MAN'S CONTROL OF WATER QUALITY

K. J. Ives

Public Health Engineering, University College, London, W.C.1., U.K.

ABSTRACT

Man has certain needs for water: physiological, domestic, agricultural and industrial. These needs are not the same in quantity or quality, in location or in time, yet they must all be met to allow for mankind's full development.

Man's use of water degrades its quality: by gross pollution, by residual materials which change the ecology of the water environment, and by persistent microchemical pollutants which may pose both long and short-term health hazards.

Man can control water quality; but first he must measure it. The criteria of acceptable quality, particularly for the protection of public health, are continually being refined; already certain contaminants are considered a hazard at the femtogram per litre level, i.e. a million-millionth of the familiar p.p.m. Even when he can measure such quantities, man must protect or treat the water to maintain the required quality standards.

The future will require refined micro-level measurement, toxicity and carcinogenic screening methods, and further consideration of water-distributed prophylaxis. Serious consideration must be given to new concepts in water management: multiple re-use, parallel supply systems and integrated treatment processes.

MAN'S NEEDS FOR WATER

Water is essential to life. Water is essential to living. Water is essential to civilization. Man's needs for water are physiological, domestic, agricultural and industrial. Fortunately these needs are not identical with regard to water quantity or quality, and they are not identical in location nor in time. These needs must be balanced so that water may be apportioned to allow for mankind's full development.

Physiological

The human body comprises about 70% by weight as water, and the body's metabolic functions require water as a solvent, a reaction medium, a lubricant and a carrier. Although a small quantity of water results from the metabolism of food, the principal intake of water is by drinking. Very few of us drink significant quantities of water directly, but usually as a beverage: tea, coffee, beer, lemonade, etc., or as food: for example, soup.

In temperate zones, our water intake by these means is about 2½ litres per day; in tropical or arid zones the quantity would be higher—if only to dilute the increased whisky consumption! When we come to consider other water requirements this will be seen to be a very small fraction of the whole. Yet it has three extremely special characteristics: it is absolutely vital to man—without it the rest of man's activities just do not exist; its quality has an immediate and absolute bearing on man's health; and it is required by us every day, without fail. For these reasons I have placed it first.

This ingested water is discharged principally as urine, some with faeces and some by perspiration. In all cases it leaves the body less pure than when it entered.

Domestic

Those of us who have camped any distance from a stream, or other source of water, know how little water one can exist with for the domestic chores of camp life. Water collected at the stream weighing 1kg/1 undergoes a gradual but magic conversion to 'heavy water' by the time it has been carried to the campsite, and this has a marked inhibiting effect on such inessential activities as washing, dishwashing and general cleaning, particularly for small children.

This may indicate that domestic needs for water are not so essential or fundamental as physiological needs. Nevertheless, in normal household management we require water for cooking, washing, cleaning and flushing. In addition we may use water domestically for garden watering, car cleaning and other outside activities. In the United Kingdom and Europe, households with piped water supplies use 130–150 litres of water for each person per day, and in North America the figure may be three or four times that value.

In a typical European household the water may be used in the following way:

(a)	cooking	2% i.e. approx	2½ litres. *per capita*
(b)	clothes washing	16	22
(c)	dish-washing	8	11
(d)	personal washing	32	45
(e)	general cleaning	4	5½
(f)	toilet (W.C.) flushing	36	50

(The remaining 2% is used for ingestion)

Of these the water required for cooking may need to have the same qualities, for ingestion, as the physiological water. But the others do not share this requirement, and in fact quite low-grade water could be used for general cleaning and flushing. This would also be true for garden watering and other outside use. The water used for washing needs to be clear, uncoloured and free from odour to be aesthetically acceptable. It may be remarked that paradoxically many women, having drawn a bath of clear water (and they would object vehemently if it were not so) then proceed to add compounds to colour it, cloud it and give it an odour!

This does mean that the water supplied to a household does not all have to be of the same quality. Also the time-demand for this water varies, not only diurnally, but day-by-day (witness the Monday washday and Friday bathnights phenomenon in the U.K.) and of course season by season. In contrast to man's very limited capacity to store in him the water required physiologically, the household normally has at least a day's water storage on the premises and can, with careful management survive short periods of water limitation.

This domestically used water mainly finds its way into the house drains, and either to the domestic sewer or to a septic tank or soakaway in the ground. Wherever it goes, it is dirtier than when it entered the house and is polluted physically, chemically and biologically.

Agricultural

In areas of abundant rainfall the agricultural need for water is met naturally, without the intervention of man. However, there are many regions of the world where farming, either with crops or animals, is only feasible if the rainfall is supplemented by additional irrigation or animal watering.

On the whole the quality requirements for agricultural water particularly for irrigation are not very exacting, and quantity dictates use far more than quality. There are certain elements toxic to plants which must not be present in significant amounts (for example, boron); also highly mineralised waters can slowly poison the soil by evapotranspiration leaving behind accumulating residues of salts, as happened in parts of Pakistan.

It is difficult to estimate the agricultural need for water: it is obviously seasonal, depending both on climate, and state of growth of crops. Generally, intensive irrigation requirements coincide with heavy water demands for other purposes, and fertile and potentially fertile areas are also areas where people congregate to live, causing a domestic and possibly industrial demand. Some examples of particular water requirements for agriculture are given in *Table 1*, but it must be stressed that local requirements may differ greatly from these due to geographical and other influences.

Table 1. Water for agriculture (England) irrigation

Irrigation required, above	0·7 m^3/m^2—*annum average rainfall*	
Grass	0·13	m^3/m^2–annum
Potatoes	0·1	,, ,,
Cereals	0·05	,, ,,
Peas	0·03	,, ,,
	Animals	
Cows in milk	50 m^3/head—annum	
Cattle and Horses	17 ,, ,,	
Sheep	2·5 ,, ,,	

Some generalizations may be made regarding man's agricultural need for water. As quality requirements for irrigation purposes are not stringent, wastewater may be used, perhaps after partial purification, and the percolation of that water through the soil to a receiving body of water usually improves its quality. However, much of the quantity is irrecoverable as it is lost to the atmosphere by evaporation and transpiration.

Industrial

The development of industry and the need for large volumes of water go hand in hand. Water for cooling, transporting, washing, rinsing, leaching, processing: the variety of requirements for industry is almost as large as the products of industry themselves. The staggering requirements of industry have so often been quoted that our senses are numbed to the appreciation of the figures: 150 tons of water to produce 1 ton of steel, 40 tons of water to refine 1 ton of oil, 20,000 tons of water to produce a single edition of a British daily newspaper. The quality requirement ranges from raw river water for power generation cooling to ultra high quality distilled water for very high pressure boiler feed, or for transistor crystal manufacture. Fortunately the former usually are sited where there is no competitive use for the raw water, and the latter process the water to their own exacting standards and maintain it in a closed cycle. However, much of industry accepts domestic supply water (although the quality may be too good for their requirements) and consequently is in competitive demand with domestic users.

In general the industrial demand is constant with time (although there may be weekend slack periods—depending on the production pattern) and does not exhibit a great seasonal variation. The industrial development of an area will be reflected in its water demand; for example in London, out of a total of 220 litres of mains water per day supplied per head of population, about 90 l/day or 40% is for industry, whereas in a rural area in Cheshire in England, from a total of 180 l/day *per capita*, 10% is used agriculturally and 25% by the local horticultural industry.

Almost without exception, the use of water by industry degrades its quality: thermally, physically, chemically and biologically, and the results of this pollution are discharged to sewer, watercourse, lake or sea, usually with some sort of hazard or disadvantage to a subsequent user.

MAN'S DEGRADATION OF WATER QUALITY

It has already been mentioned that man's physiological, domestic, and industrial use of water degrades its quality, and even some agricultural use (e.g. hosing down of stock yards and sheds) also does so. But man's activities can cause pollution even when he is not using the water. For example, the dumping of household refuse, or industrial solid wastes, may bring it into contact with surface or groundwater, in old gravel pits for example, with consequent pollution. Again, crop spraying or soil treatment with pesticides can pollute the run off from rain on the land.

In all, the pollution may be gross, so that rivers and lakes become anaerobic, foul, discoloured, lifeless waters; or the pollution may be more subtle, when treated waste water stimulates the biological potential of receiving waters with residuals of nitrates and phosphates leading to eutrophication; or the pollution may be at an insidious microchemical level where hazards to health are only apparent over long periods.

The gross pollution is usually immediately recognizable, and although objectionable in the extreme, it can usually be remedied by standard processes of treatment. If the pollution does not persist, or is successfully prevented by adequate treatment, the water can self-purify and recover its quality. Such controls may be expensive, but the knowledge and technology does exist to remedy such gross pollution. An example of this is the way in which the Thames below London has been steadily improved over its previous persistent and offensive foul state, so that although it has not returned to being the salmon river of 500 years ago, it is no longer the strong brew described previously thus in "Hints to Brewers":

> "Thames water taken up about Greenwich at low water when it is free from all brackishness of the Sea and has in it all the Fat and Sullage of this Great City of London, makes very Strong Drink. It will of itself ferment wonderfully, and after its due purgations and three times stinking it will be so strong that several Sea Commanders have told me that it has often fuddled their Murriners."

That was in 1702—230 years later the situation was still as bad, if not worse, but the last two decades have seen great improvements.

The second form of pollution is more subtle, for after proper treatment of waste water to remove gross pollution, a residue of apparently inoffensive chemical substances remains in the effluent. Principal among these are the phosphates and nitrates, some having come from the original waste water and some being the result of chemical changes during the treatment processes. Whatever their source, such chemicals give a stimulus to biological growth in the receiving water. This condition of the water, called eutrophication (Greek: well-nourished) gives rise to embarrassing growths of algae or higher aquatic plants. Although such plants oxygenate water as a result of their photosynthesis, their massive growth may be unsightly, interfere with recreation (swimming, fishing, boating), may produce undesirable taste or odour-causing metabolites, and may on death and decomposition exert a serious polluting effect in the water. This problem has been well recognised, mainly in lakes, such as in Switzerland and the North American Great Lakes, as well as in enclosed coastal waters. Vigorous programmes of research are under way on tertiary and other advanced waste water treatment processes in many parts of the world: for example, in South Africa, in the Middle East, in Europe and in the U.S.A.

The third form of pollution is the most insidious of all: micropollution. Trace quantities of persistent chemicals, many of them man-made, escape treatment processes, defy natural decomposition, and remain in our environment, unseen and virtually undetected. Some, as we shall see, are ancient environmental microfactors; some, however, are very recent due to man's industrial (particularly chemical industrial) activity, and their numbers are growing. These materials are simultaneously the threat and the challenge for the future, for we do not yet fully understand their long-term hazards for mankind.

MAN'S MEASUREMENT OF WATER QUALITY

It is almost axiomatic that before we can control water quality, in a scientific sense, we must be able to measure it. We could set up high-purity distilled water as our aim in quality, and say that departures from it represent impure water. This, however, is unrealistic when considering water as part of man's environment, and we need to look for a satisfactory criterion for drinking water. If this can be done, our other water needs: domestic, agricultural and industrial, can be related to it. Certainly most of us would find distilled water unpalatable, so it would not be acceptable for drinking purposes.

I prefer the definition enunciated by Dr Taylor and Dr Burman of the Metropolitan Water Board (London) when they wrote:

> "As a chemically or physically pure water cannot occur in nature, purity implies pleasing to the senses, that is absence of visible particles, turbidity, colour, taste and odour and freedom from excessive amounts of substances in solution not normally detectable by the unaided senses. Potability therefore, implies physical attractiveness as well as safety."

Not all so-called drinking water matches up to that definition, and the view that cartoonist Alan Dunn took in the New Yorker is not as overdrawn as we might imagine. He drew a chemistry teacher addressing his attentive class of students thus: "Now when we take three hundred millilitres of a compound containing hydrogen and oxygen in a ratio of two to one and add three millilitres of an eight-hundredths percent chlorine solution, one millilitre of a three ten-thousandths percent stannous flouride solution, and fifty millilitres of treated industrial wastes and solids, we get drinking water."

Range of concentration

Even the amounts Dunn's cartoon chemist is concerned with, are very small, marginal quantities. The quantities of impurities to be measured or removed are not of the magnitude frequently encountered in industrial production or chemical engineering processes. For example, sea water is 96·5 percent H_2O, domestic sewage about 99·9 percent H_2O, and the River Thames supplying London's water is 99·95 percent H_2O.

However, describing purity in terms of gross percentages is to take a naïve view of water quality. In the context of the human environment a much more detailed examination of the content of water is required. That percentages are a coarse measure of our scale of interests can readily be seen on *Table 2*. The scale of *Table 2.* is pivoted around 1 mg/l—the familiar ppm

Table 2. Scale of concentrations of substances in water

10^{3}	1 g/l	0·1%	total 'contaminants' in sewage
10^{2}			Ca in hard water
10^{1}			Ca in soft water
10^{0}	1 mg/l		1 ppm F. Steroid hormones
10^{-1}			
10^{-2}			
10^{-3}	1 μg/l		LSD detection
10^{-4}			carcinogenic hydrocarbons
10^{-5}			
10^{-6}	1 ng/l		1 bacterium/100 ml
10^{-7}			
10^{-8}			
10^{-9}	1 pg/l		
10^{-10}			Sr-90 MPC
			I-131 MPC
10^{-11}			
10^{-12}	1 fg/l		1 virus/100 ml

of water analysis. Our interests are already at one million-millionth, or 10^{-12} below that value: at 1 femtogram per litre for enteroviruses; although such a description of concentration is misleading as we do not determine their presence gravimetrically.

It is not possible to present all the substances of interest to the water analyst on this scale, and only a few items are included as examples to illustrate the range of concentration. Some of these items have only recently aroused interest with respect to public health aspects of water.

Calcium

At the upper end of the scale, at the level of tens or hundreds of milligrams per litre, the presence of calcium in water has been shown to have a very significant negative correlation with mortality from cardiovascular diseases. Dr Margaret Crawford and her colleagues at the London School of Hygiene have investigated the mortality statistics of 61 county boroughs in Britain and have shown that where the water is hard (that is, an average of 102 mg/l as calcium), the mortality rates attributed to cardiovascular diseases were significantly lower than average, and that where the water is soft (that is, an average of 8·5 mg/l as calcium) the converse was true. All appropriate statistical controls and checks were made to avoid other factors: social, climate, geographical, etc. from confusing the issue. If you live in a hard water area, the moral is obvious: "a glass of water a day keeps thrombosis at bay"; but it raises the interesting question as to whether we should add calcium to soft waters to protect the cardiovascular health of the population.

Fluoride

The question of adding substances to water naturally brings me to the next item, at the pivot point of the scale: the fluoride ion at 1 mg/l. This is known to be the optimum concentration for the protection of teeth against decay during the formative years of growth. Of course, the addition of any substance to water to make it purer, in the health sense, seems paradoxical. I do not intend to repeat the march and countermarch of arguments in the fluoridation campaign—most of them we have heard *ad nauseam* anyway. However, to make my position clear I would say that I do not accept the view that health is just a series of negatives: absence of disease, absence of toxicity, absence of contaminants and so on. That is only half the picture: I support the view ot the World Health Organization that "health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity." In the W.H.O. publication *The Education of Engineers in Environmental Health* this view was endorsed with respect to our control of the environment, including water. So if it is a positive contribution to more healthy living, to add substances to water, then I am in favour.

Hormones

Also this is not the occasion to wrestle with the theological controversy concerning the Pill, but the question does have a public health aspect. The widespread use of hormone compounds does mean that increasing quantities are discharged via sewers and water courses. This inevitably means that some may reach drinking water supplies where they may be indiscriminately supplied to young and old, male and female, matron and maiden. Professor Gordon Fair and Dr Elisabeth Stumm-Zollinger at Harvard have estimated our level of interest in the steroid hormones to be about 1 mg/l in water. Fortunately these substances are readily degraded biologically, so that we need sound no alarm bells at the present time.

LSD

Recently the American Water Works Association published a tentative procedure for the detection of the drug LSD in water, sensitive to 1 μg/l. It is not clear whether it is being found regularly in any water sources, or whether the Hippies have threatened to dose the water supply of San Francisco. However, invitations by Travel Agents to "Take Your Trip by Water" may take on a more subtle meaning.

Incidently, the concentration of 1 μg/l is approximately equivalent, on a weight basis, to a needle in a haystack. Consequently, we will have to call on highly refined gravimetric techniques when we go below this level, or abandon such techniques for others of a different character.

Carcinogens

At the level of one-tenth of a microgram per litre are the polynuclear aromatic hydrocarbons that appear to be almost ubiquitous in water. These have been studied intensively, particularly in Germany, as the carcinogenic benzpyrene is among this group of substances. Benzpyrene is a more familiar contaminant of the atmosphere, being a residue of the combustion of organic compounds. A number of the polynuclear aromatic hydrocarbons in water have been shown to be carcinogenic to mice, but there is no direct evidence that carcinogenesis in man can be attributed to their presence in water. In fact the only reported example of carcinogenesis in man resulting from the consumption of drinking water is that of arsenic poisoning with associated arsenic cancer of the skin and liver. As there is evidence that the polynuclear aromatic hydrocarbons are produced by certain plants, as well as from human or industrial pollution, it is likely that they have always formed a background constituent of man's drinking water, and that there is no cause for alarm at the detection of low level concentrations. However, any rise in concentration above these natural levels needs to be viewed with the same sort of care as we associate with increases in radioactivity above its background intensity. This analogy may be particularly apposite for it appears that many carcinogenic substances are also potentially mutagenic, like ionising radiations.

Coliforms

The next on our list of possible contaminants brings us down to the nanogram per litre level (or one millionth of a mg/l). However, here we have departed from chemical assay, and rely on microbiological growth to indicate the presence of bacterial contamination. I have taken the British Ministry of Health's figure of 1 coliform per 100 ml, which represents a 'satisfactory' or Class II water quality before chlorination.

Assay methods aim to detect a viable bacterium because it will multiply in an appropriate growth medium. If it is not viable, the bacterium is undetected. In this case, to hunt for it would be like looking for one rusty needle in a thousand haystacks; and if it were found, the information would be about as useful as a well-rusted needle.

Radioactivity

Like the bacteria, the radio-isotopes are only detectable in a practical way because of a multiplication factor. In this case, however, the multiplication lies in the detection instrument which magnifies either an electrical or a photo phenomenon produced by the ionising emission of the radio-isotope. Consequently our detection can be below the picogram per litre level, which corresponds to the maximum permissible concentration set for strontium-90 in water, specified in tenths of a picocurie per ml.

Those industries which provide and those which use radio-isotopes have demonstrated a model of environmental control of dangerous and contaminanating substances, which is unparalleled. This indicates that, given the willpower, legislation and finance, science and technology can achieve a remarkable degree of control over environmental pollution, even at fantastically low levels of concentration. One only wishes that similar control were available over the many other insults that man inflicts upon his own environment.

Viruses

At the lowest end of our 'impurities' in water are the viruses. So far only the virus of infectious hepatitis can be directly implicated in waterborne disease; but there is strong circumstantial evidence that certain enteroviruses have infected man via the water route. It appears that in general viruses are less numerous in water than bacteria, and consequently methods of concentration are needed before they can be assayed by multiplication in growing cells in the laboratory. Because of these, and other uncertainties, no standards have been set. However, if we set an arbitrary level of interest as 1 virus per 100 ml (that is, about 3 viruses in a glass of water), it gives a corresponding 1 femtogram per litre on our gravimetric scale.

Lower concentrations

Will we see the scale extend even further down in the future? This may be likely if we have methods of detecting the presence of single molecules in a millilitre of water, and if we have the need to be on our guard against impurities at that concentration. However, with so many new compounds being synthesised, week by week, month by month, for the insatiable demands of a consumer market, and the increasing use of chemicals in agriculture and industry, we will have enough to occupy us further up the scale of concentrations if we are to protect the purity of the nations' waters.

Certainly we are in some danger as Professor Dan Okun put it in his recent Croll lecture to the British Institute of Water Pollution Control: "They (drugs finding their way into water supply) may . . . have us all somewhat tranquillized or energized, hormonized, hermaphrodized or fertilised"—to which I might add "psychedelicized".

MAN'S CONTROL OF WATER USE

Man's needs for water, his degradation of its quality and the increasingly exacting standards required for drinking water all indicate the necessity for control or allocation of water use. More and more, civilised communities are realising that water is not a free-for-all inexhaustible resource. Consequently the management of as much as possible of the hydrological cycle in a rational manner has become for many nations a desirable, if not essential, goal.

One aspect of this is how we are going to achieve the purity demanded for human drinking requirements, bearing in mind the extremely low levels of concentration we have been discussing. The most obvious step is not to get involved with the impurities in the first place. By this I am not advocating a strangulation on industry by putting an impossible limitation on industrial effluent discharges, so that they may only release 'pure' water. Nor am I suggesting a similar exercise with respect to municipal sewage treatment. Nor am I suggesting that rivers should not be used as carriers of waste water. Most nations live by their industry, they must also learn to live with it. Rivers are parts of the natural resources of a country: they should not be reserved exclusively either for the angler or for the industrialist.

By "not getting involved with the impurities in the first place", I mean that we should take note of the difference between our physiological and our domestic needs for water. As I have already mentioned, only about 2½ litres each day are used for human ingestion; the remaining 130 litres or so supplied *per capita* to the household is used for washing ourselves, for laundry purposes, for cleaning and flushing and for food preparation. Since only 2% of the water supplied has a day-by-day health impact on us, it seems somewhat wasteful to improve the other 98% to the exacting quality criteria shown in *Table 2*. It would seem eminently more sensible to reserve, say 5% of the supply exclusively for human ingestion, and make this the water of supreme quality.

Groundwater and surface water

If in any water supply area a groundwater source exists, even of small output, it could be reserved as the top quality drinking water, leaving surface supplies for the lower grade uses. This is because groundwater is generally much purer than surface water, being more remote both physically, and in time, from pollution.

In the London (M.W.B.) area, for example, about 15% of the water supply comes from wells in the great chalk syncline and associated strata: which are sources of water of high purity compared with the other sources—the rivers Thames and Lee. This is shown in *Figure 1*, which compares the average quality of the Kent Wells with that of the Thames at Laleham (an M.W.B. intake), for the year 1966. In all the parameters that matter: nitrogen, oxygen absorbed from permanganate, turbidity and colour, the Thames water contains more than ten times the impurities in the Kent well water (note the logarithmic scale). In the case of coliform bacteria the ratio is over four orders of magnitude, or 10,000 to 1.

Although in London it would be a mammoth task financially and in logistics to disentangle the well supply from the rest and run a parallel

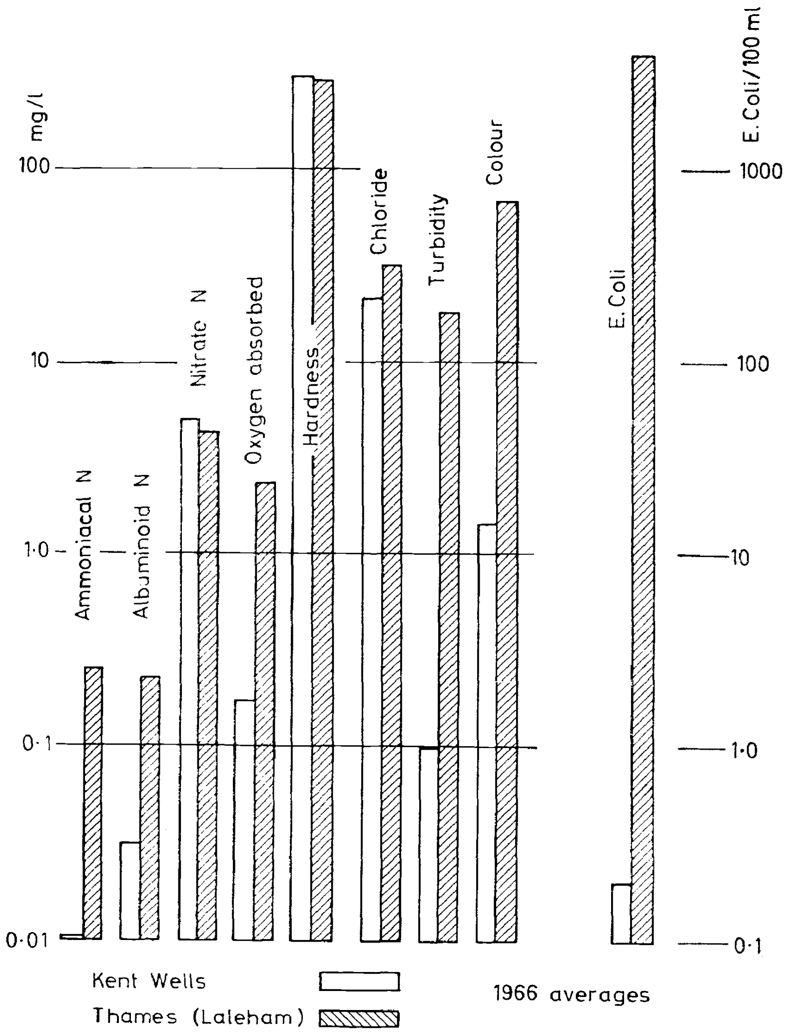

Figure 1. Comparison between Kent well water and Thames water

distribution system, the principle is plain to see, and could be applied to new communities with new supplies.

There is a corollary of this which is fairly obvious: the existing waters of high purity must be protected against degradation. Therefore it follows that groundwater recharge schemes must be evaluated very carefully where surface water of lower grade is to be introduced. There is a danger that when schemes involving water quantity are being proposed, the water quality aspect is not so carefully considered. If the recharge water is of 'drinking water quality', it is usually considered that purity criteria have been met. But the term 'drinking water quality', as we saw earlier, is subject to increasingly stringent criteria on public health grounds. Certainly it would be a pity to add the 'drinking water' of Dunn's cartoon to a pristine well water which is free from any recent history of industrial of human pollution.

Parallel systems

It is suggested therefore that a 'hierarchy of water quality' (to quote the title of Dan Okun's recent article for the American Chemical Society) be established so that higher grade water should not be used if a lower grade is appropriate and available. By this means the best quality is reserved for the most important purposes, and water degraded in quality may be used again lower in the hierarchy.

Certain precautions are necessary. Parallel systems must remain parallel, and interconnection made impossible. Perhaps different colour dyes could be used (as in the toilet flush water in some aircraft)—for example, low quality water can be used for fire-fighting (would a red dye be appropriate?). In this context, it is necessary to observe that if a domestic-use supply came in parallel with a drinking supply, to a household, the chance of occasional ingestion of the domestic-use supply would be high. Therefore, on health grounds, the domestic-use water should be 'safe'. In particular this means that it should meet the present bacteriological standards and should contain no grossly harmful substances. From an aesthetic point of view we would wish it to be clear, as washing or bathing in cloudy water is objectionable.

This whole matter of parallel systems, or dual supplies, is not new: certain places where fresh water is extremely scarce already use dual systems. These are principally island communities, for example in the Bahamas, Catalina (off the Californian coast) and parts of Hong Kong Island. The costs of such dual systems have been looked at by Paul Haney and Carl Hamann in the U.S.A. in 1965.

But it was in 1896 that Punch had the right idea, for in a cartoon celebrating the opening of a new water supply to London, the turncock instructed water consumers gathered round a standpipe, on the misuse of good drinking water:

> "Now look 'ere, don't you go a-wastin' all this 'ere valuable water in washin' and waterin' your gardens, or any nonsense o' that sort, or you'll get yourselves into trouble!"

MAN'S FUTURE CONTROL OF WATER QUALITY

No mention has been made of the various methods of treatment available for water and wastewater purification. A considerable armoury of treatment weapons is at our disposal, as is indicated on *Table 3*.

Science has already been scavenged thoroughly to reveal all the possible methods of water purification for the ever-optimistic world of desalination, and for the astronomical demands of spacecraft. Fundamentally new methods seem unlikely; but existing methods are coming under increasingly closer inspection so that they may be used more efficiently.

A growing trend in this efficient utilisation of existing treatment processes is to integrate processes and take a 'systems' view of water treatment. This avoids the concatenations of treatment processes which I criticised recently

Table 3. Water treatment processes

Dissolved	*Fine suspension*	*Toxic or pathogenic*
Precipitation	Flocculation	Chemical destruction
Ion-exchange	Sedimentation	Biological ,,
Adsorption	Filtration	Thermal ,,
Membrane separation	Flotation	Radiation ,,
Distillation		Adsorption
Freezing		

in my Inaugural Lecture "Purely and Simply—Water", and allows the specification of input to determine the nature of the treatment system. This approach requires workable mathematical models of water treatment processes, an end to which many research workers, including those in my own laboratories, are devoting their efforts.

The future challenges to the chemist and biochemist in control of water quality are to produce rapid and refined methods of measurement of micro-impurities, and to devise laboratory techniques for determining potential toxicity and carcinogenesis in water sources.

Apart from these future developments in water technology and science, a considerable challenge faces us all in water management. The nature of the hydrological cycle, and the demands of man for water of varying qualities, must be reconciled so that the human environment is controlled for man's benefit.

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