring	Control of submerged weeds	2,6-dichlorothio-benzamide	Thought to be converted to dichlo-benil after application and has a similar activity to that chemical
Maleic hydrazide	Spring	Control of grass on river banks	Maleic hydrazide	Not effective against broad-leaved plants. Action against reeds and other emergent plants not known
Diquat	May–June	Submerged and floating leaved weeds	1,1′-ethylene-2,2′ bipyridylium-cation	Very rapid destruction of weeds and thus there could be a heavy oxygen demand
Dichlobenil	Late spring	Submerged weeds	2,6-dichloro-benzonitrile	Should be used before weed growth becomes dense to avoid deoxygenation
Chlorpropham			iso propyl *N*-(3-chlorophenyl) carbamate	This was given temporary clearance in 1971. The manu-facturer did not pursue this use and the clearance has now lapsed
Paraquat/dalapon mixture	Summer	Use paraquat only in mixture with dalapon. Control of reeds and other grass-like emergent plants	1,1′-dimethyl-4,4′ bipyridylimion	Addition of paraquat improves the effective-ness of dalapon. Slow decay of plants, limited amount of deoxygenation if spraying is confined to emergent plants
Terbutryne	May–June	Control of filamentous algae also submerged and floating-leaved plants	2-*tert*-butylamino-4-ethylamino-6-methylthio-1,3,5-triazine	Inhibits photosyn-thesis and has a rapid and severe effect on dissolved oxygen levels

further work will undoubtedly follow is the dosing of water with aquatic herbicides, because this can show major economic advantages over the old time method of the land-cutting of water weed. The Ministry of Agriculture, Fisheries and Food have an approvals scheme for the use of such herbicides, but it must not be thought that this does away with the need to consider each application. Table II shows aquatic herbicides that may now be used.

At present there is much doubt as to the wisdom of using weedkillers upstream of water intakes, because insufficient is known about the effect these trace chemicals would have if present in water supply. The usual practice is to ban their use in such waters, although the increasing attractiveness of chemical control of aquatic weeds is certain to increase the pressure upon authorities to allow their use. Consequently, more information on the medical aspects of this problem is required.

INDUSTRIAL EFFLUENTS

Although the reduction of oxygen in rivers resulting from the presence of sewage effluent and other organic wastes is probably the widest ranging problem in the control of river water quality, particularly difficult problems are experienced due to the presence of non-biodegradable substances in industrial wastes. This is the area in which a problem can develop over a short period, because of a newly introduced industrial process. Such processes are rarely publicized and more frequently care is taken to keep them secret. No planning or other permission is necessary for an apparently innocuous industry to introduce a new process incorporating a highly dangerous chemical. The industry, in attempting to keep the process secret, is unlikely to consult the water authority about the effect of this new chemical when it reaches a river. This will become an even stronger case for non-declaration when under the Control of Pollution Act all information about industrial discharges is available to public scrutiny.

An example of the difficulty of tracing the chemicals present in trade effluent is given by the serious problem which arose at the Rye Meads sewage works of Harlow Development Corporation in the 1960s when there was a loss of nitrification in the activated sludge process leading to high ammonia concentration in the effluent and unsettleable sludge in the final tanks. The effluent, which formed a large part of the river Lee a few miles upstream of an important abstraction point of the Metropolitan Water Board, deteriorated considerably and the water intake was saved only because of the holding capacity of large lagoons on the sewage works site. It is understood that this upset to the purification of sewage was caused by the presence of about 1 mg/l of a chemical originating from the research laboratories of a major chemical firm. However, the secrecy associated with the process was such as to hinder the discovery of the problem chemical and it was only after a six months investigation by the Water Pollution Research Laboratory that the trouble was solved. The Lee Conservancy Catchment Board, who were the authority responsible for managing the quality of the river, had a major interest in this matter, but because of the secrecy that was insisted upon, could never be told officially of the cause of the pollution.

The reorganization of the water industry will enable the management of river quality to be more closely associated with what is happening to industrial wastes entering sewers, but there will still be the difficulty of finding information about chemicals used in new industrial processes. It is only too easy for industry to introduce new processes that can lead to such a water pollution problem.

The condition of the West Riding rivers as a result of pollution caused by the wool industry is well documented and one would imagine that the effluents from such industries would gradually be improved and the pollution solved. However, this is not the case because the foaming present below weirs on the rivers Aire and Calder has shown little reduction and may in fact be increasing. Recorded evidence is too imprecise to come to any firm conclusion on this. The information published by the Department of the Environment[14] indicates that the presence of non-biodegradable detergents has not decreased and the presence of poly-glycols has increased over recent years. This is because the voluntary agreement between the Department of the Environment and the detergent manufacturing industry to use biodegradable detergents after 1965, only applied to the domestic use of detergents and there was strong pressure not to extend this control to the industrial use of detergents. The woollen industry was concerned that their wastes were causing foaming problems in the Yorkshire rivers, but there were difficulties in changing over to non-polluting processes for the following reasons:—

(i) The industry producing detergents sold them as part of a mixture. Frequently, information as to the type of detergent and its biodegradability was not available to the user.
(ii) It was claimed that biodegradable detergents were not as efficient in their use as non-biodegradable. It was, however, difficult to obtain any evidence to support this.
(iii) It was said that biodegradable detergents were more expensive than non-biodegradable types, although in a survey undertaken in 1973 it seemed that any difference in costs was marginal.
(iv) The effluent containing biodegradable detergent has a higher BOD than that with a non-biodegradable detergent. Thus, any charges for treatment of effluent containing biodegradable detergent are greater.

The direct control over the quality of these effluents using consent conditions is extremely difficult (although not impossible) when considering the presence of these variable trace contaminants which may be of no simple chemical composition. By developing a joint working party between the wool industry and the Yorkshire River Authority, progress was being achieved in changing the type of detergent being used.

Another problem caused by the wool industry which grew over recent years resulted from the change in the use of natural oils to lubricate wool fibres to the use of polyglycols for the same purpose. The natural oils which had always been used in the past became difficult to obtain, and as a replacement it was found that certain polyglycols were satisfactory and even an improvement. At various stages in the processing of wool, the wool requires to be washed and any additives, including polyglycols, are then removed with the trade effluent. At first sight the amount discharged seems to be comparatively small but as this new chemical was introduced at probably over 100 premises on the same river, the effect was quite marked. It appears to have a synergistic effect with detergents in producing foam, and gives the foam increased stability. Because the natural oils were now not obtainable, this had introduced almost surreptitiously a river pollution problem which by the time it was recognized could not be quickly solved without causing serious industrial repercussions.

The problem of the introduction of new chemicals into the environment is one which requires more serious consideration than it has so far received. Already there is the realization of the need for control over the introduction of new pesticides. The interdepartmental Advisory Committee on Pesticides and Other Toxic Chemicals scrutinises new pesticides submitted by industry.

There is the Department of the Environment Committee on "New chemicals and materials of construction for use in public supply and swimming pools" which examines thoroughly such chemicals before approving their use. So far there is no comparable approval scheme for the introduction of new chemicals in general, and yet some of these could have a far more hazardous effect if they entered water supplies. Any such approval scheme would need to consider problems such as:—

(1) The need for introducing the chemical.
(2) Properties of the chemical and any side effects, including environmental effects.
(3) What happens to the chemical after use, and its effect of any decomposition products.
(4) Waste materials produced during the manufacture of the chemical.
(5) Methods for detection at a concentration below that which it becomes an environmental hazard.
(6) Keeping records of where hazardous chemicals are used and the quantities stored.
(7) Defining the conditions under which the chemical could be used.

There has been adequate evidence from problems that have developed over the past 20 years to justify a scheme whereby new chemicals being introduced into industry are required to be examined and to obtain the approval of an appropriate body. Such approval should be subject to conditions which, while not preventing the introduction of new chemicals, would ensure that their use did not introduce a new hazard into the environment.

Because of the serious repercussions that are possible if certain chemicals gain entry to water sources, the water industry should be represented on any group which vets the introduction of new chemicals.

An alternative to controlling the quality of discharges in order to prevent contamination of water supplies is to consider whether, if the effect will only affect the wholesomeness of the supply water, it would be more reasonable to remove the contaminating material after abstraction. An advantage of the reorganization of the water industry is that no longer is it necessary to consider effluent quality in isolation. If the removal of a trace contaminant can be more economically and effectively undertaken after abstraction, this is an alternative that can now be implemented. Possibly the removal of nitrate from water sources where this is caused by the drainage of farmland, is an example of this, as there is no indication that nitrate in the drainage can be controlled without harmful effects on agriculture, whereas methods for removal of nitrate from water after abstraction appear to be practical alternatives that are now under development.

CONCLUSIONS

The paper, in examining the control of effluents, has attempted to assess the problem in a much wider ambit than the determination of effluent standards. The reorganization of the water industry has introduced a new dimension into water quality control which allows the water manager to consider all aspects of the use of water before deciding where and to what degree controls are required. This aspect of water management is one which will repay detailed study over future years.

The following conclusions are reached:

(*a*) There is evidence that there is a need to re-examine developments that were underway in the treatment of effluents, particularly in view of the increasing cost of energy and the existing economic situation.

(*b*) It is suggested that in the treatment of sewage, appreciable economies are possible if processes are organized so that the flows being treated are balanced and the treatment processes are fully used instead of being subject to a large diurnal variation.

(*c*) The logic of applying effluent standards requires examination, and this must take into account the developing problems caused by non-biodegradable residue.

(*d*) There is need for a more rapid introduction of scientific means for deciding upon effluent standards in place of the intelligent guess.

(*e*) There have been numerous instances where the introduction of new chemicals in manufacturing processes had led to serious water pollution problems. If the maximum use is to be made of water resources and supply water is to remain safe, new chemicals being introduced by industry should be thoroughly screened before approval is given for their use.

The paper does not pretend to cover the whole field of effluent control, but has dealt with particular aspects which the water authorities should consider of particular importance under present-day conditions.

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DISCUSSION

Author's Introduction

Mr. R. G. Toms, in introducing the paper, said that the complex problems which we faced were mainly due to pollutants entering water resources from discrete discharges or were indirectly due to leaching of polluting materials on or in the ground. Consequently, the method of controlling effluent quality, and this included all effluents whether direct or indirect, was of prime importance in ensuring that the quality of water resources remained satisfactory and that water supplies remained wholesome.

It was certain that as time went by the *volume* of effluents entering watercourses would *increase* and their *composition* would become more complex—whether it be sewage effluent or trade waste. Existing legislation was only effective in stopping sudden marked changes in water quality, and in practice could not prevent gradual long-term changes. The simple question was—could the rivers and water supplies cope with such increases in effluent? Looking ahead many years and seeing the projected growth in the proportion of effluent in a number of rivers, the figures were frightening and lack of knowledge about the actual materials entering watercourses in effluents made one query whether we were really in a position to undertake proper water quality management or whether we should work merely from one crisis to another.

The legislation to prevent pollution did little to help in solving long-term problems, as it was aimed much more at day-to-day control of effluents. There was a danger of gradually being forced into the position where the proportion of effluent and the limitations to achievable quality after treatment led to a resource becoming unusable. This was not the best way to manage resources, and the Control of Pollution Act 1974 would do little to help in this respect.

Examples of the problems that had already been experienced included the introduction of detergents—which caused serious problems for ten years before it was controlled—but not the industrial use. The introduction of synthetic pesticides and herbicides which had caused many major problems but because of their nature these had rarely hit the headlines. Nevertheless, some had been extremely serious. For example, the elimination of fish over 15 miles of the river Lee in the 1960s; the tomato problem in Essex in the early 1970s when cross-county transmission of water also took with it a herbicide that was highly toxic to plants; and the introduction and widespread use of polyglycols in the Yorkshire woollen industry over the past ten years. The removal of this pollutant, once it became a problem, could virtually close down the industry.

How could we cope with this growing problem? At present, thinking was too localized and was incapable of dealing with the problems that were coming.

It had been suggested over the years by a number of eminent people in the industry that water for drinking purposes should be completely uncontaminated, collected from river uplands with poorer quality lowland water being used for industry and other uses in the home. There was a great deal of sense in this, but it would be expensive and lowland rivers would still be at risk.

The legislation in the United States, although its existing wording was impractical, did realize this problem by laying down the elimination of pollutants entering navigable water by 1985. Obviously, they would not be able to go as far as they wished but the basis for total control was there. British legislation did allow the limitation of pollutants entering rivers, but the practicalities of controlling pollutants had restricted these to a few well worn limitations and hence the frequency of BOD, SS, and occasionally ammonia in consent conditions. These were useful and necessary, but they could not go far enough.

The only long-term hope would appear to be in Section 46 of the Control of Pollution Act 1974, which enabled action to be taken to prevent a change to flora and fauna in a watercourse. However, the controls available in other parts of this Act to limit effluents were completely insufficient to attain this goal.

What then was necessary to safeguard future supplies? Ignoring Section 2 of the Control of Pollution Act 1974 (if this was possible), it was an Act which filled in some of the gaps left by previous legislation such as controlling sea discharges and giving information on effluent quality. However, it did not start to provide controls for the highly complex types of pollution, including non-biodegradeable organic matter, that was becoming more our concern. In fact, it went against this in almost taking away any control of water deterioration caused by farming practice—an area where water pollution was becoming particularly important. Now we had a delay of a number of years before this section of the Act became operative: it could provide the opportunity to recommend a complete review.

He had not mentioned the EEC conditions for water quality and presumably in the future for effluents, as these were political expediencies and appeared to have little technical relevance. They were likely to control life more and more in the future and allow less and less commonsense to be used in solving problems.

If one looked at controlling water pollution, we had to go beyond the use of consent conditions because many of the constituents of effluents were unknown and thus could not be controlled. Materials used by industry were continually changing, but rarely did industry come back for a new consent on this ground. The answer would seem to be in the control over the storage, manufacture, and use of the potentially polluting chemicals. The chemical industry was growing and its products tended to become ever more complex and more effective in their uses. Consequently, new chemicals might have serious effects on water at lower and lower concentrations—often at concentrations which could not be detected by available methods, when the chemicals were first introduced.

In order to have maximum advantages over competitors, industrialists would keep new chemicals secret as long as possible. They might be sold as formulations under trade names that gave no indication of the ingredients. While this might be of commercial advantage to the industry, it made the control of evironmental pollution extremely difficult and he asked whether, with such a system of secrecy, the disadvantages to society outweighed the advantages to industry.

A simple example of this problem was mercury which, although not new, was still subject to industrial secrecy in its uses. Did anybody know the total quantities used in various river basins, what losses there were to the environment, and how these losses were changing? The limitations to the sampling and analysis of some of these materials leaving works as effluent, made it almost impossible to use existing controls as a method of determining how much of these chemicals was entering the environment. It seemed that the only way of assessing what was happening to certain dangerous chemicals was to monitor them throughout their production, storage, and use. This could be done quite safely without industry losing any commercial advantages.

The design of industrial premises on which certain chemicals were used should be such that the chemicals could not escape. So many problems resulted from the use of unsatisfactory premises and equipment. Rarely did the problem of spillages and chemical leakages assume prominence in the design of factory premises. As a result, a spillage would either soak into the ground or escape via a surface water drain. The ground became saturated with dangerous chemicals and any heavy rain washed the chemicals out of the soil. The pollution watch-dog ought to have a much greater say in the design and safeguards at factory premises where chemicals were used, stored, and formulated. Alternatively, laid-down standards of construction for premises should be required, as in the case of the storage of inflammable materials.

VERBAL DISCUSSION

Dr. G. Mance (Water Research Centre, Stevenage Laboratory), in opening the discussion, said that he found the pessimistic tone in the author's introduction somewhat daunting.

He was pleased to hear the emphasis on the complexity and extreme variability of the composition of effluents referred to in the introduction, as this was barely mentioned in the paper. He asked the author to comment on the significance of this on the use of biological treatment processes. He would also be interested in the author's views on the possible rôle of biological tests in assessing the quality of effluents, as these would seem to offer a broad spectrum monitor for acute levels of many (but unfortunately not all) toxic substances.

The author suggested that treatment of complex effluents might be postponed to the post abstraction phase. Did he not feel that this was only postponing the problem, although it might reduce the number of substances involved?

Effluent variability was of interest when sampling programmes and standards were considered. The author had mentioned diurnal variations but he would be interested in his comments on seasonal variations and their relevance to water quality standards. Perhaps we should consider using percentile distributions in setting water and effluent quality standards.

Early in the paper the author suggested that the rate of improvement in river quality since 1950 had not been satisfactory and implied that there might at present be a deterioration in quality. Was this something that had yet to appear as fishless rivers, as there was considerable evidence of a decrease in the length of fishless rivers in the last two decades?

The work on the modelling of river quality, started at the WPRL, was being continued at the Stevenage Laboratory of the WRC.

Mr. D. D. Young (Severn-Trent Water Authority) said that in considering the rationale of determination of consent conditions, the author gave three steps, to which he suggested might be added the evaluation of the cost of achieving the stated conditions and of the benefit thereof. This might then be related to the objectives defined in the first stage which might lead to a review of these objectives and going round the cycle again.

He had always been concerned about the fact that standards were set in absolute terms, whereas river water and effluent quality were highly variable. Much had been published on the statistics of water and effluent quality by WRC in their former twin incarnations, without making the impact upon the industry which this work would justify. River authorities always used their discretion in dealing with infrequent infringements of consent but, with the opening up of the right of prosecution to any individual under the Control of Pollution Act, this would no longer do. Studies within Severn Trent had suggested that the statement of consent conditions in statistical terms could be greatly simplified and he asked whether the author believed that there was any advantage to be gained in this approach.

The present paper and others referred to the question of residual organics in treated waters derived from lowland sources and hair raising comments had been made about the carcinogenicity, mutagenicity, and teratogenicity of such substances together with the suggestion that there might be straightforward chronic sub acute toxic effects. A case in point was the frightening things which had been said about polynuclear aromatic hydrocarbons (PAH). However, a survey in Severn Trent had shown them to be well below WHO recommended levels in all of the river waters examined, except for two non-water-supply streams a short distance below sites where coal was carbonized for steel making. In even these two cases, the PAH was removed by simple filtration of the sample, indicating that it would also be removed in conventional water treatment. This experience suggested that, while we should not take the issue lightly, we were in danger of completely losing a sense of perspective over a problem which might either not exist, or might be easily controlled. Would the author agree?

Mr. L. R. Bays (Bristol Waterworks Company) said that in his introduction the author had referred to the fact that contaminants would best be removed after abstraction rather than from effluents. He queried the logic of this, as it must be more economical to remove material from a small quantity of effluent, even if that contaminor was at a high concentration, rather than remove low concentrations from much larger volumes of water. Water authorities might have to introduce treatment processes which would otherwise not be required, with resultant high capital and running costs.

Mr. D. A. Burt (D.A. Burt Associates, consulting engineers) said that he was in close contact with industry, especially in regard to effluent problems.

For many reasons it would be impossible, both practically and economically, to enforce the Control of Pollution Act 1974. In many instances management did not know which contaminants existed in its effluents. With the rapid change in industrial processes, the contaminants frequently altered. The chemical makeup of these effluents was becoming increasingly more complex, which rendered them practically impossible to analyse.

Certain factories were bound by the Official Secrets Acts. Their management neither could nor ever would divulge the contents of their effluents to persons unauthorized to receive such information.

It frequently cost ten times as much to reduce an oil content in an aqueous solution from 10 to 5 ppm as it did from 15 to 10 ppm. We were expecting industry to dig deeper into its already empty pocket. Most industries had a cash flow problem in the present economic crisis, and could not *afford* to have a conscience about their effluent. It was appreciated that legislation was required to force management to accept a certain amount of responsibility, but was it not better to agree a compromise solution with each individual factory? There was much to be said for the old system.

If the new water authorities unified discharge limits, as recently suggested, he foresaw untold difficulties. For example, these limits would be interpreted as authorization to discharge up to those limits. On the other hand, if existing limits were drastically reduced, it was possible that well-established industries would be forced to close. If new standards were to be set, they must be subject to constant review.

Author's Reply to Discussion

Mr. R. G. Toms, in reply to the discussion contribution from Dr. Mance, wrote that naturally a variable quality waste would be more difficult to treat at a sewage works than one of a constant quality, just as a variable quality river water would be more difficult to deal with at a water treatment plant. Such a variability due to uncontrolled or unexpected discharge of toxic materials from trade premises could render a sewage works inoperative within a short time and so seriously affect the river at the abstraction point. Rye Meads sewage works, in Hertfordshire, which experienced problems of this type, had about 60 acres of lagoons. These were invaluable in preventing unpurified sewage effluent affecting the river Lee during periods when industrial wastes interferred with biological purification.

The most important move forward in water quality monitoring would be in the development of biological tests which could measure the presence of acute or chronic toxicities of pollutants. The development of such tests and their use in effluent control seemed to be the only realistic way of controlling the quality of trade wastes from works putting out highly complex chemical wastes.

Undoubtedly, the main control on effluent quality must be at the discharge stage, but there were certain parameters that could be tolerated at levels in a river without causing noticeable water quality deterioration but which could interfere with water quality if the river was used for supply. If it was cheaper to remove these after abstraction than before discharge, what argument could there be for reversing this procedure?

Seasonal variations in effluent quality had been applied to a few effluents as it seemed reasonable that when the river could take an increased amount of a waste, that it was wrong to spend money unnecessarily on purification. While he understood Dr. Mance's comments regarding percentile distributions in setting standards, and indeed these were being used in considering important discharges, he would not like to see the statistical approach being introduced in deciding on action following sample analysis. This would probably result in the courts being flooded with prosecutions for pollution, whereas it was much better for the major portion of effluent violations to be dealt with by discussion and advice.

The improvement in rivers had been at a rate of about a 10 per cent removal of polluted rivers per year. However, since the economic climate changed about 18 months ago, the rate of extension to sewage works had been materially reduced, and we were in a position where development of houses was going ahead at a faster rate than the provision of sewage works to treat the waste. Unless the standards of sewage works operation following reorganization could be materially improved, this must over the next few years result in a reduction of effluent quality and consequently of river quality. The signs of this were already beginning to show on some rivers.

He agreed with Mr. Young that theoretically a fourth stage of cost benefit was required in consent evaluation and whereas he had no doubt economists would introduce it, he had grave doubts as to how one was able to put unbiased figures to it when such unquantifiable assets as recreation and amenity were involved. His comments with regard to the statistical approach concerning the application of consents would lead to more difficulties over prosecution and not less. The answer was not to lay down when the public could prosecute water authorities but to put the powers of prosecution into the hands of a responsible body.

Severn Trent were to be congratulated on the work they had done in looking at PAH values and he fully agreed that this problem should not get out of proportion. However, it would be even worse to ignore such matters and assume there was no problem.

In answer to Mr. Bays, in many cases his argument was correct whereas in others it might not be. Thus, the problem of nitrates present in agricultural drainage could only reasonably be removed by the water abstractor. This already applied in regard to bacteria as no effort was applied to remove these at the point of discharge, it being more efficiently done after abstraction.

While he did not disagree with Mr. Burt in his suggestions that the Control of Pollution Act would be impossible to enforce under present-day conditions, the point he made about the problems industry faced in knowing what was present in its effluents was only marginally altered from the requirements of existing legislation. Consequently, any industrial discharger required consent for his discharge and he was required to state the composition of the effluent. There was no exception to this made for Official Secrets and in any case the water authority was not yet allowed to divulge this information.

Water authorities were required to be reasonable in applying consent conditions to discharges and normally these conditions were applied individually to each discharge. However, there was the growing danger that EEC directives might in the future standardize discharge limits. Although industry might not afford to have a conscience about their effluent, they had to abide by the law of this country which required their compliance with consent conditions for effluents.

5. RAW WATER QUALITY CRITERIA

By A. H. Goodman, BSC, ARIC*

CONTENTS

INTRODUCTION

It is difficult to consider criteria for raw water without taking into account the wholesomeness of the water which will be produced from it and passed into supply. There are certain elements or compounds in raw water which are not removed by the normal processes of water treatment and which must therefore be considered carefully when formulating raw water criteria. These include sodium, magnesium, nitrate, sulphate, and chloride.

The quality of the raw water must dictate to a large extent the treatment which it is to receive. In the U.K. there have been no formal guidelines to assist in deciding what forms of treatment the water should receive and it has been left to consultants and others experienced in such matters to make the decision. Perhaps in the U.K. we have been fortunate in that we have considerable experience and knowledge of such matters but in the wider European context this may not be true and the European Economic Community through its Commission in Brussels set up a Committee to discuss the requirements for surface water to be made into drinking water. There were many meetings of technical experts and a basic form was produced which defined waters which (1) required little treatment other than disinfection; (2) required simple treatment such as coagulation and simple filtration and disinfection; and (3) required more comprehensive treatment if they had to be used at all. This paper attempts to discuss the relevance of some of the parameters adopted.

SOURCES

In attempting to consider raw water quality criteria one has to decide at what point they should be applied. For example, much surface water is abstracted and put into storage reservoirs and the quality may change materially during such storage so that a decision has to be made whether to consider the criteria applicable to the water abstracted directly from the river or to the water which is withdrawn after a period of storage. In their discussions with representatives of the water industry, the Department came to the conclusion that raw water criteria in the context of the European Directive ought to apply to water taken from storage, if storage was provided. Decisions over the quality of the water being abstracted from a river and put into storage would rest with the body responsible for managing the reservoir.

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PREVIOUS QUALITY CRITERIA

Although the U.K. has had no formal quality criteria for water there have been criteria which have been referred to often. Many years ago the U.S. Department of the Interior, Federal Water Pollution Control Administration, published an original list of standards[1] which has since been revised and expanded several times. The World Health Organization (W.H.O.) published editions of International Standards which have much in common with the U.S. figures. The W.H.O. published also an edition of European Standards which was rather more stringent in some respects than the International Standards, presumably since it would be possible to treat water to a higher standard in European countries[2]. Most water chemists have taken regard to the standards laid down in W.H.O. European Standards, although a point often missed is that in the introduction to this publication it is stated that they are not standards but are issued for guidance only. Some of the elements or compounds given limits, e.g. selenium, in the European Standards of W.H.O. do not appear to have great significance in the U.K. context.

In the U.K. the Steering Committee on Water Quality set up by the Department of the Environment considered water quality criteria. No firm conclusions were reached because of the difficulty in deciding upon suitable values for those elements and compounds present in many waters since toxicological or medical evidence about their significances was scant or lacking altogether. A complication in deciding levels of concentration for individual elements is the unknown antagonistic or synergistic effects of other elements and because some may be absorbed by the human body and accumulated in preference to others. For example, zinc is believed to be taken up by the body preferentially to cadmium, and the zinc uptake may be influenced by the hardness of the water. There does not appear as yet any resolution of this difficulty over the body's reaction to different elements. (This difficulty is apparently confronting the committee trying to decide upon criteria for drinking water, the subject of another EEC directive being prepared by the Commission of the European Communities in Luxembourg.)

In the U.K. it was thought that further information was required before water quality criteria could be laid down as it was thought better to delay production of criteria rather than to produce something which would need to be revised at intervals as more information became available.[3] Perhaps the urgency was not apparent in the U.K. whereas in some parts of Europe there was need for criteria to be presented immediately, and they were considered by the Commission of the European Communities[4] (EEC).

It is probably accepted generally that no surface water can be considered fit to drink unless it has been disinfected. Even water from unpolluted upland streams can contain some pathogenic bacteria, introduced by birds. However, there are sources of water sufficiently free from contamination to need disinfection only before potable use, but most surface water sources need more treatment than disinfection, and raw water quality criteria were devised to differentiate between such sources. The extent to which contaminants are removed by coagulation and filtration must be taken into account.

The EEC criteria were constructed around the effect on water of normal treatment, e.g. prechlorination, coagulation, flocculation, filtration, and final chlorination. Water which would be suitable for that form of treatment was placed in Category A2. Water of a quality better than that would require simple rapid filtration and disinfection; such a water would be Category A1. (Rapid filtration in this context is straining through a sand filter and is not slow sand filtration as we know it.) Waters of quality worse than A2, requiring a more comprehensive treatment, were placed in Category A3 and these would require intensive physical and chemical treatment e.g., chlorination to breakpoint, coagulation, flocculation, settlement, filtration, activated carbon treatment, and disinfection possibly with ozone or chlorine dioxide or chlorine. There was provision also for a worse water, Category A4, which would require some form of biological treatment to remove ammonia, or subjected to desalination, or some other advanced treatment in order to make it suitable for potable supply purposes.

In order to be aware of any difficulties which might be brought about if the directive in its original form was implemented, advice was sought by the Department of the Environment from the water industry through a special meeting of the Steering Committee on Water Quality which, for that meeting, was supplemented by water chemists invited from undertakers over the whole of the U.K. A table of the U.K. suggestions was prepared. Table I, p. 42, shows the values associated with the E.E.C. proposal and Table II, p. 43, those values agreed generally by the U.K. meeting. It can be seen that some parameters have values given under columns G and I—G indicates the guide value, i.e., the recommended value which should not be exceeded if possible, but the value associated with I is to be exceeded in no case, so that the I values are imperative and obligatory.

In the U.K. proposed values are suffixed R, O, or I—R refers to recommended values, O the normally advisable value, and I relates to those elements which are considered harmful to public health. The I values are therefore imperative values. It was not possible to convince the Commission that the U.K. proposals were better than the E.E.C. values and it is likely that the final form of the directive will be similar to the E.E.C. proposals in Table I. However, because of difficulties associated with geographical or other special conditions it is possible to seek derogations when it would be possible to continue to use water with qualities not conforming to the directive in particular respects, as long as notice of the fact is reported to the Commission with reasons why the source has to be used and where no alternative is available. In addition, the date when the directive might become binding upon member states will be some years hence, so that if emedial works need to be undertaken in order to comply with the terms of the directive, adequate time will be available.

The Commission recognized that waters of lower category than A3 were being used satisfactorily, and although the Commission's intention was that no water of worse quality than A3 should be used for potable supply puposes, it accepted that if no alternative source was available the waters could be used, provided that suitable treatment was applied. Thus use of advanced water treatment processes would not be prejudiced because of the directive.

CONSIDERATION OF INDIVIDUAL PARAMETERS

One disadvantage often quoted when standards are discussed is the possibility that quality will be allowed to deteriorate until the maximum values in the standards are reached. This is not likely to be a serious threat to water quality, because quality depends on many characteristics not necessarily associated with each other, and it would be extremely unlikely for most of these parameters to approach the maxima coincidentally. It is more likely that few would do so, and the experience and training of the water chemist enables him to assess the effect of these on the overall quality. For such a reason derogations had to be permitted in the directive.

One of the parameters in the directive which is likely to require more applications for derogation than any other is *p*H. In the European context, a low *p*H water must be one which is receiving an industrial waste and it is not thought that any water with a *p*H lower than 5·5 would be suitable for water supply purposes. In the U.K. waters down to *p*H 2·9 are known and used quite satisfactorily, so this is obviously an area where many undertakers cannot comply with the terms of the directive. There would not appear to be great difficulty in this, since it is easy to prove that our low *p*H waters are due to natural phenomena.

TABLE I. E.E.C. PROPOSALS

	Parameters	Categories					
		A1 G	A1 I	A2 G	A2 I	A3 G	A3 I
1	*p*H	6·5–8·5		5·5–9·0		5·5–9·0	
2	Colouration	10	20	50	100	50	200
3	Total suspended solids	25	—	—	—	—	—
4	Temperature, °C	22	25	22	25	22	25
5	Conductivity	1000		1000		1000	
6	Resistivity (deleted)	—	—	—	—	—	—
7	Odour	3	—	10	—	20	—
8	Nitrates	25	50	25	50	50	100
9	Fluorides	0·7–1·0	1·5	0·7–1·7	—	0·7–1·7	—
10	Total extractable organic chlorine	0·05	—	0·1	—	0·2	—
11	Dissolved iron	0·1	0·3	1·0	2·0	1·0	—
12	Manganese	0·5	—	0·1	—	1·0	—
13	Copper	0·02	0·05	0·05	—	1·0	—
14	Zinc	0·5	3·0	1·0	5·0	1·0	5·0
15	Boron	0·1	—	1·0	—	1·0	—
16	Beryllium	—	—	—	—	—	—
17	Cobalt	—	—	—	—	—	—
18	Nickel	—	—	—	—	—	—
19	Vanadium	—	0·05	—	0·05	—	0·05
20	Arsenic	0·01	—	—	0·05	0·05	0·1
21	Cadmium	0·001	0·005	0·001	0·005	0·001	0·005
22	Total chromium	—	0·05	—	0·05	—	0·05
23	Lead	—	0·05	—	0·05	—	0·05
24	Selenium	—	0·01	—	0·01	—	0·01
25	Mercury	0·0005	0·001	0·0005	0·001	0·0005	0·001
26	Barium	—	0·1	—	1·0	—	1·0
27	Cyanide	0·05	—	0·05	—	—	0·05
28	Sulphates	150	250	150	250	150	250
29	Chlorides	200	—	200	—	200	—
30	Surfactants	0·2	—	0·2	—	0·5	
31	Phosphates	0·4	—	0·7	—	0·7	—
32	Phenols	—	0·001	0·001	0·005	0·01	0·1
33	Hydrocarbons	—	0·05	—	0·2	0·5	1
34	Polycyclic aromatic hydrocarbons (1)	—	0·0002	—	0·0002	—	0·001
35	Pesticides	—	0·001	—	0·0025	—	0·005
36	COD	—	—	—	—	30	—
37	Immediate oxygen (dissolved)	7·0	—	5·0	—	3·0	—
38	BOD	3·0	—	5·0	—	7·0	—
39	Nitrogen by Kjeldahl method	1·0	—	2·0	—	3·0	—
40	Ammonia	0·05	—	0·5	1·0	2·0	4·0
41	Substances extractable with chloroform	0·1	—	0·2	—	0·5	—
42	Total organic carbon	1·0	—	7·0	—	10·0	—
43	TOC	—	—	3·0	—	5·0	—
44	Total coliforms	50		5000		50000	
45	Faecal coliforms	20		2000		20000	
46	Faecal streptococci	20		1000		10000	
47	Salmonella	not present in 5000 ml		not present in 1000 ml			

TABLE II. U.K. PROPOSAL

Parameter	Quality A1	Quality A2	Quality A3	Quality A4
*p*H	6·5–8·5 (R) 4·0–9·2 (O)	4·0–9·2 (R)	4·0–9·2 (R)	4·0–9·2 (R)
Colour (mg/l Pt)	20 (R)	300 (O)	300 (O)	
Odour	Not objectionable (O)	Not objectionable (O)		
Taste	Not objectionable (O)	Not objectionable (O)		
Temperature, °C	22·5 (R) 25 (O)	22·5 (R) 25 (O)	22·5 (R) 25 (O)	
Total suspended solids (mg/l)				
Ammonia (mg/l NH_4^+)	0·5 (R) 1·0 (O)	0·5 (R) 1·0 (O)	0·5 (R) 1·0 (O)	
Fluorine (mg/l)	1·5 (O)	1·5 (O)	1·5 (O)	
Chlorides (mg/l)	200 (R) 600 (I)	200 (R) 600 (I)	200 (R) 600 (I)	
Phosphates (mg/l) (all types)	0·30 (R) 0·75 (O)	0·50 (R)		
Cyanide (mg/l)	0·05 (O)	0·05 (O)	0·05 (O)	
Detergents (mg/l)	0·2 (O)	0·2 (O)		
Iron (mg/l)	0·1 (R)			
Manganese (dissolved) (mg/l)	0·05 (R)			
Copper (mg/l)	0·05 (R)	0·25 (R)	0·25 (R)	
Zinc (mg/l)	5 (R)	10 (R)	15 (R)	
Cadmium (mg/l	0·005 (I)	0·005 (I)	0·005 (I)	
Chromium VI (mg/l)	0·025 (I)	0·025 (I)	0·05 (I)	
Lead (mg/l)	0·05 (I)	0·05 (O)	0·05 (O)	
Barium (mg/l)	1·0 (I)			
Selenium (mg/l)	0·01 (I)	0·01 (I)	0·01 (I)	
Mercury (mg/l)	not detectable	not detectable in final water (both I)		
Beryllium (mg/l)				
Cobalt (mg/l)				
Nickel (mg/l)				
Arsenic (mg/l)	0·05 (I)	0·05 (I)	0·05 (I)	

Similarly, the attitude towards the colour of water is different between Europe and the U.K. In Europe colour is thought of in terms of industrial waste again, whereas in the U.K. colour is almost always of natural origin. Although it has been considered in the U.K. that colour due to peat and other vegetable matter is not harmful, recent work by Borneff in Germany has shown that many of the carcinogenic poly-aromatic hydrocarbons are produced by the decomposition of vegetable matter and are not due entirely to industrial activity as was thought formerly. These compounds are discussed in another paper at this meeting.

The organic acids present in such natural colouring matter may have some influence on the corrosion of metal pipes, and might also interfere with the adjustment of *p*H in order to overcome such metal corrosion. Therefore, it is likely that in future the colouring matter of water will have to be considered more carefully than it has been in the past. However, it is agreed in both the U.K. and E.E.C. proposals that the colouring matter should be not greater than 20 mg/l on the platinum scale for waters receiving no chemical treatment. Waters containing colour in excess of 20 mg/l fall into Category A2 and will require chemical coagulation.

Regarding suspended solids content, there was little difference of opinion between the U.K. and Europe except over the composition of the solids, since some solids can be removed by settlement in storage or by simple filtration (as for waters in Category A1) while colloidal solids require coagulation to remove them. The term in the proposals for suspended solids content attempts to include what we have considered previously to be turbidity.

Temperature is included in the list of parameters and possibly few people realize how the temperature of water can affect its potability although it is well known that if water is warm, as can happen when potable water pipes are close to a source of heat, the water has a flat and earthy taste. Few of our water sources are subjected to high temperatures but in more sunny climates this is so, particularly in Southern Italy. Thus, is it is unlikely that the limit of temperature given in any directive is going to cause embarrassment to the water industry in the U.K. However, the point must be noted that at higher temperatures the water contains less dissolved oxygen, which may affect its acceptability and may also influence its corrosive action on metal pipes. Limits for the dissolved oxygen content of waters have been included in these proposals for the directive. It is likely that any water deficient in dissolved oxygen when abstracted from a river would receive some aeration during treatment but the dissolved oxygen content of the river water is an indication of the organic purity of the water and its bacterial content since both would deplete dissolved oxygen. Values of 7, 5 and 3 mg/l are suggested, not as is often used, percentage saturation values.

Odour alone is included in the E.E.C. table, whereas in the U.K. often taste and odour are considered separately. It is generally assumed that taste and odour should be "not objectionable", but attemps are being made to quantify this and the threshold odour number is useful in this respect. At present it is thought that insufficient evidence has been collected by the water industry to permit limits to be proposed and it is likely that the numbers associated with odour in the E.E.C. table will be removed from the final form. The determination of a threshold odour number is a useful test and it is likely to find more widespread use. It overcomes the definition of "not objectionable", which can vary from person to person.

A test apparently common on the Continent but which is not so well known in the U.K. is the total extractable organic chlorine. This may be of increasing importance, since interest has been focussed upon the production of chlorinated compounds by the action of chlorine on organic matter. It is often said that the production of these compounds is much more likely when sewage effluents or industrial effluents are chlorinated, because the concentrations of the reactants are greater. The U.K. has never favoured chlorination of sewage effluents, but one must not neglect the fact that contaminated river water is often given heavy doses of chlorine to prevent bacterial slimes and biological activity when that water is used for cooling purposes. It is unlikely that the concentrations of chlorinated compounds produced will cause any waters to be considered unsuitable for abstraction in the U.K. Nevertheless, again it may well be that more attention ought to be paid to this parameter than has been given formerly.

Most of the metals in raw waters can be removed almost completely during treatment, but they have to be limited strictly for waters which receive simple filtration and chlorination (i.e. A1 category waters) and for borehole waters which provide about 30 per cent of our water supplies. Iron and manganese present no great difficulty since we have learned how to deal with them. Lead can be removed by filtration through a dolomite or some alkaline earth material filter which can be dissolved partially and impart sufficient alkalinity to the water in order to raise the pH and precipitate the lead. The same probably happens to copper and zinc under similar situations.

The levels for copper in most raw water criteria are likely to be to protect fish life in the river as much as to protect human health. Although it is always desirable to have fish life in a water supply river (their sudden demise being one indication of a polluting discharge to the river), it must be remembered that not all substances harmful to fish are a hazard to human health and vice versa.

However zinc is not considered particularly toxic and during coagulation zinc is often added to waters incidentally because it is an impurity in alum. The limit for cadmium and the limit for mercury are set extremely low because both these metals appear to have no use in the body's metabolism and are simply toxic, i.e. they can produce adverse reactions at almost all concentrations. Fortunately, they occur so rarely in water supplies which are not contaminated by industrial activity that we have not had to consider special treatments in order to eliminate them.

In the case of cadmium, the concentrate in surface water can probably be dealt with best by controlling discharges of industrial wastes to rivers. Cobalt and nickel are considered to have some effect upon enzyme reactions in the body, but they are essential in low concentrations only and become of interest as a toxic material when concentrations are relatively high, higher in fact than are likely to occur in the normal diet including intake of water.

Beryllium occurs so rarely that it is not likely to be a problem to us, and it most likely occurs in an insoluble form.

Vanadium occurs because it is produced by the combustion of many fossil fuels and the significance of its concentrations found in water have not been investigated sufficiently to be able to comment upon them. An interesting point which has come to light recently is that chromium is necessary for metabolism of sugars in the body and it is not entirely a material to be avoided as was thought formerly. The suggested limits for these metals ought not to cause any problems in the U.K.

Selenium is another element which is considered now to be essential in very small concentrations and although it has been a puzzle why it has been included in so many water quality criteria, it is thought that possibly in certain areas where selenium occurs in water naturally there is a danger of it producing an offensive odour to the breath and perspiration by the excretion of hydrogen selenide. No other medical significance appears to be known to explain the reason for the limit suggested in the W.H.O. Standards for Drinking Water. It has been suggested also that it is actually deficient in the diet in the U.K., and that it may assist the body to eliminate metals such as mercury contained in traces in foodstuffs.

Arsenic occurs widely but not usually in water at a concentration which is likely to cause difficulty. It was thought formerly that it was removed easily during water treatment but it is suspected now that if it is present in water it is not removed so completely and it is possible for a concentration approaching that of the limit to pass through water treatment processes. Although there are often reports of its toxicological action it is not believed to be such a serious toxic element in relation to public health as some others. Barium is probably in a similar category, and this has limited geographical distribution. If it should be present, its concentration will be reduced during coagulation with alum or by softening.

It is notable that in the proposals for a directive there is no mention of the hardness of raw water. As this is of particular interest in drinking water and has to be considered in relation to health, it is surprising that it has not been laid down as a parameter to be considered. There appears to be little doubt that there is an association between the incidence of cardio-vascular disease and the hardness of water in supply. The mechanism by which the hardness of water has an influence upon the incidence of cardio-vascular disease is not known, but there are thoughts that the concentration of calcium present prevents the adsorption in the body tissues of other toxic metals. In Germany there seems to be considerable opinion that hardness of water is essential to prevent corrosion of metal pipes which may bring into the drinking water levels of lead and cadmium near to the suggested toxic concentration. There are proposals in Germany for artifically hardening water to provide a minimum concentration of hardness[5]. As far as the author is aware this is about 50 mg/l and it does not appear to be sufficient to affect the relationship between the hardness of water and cardio-vascular disease since it is thought that the threshold for hardness to be of benefit is about 100 mg/l. Nevertheless, some content of hardness is important when attempts are made to stabilize the *p*H of a water entering supply by addition of alkali since 50 mg/l of calcium carbonate will provide a buffering action.

The ratio of calcium to magnesium has been investigated by many workers but there seems to be no conclusion to be drawn and limitation of the magnesium content is often dictated by the concentration of sulphate present since the combination of magnesium and sulphate can lead to an aperient action. Magnesium has some significance since it has been found that the heart muscle of persons dying from heart failure contains a lower concentration of magnesium than the heart muscle of healthy people who have been killed as a result of accidents[6].

The association between hardness of water and the incidence of ischaemic heart disease is confused, and at the present time it must be sufficient to say that, with respect to water quality criteria, waters should not be softened unless the total hardness is in excess of 300 mg/l as calcium carbonate, and the resultant softened water should contain not less than 120 mg/l as calcium carbonate. One point about this when it might be relevant to raw waters is that if one was in the fortunate position of having a choice between two sources which were equivalent except for hardness, one would choose the hard water on grounds of public health.

There remain the anions which are little changed by normal water treatments. Perhaps the most important of these is nitrate. This occurs in groundwaters in higher concentrations than it does in surface waters, although there have been instances of rivers which have contained nitrate in excess of the recommendation of the W.H.O. for several weeks during winter periods. The source of nitrate in groundwater is not the subject of this paper, but the nitrate does occur most often in groundwater associated with a high level of agricultural activity in the catchment, while the high nitrate content of most surface waters is associated more with the discharges of highly oxidized sewage effluents. The high levels of nitrate in groundwaters are not confined to the U.K., and they are found also on the Continent. The level of nitrate in rivers is more likely to be higher in the U.K. than on the Continent because the degree of treatment given to sewage is much higher (so that ammonia is oxidized to nitrate) in the U.K. than in most European countries.

Nitrate is not affected particularly by the normal methods of water treatment and in order to reduce the nitrate content in water an extra stage of treatment is required. The reason for concern about nitrate is well documented and it is associated with the incidence of the disease infantile methaemoglobinaemia. The disease is rare in the U.K., it having been said that less than 20 cases have been reported in the past 30 years. However, it is difficult to obtain true medical statistics since it is not a notifiable disease and it is likely that many incipient cases are not detected by doctors. However we would be unwise to neglect the risks associated with the high nitrate content in water and the levels proposed by the W.H.O. have been accepted both by the E.E.C. Commission and by those chemists of the water industry in the U.K. who have been consulted.

It seems possible that water sources will contain increasing concentrations of nitrate in future because it is related to the increase in mans' activities. Means of removing nitrate have been investigated by the Water Research Centre, for the Department of the Environment. It has been shown that for borehole waters ion-exchange methods can be used and for river waters it is possible to utilize biological activity to reduce the nitrate to nitrogen. Details of these methods have been given elsewhere[7].

Sulphate is not often a problem, except in waters derived from mines or from certain strata. The problem is that in conjunction with magnesium or sodium it can have an aperient action and for this reason the limit of 250 mg/l appears to be reasonable. In relating this to raw water one must allow for the fact that sulphate is added during most coagulation processes, e.g. from the aluminium sulphate or from the ferrous sulphate, so that due account must be made for this increase when the raw water analysis is being examined. In the making of concrete, sulphate has been suggested as being of importance in the water quality, and the same limit of 250 mg/l has been proposed.

The chloride content of water is becoming of more concern to medical advisers. If we assume that the water being supplied through the public supply system has to be suitable for all members of the community, high chloride may put some infants at risk. It has been suggested that since many infants are now fed on bottled feeds prepared with tap water, the high concentration of chloride in the water can have a deleterious effect upon their kidneys. There have been suggestions that the upper limit for chloride should be reduced to 150 mg/l but a compromise of 200 mg/l is more likely to be adopted.

The W.H.O. standards suggested a recommended value of 200 and a maximum acceptable concentration of 600 mg/l of chloride. Waters have been supplied with a chloride content even in excess of 600 mg/l and no reports have been received of harm to the general population. But dieticians are becoming concerned about the salt content of the western diet and there are indications that the sodium associated with the high chloride is of physiological significance also in hypertension. In addition, a high chloride content of water indicates that it is likely to be corrosive and it must be remembered that chloride was one parameter considered for the Turner diagram relating the tendency for a water to dezincify brass fittings to its composition[8]. It would seem wise therefore to accept that the chloride content should be less than 200 mg/l whenever possible in a raw water.

In most waters the bicarbonate content is related to the total hardness, but there are sources of water which contain sodium bicarbonate, i.e. when the total bicarbonte content is in excess of the calcium and magnesium content in stoicimetric terms. Any water containing excess carbon dioxide is likely to be aggressive towards metal fittings but it appears that in water where the bicarbonate is in excess of that expected to be associated with calcium and magnesium it is more aggressive towards copper piping and can produce serious attack upon it. This is not likely to happen if the water receives coagulation, since the addition of a coagulant will in most cases react with the sodium bicarbonate and eliminate it. But in the case of groundwaters or in those waters not receiving a coagulant dosage,the sodium bicarbonate content ought to be considered and should be preferably less than 10 mg/l as sodium bicarbonate.

Phosphates in water are of interest mainly because of their link with algal blooms when the water is stored in reservoirs. For soft waters it has been suggested that in order to control algal blooms the phosphate content should not exceed 0·05 mg/l as Phosphorus. Phosphates may be of importance when water is softened by the addition of lime, because of the production of calcium carbonate hexa-hydrate in the presence of phosphate. This form of calcium carbonate is difficult to remove[9]. The values for phosphate given in the E.E.C. Table are included for the control of algal blooms when water is taken into storage. So much emphasis is placed upon the use of the river Rhine in European discussions and water from the Rhine must be stored in reservoirs before it is treated for use that the fear of algal blooms dominates the thought of the effect of phosphate. In the U.K. waters containing over 4·0 mg/l of phosphate are taken into storage and are managed satisfactorily. There is no physiological reason for limiting the phosphate content of drinking water, and the U.K. guidance value may be higher than the E.E.C. suggests as a limit.

Surface-active agents need to be limited in raw water because with the turbulence which can occur over weirs the production of foam would be a nuisance. The limitation proposed for the content of anionic active material of 0·2 mg/l measured in terms of a standard reference material would seem to be reasonable. Surface-active agents are derived principally from sewage effluents and if much surface-active material is present, it is likely that ammonia will be present in the water also, usually in varying amounts since the discharge from a sewage treatment works is not consistent. The disadvantage associated with ammonia is that it interferes with the chlorination process of disinfection. Unless breakpoint chlorination is to be used, a limit of 0·05 mg/l of ammonia in water may be all that can be tolerated according to EEC limits, but if breakpoint chlorination is to be used it is suggested that a limit of 0·5 mg/l of ammonia could be accepted. In the U.K. it is thought 0·5 mg/l can be tolerated and under extreme conditions a limit of 1 mg/l can be successfully dealt with but there are risks then of chloramines being produced and the consumption of chlorine becomes excessive. Ammonia in itself cannot be considered toxic in any way to humans and its limitation is based entirely upon its interference with disinfection. It is likely that in the river it will be controlled through discharges because of its toxicity to fish, particularly when associated with some metal ions.

The presence of phenols in raw water is of course well known to give rise to objectionable tastes when water is chlorinated, but it must be remembered that phenols are produced not only by industrial processes but also phenoloid substances are produced by the natural breakdown of vegetable matter and these may produce similar unpleasant tastes. Suggested limits are those which will mean that the taste produced by chlorination will be just acceptable.

Because methods of chemical analysis have become more elegant in recent years, and it is possible now to detect and measure much lower concentrations of constituents of water then formerly, one tends to forget that early water quality criteria were based on bacteriological examinations and their results. In the U.K. we have insisted that the requirements in Report No. 71, the Bacteriological Examination of Water Supplies, published jointly by the Department of Health and Social Security, the Welsh Office, and the Ministry of Housing and Local Government (the last edition being in 1969) have been all that was required. The W.H.O. standards suggested a different procedure and the E.E.C. Commission has proposed standards for the bacterial content of A1, A2, and A3 waters. From the public health point of view these would appear to be unnecessary if sufficient disinfection is provided at all times. It is probably best to consider bacteriological examinations as indicators of changes in pollution trends of raw waters rather than to use figures of bacterial counts in an absolute way, and it is important that any values presented shall be considered as recommended values and taken in no way to be obligatory. Of all the parameters put forward in water quality criteria bacteriological parameters may vary the most, since when exposed in shallow films in bright sunlight even sewage effluents can have an almost nil bacteriological count while a pure unpolluted stream may contain coliform organisms and salmonellae due to the presence of ducks, gulls, or swans on the water.

There will be traces of pesticides and herbicides or their breakdown products in almost all waters draining from areas where agriculture, horticulture, or arboriculture are practiced. The concentrations will be extremely low, and it is probably only when it is known that their manufacture or compounding and packaging are carried out in a catchment that the risk of a significant concentration continuously of any one would occur in the water. Under such circumstances, monitoring the particular compounds expected would be sensible. The alternative suggested often is a test or tests likely to give indication of the presence of a mixture of such materials. These tests are not likely to be able to detect all traces, so that their value is doubtful. As with so many other chemical materials likely to be found in surface waters, the best means of overcoming occasional concentrations higher than average or, less commonly, higher than acceptable according to W.H.O. European standards for drinking water, is to provide bankside storage of abstracted river water to allow for dilution of the occasional or accidental discharge of chemicals to the river, before the water is used for potable purposes[10].

CONCLUSIONS

Water quality criteria must be related to the use for which the water is required and to the extent to which its constituents are affected by treatment given to the water before it is used for its intended purpose. The safeguards must be:—

(1) that whatever treatment is applied usually, it is not going to be saturated or overcome by a particular constituent of the raw water; or

(2) that there will not be a reaction during treatment which will produce a substance likely to give unpleasant or hazardous effects, which is not present in the raw water originally; and

(3) that those constituents not affected by the treatments applied are in concentrations below those which are believed to have significant effects on the health or well being of the consumers of the water.

In the case of waters recieving no treatment other than disinfection, the constituents of the water would be considered under safeguard (3), except for those substances reacting with the disinfecting agent, and these would have to be identified for safeguard (2).

The European Economic Community has sought through the Draft "Directive on Surface Waters intended to be made into Drinking Water" to propose limits for some constituents of raw water so that these safeguards may be met. However, it is ultimately the quality of the water produced after treatment which is important and then the requirement is for wholesomeness, a topic discussed by Price (p. 110).

Thus, raw water quality criteria must be reviewed carefully and interpreted in relation to the requirement of wholesomeness of the final water. These reviews and interpretations can be made only by those who have had experience in water quality control. Criteria should never be considered in any way as a check list against which analytical results can be compared.

ACKNOWLEDGMENTS

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DISCUSSION

AUTHOR'S INTRODUCTION

Mr. A. H. Goodman, in introducing the paper, said that as the U.K. was now a full member of the European Community it had to allow for a certain amount of give and take with its partners. Thus, there might be some parts of the directive on the quality of surface waters to be abstracted for treatment to make drinking water which the U.K. water industry considered unnecessary or in many cases quite irrelevant.

It had to be appreciated, however, that the U.K. was in a privileged position because the control over discharges to rivers was well defined and the quality of rivers was being maintained or improved. The standard of treatment of sewage works effluents in the U.K. was higher than almost anywhere in the world. Compared with this there were countries in the European Community which were in a very primitive state and where sewage was sometimes not treated before discharge and where it was treated the quality of the effluent was not good. In addition, in those primitive countries the treatment of water abstracted for drinking purposes was often minimal. Therefore, the criteria adopted in the directive had to be seen against this sort of background and there were countries where the criteria and the proposals attached for the levels of treatment required would be quite useful.

His latest information was that the surface water directive was lodged with the Council of Ministers, and it was expected that once details about the proper interpretation of the words in English and French translations had been resolved the Ministers would sign the directive in October 1975. After this signature there would be a two-year period during which each Member State would bring in relevant legislation to enable the terms of the directive to be complied with. Then a period of about eight years would be allowed for the respective water supply industries to take such steps as would be required to fulfil the terms of the directive.

It was not expected that there would be any great difficulty in promoting the suitable legislation or in complying with the terms of the directive. Although we could not expect to convert our A3 quality rivers into A2 grade rivers because it was likely that the proportion of sewage effluents in the rivers would increase rather than decrease, the quality of those effluents was of sufficiently high standard to allow those rivers to be continued to be used and it was not foreseen that there would be great difficulty in persuading the Commission that these rivers were suitable for water supply purposes because we were able to provide sufficiently comprehensive treatment.

Referring to the values in the directive, they were arrived at as a result of many meetings of technical persons with experience of water. The U.K. delegates had sought to make sure that the values presented would not create difficulties for the U.K. water industry. He did not think that those values which were listed as imperative could be a cause of argument by any associated with water supply. The guide values were provided for the water undertakers to take into consideration when proposing their own specifications which they would have to prepare under the terms of the directive. If there were sound reasons why values associated with certain parameters had to be well outside those guide values in the directive, there would be no objection to those being put into the specification, but once they had been, the water undertaker was expected to comply with its own specification. This would mean that for 90 per cent of the time the values would have to be within those in the specification but in cases of storm or flood, exception was allowed.

Referring to some of the parameters which might seem to be irrelevant, if somewhere someone published a report which said that a certain physiological effect was associated with the presence of a certain element or compound in water, it would be most unwise of the chemists in the water supply industry to neglect such a report. Only if it could be proved without doubt that this statement was wrong should it be ignored. Thus, certain parameters could appear in the criteria but it had to be appreciated that there would be a safety factor of at least 100, and more likely 1000, on the concentration which was likely to have an effect. What this meant to the water industry was simply that occasionally analyses should be carried out for that particular parameter and if in most cases it was found to be below the level of detection or at an exceedingly low level then duty had been done. If, however, it was found that there was an appreciable concentration then further epidemiological investigations would be required and suitable action undertaken to reduce the concentration of that particular material in the water supply. This was surely the responsibility of the officers of the water supply industry anyway. Complying with criteria laid down in such a directive was not reducing the responsibility of the scientists in the water supply industry in any way, since the water supplied to the public needed to be wholesome. This was not a vague idea but it was a description of an intrinsic value, such as that which made one article so much more valuable than another despite that they were the same size, weight, and shape. The difference between the two articles was often obvious but difficult to describe. The scientist would make sure that the water was of the best quality that could be obtained from the source in question.

Although his remit had been to discuss raw water quality criteria it could not be divorced from the considerations of the drinking water supplied to the public. The Commission for Europe had produced a draft directive on drinking water quality and he thought that it was likely that this directive might be subject to technical reappraisal after it had been submitted to the Council of Ministers and before our Minister appended his signature to it. It was hoped that this directive would not cause difficulties in the U.K. water supply industry and it was hoped that further consultations would take place with the water supply industry about its content.

Verbal Discussion

Dr. A. T. Palin (Newcastle and Gateshead Water Company), in opening the discussion, thanked the author for the guidance he had provided through the maze of raw water quality criteria. It was understood, and the author had so emphasized in presenting his paper, that where parameters were exceeded by "natural enrichment" the directive might be waived. If this were not so the values proposed by EEC, for instance in respect of colour, might cause embarrassment to many water undertakers in the U.K. who had for many years been successfully treating peaty moorland waters.

In the case of A2 and A3 waters the type of chemical added should presumably be taken into account in fixing mandatory limits for such things as iron, zinc, manganese, and sulphate. Taking sulphate, for example, would this mean that the imperative EEC limit of 250 mg/l was to be adjusted downwards to allow for expected sulphate addition during treatment?

He was grateful for the careful consideration given by the author to individual parameters, which was particularly helpful in understanding the reasoning behind the values selected. The question of fluoride appeared, however, to have been omitted from this survey and he invited the author to comment. It was assumed that the range of upper limits quoted was related to temperature. This normally meant air temperature, since clearly more water would be drunk in hot weather thus fluoride levels should be lower. From what he had seen of the EEC directive it was not made clear, so far as he could recall, whether the reference to temperature therein meant air or water. The higher limit of 1·0 mg/l F under A1-G in the EEC table was presumably to be related to low temperature. This seemed out of line with other official standards for drinking water itself where under the same conditions a figure of 1·7 mg/l was accepted.

The question of ammonia was a bit tricky. Here was a chemical which even in the highest amounts likely to be encountered was not harmful to consumers but a limit was considered necessary because it could interfere with chlorination by forming slow-acting chloramines. It should be noted that, for other reasons, there was some evidence, especially in the U.S.A., of a swing back to chloramination for water sterilization. While the faster-acting free chlorine was preferred from a bactericidal and virological standpoint it was still possible, given time, that adequate levels of chloramine would prove satisfactory. APHA Drinking Water Standards 1962, included a reference (p. 19) to work that indicated for instance 6 mg/l of combined residual chlorine in 1 hr could inactivate enteric viruses in water at pH 7 and 25°C. Because of present ammonia limits, however, much time and effort was being devoted by a number of research laboratories to the development of ammonia removal methods. Perhaps some attention should be given to possible methods of activating the chloramine itself so far as its bactericidal powers were concerned. Certainly in chemical reactions with indicators, such as DPD, the addition of 1 or 2 mg/l of potassium iodide had a catalytic effect. It would be worthwhile examining the possibilities that similar bactericidal effects could be demonstrated.

Finally, with regard to bankside storage it was hoped that the desirability of allowing for a by-pass had been taken into account to cover periods when the intake water was of better quality than the stored water.

Dr. R. F. Packham (Water Research Centre, Medmenham Laboratory) said that while the concept of drinking water quality standards was acceptable to many water authorities, raw water quality standards would seem to serve no useful purpose at all. In some respects EEC raw water quality standards required water sources to be of potable quality and it was difficult to understand the underlying reasoning. The guideline for conductivity would eliminate the desalting of seawater. The limit for odour, which was based purely on threshold odour number and took no account of odour characteristics, was an absurdity. Were water authorities expected to abandon the use of sources in which serious odour problems arose from time to time from natural causes such as algal decay?

Although these problems certainly caused difficulty they could be dealt with adequately using activated carbon or oxidative treatment processes. Did the limit for nitrate in raw water preclude the dilution of water from a high nitrate source? The limits set for pH, fluoride, dissolved iron, barium, copper, ammonia, and hydrocarbons could all be criticized on the basis of their being unrealistic or failing to take account of current technology. It was difficult to find any way in which the directive, if implemented, would be beneficial to water authorities in the U.K. He stressed that his criticism of the EEC proposals implied no criticism of the author's excellent paper.

Dr. W. Masschelein (Laboratories at the Compagnie Intercommunale Bruxelloise des Eaux Chemin du Croquet) said that the concepts included in the standards were generally well appreciated by the water companies in Belgium, but it seemed that they had barely been understood by the U.K.

Indeed, the U.K. had no borders but for the sea, which was not the case for other

European countries. Furthermore, the development of waste water purification was usually less important than that in Great Britain.

Unlike the U.K., in other European Countries there was not a single authority responsible for the water cycle. The responsibilities were still separate and co-operation was arguable. The question of who was to pay and who would benefit was always present. In these circumstances, and bearing in mind that he was employed by a Water Supply Authority, he could not entirely agree with the idea of maximum reuse of the water, by simply locating the intake down streams as was emphasized during the discussion.

For all these reasons, great interest was taken among the authorities responsible for supplying drinking water in the fixing of reasonable standards for the guarantee of the raw water quality at the intake.

The criteria brought out were of course a compromise but should be regarded as an attempt to maintain and possibly improve raw water quality by promoting waste water purification.

Up till now, one had always reached reasonable standards for drinking water, the main goal being the attainment of good water quality after the treatment. Again, should the general concept not be: it was better to prevent than to cure as the performance of the treatment plant was variable in time and depended on the skill of the operator? Was it not so for the technical approval of the chemicals used in drinking water treatment, e.g. polyelectrolytes?

Moreover, as far as he remembered it was foreseen that the directive might be modified or completed according to the progress made in the treatment techniques!

Dr. M. Richards (South Staffordshire Waterworks Company) said that the brewing industry recently considered it technologically advantageous to add trace levels of cobalt to their product. This practice ceased after a death, from cobalt poisoning, following continuing consumption of large volumes of cobalt-treated beers. As alcoholic beverages could be consumed in far larger quantities than water alone, should not this "enhanced drinkability factor" be considered when establishing acceptable concentrations of cumulative toxic metals?

WRITTEN DISCUSSION

Mr. N. S. Thom (Central Water Planning Unit) wrote that there was one danger of the existence of standards that, while rarely overlooked by the professional, should be more frequently stressed. That was that the absence of mention of something, for example of a particular chemical, could be taken as implying an absence of hazard connected with it. It would be wise therefore if this were always made clear.

In the absence of more adequate data, it might perhaps be safer to recommend "not detectable" for beryllium and cadmium, as well as for mercury (together with a recommended method of the maximum possible sensitivity). The same might be said of fused polycyclic hydrocarbons (PAH). The term "pesticide" (EEC list no. 35) was too vague. There might well be more than one pesticide that was chronically toxic to man on its own at levels below that suggested for total pesticides; certainly, the standard would not protect even fish, for example, against endosulfan* and an acute oral LD_{50} to the ratio of 0·5 mg/kg had been reported for TEPP, an organophosphorus insecticide**, by no means the only pesticide of that order of acute toxicity. He asked if there was any reaction during chlorination between detergents and chlorine?

* Alabaster, J. S. 1969 *Int. Pest Control*, March–April, p. 29.

** Ben-Dyke, R., Sanderson, D. M., and Noakes, D. N. 1970 *Wld. Rev. Pest Control*, vol. 9, p. 119.

He was also curious why there was no mention of viruses in the EEC standards. There was, incidentally, an excellent series of papers on viruses published recently‡.

Finally, the problem of the so-called reuse of river water for domestic supplies was of course basically a toxicological one and it seemed logical to suggest that the water should be subjected to proper toxicological testing! Were there suitable methods for this? A possible approach had been suggested‡‡ but might it not be desirable for research to be carried out?

Author's Reply to Discussion

Mr. A. H. Goodman, in reply to the discussion, wrote concerning Dr. Palin's comments that it was pointed out that sulphate was considered carefully by the working group and the effect of the addition of sulphate in the form of aluminium sulphate or iron sulphate was included. The restriction of the total sulphate in the raw water could not be justified entirely on this ground and therefore in the imperitive columns of the table the value of 250 mg/l appeared but in the guide value columns a value of 150 mg/l had been included so that there would be some freedom for addition of sulphate in treatment.

Looking at the values for fluoride, there was an apparent relationship to the values quoted in the WHO European Standards for Drinking Water. In those Standards air temperature was mentioned specifically. However, the technical groups considering the EEC values did not accept the WHO Standards implicitly and the values appearing in the table for the EEC waters were modified to the extent that it was considered that consumers would not come to harm if the level of the fluoride in the water did not exceed 1·5 mg/l. The value of 1·7 occurring in the columns for A2 and A3 waters allowed for an expected small removal during coagulation and treatment. The range given in the tables related to the mean annual air temperature that was that the lower limits would apply to the higher temperature areas and the higher limits would apply to the lower ambient temperature areas. The value of 1·0 mg/l to which Dr. Palin referred was not so much out of line as it was considered that for the purposes of prevention of dental caries this value would be sufficient and if there were any need to increase it to a higher level this could be achieved by addition of a fluoridating agent.

It would of course be quite impracticable to have a bankside storage without any flexibility and there was no requirement that bankside storage should not have a by-pass arrangement so that direct abstraction could occur from a river when the river quality was known to be high. The provision of bankside storage was to mitigate the effect on the potable water quality of any accidental pollution of the river. He agreed with Dr. Palin that the consideration of the ammonia content of a water to be treated to make potable water was difficult. There was no indication that ammonia in the sort of levels which did occur in surface waters would be harmful to human beings when that water was consumed. However, the values given in the EEC proposals were to be considered in the light of the categories. The lowest value of ammonia was for water which was to receive simple disinfection, which would appear to mean a constant small addition of chlorine. The values given in the columns under A2 were higher and would be for a plant which had greater capabilities and was under more direct control of the operators. The values given under A3 category waters were higher again and were such that considerable degree of chlorination would be required. Such heavy chlorination could bring about other changes in the character of the water and scientific supervision would be necessary. Alternatively to achieving breakpoint, sufficient retention time could be allowed for the chloramines so formed to act upon bacteria and viruses.

‡ 1974 *Journ. A.W.W.A.*, vol. 12, p. 707.

‡‡ Schubert, J. 1972 *Ambio*, vol. 1, p. 79.

The point which was made that attention should be given to possible methods of activating chlorine to enhance its bactericidal or viricidal powers was an interesting one and could be a subject for future investigation. He agreed with Dr. Packham, that the directive was unlikely to be of any benefit to the water industry in the U.K. However, it was not for the U.K. alone and there were parts of the Community that were more backward and would benefit from these values in a tabular form. Also, we were very fortunate in the U.K. in not having waters passing from one country to another, so that we had control over all our sources of water for potable supply services. Therefore, we should not be so critical of attempts to form a list of values which should be adhered to when drinking water was being considered. He was pleased that Dr Masschelein had made this point.

He agreed with Dr. Packham to some extent about the use of a threshold odour number but he considered that consumers were often more alarmed by a change in odour of water supply rather than if the odour or taste should become unpleasant. The concept of a threshold odour number was included in the EEC proposals because it was thought that the attention of the water industry generally in the Community should be drawn to the possible value of carrying out this determination more frequently.

It was important to realize that these directives could be reviewed if technical evidence showed that parameters needed to be changed and if in the light of experience the threshold odour number should be altered or removed from the list this would be done. The U.K. might be unique in the Community in the number of sources of raw water which could be used for potable supply, and it had been pointed out in discussions in Brussels that the values given in any directive should apply to water being withdrawn from storage and not to water which was put into storage. By analogy it ought to be possible to apply the values to a mixture of waters and not to each individual source, so that the point about nitrate in sources exceeding the value in the table might be overcome if it was explained to the Commission that under no circumstances would either of the two sources be used alone but that a mixture of two sources would be used always and the concentration of the nitrate in the mixture would satisfy the requirements of the directive. Such points as these would have to be subject to negotiations when the directive came into force. Dr. Masschelein said that prevention was better than cure with respect to raw water and to the addition of chemicals during treatment and he agreed with him entirely.

In reply to Dr. Richards, in the total diet studies consideration was given to the sources of toxic metals from food and drink but the input could be based only on an estimated average intake, and exceptional consumption could not be used to regulate the concentration of constituents of all food and drinks. In most instances a reasonable safety factor was introduced which ought to take care of all but the most exceptional cases, and the case that he quoted would appear to be one of these exceptions. More and more advice was being sought from medical advisers on the levels which ought to be accepted for toxic metals and other constituents in drinking waters and they took account of these deliberations over total diets. The safe levels of constituents of water were taken as aliquots of the total inputs which could be accepted by humans daily.

He agreed with Mr. Thom that failure to mention a particular parameter could be construed as implying that it was completely free from hazard, and this was a point which ought to be made in any preamble to a directive.

It would be very difficult to accept Mr. Thom's proposal that "not detectable" should be applied to cadmium, mercury, and beryllium, and for polycyclic aromatic hydrocarbons because although a recommended method might be used, the sensitivity of the method could vary from one laboratory to another depending upon the skill of the operator and upon the particular sensitivity of an instrument being used. In general, he considered that it was more satisfactory to put a figure at which people could aim and the sensitivity of the tests would have to be adapted to achieve that particular value with accepted reliability. He also agreed that mention of the value of pesticides was vague but it was so deliberately. The value attached was not intended to protect fish life. It was always realized that in practical rivers management, better values than those required for drinking water purposes would be needed to protect other interests in the river. The vagueness of the description was necessary because if an attempt was made to put limits on individual pesticides it would be impossible to include the whole list of pesticides or groups of pesticides which were manufactured throughout the world. Thus, it would be always an incomplete list and constant revision of it would be required. The vague blanket value given prevented loopholes in the directive.

It was accepted that the value was not all that might be desired and in the discussions in the group of technical experts many other tests had been suggested, in particular tests for the inhibitions of enzymes, but it was concluded that it would not be proper to recommend the widespread application of such tests because of lack of experience amongst laboratory workers in conducting them and lack of experience of interpreting the results obtained. Nevertheless, in time such tests might be included in any form of a directive.

Organo-phosphorus pesticides were not considered to be generally as important from the water suppliers view as the more persistent chlorinated hydrocarbon type. This was because the organo-phosphorus compounds were degraded and were absorbed on suspended mineral matter which would be removed by even simple sand filtration. It was thought that it was possible that there could be a reaction between chlorine and the alkyl phenyl ethoxy type of detergents. Their concentration was usually less than 1 mg/l and the chance of complete reaction was unlikely. It was possible again that chlorine would be absorbed by some amide-containing detergents. No evidence had been produced to show that harmful materials could be produced. Viruses were considered by the working group but for the reason that so little expertise was available throughout the water industry to determine the numbers of viruses present in water it was sensible to wait until the methods of tests had been made more widely known. Medical advice was that the virus content of drinking water was very low compared with the viruses present on the dust in the air which was breathed.

6. RAW WATER MONITORING

By W. M. Lewis, FRIC (*Fellow*)*

CONTENTS

INTRODUCTION

Evidence is available which confirms that raw water supplies are increasingly at risk from a variety of products as diverse in nature as the chemical industry itself. Thus, the control of pollution so as to preserve the quality of raw water, especially when used as a source for public water supply, is a matter of particular concern to the water industry. Pollution may be defined in a number of ways, but it must include anything which degrades the quality of the water perhaps so as to constitute a hazard or to interfere with its normal use. Unless such contaminants are highly coloured or possess a distinctive and persistent odour, which makes their presence obvious, recourse must be made to some other method of examination which will reveal their presence.

At the turn of the century the practical assessment of pollution was based essentially upon two laboratory tests which, together with the factor of dilution, were recommended by the Royal Commission Standards and served to evaluate the effectiveness of sewage treatment processes and to avoid nuisance conditions in rivers and streams receiving such effluents. These tests were the measure of "suspended solids" and BOD measuring respectively excessive amounts of solid matter and of putrescible substances in the water. However, in the light of present day needs of the industry, searching ever for additional raw water sources for supply, such parameters do not adequately identify raw water quality in the light of the type and variety of pollutants now gaining access to raw water supplies.

Effluents from sewage treatment plants serving an industrial community contain, in varying quantities, the host of chemicals which modern industry either uses in its varying processes or which are the unwanted end products of its activities. Pesticides, toxic metals, phenols, hydrocarbons, detergents, etc., are, but to name a few, those perhaps most readily known. The range of products emanating from the modern pharmaceutical industry or the synthetic organic chemical manufacturing industry, are almost limitless and the toxicity, to both animals, plants, and man, is frequently an unknown factor and perhaps the most critical factor of all.

Faced with this dilemma, how can the water industry abstracting for treatment, from polluted rivers, protect itself against the invisible, insinuous objectionable contaminant in the raw water supply?

Although the application of modern laboratory techniques will permit a truer assessment of the quality of a raw water there is much to be said—in fact it might be true to

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say the industry's greatest need is for a continuous, simple if possible, appraisal of the raw water quality and to prove absence of all toxic ingredients simultaneously.

By the simple process of nurturing autotrophic bacteria under favourable conditions it is possible to utilize the ammonia-destroying power of such organisms as a measure of their virility, which can be seriously impaired by the presence of certain toxic materials in raw water. Information by Stroud[1*] and by Holland and Green[2] indicates that the system may have potential as a gross pollution detector system. Thirteen compounds including toxic metals, phenol, cyanide, pesticides, and herbicides, etc., were employed, at various concentrations, and inhibition of the nitrification process was observed in the presence of the majority of substances tested.

In the absence of a reliable, all-embracing, system similar to that described above *in-situ* instrumental monitoring of a continuous nature has been the approach to date in an attempt to be aware of untoward pollution in many river systems. A comment on such stations, however, was made in the 1971 Report of the then Water Pollution Research Laboratory which is worthy of quote:—

> "In recent years, extensive field trials of a number of land based water-quality monitoring stations of UK. Manufactures have been carried out by various river authorities in co-operation with the Instrumentation and Data Group of the WRB. In general, the performance of these stations has been found to be unsatisfactory—in addition to actual malfunctioning, inadequate facilities for maintenance and standardization and the inability of the equipment to function at certain sites . . .".

The usual parameters determined, with a fair degree of proficiency, by such instruments are, at the present time, dissolved oxygen, suspended solids, electrical conductivity, *p*H and temperature. Obviously, these may not give warning of the presence of many common pollutants such as those examined by the experimental gross pollution detector system previously referred to.

Briggs and Melbourne[3] have explored the possibility of adding to the system electrodes capable of measuring pollution due to specific ions and claim that those particularly responsive to ammonia, nitrate, and other anions are of value. The authors are, however, doubtful of the value of electrodes capable of responding to metal cations due essentially to their lack of sensitivity in measuring the extremely low concentrations of the free ions (as opposed to total metal) normally present in natural waters.

Perhaps the present position regarding *in-situ* instrumental monitoring may be summarized as stated by Melbourne, Robertson, and Oaten[4] who claim the major problems of such stations are not associated with either the electronic equipment or the recording of information, providing enough money and effort is expended in designing and constructing the equipment, the two primary factors the authors claim in the shortcomings of such equipment are presenting to the sensors a representative sample of water and perhaps most important to obtain reliable sensors which maintain calibration between the manual and/or automatic checks performed.

Other authors[3,5] make the point that continuous water-quality monitoring stations are expensive to build and equip, are not cheap to operate and maintain, and that it is extremely important to determine the need for such stations bearing in mind the limited knowledge forthcoming and that they require constant attention from a person of no mean competence. The addition of further sensors, to the conventional five already mentioned, would add to the problem.

However, to be realistic it is perhaps true to state that concentrated endeavour must continue towards greater automation to provide the necessary early warning of discharges, especially of an intermittent and obnoxious nature. In the meantime, the present method adopted by most authorities as the basis of water quality surveillance is a system of routine "snap" sampling at strategically selected points specifically chosen normally to measure

* A numerical list of references is given on p. 88.

major polluting discharges and reliance upon the laboratory organization for assessment of the water quality.

Obviously, the frequency with which samples may be taken, in the routine system, depends critically upon the efficiency with which the laboratory organization can provide the water quality data. Thus, in general—except at perhaps intakes of river water abstractors for treatment—a sampling frequency ranging from once every three months at some locations to once per month at locations of more significance to even weekly sampling in locations likely to suffer the greatest pollution embarrassment is the norm. Even so, a sampling frequency of once per week appears a much higher rate than is practised in many authorities and at this rate only represents the river flow of a few minutes compared with 10 000 minutes weekly flow.

The need for increased sampling frequency, it would appear, can thus be fully justified if the objective is a realistic appreciation of the quality of the water body.

The main purpose of this paper is thus reached. In the absence of a continuous water quality monitoring system, how can the laboratory organization be so arranged to attempt to accommodate the extra sample submission resulting from an increase in sampling frequency?

Perhaps at this point it is pertinent to recall that something in excess of 90 elements are known and the number of organic compounds available are indefinable. Consequently, it is totally unrealistic to set an objective to search for this limitless number of potential contaminants. Nevertheless, whereas a few years ago the number of the determinands assayed were confined to those usually described as "sanitary analysis", the present position may be readily appreciated by consulting the list of physical and chemical parameters approved (or under discussion) by the World Health Organization (WHO). The latter organization is at present grappling with 81 such parameters of which perhaps something in excess of 40 will be basically necessary to asses raw water quality. The proposed European Water Standards include 63 parameters and of this number 18 metallic elements are listed including such cations as titanium, vanadium, arsenic, selenium, mercury, and tellurium. The organic contaminants within the classifications include pesticides, non-ionic detergents, and polynuclear aromatic hydrocarbons.

Miller and Short[6] in a paper dealing with the treatability of river Trent water based their findings on 26 determinands selected by the Economic Models, Quality-States Subcommittee. Woodward[7] set forth 45 separate determinands, of which admittedly 17 he claims were only determined in particular types of samples.

Thus, it is apparent that as the health hazard of a specific chemical is identified it almost invariably needs to be incorporated into the scheme of analysis. Consequently, the impact on a laboratory organization becomes two-fold—the necessity to increase the sample throughput in terms of numbers, and the extra burden of assaying additional, oft times difficult, determinands. The skill and expertise of the operator is extended to the limit, especially when one appreciates that the level of some contaminants in water is frequently little more than the sensitivity of the particular chemical reaction.

This imposes, in its turn, the additional burden of ensuring that the accuracy of the obtained result is within permitted limits so that analytical quality control becomes an integral part of the daily work load—additional to the sample throughput. In this way, perhaps the only way, it is then possible to ensure that the analytical data forthcoming are reliable and bear comparison.

To digress for one moment to emphasize the importance of this latter point, the topic of nitrate in water supplies at the present time is a subject not without importance. The nitrate anion may be determined in a variety of ways and frequently, as progress in analytical methods develops, newer assay techniques are tried and introduced to supersede a previous technique without ensuring comparability between old and new.

Sometimes an apparent significant quality change in the water supply results from such change in analytical procedure and the records frequently ignore reference to the change to a newer technique of analysis.

Now that larger authorities are in being, having absorbed a variety of laboratories, the quality control of analysis is of vital importance especially when the collective data are being examined centrally. A recent example illustrates the point. A pure solution of nitrate salt was distributed for analysis to a number of laboratories—each using their own method of analysis, i.e. that normally employed within establishments, which turned out to be basically five in number, with individual variations. The range of results obtained varied between 9·0 and 19·6 mgm l^{-1} Nitrate (N), the standard solution being 14·0 mg l^{-1}! How under such circumstances can quality assessments of water be honestly made and compared when errors arising in the analysis of samples adversely affect the extent to which results from different laboratories can be compared?

Returning to the main theme the problem facing the laboratory resolves into three parts (1) analytical quality control, (2) increase in the number of determinands to be made, and (3) increase in the actual sample numbers.

With the best will there is a limit to the number of analyses one individual, however skilled, can accomplish in a working day. Also, it is most improbable that such a person can achieve, throughout the working day, the same degree of precision of analysis. The human factor of fatigue plays a most important role. It must also be remembered that constant submission of individuals to this kind of pressure leads to frustration, resulting in increased absenteeism.

Finally, the allowance needed in manpower to permit holiday entitlement, day release for educational purposes, etc., requires the employment of an unacceptable and uneconomical level of staff. Thus, alternative analytical procedures to manual application must be the chief objective if the targets of analysis are to be achieved on a regular and consistent pattern.

Considerable progress has been made in the last two decades, particularly in the development of laboratory aids, which have been designed and constructed with the primary objectives of simplifying the analytical procedure, assisting the continuous throughput of analysis, and lessening the dependence upon the skill and expertise of the experienced analyst undertaking such analyses. However, it must be appreciated that such equipment needs manual attention by way of loading the turntables with standard solutions, blanks, samples and the necessary reagents. More and more water constituents are capable of being assayed and with very few exceptions almost every determination routinely performed in a chemical laboratory to assess water quality may now be performed on discrete samples by a collection of such equipment. It is true, however, that such equipment for its development for use needs the services of a skilled chemist, albeit the routine operational procedure may be in the hands of a person of trainee status.

To elaborate, if we consider the analytical task of determining the Chemical Oxygen Demand value (COD) providing adequate equipment, by way of condensers, flasks, hotplate accommodation, etc., was available it might be realistic to attempt (using the services of one assistant all day) to achieve a throughput of 40–50 such analyses per day on a routine basis. By the use of the automatic laboratory equipment referred to above we are able to achieve, in an 8-hour working day (the equipment will operate unattended during lunch break), a throughput of 160 such analyses. The technician involvement is but two hours, so that other equipment may also receive attention. Thus, at least three times the throughput is obtainable with only one-quarter of the available man hours!

Like all services, that of providing analytical data costs money and as, in general, it might be true to claim that about 70 per cent of the total cost of a laboratory organization is that of salaries, etc., to increase the man-power to achieve the target throughput makes the cost of analysis unduly expensive. To achieve a set objective, whilst being conscious of the financial implications, effort has been made over a long period to transfer to machines as many of the "normal" determinands needed in the course of routine water quality monitoring. At this point a total of 33 determinands have been successfully transferred to automatic mode, and endeavours are continuing to increase this number.

Initially, our problem was focused essentially on those determinands conventionally required in the daily assessment and control of the performance of a large sewage treatment works.

The daily sample submission, representing the treatment process before and after its various stages, numbered slightly more than 30, the results of such analysis being available

TABLE I

No.	Determinand	Rate per hour	Conditions	Concentration at FSD, mg/l^{-1}	Minimum concentration, mg/l^{-1}
1	Synthetic anionic detergent	20	Solvent extraction/ Methylene blue	15	0·5
2	Chemical oxygen demand	20	$K_2Cr_2O_7/H_2SO_4/$ $AgSO_4/HgSO_4$	500	10·0
3	Permanganate value	20	$KMnO_4/H_2SO_4$ Heat 85°C	100	5·0
4	Ammonia (N)	40	Phenol/hypochlorite.		
			Dialyser (*a*)	20	0·4
			Straight (*b*)	1	0·05
5	Nitrate (N)	60	Hydrazine/Cu at 37°C and (6)	40	2
6	Nitrite (N)	60	Naphthyl ethylene diamine HCl_2	1	0·05
7	Organic (N)	20	Kjehldahl and 4	60	5
8	Total phosphorus (P)	20	Kjehldahl/molybdate reaction (ANSA) at	20	1
			85°C	20	0·5
9	Total soluble phosphorus (P)	40	Hydrolysis $H_2SO_4/$ reaction (ANSA)	2	0·1
10	Soluble ortho phosphate (P)	40	Molybdate/ascorbic Acid 85°C		
11	Total organic carbon (C)	10	CO_2 CH_4 FID (*a*)	100	5·0
			(*b*)	4	0·2
12	Chloride	120	Conventional colorimetry	100	2
13	Sulphate	120	Performed automatically	100	2
14	Aluminium	120	,,	0·4	0·05
15	Iron	120	,,	1	0·02
16	Magnesium	120	,,	25	0·5
17	*p*H	50	Conventional electrodes		5 per cent FSD
18	Electrical conductivity	50	,, ,,		5 per cent FSD
19	Sodium	120	Flame photometry	5	0·1
20	Potassium	120	,, ,,	10	0·2
21	Calcium	120	Flame emission	0·3	0·005
22	Metal cations. Mn, Pb, Cu	180	Atomic absorption		
30	Cd, Cr, Ni, Zn, Ag, Au		Spectrophotometry		

at the end of each working day. Obviously, the range of each constituent was large between influent and effluent quality, as might be expected, in an efficient treatment plant. However, even in the effluent the concentration of some "pollutants" exceeded the level normally experienced in river water and much greater than would be tolerated in a potable water. Unfortunately, it is not usually possible to examine for quality on the same machine, within the same batch of samples, say potable waters and sewage effluents due essentially to the wide disparity in level of the constituents. As the result of an extended investigation however, by variation in some instances of a particular manifold or construction of an additional one, river waters and potable waters may now be examined in the same manner by the same equipment.

Table I sets out those determinands which at present are amenable to routine automatic analysis, the rate per hour at which they can be determined, and the range of concentration which is possible under the conditions operating.

METAL CATIONS

The technique of atomic absorption spectrophotometry is particularly useful for the determination of metallic contaminants in water especially when such are present in trace amounts. The analytical speed, ease of operation, and relative lack of interferences make the technique attractive for routine water quality analysis. The step forward from manual operation of the instrument to automation is particularly worthwhile when faced with the prospect of determining a variety of metallic contaminants in a large number of samples.

For example, with the provision of an automatic turntable feeding the samples to the instrument, and a recorder or print-out unit controlled from the turntable, it is practical to examine samples for, say, seven of the cations in solution listed (22–28) in Table I at a rate between 100 and 120 per working day of 8 hr. This rate permits the inclusion of 40 to 60 blank and standard solutions needed for calibration and quality control.

Such a system has been successfully operated by us for a period in excess of six years and with only occasional help from a second person the throughput mentioned is accomplished utilizing the services of one assistant only. Metallic cations in solution are determined on the filtrate and the total metal content is assessed following conventional treatment. Obviously, therefore, if both total and insolution values are sought the sample throughput is halved and 14 000 samples only per annum is the maximum which can be examined unless further instrument provision is available.

ALKALINE EARTH CATIONS

The examination of water for the cations sodium and potassium presents little difficulty by direct flame emission, preferably using an alternative set of equipment specifically for the purpose. The provision of the same kind of supplementary equipment, as described above, enables assessment to be automatically carried out. The cation calcium, usually a primary component in water, is preferably determined using the atomic absorption equipment, in the direct flame mode, a lanthanum salt addition compensating for the potential silicate, phosphate and aluminium interferences in this estimation.

AUTOMATIC COLORIMETRY

Several of the constituents in water which are required to be known in evaluating quality are amenable to simple chemical reactions which result in the development of a colour the intensity of which is frequently, over a limited concentration, proportional to the constituent present.

Frequently, such reactions require for their completion nothing more than the addition of perhaps two or three reagents in solution to the water under examination, dilution to a fixed volume, and a means of measuring the developed colour. Prior to the introduction into laboratories of the atomic absorption equipment, several metallic cations and some anions were determined in such a manner.

Reactions of this type lend themselves to a system of automation by the simple expedient of arranging a bank of variable pipettes, the pistons of which may be operated by the alternative application of a vacuum or pressure from a master cylinder. Precut templates control the piston thrust in each pipette and thus the quantity of sample and reagent dispensed. A colorimeter or spectrophotometer, incorporating a flow-through cell of fixed dimensions, together with a recorder completes the equipment. Using such a system the determinands 12–16 (Table I) inclusive may be assayed at a rate, including standards and blanks, of 120 per hour, and at least 100 samples may be examined for the listed, or an alternative set, of determinands per day employing the services of one assistant.

CHEMICAL OXYGEN DEMAND

This assay is considered to be of value in determining the oxidizable material, mainly of a carbonaceous nature, in water. Until the introduction of this test the empirical tests biochemical oxygen demand and/or permanganate value were employed in an endeavour to measure the potential oxygen demand which the presence of carbonaceous material imposed upon a water body. A period of five days must elapse before it is possible to obtain information from a BOD test and whereas the PV can be carried out in 4 hr plus, the information forthcoming from this test appears of doubtful value especially when examining unknown water samples. The COD test was proposed as a more suitable alternative and has been adopted as a speedier alternative to the PV test. Sometimes it is used as an additional test, in an attempt to provide further information concerning raw water quality.

However, whereas the PV test is carried out using relatively non-corrosive reagents and a temperature little above ambient, the COD determination is performed at the boil and uses a mixture of potassium dichromate and sulphuric acid. A reflux condenser is needed to retain the volatile matter and water vapour within the system. Thus, as previously mentioned, one assistant working full time may be capable of completing about 50 such determinations per day; if samples in excess of this number are to be processed, additional assistants are necessary.

An alternative procedure is to automate the process and this has now been in operation successfully as a flow-through system for about six years producing results at the rate of 20 per hour. The problem of processing the sample and reagent at the boil was overcome by the use of a glass helix, rotating over electrical elements, at a controlled speed. The reagent and sample were introduced at one end and the processed mixture was sampled from the other. Again, using a spectrophotometer (to measure the fade in yellow colour at 445nm) and flow-through cell, together with recorder, it is possible to process samples in excess of 100 (together with the necessary standards and blanks for quality control) each working day with little more than two hours of an assistant's time. The automatic handling of, and reacting together of, such chemicals at the elevated temperature takes place in a closed system resulting both in greater safety and cleanliness in the laboratory and a substantial energy saving in fuel. Additionally, the analysis, via the manual procedure, of waters having rather low COD values is extremely exacting upon the operator and generally difficult to reproduce at values below about 50, although with much experience an operator may achieve reproducible results at about one-half this value.

Using the automatic procedure outlined above a technician may successfully reproduce results at values of 10 and above.

PERMANGANATE VALUE

Such a test is extremely demanding in operator time when conventially performed and the prospect of handling samples approaching or even exceeding 100 per day can be daunting, requiring complete involvement of an operator for the working day.

By adopting a flow-through system incorporating a heating bath, set at 85°C, with a 40 ft delay coil results comparable with the conventional 4 hr procedure may be produced at a rate of 20 per hr. Additionally, the operator time, including that necessary for the preparation of solutions and interpretation of the chart data, is about 2 hr.

AMMONIA

Use is made of the development of a blue colour with a phenol/hypochlorite reagent in the presence of ammonia for the determination of ammonia concentrations in water between 0·05 and 20·0 mg/l^{-1}. This technique is extremely sensitive, especially in the presence of the agent sodium nitroprusside. Thus the system is ideal for transfer to automation using the flow-through technique. The colour development is achieved by a delay period on passage through a 40 ft glass coil and the blue colour measured at 625 nm and logged on a chart recorder.

For samples containing either colloidal material or matter in suspension, the incorporation of a dialyser unit is essential, but for low level concentrations of ammonia in potable and other water free from such contamination the samples may be processed by passing the dialyser unit. It is also possible with the latter type of sample to achieve a throughput in excess of 40 samples per hour, which is the present rate using the dialyser in circuit.

NITRATE AND NITRITE

In determining these anions using a flow-through automatic system, both are assayed as the nitrite anion using the reagents naphthyl ethylene diamine hydrochloride and sulphonamide in phosphoric acid. The nitrate for its determination is previously reduced using hydrazine and copper, the solution being warmed to 37°C by passing it through a coil in a constant temperature water bath. Both assays may be performed at a rate of 60 per hr, two ranges of concentration, depending upon the nature of the sample, being employed 40 mg/l^{-1} full scale deflection and 1·0 mg/l^{-1} FSD.

SYNTHETIC ANIONIC DETERGENT

Manual determination of this class of compound in water is a protracted and time-consuming procedure requiring the use of glass separating funnels and at least one and possibly more extractions with the organic solvent chloroform. Given the necessary equipment, an assistant could examine say five or six samples per hour and perhaps it would not be untrue to say the same person would find it almost impossible to examine 40 such samples per working day. By automating the procedure employing the agent chloroform to extract the methylene blue complex, such samples can be examined with a throughput of at least 15 and perhaps 20 samples per hr. A daily target of 100 samples plus standards and blanks may be achieved comfortably with the same precision from day-to-day. Once again, a 2 hr assistant commitment is all that is necessary.

ORGANIC NITROGEN

Using a glass helix, similar to that employed in determining COD values, the conventional Kjehldahl process using concentrated sulphuric acid and a catalyst may be transferred to a flow-through automatic procedure converting the nitrogen containing material which is present in a raw water or effluent etc., into the ammonium salt form. The latter may then be quantified by the technique described previously under ammonia. A throughput rate of 20 samples per hr ensures that a daily total of 100 samples may be achieved, plus the blanks and standards essential for quality control, well within 6 hr from "switch-on" time.

Additional advantages are the same as those described under COD—safety, closed system, and cleanliness together with the fact that the operation may be performed in the open laboratory, unlike the conventional Kjehldahl process which necessitates using a fume chamber to extract the acidic fumes.

Further, by using a dual manifold the acid digest stream on completion of the reaction may be split and the second stream utilized for the determination of the total phosophorus content contained in the sample.

TOTAL SOLUBLE AND SOLUBLE ORTHO, PHOSPHATE

For the determination of each of the above components in a water the basic colorimetric procedure is employed, being the reaction between phosphate, at a temperature of 85°C by passage through a 40 ft delay coil immersed in an oil bath, with the reagents ammonium molybdate and the reducing agent A.N.S.A. (4-amino-3-hydroxynaphthlene-1-sulphonic acid). The alternative reducing agent absorbic acid, together with the colour intensifier potassium antimonyl tartrate, is employed when ascertaining very low levels in borehole or potable water.

The total soluble and soluble ortho phosphate, when the latter is requested, are determined by utilizing a dual manifold when carrying out the ammonia determination splitting the sample stream and hydrolysing in the case of total soluble phosphate by means of sulphuric acid and passing through a heated (85°C) delay coil.

Thus, it may be seen that ammonia estimation and total soluble phosphate (or orthophosphate) estimation are simultaneously carried out using a dual manifold, two colorimeters and two recorders at an hourly rate of 40. This rate could, without difficulty, be increased to 50. The organic nitrogen and total phosphorous—using the same colorimeters and recorders are similarly estimated simultaneously at a rate of 20 per hr. One assistant is responsible for the four determinands and by adopting a procedure which ensures that the heating elements of the oxidation equipment and the helix are "up to temperature" by the time the ammonia determinations are completed an immediate switch over to organic nitrogen and total phosphorus permits uninterrupted operation. Because the equipment can operate during the lunch break, 100 samples may be processed for these four determinands per day.

TOTAL ORGANIC CARBON

As the industry has come to recognize the need to know, in terms of nitrogen, the total nitrogen-containing substances contaminating a water body so the modern trend is to have knowledge of the carbon content in a water in an attempt to obtain a measure—perhaps ultimately a more realistic measure—of the degree of water contamination due to carbon containing and thus perhaps oxygen demanding, compounds present.

A decade or so ago when faced with the prospect of determining the carbon content in a river water or effluent—assuming at least one member of staff was sufficiently skilled, one, or perhaps at most two, determinations could be considered a day's achievement. The technique of infra red spectroscopy was then adopted as a speedier more accurate replacement in that oxidation of the carbon content to the gas carbon dioxide provides a convenient form of carbon which can be measured by the above IR techniques. The results obtained by this procedure are claimed to be more consistent, more reliable, and less prone to experimental errors than those obtained by the wet oxidation method.

From the time of injection of the liquid, whose volume may be 20 microlitres, to production of the answer averages about 10 sec and normally at least three aliquots of sample are analysed—the mean value being determined. Within the range 10–200 mg/l^{-1} C the accuracy is very good, but it is claimed that results are highly suspicious below 4 mg/l^{-1} C.

An alternative procedure is now available in which the oxidation stage is followed by one of reduction of the produced carbon dioxide to the gas methane which is determined by means of a "flame ionization detector". This procedure has the advantage of excellent reproducibility of results even at concentrations of carbon below 1 mg l^{-1}. The throughput is about 10 samples per hr, but the process is amenable to automation which enables "out of hours" operation of the instrument. Consequently, the sample target may be achieved in this manner, results being displayed on a chart recorder.

FUTURE PROSPECTS

Obviously, from the examples quoted, it is apparent that by the application of chemical expertise and making use of the various types of mechanical laboratory equipment now available, it is certainly practicable to transfer to such equipment (or combinations of such) an increasing number of hitherto manual chemical tests. As the demand for further information gathers momentum, so the challenge to the laboratory organization becomes progressive.

Electrical conductivity and *p*H determinations for example have been transferred to automation and are assayed at a rate of 50 per hr. Experimental work so far accomplished raises hope that both phenols and cyanide may be similarly examined with an expected throughput of 30 samples per hr.

DATA COLLECTION

The solution to one problem axiomatically creates another and in examining, via the automated procedures outlined, a large number of samples daily for a wide range of determinands the problem of chart recording interpretation, to ascertain results, and the recording of such results plus the necessary report for various officers is a serious burden normally solved by increasing the clerical staff to meet the imposition, all of which must be considered an "on cost" for the services of analysis.

We soon discovered that these automated systems could generate data much faster than we could process them by the visual inspection of charts, processing the calculation via a desk top calculator and then manually recording the results—sometimes for subsequent typing and report.

In an endeavour to escape from this situation and at the same time release the laboratory personnel from the unproductive time spent on data interpretation, permitting them more time for analytical work, efforts are being directed towards the development of "on-line" data collection.

For those automated systems, especially using spectrophotometers or colorimeters, where the data are recorded on a chart recorder a retransmitting potentiometer is attached to the recorder slidewire which transmits the obtained data via an interface to a multi-channel analogue data logger in which the information obtained from a series (4 to 8) instruments will be recorded, in a digital form, onto magnetic tape.

A 16-bit parallel input will enable complete sample and determinand identification, and the system permits acceptance of data from the various machines each starting and stopping independently of the others, as the scan rates are variable, within 15 rates, from 0·1 to 160 sec. At the end of the automatic process the magnetic tape cassette is transferred to a replay unit which is coupled with System 2200 Wang computer. This is capable of sorting and interpreting the collected sample data and comparing such data against the standard reference solutions and transmitting the calculated results to an output writer in the form of a typewriter to complete the task of making the information immediately available for distribution to the various sources. The manpower saving will compensate for the initial expenditure, but the main essential is to be found in the potential capacity of coping with the vast amount of data collected from some 30 000 samples annually, on which determinands approaching an anticipated number of 40 will be required.

Two determinations at present—and for the foreseeable future it appears—will be resistant to successful attempts to automate and these are those mentioned at the commencement of this paper i.e., suspended solids and biochemical oxygen demand, both therefore need concentrated manpower to achieve a daily output comparable with the speed attained by the automated processes. Dealing, as one may be, with raw river water from divers sources for example to obtain a measure of the BOD value at least two dilutions and in some instances i.e. unknown effluents, perhaps three dilutions will be required for each sample submitted. At a daily submission rate of 100 samples a total of between 220 and 250 bottles will need to be manually processed which will require about 15 hr labour, which is the equivalent of two assistants. For a considerable number of years the conventional titrimetric procedure has been superseded by a more elegant measurement of the residual oxygen using a Mackareth electrode assembly and meter—the former inserted in a flow-through cell through which the liquid flows. The advantage of this technique, over the wet chemistry procedure, is the absence (and thus cost saving) of chemicals the need for their preparation in solution and standardization plus the advantage that the operator may calculate the BOD on sample 1 while the meter reading of sample 2 reaches equilibrium. The results are thus available at the completion of the run.

Suspended solids determinations are performed manually and the sample number mentioned requires the whole time attention of at least one assistant, with occasional additional help.

Faced as one often is with the problem of examining a raw water as exhaustively as possible, in addition to the procedures outlined, more sophisticated chemical expertise must be brought to bear and use is made of more elegant equipment in meeting the challenge.

In an attempt to ascertain the range of metallic contaminants, prior to quantifying the respective levels, use is made of a chelating resin column to separate such contaminants from those cations present at higher concentrations such as calcium, etc.

Between four and five litres of the sample is permitted, overnight, to flow through the resin bed and the following morning the columns are washed and eluted thus concentrating the metal ions from the bulk sample into 25 or 50 ml eluate. The latter is then processed by means of emission spectrography recording the results on a photographic plate and the spectrum lines analysed to identify elements present and quantified against an internal standard on a travelling microphotometer. Confirmation of findings may then be undertaken either via polarography or by atomic absorption technique.

ORGANIC MATTER

Organic contaminants such as organo-chlorine or organophosphorus pesticides are evaluated using gas/liquid chromatography, as also are some of the modern sulphonamide-based alternative agents. Volatile acid content and composition are determined in the same equipment, which is also extremely useful for separating and quantifying the various phenolic compounds which afflict many raw water supplies.

Making use of capillary columns gas chromatography is an ideal procedure for separating the various components of the fuel oils and may be extremely useful in conjunction with infra-red analysis in "finger-printing" the type of oil contaminant in a raw water.

The identification of anionic detergents and their estimation has been outlined hitherto, but contamination of water supplies by the apparently non-biodegradable non-ionic detergents is much more difficult and time consuming. Recent work by us making use of a macroreticular resin bed, after removal of the anionic species, enables speedy and efficient removal of the non-ionic agents which may then be eluted from the column and the relatively clean solution containing the species assayed.

Polynuclear aromatic hydrocarbons many of which are known, and several suspected, to be carcinogenic agents are the subject of WHO discussion and a limit has been imposed on the maximum permitted level in water. Recent surveys have been conducted by us throughout the region covering samples ranging from borehole water—river water—reservoir water—sewage works effluents and treated river water "through the plant" using the modern technique of high pressure liquid chromatography (HPLC).

As stated at the commencement of this paper as information is forthcoming from the organizations best qualified to pronounce on health aspects associated with the ingestion of particular chemicals the already extensive list of determinands required to be carried out at present will be further extended. This will place a greater responsibility on the shoulders of people whose job it is to provide the scientific service evaluating water quality.

Until such time as an *in-situ* continuous automatic on-line assessment of such quality becomes feasible (and that may be a eutopian aspiration) no alternative, in my opinion, to a well-equipped, competently and efficiently run laboratory organization can hope to provide comprehensive evidence enabling judgement and pronouncements to be made concerning the quality of raw water supplies.

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DISCUSSION

AUTHOR'S INTRODUCTION

Mr. W. M. Lewis, in introducing the paper, said that history revealed that chemistry first became established as the "handmaid" to the useful arts—dyeing, painting, brewing, glass-making etc. Perhaps as an essential handmaiden it similarly served the water industry which, in to-day's world, just could not function without it.

Previous speakers had rightly emphasized the multifarious substances of a chemical nature, frequently of unknown toxicity, coyly awaiting the appropriate conditions to leach into the raw water supplies upon which industry so desperately depended in an endeavour to meet the ever-increasing demands made upon it.

A recent list, emanating from the Ministry of Agriculture, Fisheries and Food, gave over 400 chemicals for use in agriculture. Many of these were of an extremely esoteric nature, and they could easily find their way into a water source! The margin of safety was becoming correspondingly thinner.

This was the problem and he suggested that few abstractors, if any, were in the envious position of being able to ignore it.

How should the water industry best meet the challenge? It was not his intention to appear in the role of protagonist for laboratory, as opposed to *in situ*, monitoring. In the paper on at least three occasions he had emphasized that the industry's greatest need was for a continuous, all-embracing, efficient, and relatively simple *in situ* monitoring device. Unfortunately such, as yet, was an aspiration—some would claim a utopian dream—but until such time as the present breed of such instruments were sufficiently improved to be acceptable recourse to the laboratory appeared to be the only alternative to ignorance.

Thus, to provide a ray of encouragement to members who were at present wrestling with the problem of deciding which monitoring route to follow, the paper was written in an attempt to illustrate how increased sample throughout plus more comprehensive examination might be accomplished with economy of personnel. Other people would have successfully followed some alternative course and he hoped the discussion would bring this out.

Whichever course one followed must, as a priority requisite, ensure that water supplies for treatment (and this must include river waters) were free from objectionable material that would render the potable supply unwholesome. It was a task which was ever more demanding and which did not become easier with the increasing pollution via leachates from waste tips of unknown composition.

Mr. V. K. Collinge (Water Research Centre, Medmenham Laboratory), in opening the discussion, asked why it had been decided to choose an engineer for this particular task. On reflection he had concluded that this was perhaps a good idea in that it might be valuable to have someone with only a basic knowledge of the chemistry involved who could stand back and look at the overall scene.

The first part of the paper was devoted to automatic monitoring devices but there was only one paragraph on the all important subject of frequency of sampling. The remainder of the paper was devoted to the theme of organizing bigger and better laboratories to deal with more samples. This, of course, was the bread and butter for the analytical chemist.

It seemed appropriate, therefore, to concentrate the opening contribution to the discussion on the design of sampling programmes, on which a lot of work had already been done but on which much more needed to be done.

The author referred to an objective of "a realistic appreciation of the quality of the water body". This was meaningless, for an objective must be expressed in quantitative terms. The following factors needed to be considered and specified in the development of this quantitative definition of objectives:

(1) Which rivers and which sites were to be specified?
(2) Which quality parameters were to be specified?
(3) What was the ultimate *use* of the resulting data?
(4) In what form was the results to be presented? Were the pollutants to be presented as concentration, or as loads (concentration x flow)? Was it required to estimate the arithmetic mean for a chosen period, or the median value?
(5) What was the tolerable uncertainty of the required results? Since frequency of sampling was inversely proportional to the square of the required precision, then the effect of increasing the precision was quite profound.

Against this background the statement made by the author that the need for increased sampling frequency could thus be fully justified was open to question.

Whilst appreciating that the purpose of the paper was to discuss the analytical methods and procedures for assessing raw water quality, these fundamental assertions about sampling requirements must be challenged.

Numerous factors affected the frequency of sampling and the time at which samples should be taken. Time did not permit a detailed examination of these, but reference could be made to some of the more important points. It was important to look for correlations between sites and for cross correlations between quality parameters at a single site. The existence of strong correlations afforded good opportunities for reducing sampling and for reducing analyses. The variability of quality parameters needed examination and this variability could be either random or cyclic. The familiar daily, weekly, and seasonal cyclical patterns could be important and if properly understood could lead to major economies of effort and much more meaningful results.

The following references* would enable the reader to understand more of the problems briefly referred to above. Other opportunities for economizing arose through equipment for automatic sampling and compositing.

Mr. D. W. C. Rodda (Water Data Unit) referred to the reliability of data. On p. 78 the author stated, quite rightly, that continuous water quality monitoring stations were expensive to build and equip and were not cheap to run. The evaluations of automatic water quality monitors that had been carried out—packages from EIL, Plessey MM4 and, more recently, Philips (report not yet available)—had demonstrated the difficulties of designing and manufacturing such equipment. It seemed that, because of the small market for these instruments in the water industry, there needed to be some co-operative venture to produce a reliable and economic instrument.

On p. 86 reference was made to data collection and the development of "on-line" facilities. Would the author comment on the reliability of the data leaving his laboratory, bearing in mind the several factors involved—sampling method and means of transferring it to the laboratory, quality of reagents in use, and even the well-being of the analyst? The Water Data Unit were developing a water quality data archiving system, and had recognized the need to be able to assess the reliability of such data and to record this assessment.

Finally, it had been suggested that flow should be regarded as another "chemical determinand"! Would the author agree?

* Deininger, R. A. (editor). 1974. Ann Arbor Science Publishers Inc, Michigan, U.S.A., "Design of environmental information systems".

Water Pollution Control, 1974, vol. 73, p. 3, "The design of sampling programmes for rivers and effluents".

Dr. M. Richards (South Staffordshire Waterworks Company) said that the author had made commendable strides towards his objective of establishing a comprehensive analytical system for potable waters. Undoubtedly this trend towards automated analytical/computerized data handling facilities would be extended in the regional laboratories of the RWAs. However, many other laboratories were required to monitor safety and quality parameters of abstraction and supply waters without recourse to such analytical facilities. Under these different circumstances limited analytical facilities must be directed towards local hazards, identified from a knowledge of local industries, farming practices, etc. The WHO publication "European Standards for Drinking Water" commended such an approach by its recommendation for increased analytical frequencies in vicinities of toxic industrial discharges. He himself saw the continuance of both approaches as compatible and complementary.

Mr. F. Bell (East Surrey Water Company) said that the list of parameters in Table I (p. 81) included ammonia, but not albuminoid ammonia. He noted also that albuminoid ammonia did not appear in Mr Goodman's Tables on pp. 62 and 63. But Mr. Bays measured albuminoid ammonia (p. 129)! Was this parameter losing its traditional place on water report sheets? Was there a prospect of an automated measuring procedure being developed?

AUTHOR'S REPLY TO DISCUSSION

Mr. W. M. Lewis, in reply to the discussion, wrote that he hoped, as no doubt most analytical chemists would, that the text of Mr. Collinge's message would be assimilated by those people for whom the analytical chemist was striving.

Within the personal recollection of many of the relatively younger chemical fraternity aspects such as frequency of sampling, accuracy of analytical measurement, analytical chemistry (*per se*) together with advice concerning remedial action required were aspects delegated—sometimes in their entirety to the chemist within an undertaking.

Today, however, the world of water was different and the resulting ratiocination had directed that sampling frequency and the required analytical precision, together with any necessary corrective action, were no longer the prerogative of the person on whom the responsibility rested to produce analytical results. Similarly, present-day awareness of some of the health aspects of various contaminants was a topic engaging the minds of many important people and the voracious requests forthcoming for more and more information either on contaminant type or contamination levels, and particularly the fate of more and more particular compounds within the water cycle, was an excellent way of ensuring that a chemist—especially of the analytical breed—was being stretched, some might claim beyond the limits of reasonableness.

In short in a laboratory, subject to the imposition of economics, to-day's analyst had a fascinating and attractive but nevertheless arduous and frustrating task, not only in keeping abreast with demands made upon his organization re sample numbers and determinand variety, but equally important in being constantly aware of the newer analytical techniques and methods which would enable him to provide some of the answers sought.

The aim of his own paper was to attempt to convey to colleagues, who found themselves faced with such problems, how we as a laboratory organization attempted, though not always as satisfactorily as one would wish, to cope with the analytical imposition placed upon us.

Within the reorganized water industry there were some people who would strongly protest that they found themselves being repeatedly called upon to make judgements, perhaps in respect to future urgent major developments, based on data concerning water quality which might be abysmally inadequate for the purpose or, in some instances, marked by its absence. Such people, in general, were seldom blessed or embarrassed with a surfeit of essential data.

Academically, as perhaps also in an idealistic situation, the criteria listed by Mr. Collinge as items (1) to (5) would be desirable objectives and he would not presume to disagree. Unfortunately, when operating in a real world with all the limitations and strictures imposed coupled with the fluctuating influences generally suffered by industry one might be forgiven for accepting that desirable objectives and practical attainments were not synonymous.

He agreed with Mr. Collinge that one should set forth desirable targets and objectives and it was certain that those concerned with water quality data were also fully appreciative of such need. Perhaps his remarks, although directed to the analyst, might be arrowed really in the direction of others. Better still, he would suggest that the Institution could bear in mind the importance of Mr. Collinge's remarks when designing a topic for future discussion at a Symposium.

Mr. Rodda's remarks concerning automatic water quality monitors were very useful and the point he stressed concerning the need for a co-operative venture between water authorities was certainly worthy of pursuing by those responsible within authorities for such equipment.

The point concerning data reliability was of paramount importance. Obviously not only was the production of valid data within the laboratory of the utmost importance, but the "validity" of the sample as being representative of the water body at the time the sample was taken controlled all else. Personally, he had decided views on the subject of samples, having spent the whole of his working life involved in obtaining data from such specimens. But perhaps it would be impertinent to express general views on an aspect of work which now, if not previously, was an area of special responsibility.

There was a growing awareness within the industry that the quality of the analytical data (irrespective of the accuracy obtained) was only as good as the submitted sample. Three basic problems were constantly posed to a person responsible for the production of analytical data:

(1) The accuracy and the reproducibility of the method of analysis employed.
(2) The factor of fatigue of personnel producing such data.
(3) The arithmetical and transciption errors.

The production of control charts and the insertion of "known" control standards throughout the daily workload was introduced in an endeavour to be aware of vagaries and shortcomings in the days analytical output.

The fatigue factor of personnel was one which might be overcome almost completely by removing from the individual the necessity to undertake numerous repetitive assays and transfer such work to semi-automatic laboratory equipment such as that highlighted in the paper. Thus, the machine would operate continuously, as long as it was supplied with samples, and it would produce analytical results with the same degree of precision at 17.00 hr as at 08·30 hr and do so throughout that period.

The kind of problem posed, that involving calculations and transcription of analytical data giving rise to errors and the demand made by such chores upon laboratory time had been overcome to a large degree. Analytical data from the automatic equipment was logged onto magnetic tape. The latter, in conjunction with a computer and appropriate software, produced directly via high speed writer the final printed report form of the day's analytical results for circulation.

Such a system obviated the necessity of calculation and transcription checking by senior personnel and analytical chemists could now devote their labour to producing analytical results!

The last question posed by Mr. Rodda was obviously a factor of significance, especially when ascertaining "loading".

In reply to Dr. Richards, his faith in the future development of analytical work in the RWAs was commendable and one could sincerely hope that it would come to fruition.

Special circumstances called for special measures, which could well be inappropriate where the area of investigation was both confined and very limited.

Conversely, this did not grant the right to assume all was well. Comprehensive examination of all sources of drinking water was necessary to be aware of a condition—the results would suggest the frequency.

However, having satisfied oneself of the "nature" of the source and confirmed at a later date that the obtained data were "normal", then Dr. Richard's comments were appropriate.

It would be perhaps unusual to-day to find a situation where analysts were "going through the motions for the sake of performing"—far too much of the subject of water quality was unexplored territory.

Mr. Bell raised the query concerning albuminoid ammonia. When alternative procedures were not available this type of empirical test had merit. To-day however in general, and certainly within the organization he himself represented, it had been superseded by the Kjeldahl total nitrogen determination.

7. EMERGENCY PROCEDURES

By M. A. Stonebridge, MICE (*Member*)*

CONTENTS

INTRODUCTION

In recent years, many factors have combined to underline the need for contingency planning for emergencies and to establish procedures for dealing with situations that require prompt action. As far as regional water authorities are concerned, such emergency situations usually relate to a threat to public safety or health.

Local authorities and others have been advised in the past on emergency procedures and contingency planning in respect of natural disasters, coastal oil pollution, and inland oil pollution.[1,2,3] However, advice on dealing with emergencies can form only the basis of the more extensive contingency plans needed by a water authority. Although it is neither possible nor practicable to have contingency plans to cover every emergency situation that might arise, procedures must be set down by authorities which allow emergencies to be dealt with adequately and the public to be safeguarded.

Prior to 1st April 1974, the responsibility for contingency planning and action in civil emergencies rested in general with the local executive bodies including water undertakers, river authorities, joint sewerage boards, and local authorities who had statutory duties in respect of the services affected. Since then, the regional water authorities have been established and many of the procedures used by their antecedent authorities and undertakers are still in use; the tendency has been to build on the framework that existed. However, with large multi-functional organizations some of the old procedures may require reappraisal and updating in an endeavour to improve the efficacy of the emergency arrangements.

There are broadly three basic types of emergency situations affecting water authorities:—

(1) *A National Emergency.*—Such a situation would be defined by and be declared by national government and may arise from, for example, exceptionally severe climatic conditions, political pressure, or widespread industrial action. Any of these may result in failure of power supplies; recent examples include the dispute in the electricity industry in 1970 and the coalminers' strikes in February 1972 and 1973.

(2) *Regional Emergencies.*—These situations may arise as the result of a drought, flooding, or industria action, and may be regarded as internal to a water authority. Such situations may be relatively long in duration, but only local in effect.

(3) *Operational Emergencies.*—These are defined as failures due to the malfunction of machinery, mains, human error or accident. They are usually localized, and of relatively short duration.

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REGIONAL WATER AUTHORITIES AND AGENTS

Although management structures of regional water authorities differ, they are often such that the division may be regarded as being autonomous; the line management responsibility being delegated through the director of operations to the divisional manager. Under normal circumstances, divisions are managed and controlled by the manager, with only exceptional matters being referred upwards. Fig. 1 shows a management structure of the directorate of operations based on that of the Thames Water Authority. Wherever possible, the emergency control structure should parallel closely that required for the normal line management of the authority; it follows then that in a deteriorating situation leading to an emergency the transition does not raise too many management problems.

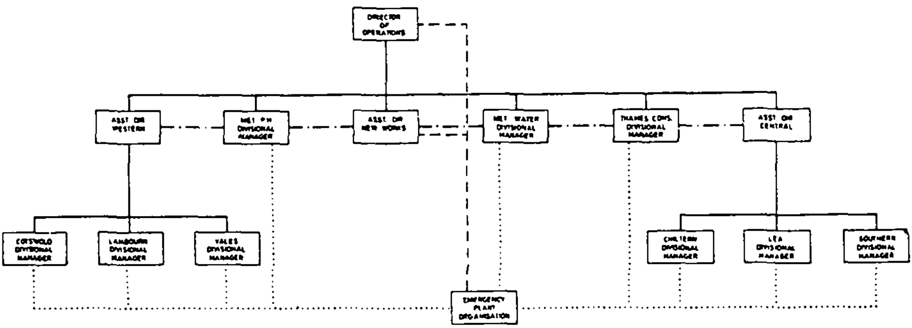

Fig. 1. Thames Water Authority—directorate of operations.

Key: ——— = line management. —·—· = inter-divisional co-operation. - - - - = emergency regional control—mobile plant. ...... = assistance to divisions.

The procedures adopted for use in an emergency should define clearly when and on what type of occasion regional management should be informed and consulted, when divisional management should be involved, and when local works management may be relied upon to deal with the situation. There are many occasions when, although a situation may be considered an emergency, it is purely of local significance and there is no need to involve higher levels of management. However, in the event of a serious or widespread emergency it is necessary to involve, as a matter of urgency, all tiers of management at divisional and regional levels and ultimately at national level.

With authorities having a strong divisional structure, it rests with the divisional manager to alert regional headquarters and vice versa of aspects of normal or emergency management that may have regional or national implications. It follows, therefore, that clear lines of communication for the flow of information in appropriate directions between various levels of management must be defined, in order that effective emergency control may be exercised by line management, and for that control to remain effective at all times throughout diverse and adverse circumstances.

Within a water authority's area, many of the local authorities act as agents for maintaining and controlling the sewerage function. These authorities have been reorganized recently and at present the new metropolitan, county, and district councils are evolving their own emergency structures and arrangements. Many of the old local authorities had efficient organizations which operated satisfactorily under adverse conditions. Local authorities tend to form a focal point for many emergency procedures and where there existed an efficient organization that could deal adequately with an occurrence, it should be utilized and wherever possible integrated into the water authorities' overall emergency procedure strategy. Often, when adverse conditions of any kind occur and emergency procedures are necessary, the local authority services become directly involved one way or another.

Although water companies may have their own emergency organizations for dealing with incidents, in so far as they are agents of the water authority it is necessary that divisional and regional management gives and receives adequate information and warnings concerning serious adverse circumstances arising in a company's area, particularly those involving requests for assistance. It is therefore imperative that the companies organizations are also integrated within the overall emergency plan.

COMMUNICATIONS

Although control procedures may be specified, written up, and studied by staff such intructions are, nevertheless, completely worthless unless adequate lines of communication have been established. It is essential that the various levels of management from plant operator to director or chief executive know precisely where they fit into any control procedure or communication system, in order that should any problem arise, they will know where to turn for assistance from within their own management structure.

Any control procedure or communication system should conform and be compatible throughout an individual water authority area. However, if divisions of authorities are autonomous then it might be considered acceptable that procedures should be compatible only within the divisional structure. Such a policy could prove to be erroneous, as in any emergency involving one or more divisons or perhaps authorities, the larger the integral unit possessing compatible procedures and lines of communication the more efficient is the service which may be provided on a regional or national basis.

Communication between local and divisional management is generally by personal contact or telephone; however, there are some divisions where radio equipment is available for normal and emergency control communication. Generally, radio communications had been acquired by the antecedent water undertakers, but little radio communication is available within or between the sewerage and sewage disposal functions.

In emergency planning the system of communication adopted must be reliable, and it may be considered that the telephone or telex system or any system involving the use of the public electricity supply for a power source is not sufficiently reliable. However, the degree of reliability inherent with any system may be increased by having dual systems of communication. In emergencies which occur in peacetime a system involving both the use of telex/telephone and radio may be the best available. Several water authorities have installed telex systems at divisional offices and at headquarters; these are likely to prove to be useful during emergencies or may be just desirable pieces of equipment. The use of the telex system has been found effective, as people tend to act on receipt of a telex and not to place it in the pending tray with correspondence of lower priority.

If an emergency control room is not manned continuously then a facility must be available to receive and scrutinize all messages whether by personal contact, telephone, telex, or radio, which may include warnings of adverse circumstances requiring urgent action as well as complaints and trivia. This can be done by the utilization of a continuously manned telephone switchboard, together with procedural instructions for dealing with various occurrences outside normal office hours. The vast majority of "emergencies" are minor in extent and, very fortunately, major disasters involving full-scale emergencies occur infrequently.

Emergency procedures are initiated by a regional water authority after warning or notification of some adverse circumstance is received from *inter-alia* government, the general public, the fire brigade, the police and statutory undertakers. Warnings are often received by telephone, and there has been recently some discussion on the number of telephone numbers that should be given by a water authority to other organizations. For example, it has been proposed that one telephone number should suffice for the whole of a water authority area. Bearing in mind the extensive areas covered by some authorities, members of the public are likely to be confused by a requirement to report flooding or burst mains to an office perhaps 150 miles away; often the reporting of incidents is more efficient when local phone numbers are used. However, if it appears that one telephone number for the whole of the area is sufficient, then the authority must ensure that any emergency or complaint reported on that number is dealt with quickly by the division or local management concerned. Whatever system is adopted, it should be compatible and acceptable to the police, on whom authorities rely to a large extent for warnings of incidents.

"Ansaphone" systems have been installed at several locations which are manned for part of the day only; the systems are monitored from time to time outside office hours to ascertain if any reports requiring immediate action have been left on the tapes. This appears to work satisfactorily and, with increaing use of automatic monitoring and reporting, perhaps more extensive use of such systems would be advantageous.

In the longer term it is envisaged that radio systems will extend to cover the whole of each water authority's area, possibly with links between neighbouring authorities. Such a network would enable information to pass between divisions, regions, and nationally, entirely independently of land line networks. It will be several years, however, before a radio system extending over a water authority area can be established. Meanwhile it will be necessary to rely on personal contact, telephone, and such measures of radio communication as are available.

CONTINGENCY PLANS

In a pending or actual drought situation, water authorities or water companies may apply to the Secretary of State for the Environment for a Drought Order to conserve supplies. The procedure when applying for an order is set down in Circular 54/58.[4] Much of the evidence required is of a technical nature and should include information on rainfall, source yields, river flows, quantities in store, groundwater levels, measures taken to reduce consumption, temporary works, etc. Now that water authorities control, either directly or through their agents, all storage reservoirs in their area, there are some aspects that may be investigated long before a drought arises. Procedures should be established and recommendations made for:—

(*a*) The optimum apportionment of reservoir depletion amongst groups of reservoirs, and the potential for interconnecting reservoirs.

(*b*) The collection of flash flows in rivers due to intense summer rainfall of short duration.

(*c*) Limitations on the use of stored water such as filterability, pumping rate, and draw-down depths, nitrate levels and other quality considerations in rivers and reservoirs.

The amount of standby generation provided at installations may require reviewing with respect to certain emergencies. However, when assessing requirements for standby generation it should be borne in mind that the Central Electricity Generating Board have their plans for dealing with adverse situations and these include the furnishing of priority supplies to essential services, including the water industry. Only in cases of exceptionally severe national emergency is prolonged failure of electricity supplies to water authorities likely. However, the water authorities would be expected during such emergencies to play their part in alleviating the situation by reasonable use of standby plant, particularly during peak hours, in close liaison with the Generating Board at local and divisional level.

To facilitate giving and receiving assistance, a composite list should be available giving names, addresses, and day and night telephone numbers of persons representing other organizations from whom assistance may be sought. Lists were available normally within the old local authorities and undertakers; some are being updated at present to incorporate the names of representatives of water authorities, new district councils, and those of other relevant organizations. It may be that such a task should be undertaken at national level so that a composite document covering all water authorities could be prepared.

The oil industry have a working group jointly with the water industry (OWIWG) and agreed procedures have been set down for dealing with emergency situations arising from the spillage of oil[5]. The working group is a useful forum on which both sides put forward their views. So far, it would appear that few difficulties have occurred in dealing with oil spillages on land. However, oil spillages at sea and in estuaries are another matter, and it is not proposed to deal with them here. In 1973 a survey by river authorities[6] showed that there were some 1400 spillage incidents involving an estimated 1 760 000 litres of oil.

Last year water authorities were requested to prepare a list of "key points" in the water services. The list enumerated installations that must be kept in operation in order to prevent risks to the public. A number of people had grave misgivings concerning the preparation of such a document. Whilst the value of the list in an emergency situation could not be denied, the possibility of it falling into the hands of people having anti-social or terroristic inclinations could not be overlooked. It was considered by some that the risk inherent in the existence of a single document listing all the key points which, if attacked would render parts of the water system inoperative, was such that it outweighed the value of the document. In practice, however, a list of key points does provide management with a valuable reference document detailing those places where procedures should be set down for the security, control, or need for assistance in the event of an emergency. The list in wrong hands, however, would also be an aid to those who wished to disrupt the system. From the security aspect it is essential that the information should be treated as confidential. It must not be forgotten that information usually falls into the wrong hands if those hands wish to find it.

Many water authority installations are situated in remote areas of the country and when preparing plans to meet with emergencies these installations should not be overlooked and the difficulties in reaching them should not be underestimated.

When damage to equipment, buildings, and the services around has occurred, it is essential that a set of working drawings of the plant are available readily at a nearby location for transport to the scene. Very often the only record/working drawings are held some distance away and are not obtainable readily. If "one-off" drawings are destroyed difficulties arise, and it is considered that duplicate drawings and/or microfilm records should be held in safe and secure places, accessible readily when required in an emergency.

Information should be published giving details of the procedures for leaving operational plant in a safe condition when it becomes necessary to evacuate a building in an emergency. It must be remembered that there may be little or no warning given for the operatives to leave a building. Even when the emergency is found to be a hoax, it might be several hours before personnel are allowed back to service plant. The position of all master controls and switches should be established, but not necessarily marked. It may be considered that certain plant must be kept in operation at all times—electrically driven plant may be shut down quickly; however, steam generating plant cannot.

When designing future pumping stations and treatment works the security of the site and buildings must be considered. Another design/operational aspect concerns the need to by-pass or isolate a plant without disrupting seriously the reticulation, whether water or sewerage, of which the plant forms a part. If the station or works is of significance, then the quantity of spares held in store or standby facilities needs careful appraisal, as would the methods of connecting up standby facilities into existing systems.

PROCEDURES

Some authorities may have set down in writing the various procedures to be followed at each individual works, in a division or throughout the authority when adverse circumstances arise and emergency measures become necessary. To the operator of a water or sewage treatment works it is likely that the failure of a valve or the malfunctioning of a large part of the plant will consitute an "emergency". However, it may be possible to deal with such an occurrence as a matter of almost routine. Whilst it is necessary for operatives to know exactly what steps should be taken, it is probable that even if the procedure has not been detailed, it is known by rote. It rests with management to ensure that procedures are placed on record so that necessary action may be taken by those who operate the plant under normal conditions, and those who might be called upon to service plants in an emergency.

Moving upwards in the management structure, divisional level is reached. Here again, how many divisions have their control or emergency procedures in such a form that management and operatives can readily refer to them? In some of the heavily populated areas of the country the antecedent constituent authorities had 24 hr manned or "on call" control rooms which dealt with emergencies. However, these are few and consideration should be given, in the longer term, to the establishment of regional and/or perhaps even divisional control centres that could be used round the clock. Failing this, authority-wide procedures must be established whereby staff may be assembled quickly on receipt of an emergency warning from a division or government.

There are a number of options open to an authority for emergency organization. For example, there may be a control room manned on a 24 hr basis by staff instructed in the procedures that should be adopted or initiated, and provided with a list of staff who should be called out or alerted when a reported emergency occurs. Such a control room would be located either centrally or at an authority's headquarters and have adequate communication facilities. It should be equipped with a detailed map of the whole region together with a comprehensive list of pumping stations, reservoirs, and works with details of their exact location.

It is considered, however, that a control centre need not necessarily be manned at all times, but only after a declaration from management at director level that some emergency existed which necessitated or warranted the 24 hr operation of the control centre. Such a system is flexible and does not entail fixed rotas of managerial staff and others. However, it tends often to rely on the good will and professionalism of a few responsible staff.

When notification has been received at divisional level of an emergency or possible emergency, more serious than that which can be dealt with at the local level, the procedures adopted should include amongst other things the items suggested in the next three paragraphs.

An immediate and rapid survey of the incident or situation should be carried out by divisional water authority staff with outside expert help, if required. The staff deployed should have a thorough knowledge of agreed emergency procedures and, if possible, experience in a similar type of emergency. The survey should ascertain the extent and implications of the incident and areas where assistance was needed forthwith to prevent, if at all possible, a deterioration of the situation. It should include also a rapid assessment of such matters as: dangers to the general public, housing and other property, the availability of power supplies, communications with the scene of the incident, dangerous working conditions, access and the proximity of other services, and should generally appraise the situation in order to ascertain any other special requirements. The name of the police officer in control should be ascertained, together with the location of the control post for the incident.

At this stage it would be beneficial for the authority officer in control to make an interim report to the divisional manager to enable him to decide whether or not regional assistance was required to deal satisfactorily with the situation. If the divisional manager elected to call for assistance, it would be then for the senior management of the water authority to decide whether the situation warranted the declaration of a regional emergency and/or the deployment of the regional emergency group.

If appropriate, the initial survey would be followed by a more detailed overall assessment and preparation of an action plan including requirements for men, plant, materials, welfare, replacements and standby groups, transport and communications, etc. Although it might be considered that some of these preliminary procedures are unnecessary and time-consuming in an emergency, if useful assistance is to be provided then it must be to the correct specification for the task to be undertaken, otherwise considerable wastage of effort may occur with consequent loss of time and even lives.

Whilst emergencies often appear similar at first sight, each tends to be unique. Consequently, procedures which may have been set down must be considered as guidelines only, and a considerable degree of managerial/operational latitude be allowed to those engaged in dealing with the situation.

From time to time incidents occur which involve the possible contamination, structural safety, or stability of a reservoir, intake works or pumping station. Attention should be directed therefore to the security of the more vulnerable aspects of organizations and to the related emergency procedures. It would be wise to ensure uniformity at least within a water authority area regarding inspection of reservoirs and for the recording and reporting of inspections having regard to the relevant statutes. Procedures should be established, if not already in existence, whereby reservoirs are inspected often and at specific intervals by both attendants and management; all events taking place in the reservoir area should be noted, particularly at those points vulnerable or open to attack. Any untoward occurrence or development likely to affect the safety of the reservoir, or any other structure, should be reported to divisional level, and the police informed immediately if sabotage is suspected.

The security of strategic pumping stations and plant will have been appraised, in all probability within the last few months, to ensure the safety of men and plant from bomb attacks. Advice given to staff must include the instruction not to touch or move any unauthorized packages but to notify the police and if necessary the emergency services. Advice on receiving or noting telephone calls relating to bomb scares needs to be given, so that not only is the location ascertained, but some details, however slight, of the person making the call are obtained.

In all situations there is a need for light, and some form of transportable emergency lighting equipment, generators and batteries should be available for use. Hand torches and lamps have only a limited use; it is much safer and preferable to have adequate all-round lighting when working in, for example, a badly damaged building or sump than to rely on a helmet or hand torch. Some of this equipment, if not all, should be flame proof and waterproof.

After a recent incident involving sabotage, the following basic items were regarded as being essential requirements so far as the water authority was concerned:—

(1) Informing other services at the scene of the name, etc., of the water authority officer in control of the incident.

(2) The name of the police controller in charge. There may be several senior officers at the scene; however, one of them is in charge and his name should be ascertained.

(3) The position of the police control vehicle.

(4) Details of other emergency services control vehicles present at the scene.

(5) When services or the police wish to leave the scene a formal handover should be carried out so that the water authority officer knows exactly when the police or others are leaving, and the extent of any police coverage that might remain on or near the site.

(6) Measures to prevent trespass at the scene by the press and the public.

(7) Once the police have left, it then rests with the authority to patrol the site and adequate security arrangements to keep people away should be put in hand. The use of dogs with handlers is recommended.

Finally, one important observation on emergency procedures should be made. When, at an emergency, an officer from any level of management is placed in control, then that person should be given complete control, irrespective of any higher levels of management who may attend the emergency from time to time.

EMERGENCY ORGANIZATIONS AND ASSISTANCE

The quality of the emergency labour organization that can at present be utilized effectively in an authority's area will depend still to a large extent on arrangements which existed prior to 1st April 1974. Although it may be assumed that new emergency organizations have been established within the water authorities, few have yet been tested under actual or simulated emergency conditions.

There are advantages to be gained by the establishment of emergency organizations at divisional level to deal with emergencies occurring in individual divisions. However, these should be backed by a highly trained mobile force available for duty throughout the region and serviced by one of the larger divisions. This group would be deployed as and when necessary throughout the whole of the authority's area and, if requested anywhere in the country. During an emergency the group would come under the direct control of the director of operations and/or the regional water co-ordinator. If such procedures were adopted then it would ensure that at least ten well equipped and trained gangs would be available to meet regional and, as a combined force, national emergencies.

The mobile emergency group should be formed, where possible, from a pool of volunteers, as in the situations that arise during emergency work the gang will be called upon to work long hours often under very unpleasant conditions. Experience indicates that, although adequate reward is offered for the work, those who volunteer for this type of employment do have an extremely high output and capability in such situations. A parallel might be drawn to the Life Boat Service in this kind of operation.

The size of the working gang needs careful consideration in respect of the emergency to be dealt with. A large gang cannot in some circumstances be controlled adequately and the total work output declines. It is preferable that the personnel are trained as a team. During the course of training they will gain confidence in one another as well as establish the shortcomings of their fellow members; this helps considerably in building an emergency team and preparing it for action at an incident.

Regional water authorities are empowered to request Government for assistance to ensure that key points are maintained. Naturally, a request of this nature should be made only when very serious disruption is imminent or has occurred. Before requesting assistance it should be borne in mind that whilst it may be possible to keep a small number of units operational with outside help, assistance cannot be provided readily on a national basis. Considering the number of sewage, water, or river pumping stations and treatment plants that are of the utmost importance in maintaining the welfare of the community, and the number of staff employed at each station, it is simple logistics to ascertain how many outside personnel would be needed in the event of a large scale emergency. Regional water authorities have the job to look after themselves; there will be occasions, however, when national emergencies have to be treated on their merits. If the use of outside help at both regional and national level is considered prudent, then arrangements exist and could be implemented at the request of a water authority.

Although assistance may be mustered fairly quickly, it might however take some time to reach the disaster site. There may be a period of time between the beginning of an emergency and the arrival of help, during which some form of emergency aid must be provided by the authorities themselves. It is during this period that the organization for emergencies and the associated procedures is significant. Management may find it necessary to operate the plant. How many managers are capable of operating plants for which they are responsible? It behoves all to ensure that managerial personnel and others are trained adequately in the basic requirements for operation of electrical, mechanical, chemical, or biological plant. The need may arise and it is up to the authorities to ensure that the capability is provided and safeguarded.

EMERGENCY SITUATIONS

In the past many emergencies in the country have resulted from flooding which occurred because rivers were not able to deal adequately with the flow arising in their catchments, and have often involved local, regional, and national emergency services aided and supplemented by the armed forces. The flooding that occurred over much of the country after the thaw in 1947, the disaster at Lynmouth in the early 1950s, the East Coast floods in 1953, and the flooding in south-east England in September 1968 are four instances that illustrate the necessity for the existence of procedures and communications which enable emergency services to be alerted quickly, and for those involved to have knowledge of the extent to which their own organizations can give help to others involved.

A type of emergency that occurs frequently on a small scale, and fortunately less frequently on a large scale, is the pollution of a river by accidental discharge of oil or other toxic chemicals from, for example, industrial premises or a tanker involved in an accident. It would appear that it has been the practice for the police and the fire services to notify the antecedent river authorities of occurrences involving the pollution of a river. This practice should continue in respect of the water authorities. It is a simple procedure, on receipt of such information, for an authority to alert divisions and if necessary instruct them to close the raw water intakes serving their reservoirs or water treatment plants. Where adequate reservoir storage is provided, there need be no interruption of supplies to either the public or industrial consumers, even if the emergency lasts for some time. However, there may be some difficulty if the bulk storage facilities available are insufficient or non-existent.

In the Thames Water Authority's area there are adequate bankside storage reservoirs between river intakes and the respective treatment works. In the London area, for example, these can provide some 90 days' supply at average demand. Thus, although the occurrence of such an emergency or drought might impair the yield of the river/storage reservoir system, there would not be an insurmountable problem. In 1971, when the dirty workers strike necessitated the closure of some water supply river intakes, in the Thames and Lee catchments there were no disruptions to water supplies.

The Steering Committee on Water Quality, set up by the Department of the Environment, put forward a recommendation[7] that at least seven days' storage should be provided by water undertakers between the abstraction point and the treatment works. There are divergent views on the validity of the recommendation in all circumstances. In the longer term, however, it would appear to be prudent and safer to have such storage capacity than to be without it, particularly where the abstraction point is situated on the lower reaches of a river system.

The Thames Water Authority has several large reservoirs in the vicinity of London Airport. The possibility of an aircraft crashing into one of these reservoirs has been considered, and a simulated exercise has been carried out in collaboration with the outside emergency services which might be involved if such a diasaster occurred. All those who took part are aware now of the shortcomings and difficulties involved in mounting such an operation in practice. The availability of emergency lighting units and communications were important factors, and it was agreed subsequently that each service should have adequate and preferably compatible communication systems. It has been shown recently that these communication systems should not be capable of being monitored by the public generally. The question may be posed, how many other reservoirs in the vicinity of an airport have readily available equipment to remove bodies or materials from their depths or surface? From where would such equipment be obtained in an emergency, and is it possible to reach the reservoir site?

Chemical, oil, and other materials are carried by road and rail in ever increasing volumes. There have been accidents involving transporters with the consequent rupturing of the containment tank. These occurrences are reported usually very quickly; the fire brigade, often with the help of industry, is efficient now in dealing with the spillage of chemicals. Along with other services, the water authorities are notified so that their emergency procedures can be initiated and any substance which may find or indeed has found its way into a watercourse or underground water-bearing strata can be dealt with.

However, it should not be overlooked that an accident might occur and go unreported. For example, if a road tanker fell at night into a river or open reservoir, the incident need not be noted for several hours, and considerable deterioration in water quality would have taken place. Many rivers in the country are used as sources for potable water and industrial water supplies, but few are monitored continuously to determine water quality and give warning of exceptional circumstances. This is an aspect of the problem which merits further investigation. In any case, the movement of all road and rail tankers carrying toxic compounds should be more carefully controlled and routed.

Often, it might appear that the easiest way to dispose of chemical spillage or other unwanted liquid and solid is by discharging it to the nearest sewer. Such action can be very dangerous, since sewers discharge their contents, after treatment or untreated, into rivers. If a sewerage system is extensive and the sewers large enough to permit men to work in them, then the discharge of certain chemicals into sewers could create hazardous conditions, particularly when a volatile liquid finds its way into the warm conditions prevailing in a sewer. Also, there are chemicals such as cyanide which render ineffective the operation of the bacteriological processes essential to sewage treatment and by so doing create additional polluting loads on the receiving waters. Co-operation between engineers and scientists engaged on the day-to-day operation of trade effluent control, sewage treatment, river management, water storage and supply is necessary to ensure that the potability of water is acceptable at all times.

THE FUTURE

In a sense the paper has been concerned with the future, as it has dealt with procedures for emergency situations the exact details of which cannot be known in advance. It is beyond the wit of man to prevent or foresee the occurrence of all emergency situations. Even the most sophisticated (and expensive) instrumentation devised by modern technology will not relieve in any way the necessity to make contingency plans.

However, continuing development in the fields of, for example, management, communication, instrumentation, automatic sampling, chemical and physical analysis, monitoring and telemetry, computing, weather forecasting, planning and operational methodology should enable the water industry to avoid completely the occurrence of some emergencies and to alleviate the effects of others, by either foreseeing them or dealing more efficiently with their consequences. The time span between an occurrence and the receipt of a warning may be decreased, but only if the advance warning of the onset of emergency conditions can be utilized will those conditions be mitigated.

The new regional water authorities are in a more advantageous position than the antecedent authorities and undertakers to benefit from developments and there has been progress already towards this end. The integrated resources and expertise available to a water authority are considerable and, subject to efficient management, this presents significant advantages in the face of emergencies. For example, there has been an increased awareness of the potential for conjunctive use of the industry's resources to alleviate flood flows and drought conditions.

In the short period since reorganization the combined potential of the new management structure in the industry and the technological and other developments has already become clear. There has been a growing awareness that water supply and sewage treatment and disposal and river management are all concerned with water and not with three separate and different "species" of water.

Again, with regard to pollution of watercourses the increased use of continuous water quality monitoring apparatus may in the new authorities be linked by telemetry systems with water abstraction to improve arrangements for preventing the potentially serious effect of pollution on potable water supplies. Region-wide telemetry schemes may provide instaneous information concerning rainfall, river flows, and by a judicious use of the computing facilities available in a large water authority, prediction of rainfall and flooding, storm paths, storm flows in sewerage systems, etc., become real possibilities.

Finally, whether the emergency occurs now or in the future much depends on the organizations that exist already, communications and co-operation between all levels of management, and the professional skills that can be found within the water authority. In this connexion the new structure of the Institution should play its part as it contains now engineers and scientists who, by using their combined talents, should be able to develop the necessary procedures and contingency plans to deal with any emergency that might affect the water cycle, whether it be from the water supply, sewage disposal, sewerage, or river management aspect.

ACKNOWLEDGMENTS

The author thanks Mr. E. C. Reed, DFC, Director of Operations, and staff of the Thames Water Authority for their help in the preparation of this paper.

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DISCUSSION

AUTHOR'S INTRODUCTION

Mr. M. A. Stonebridge, in introducing the paper, said that 18 months ago, few understood or realized what was implied when the then Secretary of State, in his forward to the Ogden report, referred to the Regional Water Authorities as all-purpose bodies responsible for the whole of the hydrological cycle. Now we were experiencing and appreciating the complexity of the task involved in the efficient and effective management of such authorities under normal conditions, and unfortunately, when emergency situations were involved.

Water authorities, as organizations, were matched by few other authorities in the range of their responsibilities. Dealing with emergencies was an important aspect of their service to the public. If it was technically and financially feasible, the possibility of an emergency situation arising should be prevented. If one did get into an emergency situation then it was the duty of the authority to alleviate the consequences. It was important that an authority's public image, in relation to the quality of service which was provided, was efficient and was seen to be efficient.

Nowhere was the complexity of a water authority more evident than when we sat down and attempted to draw up contingency plans for meeting the many and varied types of emergency situations which might be met. To many of us, the problems might be outside previous experience, and the duties in this respect were challenging and exciting.

A key point in any authority's emergency procedures was the reception point of any incoming report. All these had to be sifted, and it was obvious that a degree of discretion must be exercised on occasions by even the most junior of staff. Perhaps a guiding principle in setting up procedures should be that, apart from very senior management, no staff should be expected, or relied upon, to shoulder a wider range of discretion under emergency conditions than during their normal duties. When preparing procedures and reference documents, these should be drawn up bearing this in mind.

When confronted with a situation whereby sooner or later emergency procedures and services would be required, one particular aspect became paramount—communications. This applied not only with the organization, but also with the general public who were usually on the receiving end of most emergency situations.

The way in which the public were kept informed and made aware not only of the actual situation but what was being done about it, how it might effect them or others, and how they might help, were all points which should be got over to the public, local dignitaries and politicians in any serious situation. It was no good ignoring a situation and hoping it would disappear and that non-one needed to know or be told about it; that policy was courting disaster. Of course, in retrospect there would be many people who would criticize and generally find fault. Only by involving these people, who were usually quite well known, would adverse and often unwarranted criticism be diverted, and the true facts get published. We lived in an age when hard facts got overlooked, or so blurred at the edges as to be unrecognizable.

It was up to the authorities to project their image to the public, and at what better time than during an emergency when they could be seen to be helping or doing something positive.

Unless lines of communication were adequate, quite serious incidents often with far reaching effects could go unreported to management. Then, when nothing was done by the authority, and the first report was a story in the press, the administrative and political difficulties that arose followed an all too familiar pattern. There should not, however, be an over-reaction, to situations which had resulted from some trivial matter, particularly if these had been blown up out of all proportion during the communication or reporting procedures.

At the present time it was essential for all engaged in the water industry to be aware that an explosive device could be planted in any location within a water or sewerage system.

Everybody concerned with the incident would be much wiser after the event. Bearing this in mind, it was worthwhile to check on the security aspect and repair deficiencies. There would be some in most places. For example, check the locking of gates and doors, especially those at the back pumping stations. It was a simple exercise. Where shift work was involved, a quiet physical check on what actually happened when shifts changed could prove an enlightening and salutary exercise for many managers!

It was unfortunate that we lived in an age where sabotage and violence appeared to form an ever increasing aspect which must be taken into account. This was sad, as many authorities were now opening to the public gathering grounds, reservoires, and other installations. This must be borne in mind when designing new pumping stations, treatment plants, or remodelling existing plant. Security generally, and the vulnerability of key equipment, needed to be considered much more than in the past.

It was appropriate to refer briefly to some of the advantages which had already accrued as a result of the integrated management of the water cycle, with special reference to emergency situations and procedures.

It was now generally recognized, and even accepted, that some antecedent authorities who had been responsible for part only of the water cycle adopted a somewhat blinkered approach in that they were only responsible for part of the cycle and really needed to take no interest in anything but their own functions and where these were only directly affected.

Significant benefits had been reaped already from reorganization, derived from the pooling of resources of all kinds to meet emergency situations. Reorganization had brought with it the will as well as the resources for dealing with the complex situations involved. His own comments would be confined to experiences in the Thames Water Authority.

During November 1974, widespread flooding throughout the area had created a serious situation which was more easily dealt with by regional resources than by purely local resources. The staff and equipment of two river divisions were quickly fully extended and were accordingly augmented from the other multi-functional divisions. In addition, abstraction at raw water intakes was maximized in order to give such local relief as possible. Before reorganization such an occurrence would have been unthought of.

Regarding communications, the former authorities had purely functional arrangements. These had now been made available to multi-functional divisions covering water, sewerage, sewage disposal, and river works. Radio systems, in particular, could be utilized across the board during an emergency, under the integrated management of a regional water authority.

When proposals for remodelling or providing new resources, pumping stations, treatment works or other installations were being considered, and their use or need in an emergency must be justified, then whilst the proposal might be sound in isolation it might not be so pressing if the unreliability of the plant was set against the greater regional emergency capability that could be called upon in the water authorities. In fact, some schemes could even be deferred on this account.

Finally, emergencies affected property, as well as the livelihood and well being of individual members of the public. A public authority faced with an emergency situation was in the limelight and at no other time was it liable to be judged more critically than in the handling of an emergency. It was up to all regional water authorities to ensure that their emergency procedures were sufficient to enable them to deal satisfactorily with virtually any situation.

Verbal Discussion

Mr. E. C. Gordon (South West Water Authority), in opening the discussion, welcomed the references to actual emergencies. The author had commented that few of the emergency organizations of the new authorities had yet been tested. If this was so, it was surprising but there was undoubtedly a general reluctance to publicize those pollution incidents which had recurred. After a previous paper, mainly devoted to case histories of pollution, many stories of similar instances came out, but always in private conversation.

Regarding the final paragraph in the section on "Procedures" (p. 101), of course top management must delegate. It must give support where needed but not succumb to the temptation to take over from the field staff. Later, the author mentioned the need for management to operate the plants themselves in an emergency. This might relate to situations such as the "dirty workers" strike, but was it really practicable? Perhaps the mere hint that office staff were to be let loose on their plant might be enough to drive attendants and technicians back to work!

The author's coverage of the subject was most comprehensive and left one wondering how authorities were actually measuring up to these procedures. In the case of his own Authority, it was felt that good communications were so essential that it was proposed to put in a direct telephone line from a sewage treatment works to the downstream water abstraction and treatment plant rather than to have vital messages go by an indirect route.

The setting up of emergency teams by each authority, so that they would be capable of acting together in a national emergency, seemed a sound proposal and, together with measures for the pooling of emergency plant and mobile generators, now awaited organization on a national scale.

An omission from the procedures listed in the paper was a measure to deal effectively with the press. The presence of the public relations officer at the incident centre was important if the wrong type of publicity was to be avoided.

Little had been said about the periodic practices that were necessary to train and test the emergency organization. We normally had fire alarms and gas mask drills but could learn from the specially set up incident drill used by the fire service, even if we would not want the equivalent of a home office inspector to check effectiveness.

Finally, in looking in such a detailed way at procedures and organizations, were we in danger of losing sight of what had been said so many times in previous papers, that prevention was better than cure? There was no substitute for the maintenance of a high degree of professionalism in staff, with an attitude of constant vigilance at all levels of staff and a direct line of communication.

Mr. R. G. Toms (Wessex Water Authority), commented that it was usually a breakdown of communications that led to problems in dealing with emergencies. He disagreed with the author on the use of "Ansaphone", as it was ludicrous that a person with a serious problem such as flooding, should ring into the office and be asked to leave a recorded message. This was not the way to deal with emergencies, and it gave a poor public image of the service provided by the authority. Time was the essence of successful operation in an emergency, and a 24 hr manned service was essential.

He referred to the emergency service used by his own authority in dealing with pollution complaints. This depended on a 24 hr communication centre at Warminster (with a freephone service from anywhere within the region), and a stand-by service consisting of an incident controller and a field officer. The former would become the centre of communications once he had taken over the incident and would remain at a point where he always had means of communications with authority staff and anybody else effected by the incident. The field officer would undertake the inspection and general field work under the guidance (via radio) of the incident controller. Thorough training was an essential part of their preparation.

Mr. G. Robinson (Northumbrian Water Authority) said that on p. 94 the author had listed three types of emergency situations. However, in writing the paper and presenting it he had concentrated on the first two categories— a national emergency and a regional emergency—almost to the exclusion of the third category, operational emergencies. Whilst the reason for this was obvious, it was essential when setting up emergency procedures to bear in mind that operational emergencies (such as fractured mains) occurred every day, whereas national and regional emergencies rarely occurred. In deciding the location and number of control centres for example, it should be remembered that the control centre staff would be dealing every day with operational emergencies and therefore these centres should be located at divisional headquarters rather than at regional headquarters.

The Ansaphone system, referred to on p. 97, was entirely unsatisfactory. When a consumer telephoned, he ought to have an immediate response and know with confidence that the matter was receiving attention.

The author had asked whether operational staff or scientific staff should take control in an emergency. It was only operational staff who would fully appreciate the consequences of the actions which had to be taken and therefore they must remain in control during an emergency as they were at all other times, supported by whatever expert advice was required. In some cases, the operational staff involved would be scientists.

Author's Reply to Discussion

Mr. M. A. Stonebridge, in reply to the discussion, thanked Mr. Gordon for his contribution.

There were several things that were learnt from the Woodford explosion. Firstly, the importance of communications, both within one's own Authority and with the other statutory bodies and services who were represented at the scene of the incident. Secondly, listed on p.101 were seven points all of which, when considered with the benefit of hindsight, were seen as matters which should be cleared at an incident in order to make things a little easier for those having to control the situation. Thirdly, he drew attention in his introductory remarks to the value of examining from time to time the procedures adopted and actual happenings taking place in and around one's installations.

Fortunately, so far there had not been an accident at a reservoir involving aircraft. The exercise held in the Thames area was carried out following the crash of a Trident aircraft at Staines, which occurred in close proximity to several major storage reservoirs operated by the Authority.

It had been found that an emergency mobile gang was extremely useful in dealing with situations within our area and in providing assistance to others. In fact, some of the emergency force were at present helping out in the Glasgow region in laying a temporary/permanent trunk main.

As the division was in most authorities the executive unit, it followed that the majority of emergencies should be dealt with at divisional level. Only those with serious regional implications should be dealt with by the headquarters organization of an authority. In most water authorities the divisional manager was responsible to the director of operations for the management of his division and for the provision of services to the public during normal and the vast majority of emergency situations.

It was interesting to hear from Mr. Toms about the emergency set-up in Wessex, on the pollution control side. It would appear that his authority had gone some way to meet any situation that was reported by providing a freephone service and that he also regarded the communication aspect of a situation as being very important. He agreed with his comments on exercises; it was only by constant practise that one made perfect the procedures that were set down on paper. When the crunch came and one was called upon to act in an emergency then, and only then, did the loop-holes that one had attempted to close so carefully became apparent.

Mr. Robinson considered that the list of three types of emergencies was a little short. This could well be so, but his own view was the shorter the better. He agreed that there were many more of the local operational type of emergency than the regional or national emergency. Certainly, the minor ones were just as important in their own context as the major ones, and when considering emergency procedures from an overall headquarters point of view, it was important not to overlook the fact that the division was the operational unit and must deal as far as possible with its own emergency situations.

Summing up, he had found the points put forward in the discussion useful. Some had raised the possibility of other procedures and guidelines which were worthy of a place in any emergency procedure document.

8. REQUIREMENTS FOR A WHOLESOME WATER

By D. H. A. Price, CBE, BSC, FRIC*

CONTENTS

WHOLESOME

Although there is no statutory definition of wholesomeness, the application of the word to potable water is appropriate and has, in practice, proved its worth. There may be differences in detailed interpretation of the expression but most people agree on its general meaning. The essential requirement for potable water is that it shall not give rise to any ill-health; if it does, it is not wholesome. But wholesomeness is more than the failure to cause ill-health. It implies that, even if harmless, the water will not give rise to any feelings of disgust and will be attractive to the drinker. The water must therefore be free from objectionable taste, odour, or appearance and if it does not comply with these negative requirements it is not wholesome.

Key[1]** has gone further in considering wholesomeness and has stated:—

> "... no substance not naturally present in water, and therefore proved safe by decades of experience, should be present if its presence can reasonably be prevented, or be removed, even if no evidence that it does harm exists. I do not think I want to drink anything merely because it does me no harm".

While not disagreeing with this view it is one which is increasingly difficult to maintain under modern conditions and scarcely practicable to justify as an essential criterion for wholesomeness.

Having agreed in general terms as to what are the requirements for a wholesome water from the consumer's viewpoint, the next step is to convert these into corresponding restraints upon the supplier who needs them to be defined in terms he can measure and monitor. He wants numbers and much time and talk has been expended in preparing lists and figures to meet this requirement. It is not proposed here to reproduce any of these lists or to discuss them exhaustively because the paper is addressed to water specialists who are already well informed on what might be termed the "text book" aspects of the subject. Formulation of standards for drinking water is a complex subject and one in which current thinking is changing rapidly. The remainder of the paper is concerned with the general approach to the problems and with some of the more topical aspects.

There are three groups of potential constituents of water, i.e. bacteria, other organisms, and chemical substances and the wholesomeness depends upon the harmfulness and the acceptability of each of the three groups.

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** A numerial list of references is given on p. 119.

BACTERIA

These were the original major health hazards of drinking water but the combination of physical precautions and chemical treatment which has been developed can now ensure, in this country, an extremely high standard of safety. The bacteriological standards recommended officially[2] have been proved by long experience to be adequate to define a wholesome water so far as bacteria are concerned.

Bacteriological monitoring by *E. Coli* is indirect in that it is based on the observation that the pathogens are always accompanied by *E. Coli.* The ratio of *E. Coli* to pathogens is not a constant but will depend upon the ratio of the sources of the pathogens to the total population contributing to the pollution. It seems likely that over the years in the U.K. the number of sources will have fallen and if that is so the ratio and therefore the safety factor will have improved.

So far as the acceptability of the water is concerned, bacteria may form or subsist in biological slimes in the distribution system but this seems to be an uncommon and controllable phenomenon.

OTHER BIOLOGICAL ORGANISMS

Viruses

This is a subject about which there is a lack of knowledge, arising in part from the difficulty in detecting and counting the organisms. It is claimed that there is no conclusive demonstration of the transmission of virus disease by drinking water although there is a strong presumption that an outbreak of hepatitis in New Delhi in 1955–56 was water-borne. Clearly, more work is needed but at present the evidence does not appear to justify the monitoring of all drinking waters for viruses. Accounts of viruses in water have been given by Poynter[3] and by Poynter, Slade, and Jones[4].

The WHO[5] state "... 0·5 mg/l of free chlorine for 1 hr following normal water treatment processes should be sufficient to inactivate viruses even in water that was originally polluted". It may be that control, if thought necessary, could be exercised by stipulating minimum treatment as distinct from the usual standards and analytical monitoring.

Parasites

Intestinal parasites do not appear to pose a problem in water supplies in this country, but filtration to remove bacteria would be expected to remove parasites also. Their presence in water would render it unwholesome.

There is a wide range of animals which may infest the distribution system and either emerge from the tap or cause discolouration or taste or odour. There is a comprehensive survey of the problem by Smalls and Greaves[6]. While none of these organisms poses a health risk, they not merely detract from the appearance and attractiveness but render it repugnant and few consumers of such water would accept the description of wholesome.

CHEMICAL SUBSTANCES

Toxicity

The toxicity of chemical substances may be acute or chronic. Where the toxicity is acute and the ingestion produces a rapid reaction the connexion between cause and effect is easy to establish and assessments of the dose/effect relationships can be made. The acute poisons are mostly well known and the introduction of any new substances in this group is usually not difficult to detect.

In contrast the chronic toxic substances produce an effect following long exposure to low levels. This may be because they accumulate when their rate of intake exceeds the rate of excretion or because their effect though small is irreversible and cumulative. When a substance produces an effect at low concentration only after long exposure its recognition as a harmful chemical may be long delayed. The longer the time which elapses between the onset of the exposure and the emergence of a harmful response the more difficult it becomes to detect the relationship. The response may be carcinogenetic, mutagenetic, or teratogenetic and hence delayed for years or even one or two generations. There is a useful discussion on these substances by WHO[5].

Toxicity Limits

The physiology and metabolism of all men is fundamentally the same and it might at first sight appear to be feasible to lay down limits for toxic substances which would be of universal application. Closer consideration demonstrates the complexity of the problem. The answer to the question of what concentration of a substance in water will not cause ill health depends on answers to a number of other questions.

Firstly, "*what other intake?*" The effect of a substance on man depends upon his total bodily intake and the safe limit is expressed as the acceptable daily intake (ADI). The contribution permitted from water will vary according to the contribution by food. A well known example is lead where under normal circumstances and the accepted limitations the lead input from water may be 20 per cent or less of the total body intake. One consequence of this is that variations in the permitted intake from water are not so significant proportionally as might appear. If the permitted lead input from water were to be reduced to one-half it would reduce the total body intake by no more than one-tenth on the basis of the previous figure. Where there are multiple sources of a substance and reduction of the total body intake is deemed necessary, it is clearly desirable to take action where it is easiest, which may, or may not, be in water.

The second question is "*when is a substance toxic?*" There is an old saying that there are no toxic substances only toxic concentrations. A number of substances with restrictions upon their maximum concentrations are essential elements. Examples are copper, manganese, molybdenum, selenium, zinc, and trivalent chromium. For these substances there is not only a maximum ADI but also an optimum and a minimum and the acceptable amount or the required amount, if any, in water will depend upon the intake from food.

A well known example of a substance with an optimum and a maximum permitted intake is fluorine. Could it be argued that if the concentration in the water is below the optimum and therefore permits a deterioration in bodily health, as say an increase in dental caries, that the water is not conducive to health and is therefore not wholesome?

Another question to be answered is "*to whom?*" There may be markedly different responses to the same body intake by young children, old people, pregnant women, and people suffering from various illnesses. These people may be much more vulnerable than a healthy adult. An obvious example is the effect of excessive nitrate on children during the first few months of life. This raises a question of how far provision should be made for the requirements of small minorities by restraints upon the whole water supply or whether alternative means of protecting such people should be employed.

A further question is "*where?*" Water consumption, and therefore total daily intake through water, varies according to ambient temperature and this can be and is recognized by differences in concentration limits between places with hot and cold climates. Water consumption will for a similar reason vary between winter and summer, but no attempt seems to have been made to cater for this. It may be of less significance for substances whose effectiveness is long term and where limitation of the annual intake is sufficient. People accustomed to a particular supply may be acclimatized to a level of a constituent of that supply which may affect a short-term visitor. A high concentration of total salinity is an example where the visitors may not agree with the residents as to the "wholesomeness" of the water supply.

The question "*in what form?*" includes such instances as chromium which is more toxic in the hexavalent than the trivalent form, and the notorious methyl mercury as distinct from say, calomel. It is simple to designate these forms in chemical terms but there may be a possibility of conversion from one form to the other *in vivo,* and perhaps in the wrong direction.

The last, and perhaps one of the most difficult questions is "*what else?*" because it raises the question of synergism and antagonism. A useful review on these subjects has been made by Shakman[7]. Ascorbic acid counteracts the toxicity of hexavalent chromium, by reducing it to the trivalent form, reduces the toxicity of zinc and cadmium and also reduces the effectiveness of nitrate in producing methaemoglobinaemia. Cadmium and zinc are antagonistic, the less toxic zinc replacing cadmium in bodily metabolism. Selenium, itself highly toxic, counteracts the toxicity of cadmium, mercury, and arsenic. It might perhaps be maintained that in arriving at permissible concentrations antagonistic effects should be ignored because they cannot be relied upon to be present at all times. They might perhaps be regarded as gratuitous safety factors.

ACCEPTABILITY

Those characteristics affecting the acceptability as distinct from the health effects are sometimes termed organoleptic, a word not in general use in the U.K. The term covers the following characteristics—colour, taste (sometimes translated as flavour), temperature, turbidity, foaming, and staining propensities. Most of these characteristics can be described in numerical terms although the determination of some of them is of necessity subjective. The acceptability of the different items will vary between populations of consumers depending upon latitude. The people of Inverness will regard as normal a peaty colour which would cause alarm if it emerged from the tap in an area supplied in the South East by groundwater. People accustomed to soft water complain about washing in hard water and in reverse, hardwater users complain because they cannot wash off the soap in soft water areas. Nevertheless, there are characteristics which would be generally agreed can be unpleasant and one of the commonest is taste.

Regarding odour, an interesting paper has been produced by Zoeteman and Piet[8] in which they made comparisons between the minimum level of odour detection in water and the toxic concentration of about 100 organic substances. They state:—

> "... the human sense of smell is an excellent warning for the presence of toxic organic micro-pollutants in water. There are no substances found that will cause acute toxic effects in man by consuming contaminated drinking water before their presence in water can be smelled".

This observation is reassuring and supports the belief long held in some quarters of the water industry that accidental pollutions by oil and other organic substances do not represent a serious health hazard because they taint the water well below the harmful level. There may be an element of natural selection in the development of this sensitivity in man.

ORGANIC MICROPOLLUTANTS

This is a group of substances in which special interest has been displayed. During the last three or four years there has been a substantial international research effort in the subject. So far as the writer is aware no account of the international work has yet been given in this country and since he has been concerned with the project from its initiation it is appropriate to describe it here in some detail.

The idea originated as a result of the question "how much sewage effluent can we tolerate in drinking water?" It was difficult to find a scientific basis for any figure beyond saying, as Key was quoted earlier, in effect "the cleaner the better" or to put it in a more picturesque American fashion "virgin is better than repentant water".

Public water supplies derived from rivers may contain several milligrams per litre of total organic carbon. Little was known about the composition of these organic residues or their effects upon the consuming population. It is true that the quantities are small but the exposure is for a life time. It was believed that residues of natural origin, i.e. from vegetable or animal sources might be less potentially harmful than those originating from artificial, synthetic sources, but this was an assumption. It was decided by the Department of the Environment to commission both the Medmenham and the Stevenage laboratories of what is now the Water Research Centre to attempt the difficult analytical task of identifying and determining as many of the organic constituents in surface and drinking water as was possible. Stevenage investigated mainly effluents and Medmenham river and drinking water. Medmenham installed a gas liquid chromatography-mass spectrometer combination and Stevenage concentrated on liquid-liquid chromatography. A review of the subject was made by Croll[9] in 1972.

In 1971 the European Economic Community (EEC) set up a committee to consider projects for joint research within the Six and invited European non-member countries to collaborate. There was a number of subcommittees including one for "nuisances" covering air and water pollution. A water group, chaired by the U.K., was asked to propose appropriate topics and suggested two, one dealing with sludge treatment and the other with the establishment of analytical techniques for organic micropollutants in water. The two projects were accepted and that for micropollutants was designated, for historical reasons, as Cost 64b.

COST 64b

The terms of reference for the project are:—

> "Development of methods for analysing as completely as possible the organic pollutants present in a sample of water. The method should cover the whole range of organic constituents and enable them to be identified and their concentration to be determined to stated limits of detection".

The terms are incorporated in an agreement signed by the Governments of 12 European countries in Brussels on 28th February 1972.

An agreed programme of work is carried out on an "action concerté" basis. Each country volunteers to undertake work on a chosen section of the programme, committing itself to an appropriate annual expenditure. There is no transfer of money and all contributions are in kind. The project is directed by a Management Committee comprised of delegates from each of the signatory countries and the Committee is autonomous. It is serviced by the EEC and during the first year was chaired by the Swiss delegate; in the subsequent and current year the U.K. delegate has been, and is, chairman. The agreement lasts for three years, expiring at the end of 1975, but the project will continue under somewhat modified administrative arrangements with greater involvement by the European Commission.

The signatory countries and the number of participating laboratories in each are:—

Country	*Number of laboratories*
Denmark	2
France	5
Germany	2
Ireland	1
Italy	2
Netherlands	2
Norway	1
Portugal	1
Spain	1
Switzerland	5
United Kingdom	2
Yugoslavia	5
EEC	1
	30

The participating laboratories in the U.K. are Medmenham and Stevenage and their contributions arise largely from work already commissioned by the DOE. The U.K. has played an influential part in the project and the involvement has been of substantial benefit to the course of our own work.

The programme of work was originally divided into five sections and later expanded to six.

Participation in the work of the different sections or study groups is on a laboratory and not a country basis. For each group there is a co-ordinating laboratory which organizes group meetings and collaborative tests, collates the work of the group and reports annually to the Management Committee. The Committee in turn produces an annual report which includes summaries of the group reports. As was to be expected, the first year was largely an information exchange and planning phase but collaboration developed quickly and in the second report concrete results are seen to be emerging. The work of each of the six study groups is now briefly described.

Study group 1: Sampling and sample treatment co-ordinating laboratory, Water Research Centre, Medmenham Laboratory, U.K.

The work of the group is ". . . to evaluate, refine and develop methods of separating organic substances from water and pretreating the extracts so that they are in a form suitable for presentation to equipment for separation and detection".

The group has interested itself in a wide range of techniques for the isolation and processing of organic constituents of waters and the associated risks of modifying or contaminating the samples. The methods considered include solvent extraction, absorption, head space vapour analysis, evaporation and steam distillation, freeze concentration, and zone refining. They have also been concerned with the analysis of living organisms and seston, i.e. particulate matter in water. The group have evidence that there are serious problems arising in the storage and preservation of samples at all stages.

Study group 2: Liquid chromatography co-ordinating laboratory, Water Research Centre, Stevenage Laboratory, U.K.

This study is of particular interest because the gas liquid chromatography methods do not determine the non-volatile organics and therefore ignore perhaps 60 per cent of the total organic carbon in water whereas the liquid chromatography methods cover the non-volatile compounds. The use of high pressure liquid chromatography is promising but is at present limited by the inadequacy of the detector systems available; developments in this field, however, are rapid. Attempts are being made to obtain a sensitive and universal detector, to employ the technique for separation and also to find means of interfacing liquid chromatographs directly to mass spectrometers. The method is being developed for the determination of polynuclear aromatic hydrocarbons in water. It is perhaps in the field of high pressure liquid chromatography that the best promise of future progress lies.

Study group 3: Separation and detection techniques co-ordinating laboratory, EAWAG, Dübendorf, Switzerland.

In order to compare the various separation and detection techniques employed in different laboratories the co-ordinating laboratory circulated, to the 13 laboratories in the group, replicate samples of a test mixture containing 18 different compounds.

The participating laboratories have reported on a whole series, 12 in number, of special separation and detection methods. There is a trend towards the adoption of high resolution capillary gas chromatography and the co-ordinating laboratory organized an instructional course on this technique. The co-ordinating laboratory hopes to incorporate most of the existing methods into a common flow scheme providing a comprehensive structure for the analysis of organic compounds in water.

Study group 4: CC/MS coupling and operation co-ordinating laboratory: CERCHAR, Creil, France.

This group has been investigating and comparing the performance of the varying technical equipment available in the 16 participating laboratories. Two circular analysis programmes have been carried out on prepared and natural samples, but limited to qualitative aspects of separation and detection. A programme for quantitative inter-comparison is to be initiated shortly.

The laboratories report on and discuss improvements of equipment and techniques.

Study group 5: Reference data, co-ordinating laboratory CEA, Grenoble, France.

This group is compiling a collection of mass spectra, in a standardized form, of compounds appearing in water for use by the laboratories of 64b. The compounds are indexed under reference numbers, molecular mass, molecular formula and height of the ten highest peaks. The information includes published data on the IR-, UV-, NMR and Raman spectra. The number of mass spectra in the collection is now about 1000.

Compilation of chromatographic data has been started using an agreed format applicable to the operating conditions in the different laboratories.

Study group 6: Data processing co-ordinating laboratory, Institut fur Heisse Chemie Kernforschungszertrum, Karlsruhe D.

During the initial stage of 64b it was agreed to defer establishing a study group on this topic until data began to accumulate. A meeting was held in Karlsruhe in March 1974 and Group 6 was set up with the main task of the collection of G.C. and M.S. data and the exchange of the data between the laboratories by means of paper tape. The input to the co-ordinating laboratory is processed and included in a master library which can be copied to all laboratories. The group works closely with number 5 group on reference data whose output is included in the master library. A data format has been agreed and a plan for the whole of the necessary software package has been prepared and is under test. Collaboration with other data banks of mass spectra is under consideration.

In March 1973 a technical symposium was held in Beaconsfield attended by representatives from about 30 different laboratories and in October 1974 a similar symposium was held in St Witz, outside Paris. These symposia provided an opportunity for the analytical workers to report their results, to exchange experience on methods and equipment, and to consider the direction of future work. These meetings proved to be most useful and a third is to be held later in 1975.

THE USE OF 64b

The original purpose of 64b was the development of analytical methods but these were means to the further purpose of identifying and determining organic micropollutants. By common agreement the Management Committee extended the scope to include the collection and listing of organic micropollutants detected in water by the participating laboratories. A first list of about 240 compounds was prepared and circulated by the Stevenage laboratory of WRC and in October 1974 the Stevenage laboratory produced an extended list of over 1000 compounds. The list includes data from the 64b laboratories and from the literature from 1960 onwards. The substances have been divided into 22 groups in order of general toxicity. The observed concentration is given but the list includes compounds which have been identified although it has not been possible to determine their concentration. It includes samples from most types of natural fresh surface water, from a range of effluent discharges, from underground waters, from tap waters and from some relevant solid samples.

An inspection of the list indicates that the number of samples of tap water investigated is relatively small. It is the intention in the U.K. to concentrate more of the effort on the analysis of tap waters and the corresponding raw waters from which they are derived and this shift of emphasis has been suggested in the Management Committee also.

THE ULTIMATE PURPOSE OF 64b

The identification and determination of organic micropollutants is still but a stage to the ultimate purpose of 64b, which is to assist in reaching decisions about the wholesomeness of a water supply. The analyst having drawn up his list has then to pass it to the toxicologist for his views. Adjudication on the list is by no means easy. Knowledge on the effects of long-term exposure, i.e. a lifetime exposure at these very low concentrations, is difficult to obtain and long-term toxicological studies involve a considerable research effort. Moreover, at these concentrations the determination of the "no-effect" level or the threshold level, if it exists, is almost outside the range of scientific experimentation. It has been suggested that the extremely small concentrations of some of the compounds listed represent exposure so low that they are unlikely to have any significant effect.

In January 1975 the WHO Reference Centre for Community Water Supply convened a a working meeting in Amsterdam on health effects relating to direct and indirect re-use of waste water for human consumption.

The first 64b list of 289 compounds was submitted to the specialists attending the meeting, who classified selected compounds in terms of known acute and sub-acute toxicity and identified those known to create odour problems. They also prepared lists of substances requiring a full scale chronic toxicity study and others needing a sub-acute toxicity study. The report of the meeting is not yet available and no action to implement the recommendations has, so far as the writer is aware, been taken. During this meeting the larger list of 64b became available.

OTHER APPROACHES TO MICROPOLLUTANTS

Cost 64b is the analytical "needle in a haystack" approach which is now beginning to yield results, but it is not the only one. Epidemology is sometimes referred to as a blunt and clumsy tool but it has been responsible for the recognition of many unwholesome constituents, both biological and chemical, in water. Our present preoccupation with mercury and cadmium arises from epidemological observations. Would it be possible to carry out studies of comparable populations supplied with completely raw water and with water containing a high proportion of sewage effluent, or upon populations where a substantial change has or will occur in the proportion of effluent in the raw water?

Attempts have been made to accelerate the effect of selected waters upon experimental animals by supplying them with water in which the concentration of dissolved solids has been increased by evaporation or similar processes. These trials are open to the criticism that the process of concentration may lead to chemical changes, and that it assumes a constant relationship between exposure and effect over the concentration range which may not be true.

Because of our lack of knowledge of the organic components we can fall back on the adage, "the less the better". The total organic carbon content of what is regarded as a good drinking water may be several mg/l and a tentative acceptable limit of 5mg/l has been proposed. It is possible to reduce the organic carbon content further by activated carbon and on the supposition, which may not be valid, that the activated carbon does not discriminate between the good and the bad, the water may become more wholesome as the organic carbon content is reduced by treatment.

There is an assumption that substances of artificial origin, i.e. synthetic compounds, may in general be more objectionable than those of natural, i.e. biological, origin, such as humic acids. Since the humic acids tend to be non-volatile, the volatile organic carbon content might be a more reliable indication of the presence of potentially harmful compounds than total organic carbon.

STANDARDS

There are numerous interacting factors which influence the answer to the question what is a wholesome water and the attempts to lay down figures for maximum permissible concentrations which will cover all circumstances must involve compromises whose adequacy, and inadequacy, will vary according to the circumstances.

The practice in the U.K. of relying upon local judgement based on the knowledge of the individual circumstances has been vindicated by the high degree of safety attained. There is a need for guidelines on the criteria used as the bases for decisions, and their relevance, importance, and application. The "European Standards for Drinking Water", prepared by the WHO[10], have no mandatory force but considerable reliance is placed upon them as guidelines. There are official American, Swedish, and Canadian publications of guidance on the assessment of water quality requirements according to use and the French have recently published an excellent manual on the subject[11]. The Technical Panel of the Water Quality Steering Committee embarked on a programme to compile a water quality manual for the U.K. but was unable to complete it. There is still a clear need for such guidelines.

Despite the difficulties there is a growing tendency towards the formulation of international mandatory limits for drinking water. The blind adoption of such standards could lead either to unnecessary expenditure or to reduced protection of the consumer. It would force us all into a Procrustean bed and leave water quality control to an autoanalyser and a lawyer.

ACCEPTABLE RISKS

The risk of ill health or death arising from the bacteriological contamination of drinking water in public supply has, in the U.K. been reduced to chances which are so small that they might be termed almost negligible. The risk from acute chemical poisoning from water is also very small. Against both these hazards we have devised and employed thorough and effective safeguards and the risks have dwindled away.

The proportion of waste water in our drinking water is increasing and the trend will continue as demand rises. It is here that risks, long-term and insidious to health are difficult to assess. Nevertheless, progress is being made and while the risk can never be eliminated the chances of harm can be reduced.

The dramatist wrote "Death hath so many doors to let out life" but there seems to be a far greater reluctance to depart by drinking unwholesome water than to leave by say drowning in it. The recent stomach upset of a party of aeroplane travellers, due in this instance to food and not water, was international news but the drowned bather, or the dead motorist, barely rate a mention in the local newspaper. The bather and the motorist accept risks which are many times greater than they will tolerate as water drinkers. This somewhat illogical attitude towards the differing risks of illness or premature death, and the demand for a much greater measure of protection against death by drinking water than by most other means, probably arises from the ingrained conviction established literally over generations that if water comes out of a tap connected to the public supply it is safe. What better tribute to the water industry of the U.K. in achieving its objective of supplying wholesome water?

ACKNOWLEDGMENTS

The author expresses his thanks to his colleagues, both within and without the Department of the Environment, with whom he has from time to time discussed the subject of this paper. The opinions expressed are purely personal and cannot by taken as indicating in any way the official views of the Department of the Environment.

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DISCUSSION

AUTHOR'S INTRODUCTION

Mr. D. H. A. Price, in introducing the paper, wondered if it were possible to devise an exact, all-embracing definition for the wholesomeness of water. Qualifications about when, where, and to whom always seemed to be required. As an example the WHO had recommended maximum limits for the nitrate content of drinking water, but it was extremely unlikely that water exceeding the recommendations would be harmful or unwholesome to anyone present at the symposium. Furthermore, the risk to babies arose only when they were not fed naturally by their mothers.

Fixed universal standards for drinking water might, as in other fields, involve either unnecessary restriction in some areas and inadequate safeguards in others. There was still need for the exercise of scientific judgement in determining the requirements for a wholesome water in any given circumstances.

There was considerable information on the short-term dose-effect relationship of many substances which might find there way into water, and he thought the major problem was identifying substances whose effects might be produced only by long-term exposure. The greater the period elapsing between cause and effect the more difficult it was to establish the relationship. This applied in particular to trace organic material, much of it unidentified. He had taken the opportunity to give a brief account of the international research effort into the detection and determination of organic micropollutants under the aegis of the EEC. This work could usefully be supplemented by epidemiological studies on comparable populations supplied with new water and with water containing second-hand water, and he understood such a study was under consideration.

He had two positive suggestions to make. Firstly, when new or extended sources were under consideration the quality of the raw water should always be a factor to be brought into the decision making. In calculations based on the relative merits of different possibilities there should be included not only the costs for unit volume but also the assessment of qualitative advantages and disadvantages bearing in mind that there was a difference between minimum acceptable and desirable qualities. The current and future costs of protecting and treating vulnerable waters should also be included.

Secondly, while he did not advocate uniform national standards for drinking water he believed there should be a unity of approach. There was a need for a manual of guidelines on all the considerations and the pros and cons to be taken into account by local people in assessing their individual water quality requirements. Such guidelines had been in existence for some time in various countries including Canada, Sweden, and the U.S.A.; the United Kingdom lagged behind.

Verbal Discussion

Mr. H. F. Kaltenbrunner (N. V. Waterwinningbedrijf Brabantse Biesbosch, Rotterdam), in opening the discussion, congratulated the author for outlining a philosophy of the formulation of drinking water standards and for giving a survey of the activities of the various research institutions and committees concerned with the problem.

Starting with the definition of wholesomeness, the author considered three groups of potentially harmful constituents of water. Concerning the first group, bacteria, it seemed worth mentioning the problems which had been experienced on the Continent with aftergrowth in the distribution systems where ozone was used as one of the final water treatment steps. In the second group, described as "other biological organisms", only viruses and parasites were mentioned. However, experience had shown that the decomposition of organic matter by actinomycetes and other micro-fungi could cause serious taste and odour problems in distribution systems.

In the third group, the author dealt with chemical substances and their toxicity. He drew a distinction between acute and chronic toxicity. He could not agree with the author's statement that acute poisons were mostly well known and that, usually, the detection of such new substances being introduced posed no difficulty. No *a priori* classification could be given of a chemical substance as an acute poison; it always depended on its concentration if it exerted acute toxicity, chronic toxicity, or any toxicity at all.

Concerning the problem of synergism and antagonism of chemical substances in drinking water, he agreed that the beneficial effects of antagonism should be ignored because they could not be relied upon to be present at all times. However, in the case of synergism it would be very difficult to obtain quantitative results. It would therefore be interesting to discuss how these very complex mechanisms of synergism could be considered in the formulation of guidelines or drinking water standards.

The author gave special attention to the problem of organic micropollutants and the current lines of EEC research. It was interesting to observe how the original scope of the "Cost 64b" project was expanded from the development of analytical methods to the compilation of a data bank for the identification and determination of organic micropollutants. We learnt that this development was only one step towards achieving the ultimate purpose of Cost 64b, which was to assist decisions concerning the wholesomeness of a water supply.

He agreed that this was the correct approach. Nevertheless, was there a real chance of obtaining quantitative results on the effects of long-term—low level exposure to organic micropollutants and on the "no effect" levels of these substances? Even if this was feasible, and he had his doubts, we must consider that such an ambitious long-term programme must find its complement in the form of a workable and efficient short-term programme. On the Continent one tried to set up such a short-term programme by compiling "black lists" of organic micropollutants, the use of which should really be forbidden or at least progressively restricted. This solution to the problem was by no means ideal and it would be worthwhile to discuss possible alternatives.

Under the heading "standards" (p. 118) the author stated that concerning the quality of drinking water, the practice of relying upon local judgement based on the knowledge of the individual circumstances had been vindicated by the high degree of safety attained. Nevertheless, the author considered the increasing pollution of raw water sources by advocating the introduction of guidelines supporting this local judgement.

He himself agreed that the blind adoption of international mandatory drinking water standards was dangerous, but felt there were many workable compromises between the outright rejection and the blind adoption of mandatory limits, particularly under consideration of the entirely different character of water quality parameters. There was an urgent need for such a workable compromise, because drinking water standards should be considered as the key to water quality management. They were the starting point for the deduction of raw water quality standards or categories based on the assumption of certain combinations of water treatment processes.

Finally, he referred to a point not covered by the paper, i.e. the legal framework for guidelines and for standards. This legal framework was not only decisive for the allocation of responsibilities but also for the interpretation and application of such guidelines or standards.

Dr. R. F. Packham (Water Research Centre) thanked the author for introducing some perspective on the chemical composition of water in relation to public health. His point about the relative hazards of drinking water and drowning in it was very relevant. The hazards associated with the consumption of water in a developed country, although small, had still to be properly assessed. Only now did we have available really effective tools for determining in detail the chemical composition of water. The results of the international project cost 64b exemplified this and would surely provide a sound basis for the assessment of potential health hazards in the future.

The author had referred to the WHO organized working meeting held in January 1975 on "Health effects arising from the direct and indirect reuse of wastewater for human consumption". At this meeting an early version of the Cost 64b list of organic substances found in water was reviewed in the light of available toxicological information. Some toxicological data were available for about 45 per cent of the listed compounds. However, this often related only to acute effects and chronic toxicity data were very sparse indeed. A full evaluation of the potential health effects of known water contaminants was therefore a major task. At the WHO meeting a list was made of six substances for which a full-scale chronic toxicity study was considered to be a matter of high priority. A further list was compiled of 41 substances for which a sub-acute toxicity study was considered to be of high priority. Proposals were made also for other epidemiological, toxicological and analytical studies relevent to the evaluation of health effects arising from the consumption of water derived fully or partially from sewage effluent. The Group recommended that the WHO International Reference Centre for Community Water Supply should assume the role of international co-ordinating agent for these studies and an advisory group was being established to consider how best to implement the proposed research programme.

The report of the working meeting was awaiting publication. The Water Research Centre was presently discussing some research proposals that were strongly aligned to the recommendations of the Amsterdam meeting.

Mr. E. N. Thomas (Public Works Department, Bermuda) said that the author had defined "wholesomeness" of water (penultimate sentence of the first paragraph of the paper) in a manner which the public had come to understand, i.e. that the water was safe to drink. The requirement under the Water Act 1945 was to supply a pure and wholesome water, and the present requirement was to provide a wholesome water. For 30 years water authorities had discharged their responsibilities to supply without the need to define pure and wholesome. To define wholesome in the terms suggested would add to the distribution engineer's burdens. It was preferable, if the question of a definition was to be pursued, to limit the definition to the public's current understanding and confidence that the water at the tap was safe to drink.

He did not agree that it was only necessary to issue guidelines and not a safe drinking water standard. This was possibly adequate for U.K. water authorities with the advanced state of development of the industry and bearing in mind that the engineer had a qualified and experienced chemist and bacteriologist at his side. But many overseas engineers, who did not have the services of experienced waterworks chemists, looked for something more than guidelines.

He agreed with Dr Packham's remarks concerning the proposed EEC raw water criteria standards. These, if adopted, would lead to confusion and possible abuse by irresponsible laymen. The condition of the raw water resource was only of interest to the engineer and chemist in determining the treatment required to provide a safe potable water. What was required was a universal drinking water standard. At the moment we had a U.S. Standard, a World Health International and European drinking water standard, and now a proposed EEC standard. There was a need for these international bodies and for the medical bodies to work together to produce a single standard with maximum permitted limits both for the long-term and short-term emergencies. For example, it was now suggested that the upper limit for chloride should be reduced to 150 mg/l. One needed to know if this limit might be exceeded, and if so by what amount, period, and frequency.

Author's Reply to Discussion

Mr. D. H. A. Price, in replying to the discussion, wrote that Mr. Kaltenbrunner had questioned the use of the expression "acute poisons" on the grounds originally raised by Paracelsus that "there are no toxic substances only toxic concentrations".

Toxicity, however, was relative and it was surely feasible to grade substances according to their dose-effect relationships on a specific target such as man. The significances of say 1 mg/l of cyanide, of 1 mg/l of organic mercury, and of 1 mg/l of sodium chloride in a water supply were all quite different.

The assessment of the long-term effect of identified organic substances was a difficult task but toxicologists at a meeting in Holland earlier in the year had made a start by classifying substances listed by the 64b workers.

Mr. Kaltenbrunner advocated some form of compromise international drinking water standards but his own experience and that of his colleagues in Brussels during the past two or three years had demonstrated the extreme difficulty in reaching agreement on such matters. Geographical differences could not be ignored. For example, the total daily body intake of a substance from water was the product of volume and concentration, but in the warmer southern countries of Europe the daily intake of water was substantially greater than in the colder northern countries. The safe concentrations would therefore be lower in the south and higher in the north. There was a need for guidelines, either national or preferably international, to ensure a common basis for the setting of standards —a uniformity of approach rather than a uniformity of figures.

Mr. Kaltenbrunner raised the question of a legal frameworks for standards, and in the U.K. this was simple. The water authority had a statutory obligation to supply a wholesome water, complemented by a civil liability and public accountability. When EEC standards became the subject of a directive, the situation would need to be reviewed.

It was understandable that countries who were compelled to rely upon water sources originating outside their national boundaries should adopt a somewhat different attitude towards the need for enforceable, international standards than countries, like the U.K., which were self-sufficient.

Dr Packham had supplemented the information on 64b and the use of the results. He himself took the opportunity to pay tribute to the valuable contributions Dr. Packham had made to this work together with his colleague Dr Waggett and the laboratories of the WRC.

Mr. Thomas had doubted if some countries had the facilities necessary to permit the use of discretionary guidelines rather than firm standards. He agreed, but thought that in some of these countries application of all of these standards was difficult if not impracticable. Mr. Thomas had stressed the need for uniform international standards and then asked what variations would be permitted.

Mr. Lewis, in his paper, had referred to the total organic carbon content and while this was a useful indicator of quantity it gave no qualitative information.

9. TREATED WATER

By L. R. Bays, BSC, FRIC (*Professional Associate*)*

CONTENTS

INTRODUCTION

Water authorities in the United Kingdom have a statutory duty to ensure that the water they supply is wholesome (Section 11, Water Act 1973). No explanation is given of the word "wholesome", but it is generally accepted as describing water which can be consumed without risk to health. But, of course, this is not sufficient. For example, one may drink a turbid concoction of sterile water and sterile clay particles which, while not having an injurious effect, could not be considered to be wholesome aesthetically. Perhaps a better definition would be to describe wholesome water as "not being prejudicial to health and not giving offence aesthetically or physically".

To be more precise, the water industry usually considers that the water leaving a treatment works should be free from visible suspended matter, colour, taste and odour, and from all objectionable bacteria indicative of organisms prejudicial to health; should contain no dissolved mineral or organic matter which could render it dangerous to health; and should not dissolve substances injurious to health.

One might suppose that, having produced a water of this nature, the water authority could relax in the knowledge that the water would reach the consumer in the same condition as it left the treatment works or pumping station. Unfortunately, this is not so. There are many hazards *en route* from plant to consumer and many changes that can take place in the water before consumption so that the water received can bear little or no relationship to that dispatched. In some cases the only recognizable common quality parameter between water dispatched and water received is that it is still wet!

With the increasing demand for water, attention has turned away from relatively pure underground or upland sources and there has been a gradual increase in the use of more polluted surface sources for supply purposes which, in turn, has led to a corresponding increase in problems encountered.

The paper attempts to outline some of the problems encountered between the treatment plant and the consumer which, for convenience, are examined under the following headings:—

Bacterial quality
Algae
Animals
Discoloration or "dirty water"
Taste and odour
Consumers' premises

* Distribution and treatment works manager, Bristol Waterworks Company.

BACTERIAL QUALITY

Remarks made in this section are confined to those bacteria of pathogenic origin; the subject of after-growth of colonies growing at 22°C is dealt with later. If coliform organisms are taken as an indicator of pollution, the presence of *E. Coli* should be taken as a definite identification of faecal pollution, calling for immediate action. The presence of coliform organisms in the absence of *E. Coli* should give rise to concern as possibly indicative of old faecal pollution, and investigation is required. Instances have often arisen where coliform organisms found on one occasion have been later replaced by *E. Coli* and other definite signs of pollution occurring after heavy rain[1*].

Roof leakage into covered service reservoirs and elevated tanks, and access of insects and birds through damaged protective netting on ventilators or overflows or through holes drilled in the roof for level probes, are common causes of quality deterioration in the distribution system. In each case the cause should be located and rectified as soon as possible. It should be remembered that the coliform test does not differentiate between the excreta of man, bird, or beast and the assumption that pollution in service reservoirs is not due to man should not be made.

One obvious source of contamination can occur in the laying of new mains and the repair of mains when pipes are handled in all manner of contaminating conditions. Although there are no statutory regulations concerning the disinfection of mains, certain recommendations are to be found[2,3]. These recommendations, coupled with the use of a foam swab and perhaps a bactericidal lubricant[4], should ensure a high measure of success in establishing satisfactory water from new mains. It must be stated, however, that more careful attention to mainlaying can eliminate some of the difficulties of satisfactory disinfection, and chlorination should not be used to overcome bad mainlaying practices. There appear to be no standards for the acceptance and use of a new main after disinfection. A suggested standard is that a main should not be passed for service if *E. Coli* is present at all and if the total coliform (non-faecal) exceeds 2 per 100 ml.

Repairs to burst mains should be accompanied by application of a disinfectant such as chloros. Although it is realized that a repaired main may have to be put back into service before a result is obtained on a bacteriological sample, a sample should still be taken to ensure that procedures are adequate.

The possible transmission of enteric bacteria to water supplies by waterworks employees raises some interesting points. The memorandum "Safeguards to be adopted in the operation and management of waterworks"[3] states "Care should be exercised in the selection of men to be employed on works where a risk to purity of the water supply is likely to arise".

There is no standard practice, although it is usually accepted that any employee whose duties will bring him into contact with treated water should be examined. Is this sufficient? Is there not a risk that canteen staff who are not examined could transmit some harmful bacteria to staff already examined and cleared? Should staff be re-examined on a return from holidays abroad in certain areas? Employees should be checked before being allowed back to work if they have suffered from enteric disorder, and does this include an ordinary stomach upset? Are men to be kept at home until cleared and if so, is this not going to lead to malingering? It is felt that some further guidance is needed on a national basis on these points so that a standard practice can be established.

Reorganization of the water industry has thrown up some new factors for consideration. If the industry is to be multi-functional are we to find maintenance teams working on sewage pumps, then say on raw water pumps and then perhaps on treated water pumps

* A numerical list of references is given on p. 136.

in centralized workshops? Central workshops could be more economical and efficient, but what are the dangers?

With centralized laboratory services, are sampling officers to sample at sewage works and then at waterworks? Only the specialized epidemiologist can answer these questions, but it is suggested that answers are going to be required before detailed reorganization goes too far. Some water authorities have already thought about these points, but are such important matters to be left to individual authorities to formulate their own policies?

ALGAE

The increasing use of surface waters has focused more attention on algal problems. Where storage of such waters takes place as a means of balancing out variable quality and quantity, nutrients, e.g. phosphates and nitrates, are also stored and can lead to a proliferation of algae in such storage reservoirs. With conventional treatment of these waters, e.g. flocculation, coagulation, and rapid gravity filtration, it is inevitable that some algae will pass to the distribution mains and service reservoirs, there to accumulate and decay.

If the amount passing to supply is significant it may not be long before odours are noticed by consumers. But even in cases where these are not noticeable small amounts of algae in supply can have great significance in other ways, e.g. animals and discoloured water (q.v.). The practice of slow sand filtration reduces the passage of algae into the distribution system[5], but not all waters are amenable to slow sand filtration without expensive pretreatment.

The cleansing of mains by the use of foam swabs and flushing will help in some cases, but it is far more important to prevent algae reaching the system by efficient treatment than to try to remove it from the system afterwards.

ANIMALS

Much work has been carried out on the subject of animals in the distribution system[6,7], but it is perhaps sufficient to say that probably all distribution systems have some animals present to a greater or lesser degree. However pure the source of water may be, organsms associated with free flying species, e.g. Chironomids (or blood worms) from midges, can be found—probably gaining access through the covers of service reservoirs and overflows.

Suggested methods of control of animals, etc., are to be found in the literature[8,9], and in the case of free-swimming organisms flushing or combined swabbing and flushing may suffice.

Perhaps the most interesting example of animals which are attached to mains is provided by asellus aquaticus which is the main offender in finished waters giving rise to numerous consumer complaints. This species has been found in many systems and there are various ways in which it could have arrived in the first place, e.g. during the laying of mains. Very little trouble was experienced until more polluted surface waters were used for the production of potable waters. There is a school of thought that if food is not provided for the asellus the number present will be kept under control by cannibalization. On the other hand, if food is provided in the form of algae or bacteria, then instead of scavenging amongst iron deposits the asellus suddenly become well fed with the sort of food on which they appear to thrive. In this change of environment from "fish and chips to caviar" they can reproduce merrily and they are no longer kept under natural control.

This means that in certain systems, although animals may be present without giving rise to consumer complaints, when a new surface water is introduced a proliferation of these animals can take place without the animal being introduced by the new water. A great deal of time and money can be expended on an examination of the filters at the new source works, all to no avail.

An interesting case history to illustrate this point is at Bristol, where a new source was introduced from the Gloucester and Sharpness canal in 1965. A few years later, complaints of the presence of asellus aquaticus occurred in only a limited part of the area supplied where one particular source had been utilized previously. At no time prior to this had complaints been received from consumers. After 10 years' operation of the new source, complaints are still confined to this limited area.

Control of asellus aquaticus has been effected by a "once off" thorough treatment with pyrethrin of the mains system on a district basis followed at six-monthly intervals by pyrethrin dosing of the outgoing water at the source works and flushing the dead ends in the particular area.

DISCOLOURATION OR "DIRTY" WATER

Before polluted surface waters were used as raw water it was usual to associate complaints of "dirty" water arising from the distribution system with mains repairs or excessive velocity or reversal of flow, which it was assumed had caused disturbance of the loose rust deposits existing in the pipes. These as a rule could be cured by flushing ends, and recurrence in the same area was minimal.

Some complaints arose from consumers' own premises as a result of corrosion, or the removal of protective galvanized coatings on service pipes and tanks.

The advent of washing machines with separate spin-rinse process accentuated problems by drawing very small quantities of sediment to the notice of the consumer[10], but in general authorities using underground or surface waters of good organic quality for supply purposes received few complaints.

The use of lowland surface waters, often of high organic content, has tended to change the picture and more complaints of discoloured water are now being received by authorities, particularly in relation to old distribution systems. There is no doubt that the dirty water problems is a complicated subject involving such things as organic quality, after-growths of bacteria, state of mains, travelling or retention time of the water, etc.

Most discoloured water complaints are associated with iron and manganese and it is interesting to study how these are present in mains.

The European Standards for Drinking Water[11] give an upper limit for iron as 0·1 mg/l as the water enters the distribution system, but add that in installations in which the removal of iron would be uneconomic or where iron is present in a stable form, a level of 0·3 mg/l could be permitted.

The European Standards also give a limit of 0·1 mg/l for manganese, above which deposits in pipes may occur.

Despite these figures, water from many sources, especially boreholes, has been distributed for many years with higher contents of iron and manganese than those quoted, as former standards were far less stringent and, indeed, were sometimes ignored.

In the case of underground waters, iron is usually found dissolved in the form of ferrous bicarbonate and freshly abstracted waters are clear and bright. Exposure to air or chlorination oxidizes the soluble ferrous bicarbonate to insoluble or colloidal ferric hydroxide. A deposit of this insoluble material can then form in the distribution system.

Deposits of manganese form similarly in distribution systems but once formed they appear to catalyse the precipitation of further manganese. For example, a water containing 0·05 mg/l manganese in soluble form can be put through a new pipe without a reduction in manganese content taking place, but if it is put through a pipe containing deposits of manganese compounds, complete removal of this 0·05 mg/l can take place.

While it is not suggested that water authorities have supplied water with quantities of iron and manganese that cause the water to be of therapeutic benefit, it should be remembered that even small amounts can give rise to large deposits in mains and service reservoirs. A $20 \times 10^3 m^3$/day supply at 0·3 mg/l of iron can deposit 2½ tonnes of material in a year somewhere in the system.

Some iron deposits will result from the corrosion of mains, depending on the quality of the lining of the main.

One of the natural constituents of water is calcium carbonate in a dissolved form as calcium bicarbonate retained in solution by carbon dioxide. Each and every water has a stability factor which can be calculated. The work which is best known in this field is that of Langelier[12] and this work enables a calculation to be carried out to determine the *p*H at which the water is just saturated with calcium carbonate, i.e. that *p*H at which it will not take any more into solution nor yet deposit any supersaturated calcium carbonate which may be present. This is known as the *p*Hs. The difference between the actual *p*H of the water and the *p*Hs is known as the Langelier index. Where the *p*H is greater than the *p*Hs then the water will have a tendency to deposit calcium carbonate on the main, i.e. *p*H—*p*Hs is positive.

Where the *p*H is less than the *p*Hs, then the water will have a tendency to remove existing calcium carbonate deposits from the main, i.e. *p*H−*p*Hs is negative. The Langelier index of a water only indicates its tendency to deposit or remove calcium carbonate and does not indicate the liability to cause corrosion.

Many forms of calculation have been given in the literature, and data for the rapid calculation of the Langelier index are published by Nordell[13] which takes into account total dissolved solids and temperature. However, the most simplified version is given by the formula

$$p\text{Hs} = 11{\cdot}6 - (\underset{\text{as } CaCO_3}{\text{log alkalinity}} + \underset{\text{as Ca}}{\text{log calcium}})$$

It should be taken into account that if for several years a water has been used that has deposited calcium carbonate and then a water is supplied from a new source that has a negative index, the calcium carbonate is removed by dissolution. Existing deposits may be associated with iron and manganese and these will be loosened and accumulate at dead ends or pass to consumers.

It is well known that deposits in mains can get so great that they have to be scraped and the mains relined. The foregoing serves to illustrate that in any large distribution system there may exist mains in all conditions from new mains with their linings intact or mains with loose deposits at dead ends or "no flow" zones, to those with nodules or heavy encrustrations, often where corrosion is taking place under the nodules and linings have been destroyed. Even with these conditions there may be little trouble with discoloured water complaints until a new water, particularly a lowland surface water, is introduced to the system.

Let us now examine some of the properties of such waters to try to understand why changes, often of startling proportions, take place.

A surface water taken from the middle and lower reaches of a river will contain a proportion of previously used water. The major differences that may be found, as compared with purer sources, are increases in turbidity, bacteria, nitrogeneous compounds, phosphates, chlorides, and organic matter. Various treatment processes such as storage, prechlorination followed by flocculation and coagulation, rapid gravity filtration and super and de-chlorination might be expected to produce a treated water of first class

TABLE I. ANALYSES OF 500 SAMPLES OF RAW AND TREATED WATERS

	Raw water		Treated water		
	Average	Range	Average	Range	
*p*H	7·8	(7·5–8·5)	8·1	(7·7–8·3)	
Turbidity (Silica scale)	40	(10–124)	nil	(nil–1)	mg/l
Saline Ammonia (N)	0·36	(0·05–0·72)	0·06	(0·02–0·11)	,,
Albuminoid Ammonia (N)	0·30	(0·12–0·88)	0·16	(0·02–0·49)	,,
Oxygen Absorbed	3·2	(0·80–7·6)	1·20	(0·08–2·72)	,,
Nitrate (N)	4·2	(2·0–6·6)	4·4	(2·2–6·7)	,,
Nitrite (N)	0·10	(nil–0·32)	nil		,,
Alkalinity ($CaCO_3$)	204	(154–254)	115	(108–140)	,,
Total Hardness ($CaCO_3$)	272	(185–350)	214	(180–240)	,,
Chloride (Cl′)	40	(21–78)	51	(24–86)	,,
Silica (SiO_2)	7·2	(nil–15·2)	7·5	(1·2–10·5)	,,
O-Phosphate (PO_4)	1·12	(0·02–4·18)	0·30	(0·03–1·8)	,,
Total Iron (Fe)	0·62	(0·12–3·6)	0·01		,,
Total Manganese (Mn)	0·06	(nil–0·52)	0·01		,,
Aluminium (Al)	nil	(nil–0·20)	0·08	(nil–0·15)	,,
Residual Chlorine Total	—		0·15	(0·10–0·22)	,,
	—				
Bacteriological quality					
Faecal Coliforms	6064	(nil–180·000+)	nil	nil–nil	
Total Coliforms	14 180	(11–180·000+)	nil	nil–1	
3-day bacterial count @ 22°C	92 000	(100–2 × 10^6)	5	nil–162	
2-day bacterial count @ 37°C	2560	(20–2 × 10^5)	nil	nil–15	

quality. This is the treatment practised at the two works treating water from the Sharpness canal with the additional use of powdered activated carbon for taste control and some softening. Table I gives details of the analyses of both the raw and treated waters based on more than 500 analyses.

From these analyses it appears that a reasonably satisfactory water is produced. The only points which warrant comment are, perhaps, that the oxygen absorbed figure may be a little high; the phosphate figures are high; and the free ammonia figure is difficult to understand when the water has been subjected to super- and dechlorination with a chlorine excess after break point of 3 mgms/l for at least 2 hr before dechlorination. This fact has been noted on the treatment of a number of surface waters, and is thought to be due to organic nitrogen compounds giving a false result for free ammonia.

Water of this nature was passed to supply in 1965 from the Gloucester and Sharpness canal via the Littleton works and from 1968 onwards it was noted that the number of dirty water complaints received was steadily increasing from certain parts of the distribution system while from others no complaints were received. These complaints were kept in check by flushing and occasional swabbing, but recurrence suggested that a satisfactory solution was not being found.

Much work was carried out on this subject and the following facts emerged:

(1) Examination of mains in the affected area showed them to be badly nodulled, or to have fairly substantial deposits of calcium carbonate, iron oxide, etc.

(2) Complaints increased with increasing temperature of the water supplied. Complaints appeared to start at or around a water temperature of 14°C, increased as temperature rose and virtually ceased when the temperature fell below 14°C in the autumn.

(3) All dirty water complaint samples examined showed not only the presence of oxides of iron but were always accompanied by organic debris, protozoa, algal cells, etc.

(4) Complaints of dirty water came from the same areas as asellus complaints in general.

(5) After-growths of bacteria capable of growth at 22°C occurred in the system, increasing steadily with retention time whether in the dirty water area or not.

(6) Chlorine residuals could not be maintained in the distribution system.

(7) Change of water to the zones affected, from another source, reduced the complaints.

(8) The type of material in the complaint sample was mainly of a flocculant nature as distinct from the granular nature of the mains deposits. Very low water velocities were required to move this material.

Water from the new Purton works was introduced to the distribution system in the spring of 1973 and by coincidence was put into the troublesome area. A substantial increase in dirty water complaints occurred from this area during the summer months (Table II). The treatment of the two waters at Littleton and Purton was identical but examination of distribution samples showed a much higher after-growth of bacteria reaching some tens of thousands/ml as a result of the longer travel time of the Purton water.

TABLE II

Year	1968	1969	1970	1971	1972	1973	1974
Number of dirty water complaints	58	80	117	180	195	437	600

Laboratory work has been carried out on the treated water from Purton and it is shown that after-growths of bacteria identified as *Pseudomonas fluorescens* can take place. The rate of after-growth is very rapid, depending on temperature. Fig. 1 illustrates this compared with a borehole supply seeded with *Pseudomonas fluorescens*. It is thought that the level of growth reached is limited by the organic carbon present and other nutrients. This gives some indication of the effect of retention time on such a water in supply.

The loss of residual chlorine after superchlorination and dechlorination to a residual

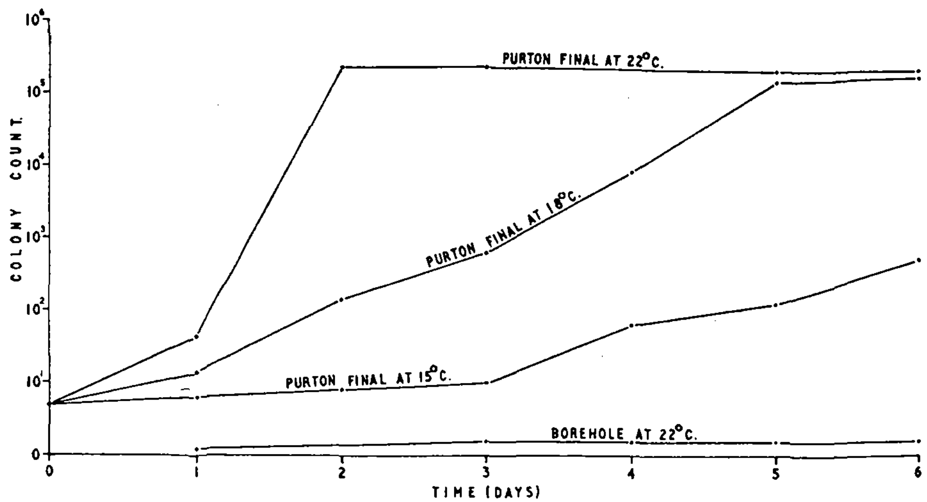

Fig. 1. Growth of bacterial colonies with storage time.

of 0·2 mg/l is thought to be due to the presence of organic nitrogen in the final water. Taras[14] has found that ammonia nitrogen is lost completely with 1 hr of contact time, amino nitrogen of the common amino acids is consumed more slowly over many hours, and protein nitrogen shows only a negligible loss even after many days. The presence of urea as a result of sewage discharges could also create problems if there is a lack of the enzyme urease to break down the urea. The loss of chlorine could continue for many hours. The break-point curve for chlorination of the canal water shows the typical plateau of waters containing organic nitrogen[15,16]. Further examination of samples from the distribution system has shown some very low dissolved oxygen levels, low *p*Hs, and the presence of ferrous or soluble iron in some of the samples. A particular section of mains has been left standing for some time (about three months) and the oxygen level of the water had fallen to only 2 per cent with substantial quantities of ferrous iron being present.

It is postulated that the mechanism can be as follows. Residual chlorine is slowly taken up by organic nitrogen in the treated water. If bacteria such as Pseudomonads are

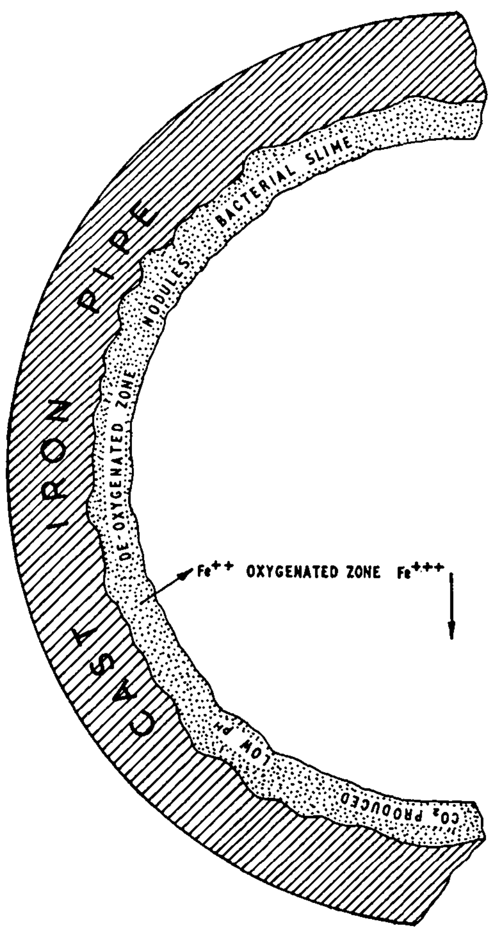

Fig. 2.

present they can then utilize the organic matter in the water and multiply very rapidly, depending on the time available. These bacteria then accumulate at the dead spots in a distribution system, forming heavily populated slimes on the main walls. As these "dead spots" will also be a home for asellus, protozoa, etc., an ecological system is built up. At the perimeter of the main, local deoxygenization takes place allowing ferrous iron to pass to solution. Movement of the water after a time moves this localized ferrous iron to the body of the water to precipitate as a flocculant material. Alternatively, excessive bacterial growths can create regions of low *p*H at the pipe wall by the liberation of carbon dioxide. It would be possible for this localized low *p*H water to attack the pipe wall and create corrosion (Fig. 2).

Other writers have studied the phenomenon of dirty water complaints and have reported similar findings. Hash, Connor, and Edwards[17] found a highly diversified and stable bacterial population in the mains system of Sioux Falls coupled with depletion of oxygen and stated that the more remote the location the lower the dissolved oxygen.

It appears that the main requirements for controlling the problem are:

(*a*) The maintenance of a residual chlorine level throughout the system. This may not be possible for some years in areas of poor mains. Other methods such as chloramination or chlorine dioxide may prove to be successful in the maintenance of residuals.

(*b*) Another possibility is the lowering of the total organic carbon (TOC) levels of waters so that nutrient is not available. This can be achieved by the use of granular carbon filters, but it has to be determined to what level the TOC must be reduced to prevent bacterial after-growth. This work is proceeding at the moment, but is there any point in reducing the outgoing organic carbon levels if much organic matter is already in the mains system?

(*c*) Getting the water to the consumer in the minimum possible time. In the early days of operating a large scheme the retention time in mains and service reservoirs may be high. It is possible that only one-half of a service reservoir should be used to minimize retention.

There is no doubt that a biological process somewhere in the treatment plant is an advantage. Authorities with biological treatment, either by pretreatment or by slow sand filtration, do not experience problems of the same magnitude. The organic carbon is reduced by the biological process, but care must be taken in the use of high doses of chlorine or ozone after filtration as non-biodegradable material may be changed in state to more readily biodegradable material available for further bacterial growths[18].

The increasing use of surface waters will bring with it problems similar to those experienced by many authorities all over the world. The subject of dirty water is one that warrants national attention, so that guidance can be given on the correct treatment.

TASTE AND ODOUR

It is essential to supply consumers with a water that is free from objectionable taste or odour. No water can be considered satisfactory if it possesses such a taste. It will cause suspicion in the mind of the consumer, even if it is perfectly safe to drink.

As already noted, it is possible to supply a water leaving the works that is entirely satisfactory to the palate but which can be become unsatisfactory in the distribution system.

Any deterioration can be caused by one or more, or a combination of, the following:

(1) Tastes having a direct connexion with chlorination.

(2) Presence of bacteria, algae, fungi, protozoa, etc., in the system. Tastes from these causes are often accentuated by rises in temperature.

(3) Metallic contamination, e.g., iron, manganese and copper.

(4) Backsiphonage.
(5) Outside agencies.

Tastes.—In this category would be included tastes produced which would otherwise not be noticed if the outgoing water did not have a residual chlorine content. Algae in mains will often decompose to liberate phenolic substances. If these are subjected to free chlorine then chlorophenolic substances will result having the objectionable medicinal taste (TCP). It is also reported that chloramines will slowly chlorinate phenolic substances (several days to a week at water supply concentrations) which may account for some taste and odour development in the dead ends of distribution systems[19].

Many other sources of phenolic substances are encountered in the supply of water between works and consumer. Antisplash fittings, tap washers, sealing gaskets in electric kettles, and protective paints applied to cisterns are all common hazards. Rubber jointing rings and bituminous linings in the mains system are also possibilities. It should be noted that phenol can be detected after chlorination at a concentration of 0·001 mg/l[20].

It is of interest to note that the new British Standard for materials for water tap washers (BS 3457: 1973) has been modified to include a test for the production of chlorphenolic taste, in that the material should be immersed in a water containing free chlorine. This could mean that the tap washer taste problem will diminish, but not all washers sold in hardware stores are manufactured to British Standard specification.

Presence of Bacteria, etc.—Odoriferous substances may be given off by organisms in a distribution system during life or released after death. The decomposition of organic matter and the decay of aquatic plants and animals will, if present in sufficient quantity, give rise to such complaints as "mouldy", "earthy", or "musty" water. These complaints are becoming more apparent in water supplies since the use of surface waters increased. Recent[20,21] work has shown the main causative organisms of earthy-musty tastes and odours in distribution systems to be actinomycetes and other odoriferous micro-fungi. These organisms may pass through filters to multiply in distribution systems if the right conditions apply. Like any other organisms they require food for growth and this can be found in increasing quantities of organic matter, phosphates, nitrogenous substances, etc., that pass to supply when surface waters are being used. Thus, organisms such as *Streptomycetaceae* can find areas of low water velocity in systems, and can be well supplied with nutrient and cause problems to consumers.

In modern water treatment plants activated carbon can be used either in powdered or granular form to produce a water at the works free from taste and odour. However, the earthy taste removed can manifest itself again in the distribution system. This phenomenon is perhaps best illustrated by the following simple diagram. The zero point is

$$\text{etc. } -10\ -9\ -8\ -7\ -6\ -5\ -4\ -3\ -2\ -1 \ \overset{0}{|}\ +1\ +2\ +3\ +4\ +5\ +6\ +7\ +8\ +9\ +10 \text{ etc.}$$

taken as the taste threshold value. On the negative side no taste is apparent while on the positive side the noticeable taste or odour is increasing. Each water free from taste will be at a variable position on the negative scale dependent on the concentration of organic compounds capable of imparting taste if present in sufficient quantity. On passing through a distribution system the chemicals responsible for earthy taste can be absorbed or dissolved by the water in increasing quantities, and at some point the threshold value may be exceeded, giving rise to complaint. It is likely that in many cases the threshold value will not be exceeded, the water moving from, say, −7 to −2 on the scale. However, in waters where the treatment has to include the use of activated carbon for the removal of earthy taste at the works, the authority will probably employ the minimum amount of carbon so that the taste or odour just disappears. In these cases the water may be only at position -2 on the scale as it leaves the works. The same amount of "pick-up" in the distribution system as above would result in a final position on the scale of $+3$ at the consumers' premises with resultant complaints.

Experience at Bristol in treating water from the Sharpness canal has shown that on many occasions in the warmer months the raw water has had an earthy-musty odour. The use of activated carbon has meant that water leaving the works has been free from odour, but this has reappeared in the distribution system in increasing intensity with travel-time. An increase in the carbon dose at the works has made no noticeable difference in the outgoing water, but has removed the problem in the system, with the possible exception of a few dead ends which can be dealt with by local flushing or swabbing.

It has also been the case that the introduction of a new water to an old distribution system has given rise to these circumstances, despite the fact that neither water tasted at the works and the previously used supply had never given rise to complaints.

If no odour or taste is detected in the raw water or in pilot plant tests, there is a danger that facilities for the use of activated carbon may not be provided on a new works. Some time after passing the water to supply, complaints are received and difficulty is experienced in altering the works design to provide the correct facilities. It is suggested that all works treating lowland surface waters by coagulation, filtration, and rapid gravity filtration should have space left for the provision of activated carbon use at some future date. It may be that the use of activated carbon will be compulsory in the future[22].

Most of the taste and odour problems in this category are accentuated by increase in temperature and can manifest themselves in consumers' premises, especially in blocks of flats, hotels, drinking fountains in schools, etc. Warm, slow-moving or near-stagnant conditions favour the growth of taste-producing micro-fungi.

Metallic contamination.—This can be responsible for some taste complaints. Copper can be dissolved from new copper pipes before a protective coating has been laid down, and consumers can only be advised to run their taps to waste each morning until settled conditions are achieved.

Soluble iron and manganese in water will give rise to complaints of astringent or metallic tastes, as also will water containing excessive amounts of soluble residual aluminium through faulty treatment.

Backsiphonage.—It would be impossible to consider all the tastes that could be produced by backsiphonage. It is sufficient to say that the possibility should not be ignored, despite stringent inspection. A recent case experienced by the author was one in which numerous people complained of the water tasting "salty"—this was traced to a faulty launderette water softener, regenerated with salt, coincident with a burst main in the district concerned.

Outside Agencies.—The use of Polythene pipes for services has resulted in some unusual taste complaints. For example, if a gas pipe leaks adjacent to or underneath a service pipe the gas can pass through the Polythene into the water and cause taste. The same transfer of gas or vapour can occur as a result of spillage of Diesel oil or oil for central heating systems at or near a Polythene service pipe.

CHANGES OF QUALITY ON CONSUMERS' PREMISES

There are possible dangers threatening the quality of drinking water through faulty plumbing installations on consumers' premises. Industrial processes are becoming more complex, with a wider use of various elements, and many new appliances are being introduced to households.

The legislation for the prevention of contamination of water by backsiphonage is Section 17 of the Water Act 1945, under which an undertaking normally has byelaws, based on Model Water Byelaws of the Ministry of Housing and Local Government, to protect its interests. Model Byelaw 8, "connexions which could cause contamination of mains water", is the principal byelaw prohibiting cross-connexions and specifying minimum requirements of storage receiving "potable" and "non-potable" water. It is interesting to note that the model byelaws do not give any guidance on classes of risk of different installations nor do they recognize degrees of protection other than storage with the inlet 6 in above the top edge. Recently published literature[23,24,25] does, however, include "league tables" of classes of risk and recommended degrees of protection.

If water byelaws are to be superseded by building regulations authorized under Section 61 of the Health and Safety at Work, etc., Act[26], will the new regulations include tables of degree of risk and required protection? In these days of advancing technology, and bearing in mind the style of the existing building regulations, it would seem a logical step that they should.

It is considered that the technical aspects of maintenance of water quality on consumers' premises are fully documented. It is also considered that the administration of present legislation, primarily for economic reasons, is in many cases weak.

The first conclusion of the section of the Backsiphonage Report[24] dealing with the incidence of backsiphonage and survey of domestic installations states that the existence of byelaws will not ensure adequate protection unless installations are regularly inspected and the requirements of the byelaws are enforced. The conclusion could hardly be more obvious and yet how easily overlooked.

On the point of enforcement, it would be interesting to compare the approach of water aurhorities to consumers permitting waste or contamination. With waste control, undertakings will serve a 48 hr notice and if necessary "cause the said repair to be effected and recover summarily as a civil debt the expenses reasonably incurred in so doing". If this officious approach is justified in waste control, how much more necessary it must be with a risk of contamination! Yet we often resort to a series of visits by inspectors, exchanges of letters and general cajoling, with subsequent delays, in order to achieve compliance with the byelaws. When a particular fitting rather than an installation is infringing the byelaws it might well be argued that the vendor of the fitting which does not have NWC approval should have some responsibility rather than the consumer who has purchased and installed the fitting in good faith.

The changes which the Health and Safety at Work Act might introduce will present an opportunity, if not an obligation, for the industry to reconsider the maintenance of water quality on consumers' premises at possibly a very much increased cost. It is interesting to consider a few of the problems which might arise, in order that possible solutions may be considered:—

(*a*) Will a developer receive approvals of plans from the local authority and water authorities separately or jointly, with the possibility of subsequent communication problems?

(*b*) What additional staff will water undertakings require to check plans and specifications?

(*c*) Will water undertakings be liable for failure to inspect every new installation?

(*d*) Will additional legislation require a higher standard of inspector in the future, and should training be considered now?

(*e*) Will all services have to be chlorinated, and who will carry out this work?

Despite requests, the public do not notify water authorities when changes are made to plumbing systems; inspections can only be carried out at random, and laboratory sampling will only indicate when something had already occurred.

CONCLUSION

A distribution system is not just a series of pipes of various sizes and materials joined together and interspersed with reservoirs, valves, or hydrants. It can be likened to the female species—dynamic, sensitive, living individuals who must be handled with great care!

Although water authorities may produce a wholesome supply at the works their ideals can be destroyed between the works and the consumers' taps. This paper has attempted to describe some of the difficult areas and the cause of problems that may be encountered. Only by being aware of such problems and by having the maximum co-operation between all disciplines concerned will water reach the consumers in the condition which they have the right to expect.

As well as using a laboratory for quality checking, water authorities should encourage their consumers to complain at the first sign of any abnormality. A full explanation of the problems to a consumer will usually be met with understanding. In dealing with complaints it is essential to make an immediate response and establish full liaison with the Environmental Health Departments of District Councils.

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DISCUSSION

Author's Introduction

Mr. L. R. Bays, in introducing the paper, said that most of the previous papers had dealt with protective measures to be taken, the objective of which was that the consumer should have decent water. He himself had concentrated on the discoloured and dirty water aspect, stressing that this was an area where a great deal more understanding was needed before the problem could be cured. Factors affecting dirty water could be residual organic matter after treatment, changes in residual organic matter through distribution systems, changes in *p*H in a mains system, food availability for aftergrowth of bacteria, retention times in and design of distribution systems, age and conditions of existing systems, and the type of water that had gone before. All or any combination of these factors could play their part in creating problems. The introduction of more polluted sources for the production of drinking water would highlight many problems not previously experienced by the majority of water undertakers.

Verbal Discussion

Mr. W. M. Lewis (Severn-Trent Water Authority), in opening the discussion, referred to the section of the paper (p. 127) on "dirty" water. The author instructed the uninitiated into the mysteries of *p*H of stability, but avoided any explanation how he, at Bristol, translated the theory into practice throughout the seasons of the year. His major problem was detailed on p. 129 and he succinctly clarified the difference between the two systems of distribution setting out a series of observations resulting from investigation into the problem.

Why was prechlorination being practised? It appeared to be established that coagulation and flocculation effectively reduced a considerable proportion of the raw water bacterial loading—so perhaps this was not the reason! What advantages if any had this practice over say breakpoint chlorination at, for example, the coagulation stage?

Claims made by the WRC stated that biological sedimentation (as an effective ammonia removal process) was economically viable compared with breakpoint chlorination at ammonia nitrogen values in the raw water as low as 0·1 mgm/l. As this process had also other inherent advantages for the treatment of lowland river waters, had the author ever practised this procedure and if so with what success?

There were two important facts which must be kept in mind when considering the problem of aftergrowth in distribution water:—

(1) *All* waters when placed in sterile containers would, with time, undergo rapid growth of microbiological life—the rate increasing with temperature.

(2) Most foreign bodies in contact with water, glass for example, appeared to influence upwards microbial growth in water.

It therefore seemed reasonable that if one wished realistically to ascertain microbial changes in a particular water with time—the original water-body temperature should be used and all experiments should be carried out in borosilicate glass as also should be the sample collection vessel. Had the author operated a control procedure on these lines, under the suggested conditions, parallel with the procedure he described?

Aftergrowth problems, when conditions were favourable, might be appreciated when one considered a single cell of Ps fluorescens with a generation time of 20 min and would therefore produce, by exponential growth, 2^{144} cells or $2{\cdot}23 \times 10^{43}$ cells in 48 hr! Simply translated this mass would correspond to a weight of 2×10^{26} tons, a quite forbidding prospect fortunately controlled to more realistic proportions by counter productive agents co-existing in the water.

It therefore became necessary seriously to consider the "apparent requirements" (p. 132) (*a*), (*b*), and (*c*), for controlling aftergrowth problems. Experience, ferrying a treated river water some 50+ pipe miles from treatment works to storage reservoirs, had taught one that when raw water temperature approached 15°C disinfection procedure required modification to avoid the problems described by the author.

Below 15°C, outgoing treated water normally carried a free chlorine residual but above such temperature terminal ammoniation converted free excess chlorine into chloramines which persisted as such in the distribution system maintaining a bacterially stable water. Had the author tried this relatively simple expedient to counteract his problem?

All would no doubt agree with "apparent requirement" (*c*), although one could envisage the practical difficulties in applying the principle to many existing systems.

With the "apparent requirement" (*b*) one must strongly disagree in that such proposal, if adopted, would incur great trouble and expense, obviously readily acceptable if the rewards were correspondingly beneficial. In this case fundamentally the proposal was entirely speculative. For example, a good quality borehole water might be expected to have a TOC value of 0·1 mg/l and with bacterial metabolism approaching 90 per cent. biological efficiency this would correspond with 0·09 mg/l available carbon in such water.

The cellular matter of bacteria of the Ps fluorescens type contained within its structure 50 per cent carbon (N = 15 per cent, P = 1 per cent) and the total dried weight of 1 000 million (10^9) Ps fluorescens cells = 0·32 mgms, which represented a carbon weight of 0·16 mgm.

Thus, on this data, 1½ l of good quality borehole water would contain enough carbon to support the growth of 10^9 Ps fluorescens! To attempt, therefore, to reduce the carbon content of a lowland river water to values of this magnitude as a means of controlling aftergrowth appeared not only impracticable but also a futile exercise.

Microbial aftergrowths in distribution systems appeared to be primarily due to lack of sterilant in the affected distribution area, such growth, when it did commence, being accelerated by increase in water temperature. Had the author any positive evidence to the contrary?

The statement at the foot of this section which warned against the possibility of degrading non-assimilable large molecular weight carbon compounds, by the two disinfecting agents, into simpler readily assimilable material might well be a point of debate. However, even assuming the statement to be fact it would in no way influence the growth of microorganisms in a water body if such water contained adequate residual disinfectant.

The author had left unsaid—no doubt due to restrictions of space—many aspects of water in distribution systems. He made no mention, for example, of the unhealthy contribution to such water by leaching from bitumenized-lined mains, etc.

Dr. W. Masschelein (Laboratories Compagnie Intercommunale Bruxelloise des Eaux Chemin du Croquet) said that the problems relating to the stability of water quality in drinking systems were not limited to a restricted area! Until recently, the Brussels Water Board, formally a classical groundwater undertaking, exploited about 156 groundwater catchments of all kinds. In 1973 an important surface water treatment plant was partially put into operation providing more or less 15–20 per cent of the total delivered quantity. This amount would gradually increase to reach 40–50 per cent of the total needs.

The untreated water passed through a series of operations comprising flocculation with aluminium sulphate. Consequently, the water was aggressive unless corrected. Sodium hydroxide was used as the correcting agent. He asked if this, or another similar method, was practised in the U.K.?

For 40 years now, chloramines (i.e. chlorination with postammoniation) were applied at the starting points of the adduction which might be located 70–100 km from the service reservoirs situated at the entrance of the distribution network. Chlorine was bacterial-killing whilst chloramines acted as bacteriostatic agents during the transport stage.

At the entrance of the reservoirs, an additional sterilization phase took place using chlorine dioxide. This procedure could be replaced if desired by chloramines. The CIBE had already used chlorine dioxide for the past ten years.

During the first two years' experience of this "mixed adduction" (groundwater + ozonated surface water), revivial and aftergrowth (especially pseudomonas fluorescens) did sometimes occur in the adduction system, i.e. in the pipelines leading to the service reservoirs.

However, owing to repeated disinfection, critical aftergrowth had been overcome except in some rare cases such as cast-iron ends. Therefore, a total active chlorine residual concentration of 0·05–0·1 ppm should be reached and maintained in the distribution system.

Chlorine dioxide seemed to cause formation of chlorite acting as a bacteriostatic agent. There was the need to develop a reliable analytical method for this compound. If present in water as a trace compound at the same time as other oxidizing chlorinated compounds, the usual methods seemed to be mere arithmetical artefacts. Did the author have any suggestions?

It seemed necessary to widen the investigation of the first stages of eventual bacterial developments. If one used appropriate counter-acting measures in time, the "cannibalization" of higher organisms might be promoted.

Like the author, he had found that pseudomonas fluorescens probably multiplied in the first instants of aftergrowth*. Were there any other early indicators of bacterial aftergrowth in the mains? Early warning seemed essential where appropriate measures and time were concerned.

Mr. J. Jeffery (North Surrey Water Company) said that the author suggested that a new main should not be passed for service if the total coliform count exceeded 2 per 100 ml. He himself believed that the general standard should be for coliform bacteria to be absent from 100 ml. Only in exceptional circumstances and after much testing should this standard be relaxed.

Several interesting points were raised by the author on medical examination/blood

* Masschelein, W. J. 1975. *Bull. de l'Anseau* (Association Nationale des Services d'Eau), p. 121, "Maintien de la potabilite de l'eau dans les reseaux de distribution".

testing of employees. Because of the risk of indirect transmission of bacteria, and the problem of where the line should be drawn, all staff employed at an operational site, whether in the office or out on the works, should be examined. His own Company's policy was to examine any member of staff who was away from work for more than three days with an illness "associated with looseness of the bowels".

One aspect of bacterial quality of treated water which might have been mentioned was the microbiological growth which could occur on plastics and which was currently being investigated by the National Water Council and the British Plastics Federation.

The author described the control of asellus using pyrethrin. What was the size of the area in which flushing was required? His own Company had had fewer complaints of animals in the water in 1975 than in 1974, and this was thought to be linked with the start of the addition of chlorine dioxide in August 1974 to the water entering the distribution system.

The author mentioned the effectiveness of biological processes in reducing organic carbon levels. His own experience was that the total organic carbon content of Thames-derived mains waters was higher in one which had been stored and slow sand filtered than in another which had been coagulated with alum and filtered through rapid gravity filters.

Written Discussion

Mr. G. Robinson (Northumbrian Water Authority) wrote that on p. 125 it was stated that "...chlorination should not be used to overcome bad mainlaying practices". Even when good mainlaying practices were employed some debris would be introduced into the pipes and in any case the main would be contaminated from other sources. In his own Authority a strict procedure for swabbing and chlorinating new mains was practised and he suggested that swabbing was an essential prerequisite to chlorination.

In the last paragraph on p. 125 the author raised the important question of the possible contamination of potable water caused by employing the same men to maintain sewage equipment and water supply equipment.

His own Authority had established a working party to study and make recommendations on this subject. The study was not yet complete, but tests so far made to establish the degree of contamination on tools and equipment at various works such as sewage treatment works, water treatment works, multi-function and single-function workshops, indicated that there was little difference in the numbers of non-spore-forming bacteria such as E. Coli (probably because of their inability to survive in dry conditions). However, the spore-forming bacteria such as clostridium perfringens did appear to survive on tools and equipment and might prove to be a real hazard.

The Wear Division of the Authority had experienced outbreaks of dirty water problems in the summer periods following a change in water treatment. For one year Calgon was added and the number of dirty water complaints were considerably reduced, but numerous taste complaints were received which were not experienced prior to or after the use of Calgon. He asked the following questions:

(1) Had the author any evidence of earthy taste and odours being produced by organisms other than micro-fungi?

(2) With reference to pseudomonads, had the author any experience or guidance to offer on:
  (*a*) The number of pseudomonas present in samples taken in association with incidents of dirty water?
  (*b*) Any relationship between the number of these organisms and the level of iron in dirty water?
  (*c*) Any evidence on the effectiveness of chloramination in countering pseudomonas and the concentration required?

(3) What did the author consider to be a reasonable retention period for water in a distribution system?

Mr. J. F. Tougher (DOE for Northern Ireland), wrote regarding the repair of mains and the laying of new ones. Any new fittings being used should be washed with Chloros. New pipes should be inspected for solids as they were being laid. Rather than using Chloros, portable chlorination plant should be employed adding a strong dose of chlorine with a contact time of not less than 2 hr, if possible, followed by a flush out and sampled the next day after the water in the main had settled, if time permitted. This would be more successful than Chloros treatment.

Regarding sampling at sewage works and then at waterworks, this would be bad practice and should be avoided if at all possible. Separate vehicles should be kept for water and sewage work, and also all equipment.

If only a small number of men were available they could be employed, say, on a weekly rota basis on sewage and water sampling. Engineers, scientists and others making routine visits or inspections should programme their calls so that they called at waterworks before visiting sewage works.

It was interesting to hear chloramine treatment being mentioned again, as this had been frowned upon for many years. There were situations where it could be very effective, namely, large distribution systems supplied from covered reservoirs which would not be contaminated with atmospheric phenols during autumn and winter. If this treatment was performed in the order chlorine-ammonia it should prove very effective against aftergrowths in the distribution mains.

AUTHOR'S REPLY TO DISCUSSION

Mr. L. R. Bays, in replying to the contribution from Mr. Lewis, wrote that the question of *p*H control had always proved difficult, especially on a partially softened water of average alkalinity 115 mgm/l $CaCO_3$. The water leaving the works was controlled at *p*Hs + 0·2. Any higher *p*H than that caused deposition in pipework at or near the works. Regular monitoring points were checked in the distribution system but he was setting up research into the change in *p*H occurring in the system especially at the pipe walls where it was suspected that low *p*Hs would be found contributing to the discolouration problems.

Prechlorination was practised at the intake for the prevention of mussel growths only. Breakpoint chlorination was then practised at the coagulation stage to benefit manganese removal, etc.

The biological sedimentation would indeed be beneficial to the treatment of Sharpness water. However, despite many attempts on a pilot plant scale, including using sludge from the tanks at the Mythe waterworks, Tewkesbury, and also using sand as a nucleus, they had been unable to keep the tanks working for more than two to three weeks at a time. The reason was not known, but it was suspected that the quality of the canal was responsible for the breakdown of the bacterial action.

Control procedures were carried out on all tests for aftergrowths and various methods were used for obtaining results so that the effect of outside agencies (of which many were encountered as Mr. Lewis stated) could be overcome.

Chlorine and ammonia treatment had been tried with some success. However, local problems did exist in that in certain areas of the distribution system mixtures of the treated Sharpness canal water and other sources took place. If the chloramminated water was then mixed with waters containing free chlorine, vile tastes resulted in certain instances. To avoid ammoniating the other sources, chlorine dioxide had been used for maintenance of residuals but the author was also convinced of the merits of chlorammination, which would be used again next summer. One other problem of chlorammination was that the chlorinated Sharpness water gave false indications of combined residuals when using the DPD method of determination due to chlorinated organic compounds, and this made actual control of residuals in the distribution system very difficult.

He agreed with Mr. Lewis regarding activated carbon filters. As could be seen from the paper, he was not convinced of the merits of this process and it was a very expensive way of finding out that the results were not much improved! Most of the laboratory aftergrowth experiments carried out did show growths in the presence of small amounts of carbon, but on the Sharpness water it might well be that combinations of carbon and phosphorus were the main nutrient providers.

He thanked Dr. Masschelein for outlining the similar problems experienced in Brussels. The treatment process used there would be similar to those practised in the U.K. although occasionally lime was used for *p*H correction in lieu of sodium hydroxide. He was grateful for the assurance that chlorine dioxide was beneficial, although as previously stated, it was likely that chlorammination might be superior in retaining residuals to the ends of systems.

Dr. Masschelein was quite correct about the methods for detecting chlorite. The method used at Bristol was that of Palin*, but did rely finally on arithmetical difference.

He had no additional information regarding tracer organisms. He still relied heavily on the general three-day count at 22°C technique, a test now omitted by so many laboratories.

Mr. Jeffrey had raised the point of sampling from new mains. He agreed that E. Coli should always be absent, but believed that the 2 coliforms per 100 ml standard for non E. Coli was far more stringent than practised in a number of laboratories.

An interesting point was raised concerning asellus. He agreed that the use of chlorine retention agents such as chlorine dioxide could reduce the problem, but it had been found that the asellus were concentrated further towards the end of the system that as yet had not had a residual.

In reply to Mr. Robinson, he hoped that the impression had not been gained that good mainlaying practice could avoid chlorination. He agreed entirely with Mr. Robinson and used the same procedure of swabbing before chlorination.

Why was it necessary for the Northumbrian Water Authority to have a working party on staff transfers into multi-functional activities? The point he himself was trying to make was that there should not be ten local policies but that national guidance from skilled epidemiologists was required.

The answers to Mr. Robinson's specific questions were:

(1) No—all earthy-musty tastes had been associated with actinomycetes and he also had found that this could be accentuated by using Calgon—could this be due to phosphate nutrient after hydrolysis?

(2) (*a*), (*b*) The number of pseudomonas could not be taken as a guide to incidents of dirty water. On routine sampling only the motile were sampled and not those attached to pipe walls. Counts ranging from 100 per ml to 100 000 per ml had been found in practise.

(*c*) Residuals of 0·3 mgm/l had been found to prevent growth.

(3) It would be true to say that if residuals could be maintained then time would not matter, but the only answer could be that water should get to the consumer as soon as was possible, bearing in mind the practical difficulties in achieving this. He himself would like to see all water received less than 48 hr after treatment.

Mr. Tougher outlined the problem of multi-functionalism, again adding weight to his own view that a firm policy was required nationally.

* Palin, A. T. 1967. *Journ. I.W.E.*, vol. 21, p. 537, "Methods for the determination in water, of free and combined available chlorine, chlorine dioxide and chlorite, bromine, iodine and ozone, using Diethyl-*p*-Phenylene Diamine (DPD)".