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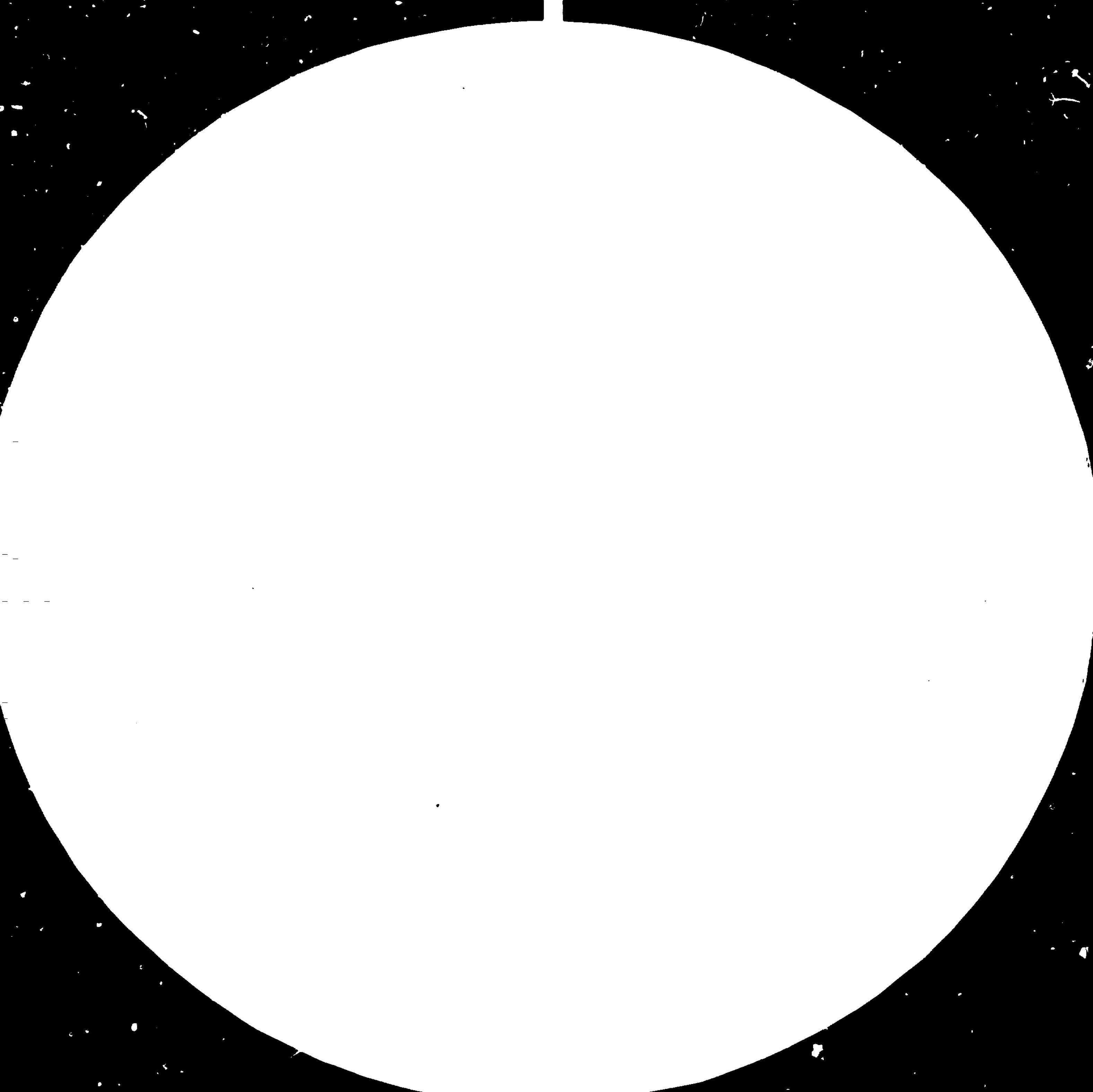

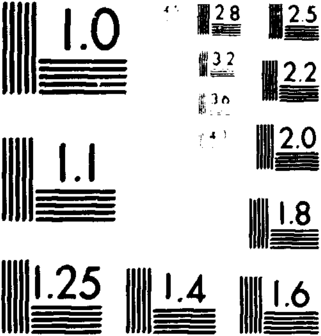

MICROCOPY RESOLUTION TEST CHART

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TEXTILE MONOGRAPHS
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WATER CONSERVATION IN THE TEXTILE INDUSTRY

Based on the work of G. J. Parish, Shirley Institute, Manchester, United Kingdom

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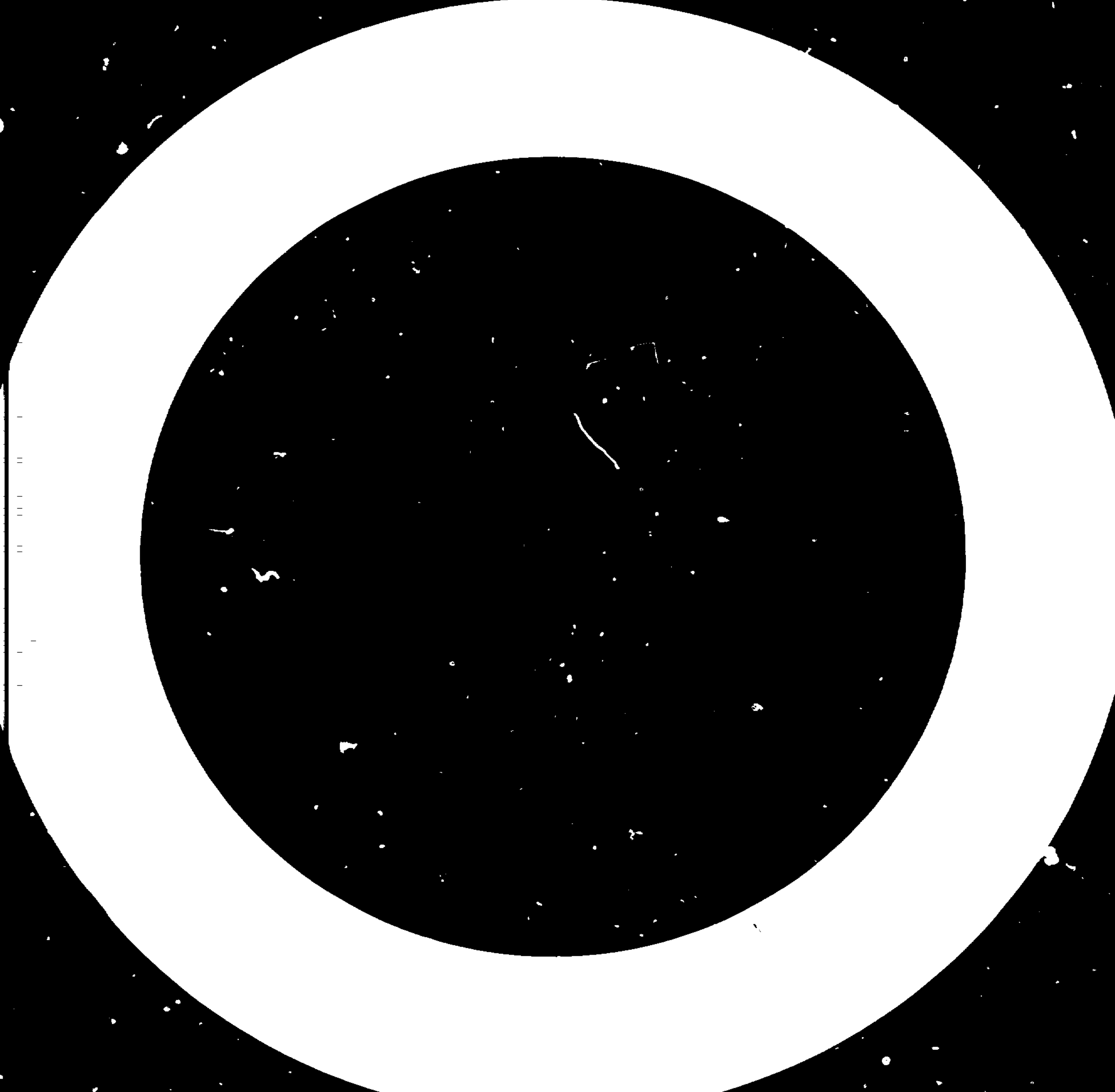

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INTRODUCTION

Water consumption in the industry

The textile industry consumes large amounts of water in its varied processing operations, but in the mechanical processes of spinning and of fabric production water is used primarily for steam raising and humidification in air-conditioning systems. These services are not specific to the textile industry and their water requirements have no features that are peculiar to the textile operations concerned. In these areas there is only a limited number of activities, such as warp sizing and water-jet weaving, where the water consumption is associated directly with the textile material and it is small compared with those found in the wide variety of processes employed in textile dyeing and printing.

It is reasonable therefore to restrict a consideration of water consumption in the textile industry to the activities loosely defined by the term "finishing", where it is both most substantial and directly determined by processing requirements. Textile finishing includes the preparatory processes of desizing, scouring and bleaching as well as the operations of dyeing and printing and various supplementary processes such as the application of resin or finishing agents. Appropriate operations in this group are applied to textile materials in the form of loose fibre or yarn as well as to fabric.

The most readily available figure for water consumption is the overall specific consumption, i.e., the total amount of water used by all processes in finishing divided by the total weight of material processed in the works. However, such data show a remarkably wide range of values: one survey [1] quotes a range from under 5 to over 500 l/kg. Much of this wide variation - the ratio of the extremes is over 100 to 1 - is ascribable to major differences in the extent and complexity of the processes involved, but even when similar categories are compared the ratio of the extremes may be 5 or 6 to 1. In these circumstances it is virtually impossible to detect consistent differences in the water consumption of different processes, for example, yarn and fabric dyeing.

Because of this wide range of values of overall specific water consumption, the average value for the industry as a whole has limited significance. At present this average probably lies in the range of 100-120 l/kg and may provide a guide to the water consumption in a district or region in relation to its production of finished textiles. It is of little assistance to the individual finisher, who must look more closely at his own data and at the relevance of comparable or target figures if he is to attempt a logical approach to water conservation.

There are, however, a number of points worth making. The average specific water consumption for the industry as a whole lies in the upper part of the range quoted above. It is the very small consumptions that indicate abnormal situations; for consumption above approximately 30 or 40 l/kg some common features are likely to be observed. A works with a consumption at or above this level must be carrying out a significant number of individual operations in preparation and dyeing or printing, and such a works will typically have a steam consumption one quarter to one sixth of the direct water consumption in processing; in other words, for each ton of steam produced some 4-6 tons of water will be used in processing. This narrow range is in marked contrast to the wide range of individual water (and steam) consumptions. It results from the fact that a substantial proportion of steam is used for water heating and that alternative processes do not employ dramatically different temperatures.

Actually less than 1 ton of water is consumed in the production of 1 ton of steam. The amount of fresh water fed to the bo[illegible]rs depends on the percentage condensate recovery and losses associated with the boiler operation, and in a typical situation fresh water may be required to make up roughly 50 per cent of the steam produced. It follows that boiler make-up water is likely to represent roughly 10 per cent of the water supplied directly for processing. This fraction is not large enough to have much significance for average water consumption figures, so it is unimportant whether process water alone or process water plus boiler feed water is quoted, but it is large enough to be significant when considering in detail the situation at a specific works.

Of the steam which is not returned as condensate to the boiler, a part, at least, will be condensed in process water baths, effectively augmenting the direct water supply. This effect is offset by losses arising from deliberate and inadvertent evaporation and by leakage, so the effluent flow from the works is typically 5-10 per cent lower than the inflow of process water.

T[illegible] staffing levels in textile finishing works are such that the domestic water consumption is likely to be only 1 or 2 per cent of the process water demand.

Quality and quantity requirements

In textile finishing operations water is used mainly for two purposes: first as a solvent for processing chemicals, and secondly, and still by virtue of its solvent action, as a washing or rinsing medium. In either situation it must not contain any contaminants that would adversely affect the chemical process or the washing operation, and it must be present in sufficient quantity to provide a contact with the textile material adequate for the uniformity of processing demanded.

In principle, the quality requirements may differ from process to process, so that waters of different degrees of purity could be employed, but the complications of using a multiplicity of supplies of different quality are such that the normal practice is to have a single supply of a quality sufficient for all purposes. In only a few instances are additional, purified supplies used for particularly critical processes. It is therefore reasonable to speak of a single quality requirement, and there is general agreement on quality criteria. Several authors have specified acceptable impurity limits, an extensive list being given by Little [2]. There are some discrepancies between the numerical values proposed by different authors (table 1), but these recommendations reflect reasonably accurately the characteristics and the variability of water currently employed for satisfactory processing. Many water supplies, from surface or underground sources, can be purified to some degree by filtration and softening, although special treatment may be required for particular contaminants.

Table 1. Suggested limits for water contaminants

Author	Colour (Hazen)	Turbidity (FTU)	Alkalinity (as $CaCO_3$)	Hardness (as $CaCO_3$)	Total solids	Fe	Mn	Cu
			mg/l					
Little [2]	10	5	100	70	500	0.3	0.05	0.01
Hirst and Rock [3]	25		60	100		0.5	0.1	
Harker and Rock [4]				70	500	0.3	0.05	0.01
Nordel [5]	10	5		500		0.1	0.1	
Cotton Handbook [6]	5		75	15	200	0.05	0.02	
Fair and Geyer [7]	20	5			200	0.25	0.02	
Hetherington [8]	5		75	10	200	0.05	0.02	
Morton [9]						0.3	0.05	

The water quantity requirement (i.e. sufficient water to achieve the required uniformity of processing) is to a considerable extent a function of machine design. Different machines have their own characteristic features that set lower limits to the amount of water they require in order to process a given quantity of material. This is most obviously the case with batch-processing machines; one with a high liquor-to-material ratio, such as a winch or a hank dyeing machine, cannot be expected to offer the same water economy as one with a low ratio such as a jig or pack dyeing machines.

In a similar way, the specific water consumption for a process depends on its complexity (the number of individual operations in a particular process). As the choice of the machine to be used for a particular process may be a question of availability or preference and as the complexity of processing also admits of much personal choice, a wide divergence may exist between the total water consumption at two works, although those works perform the same general type of processing.

Where water is employed in the preparation of chemical baths there is little tendency to use it extravagantly since water consumption must be matched by chemical consumption to maintain the specified bath concentrations. However, this restriction does not apply to washing processes which cannot be adversely affected by using "too much" water. It is in washing processes that personal choice is most evident and more water is used rather than less. Therefore, substantial water savings can be made but the finisher must be satisfied that such savings will be worthwhile and safe and find the correct way to implement them.

Substantial reductions could be made in process-water consumption either by using less or by reuse, but these alternatives have quite different effects on quality and quantity, the criteria for which are basic to the industry's water requirements. A direct reduction in process-water consumption would mean that production requirements must be maintained with a lower quantity of water, but with the quality unimpaired. Reuse would permit the quantity of water employed in processing to remain unchanged at the expense of possible deterioration in quality. There is clearly no single solution; both alternatives must be considered in relation to the requirements and the opportunities at each particular site.

Reasons for conservation

Water conservation is necessary when there is a reduction in the available water supply, when a fixed supply hinders expansion or when there are increasing demands on a region's supplies.

The necessity of water conservation may also result from restrictions on the disposal of effluent, but this situation is less likely since water conservation alone is an effective solution only if the restriction is exclusively on the volume of effluent discharged. More general effluent restrictions require different corrective actions in which water conservation may play a minor part.

It may be possible to solve the problem by tapping a more remote water source or by treating an available water supply of unsatisfactory quality. However, the financial arguments (the cost of water and of effluent treatment is approximately 4 or 5 per cent of total processing costs) generally favour conservation and are the main incentive where there is no physical limitation on water quantity or quality.

Even if external incentives are not sufficient to justify conservation, internal factors must be taken into account. Because of the close correlation between steam consumption and water consumption in textile finishing, in any situation where water is heated a saving of water will produce an automatic saving in energy. If the water is heated close to boiling point, the financial benefit from the energy saved will be five or six times as great as the savings in water and effluent costs. Energy is saved most effectively by a direct reduction in process-water demand. Although energy can also be saved by the reuse of hot water, it is not necessary to reuse the water in order to recover the heat it contains.

Substantial savings can also be expected if water conservation leads to reduced chemical costs, but the situation here is not so clear-cut. A reduction in chemical consumption can be achieved by reducing the volume of chemical baths, but water consumption in this area tends already to be limited because, as already pointed out, it must be matched by chemical consumption. A saving in wash water will not directly affect chemical consumption and the main scope for saving appears to be by the recovery of chemicals in reused water. At present this is practicable only in a limited number of situations, although where it can be employed the chemical saving is a major importance.

On balance, energy conservation is likely to be the most consistently significant incentive. Its importance is such that, whatever the external situation, potential energy savings alone are sufficient to justify serious consideration of any opportunities for water conservation.

Approach to conservation

It is perfectly feasible to reduce water consumption in a piecemeal manner, seeking good-housekeeping measures here and there and larger savings by machinery replacement or by introducing water reuse on one or two machines. Such measures will generally be successful, but they cannot lead to any real understanding of the water consumption situation or provide any assurance that the measures are being applied where they will do the most good or that their results represent satisfactory rather than moderate or poor performance.

If the problem is to be tackled in a systematic way, it is necessary first to establish the pattern of water consumption at the works in question and to compare these results with appropriate target figures, secondly to examine alternative conservation procedures, and finally to introduce a conservation programme based on these considerations. This sequence of actions demands a more quantitative attitude to water consumption than is yet widespread in the industry but is an unavoidable prerequisite of the comparison process; it is equally essential whether the performance of a particular machine is being compared with a target figure or the improvement in the machine's performance is being determined following the introduction of conservation measures.

The measurement of water consumption, then, involves conducting a "water audit" for the works in sufficient detail to establish the major water-using operations and to derive specific water consumption figures for these operations. It is necessary to examine the situation in such detail since it is only at this level that meaningful comparisons can be made with target figures or guidelines derived either from similar measurements at other works, of which sufficient have been published to serve this purpose, or from theoretical analyses of the processes involved. In either case the target values will relate specifically to process-water demand and to conservation achieved by reducing this demand. The pros and cons of conservation by this means and by water reuse must then be examined so that the most suitable conservation programme can be introduced.

I. MEASUREMENT OF WATER CONSUMPTION

The type of measurements required for water consumption is dictated by the format in which target values are presented, and target values are only meaningful when they deal with individual unit operations, that is, with a particular process performed on a particular type of machine. The more precisely the target values are defined, the easier it is to compare data. Target values are of necessity expressed in terms of the specific water consumption, the amount of water used divided by the weight of textile material processed.

Considering the wide range of combinations of machines and operations, studying each combination in detail might well be more confusing than helpful because of the mass of data produced. Steps must therefore be taken to reduce the data to be evaluated.

First, the important machines must be identified. It is likely that a works' staff will be able, without recourse to any measurements at all, to identify the small number of machines or groups of similar machines, perhaps four or five, that are responsible for one half to two thirds of the total water consumption of the works. One or two measurements should be made to check these conclusions and to extend the list to provide coverage of 70-80 per cent of the total water consumption, but the effort required should not be great and it would probably be uneconomical to aim for a more detailed coverage. It should be possible to reduce the number of machines requiring detailed investigation to about ten in a typical works. Where substantially identical machines are performing similar work(for example, a row of jigs or pack dyeing machines), only one or two should be selected to represent the group.

The next step is to consider the operations performed on the selected machines. Again, it should be possible to identify a small number of classes of work that together make up the major part of the machine's work-load. This number may be as few as one or two and will rarely be more than six. In the latter circumstance consideration may be restricted to two or three as typical of the group. By this procedure it should be possible to reduce the number of operations requiring evaluation to manageable proportions, say not more than 25 or 30 in a works of average size.

One consequence of such a selection procedure is that coverage of the total water consumption is far from complete. The situation is not helped if the measurements are made by the simpler means that in general are suitable only for spot readings or for measurements over a limited period. Nevertheless, it is desirable to attempt to produce some form of water audit, which if possible should include the measurement of consumption in individual sections of the works as well as the total consumption. If this is not done, significant items of water consumption may be overlooked.

A description of the simpler methods applicable to individual machines is given below followed by the techniques suitable for the measurement of total and sectional flows.

Simple methods for batch-processing machines

The essential requirement for determining specific water consumption by batch-processing machines is to ascertain the volume of water used each time the machine is filled and to count the number of fillings in the processing of a known weight of material. It is necessary to note what each filling is used for (dye bath, rinse etc.), unless this information is already available from processing records.

The simplest procedure to determine the volume is to calculate it from the dimensions of the vessel. If the vessel has a regular shape, the only equipment required is a rule or tape.

If the vessel has a complex shape or is much encumbered below the water level (with fabric guide rollers, for example) it is preferable to measure the water volume directly. This can be done most simply by pumping the water from the vessel into a container of known volume. Alternatively, the "bucket-and-stopwatch" procedure may be used: the flow from a hose is calibrated by measuring how long it takes to fill a container of known volume and the filling of the processing vessel with the hose is timed.

Another alternative makes use of the dilution principle. The vessel is filled with clean water and a known amount of some test substance is added; the solution is thoroughly stirred, a sample removed and the concentration of the test substance determined. This test may be conducted, for example, with a dyestuff, the concentration of which can be determined by a spectrophotometer or colorimeter, or by sample-dilution and visual comparison. Alternatively, a readily available inorganic salt, such as sodium chloride, may be used; this can easily be measured by conductivity.

Each of these procedures requires access to the machine in order to make the measurements, but interference with production is brief.

One or other of these four measuring procedures is suitable for most batch-processing machines in their normal mode of operation; that is, when the vessel is filled only at discrete intervals. The methods are not applicable, for example, to overflow rinsing on jigs or winches or to those jet dyeing machines that must be kept full of water, in which case, the water flow is continuous or semi-continuous and the measurements must be made by the methods appropriate to continuous operation. On the other hand, "standing baths" in continuous washing ranges should clearly be treated as batch processes.

The determination of water volume has been described above as though it required measuring once only for each machine; that is, as though each machine had a unique volume associated with it. In some instances, where for example the machine must be completely filled with water, this is true, but in open vessels it is not necessarily so. In the latter case, it is important either to check that the water depth is the same each time the vessel is filled or to prepare a simple volume indicator in the form of a dip-stick or calibration marks on the side of the vessel. If the water volume is observed to vary appreciably the measurements should be repeated once or twice to obtain a better average and to have some indication of the range of variability in water consumption.

All measurements should be made under normal operating conditions, therefore, it is important that operatives should not be unusually economical or careful during the measuring period.

Simple methods for continuous machines

The essential requirement for continuous machines is to determine the total quantity of water consumed during the processing of a certain mass of textile material. In contrast to batch-processing machines it is primarily flow rates that must be measured, but a complicating factor is the volume of water contained in the tank or tanks of the machine. These tanks are commonly filled with fresh water either at the start of a particular run or at the start of a shift or a day, and the question is whether or not this volume makes a significant contribution to the total water consumption.

The relative tank capacities and flow rates in a conventional washing-range are such that the through-flow is equal to the total tank volume in a time typically between 20 and 60 minutes. If processing is continuous (in the sense that the tanks are not drained and refilled) for a whole shift or longer, the effect of the tank capacity is relatively slight; in much shorter runs it could make a substantial contribution to water consumption.

The ideal procedure for dealing with continuous-processing machines is to measure the tank capacity (any of the methods appropriate to batch processing may be employed) and the water-flow rate, and then to record the total mass of fabric processed in a particular period, taking note of machine stoppages and whether or not the water flow is turned off during these intervals, in order to arrive at an accurate figure for the total water consumption. This is inevitably a time-consuming procedure, and the less accurate results obtained by measuring only the water through-flow and calculating the fabric throughput from the processing speed are likely to be adequate for most purposes.

Water flow rates may be determined by the counterparts of two of the procedures applicable to volume measurement. A direct measurement is provided by the bucket-and- stopwatch procedure if a container of suitable size can be inserted under the inflow or the outflow (it is immaterial whether the water input or the effluent is measured). Sometimes this may be difficult to do, as for example when the input is distributed via a spray pipe at a nip, and in any event the container size is likely to be limited and timing possible for a few seconds only. The timing can be extended and accuracy improved by using the tank on the machine as the container; having determined the tank volume, it is only necessary to measure how long it requires to fill.

In a multi-tank machine, such as a continuous washing range, there may be several water inputs and care must be taken that none is missed. If the effluent stream is readily accessible it is an advantage to measure the total flow there. Furthermore, measurements can be made on the effluent without interfering in any way with production.

The simple methods of flow measurement effectively give only spot readings, and their reliability is dependent on the extent to which the actual flow rate is likely to vary over an extended period and on the accuracy with which a control valve setting is repeated when the flow is stopped and turned on again. A number of measurements on different occasions is desirable to provide an indication of this variability.

Instruments for flow measurement

The obvious application of flow meters is in permanent installation for the continuous measurement of total flow or of the flow in sections of the works, although they may equally well be employed on individual machines or groups of machines if this is warranted.

The flow of supply water in completely-filled pipes is readily measured by flow meters of the conventional type, in which an impeller is driven by the water flow, or by devices, of which there are now an appreciable number, that measure some other property of the flow. Effluents, which, in addition to being contaminated, commonly flow in open channels or incompletely-filled pipes, require a different measuring procedure. Their flow is usually determined by introducing into the channel an obstruction, and this head is measured in some way and the measurement converted into a signal proportional to flow.

The permanent installation of a flow meter to measure either the total water input or effluent discharge is essential, and serious consideration should be given to the metering also of flows to sections of the works and to the most important individual machines as part of a more quantitative approach to water consumption. The most important information to be derived from a permanently installed meter is the total water consumption over a given period. Instruments that give only a reading of the instantaneous flow rate are not suitable; a direct reading of the total quantity should be provided. The recording of flow rate on a chart is helpful for identifying periods of high or low consumption, but a chart should not be the only output provided as the computation of the total water quantity can then be a tedious business. A combination of flow-integration plus recording is ideal, although it may well be found that the recorder charts are rarely consulted.

Where permanent installation of a flow meter is not felt to be justified, a temporary installation may be made; in this way one or two meters with appropriate measuring ranges may be employed over a period to quantify the consumption throughout the works. However, the inconvenience attendant upon the installation of a conventional flow meter in a water line and, equally, its subsequent removal for use elsewhere makes this exercise worthwhile only if monitoring at each location is carried out for at least a week or two. More rapid testing is possible using "non-invasive" meters, which do not require the pipeline to be broken into; devices of this type, although relatively expensive, are available as transportable units. Temporary installations may also be set up to measure effluent flow rates where a suitable location can be found for the introduction of a temporary weir; here again, portable measuring devices are available.

Water audit

Measurements of water consumption by individual machines are made principally to derive specific values for selected unit operations. The same measurements, combined with data from production records, provide average values for the total water consumption to be expected on each of the important machines in the appropriate period, which may be, for example, a day or a week.

These values may then be compared with one another and summed for comparison with the corresponding figure for the works as a whole and, if these data are available, for individual sections of the works. At this stage all sources of water consumption not directly related to processing must be considered such as the water employed in washing-down machines, floors or dye-mixing vessels. Where such water consumption occurs in a controlled way, as is frequently the case, for example, in the washing of printing screens, it is worthwhile attempting some simple measurements (using, say, the bucket-and-stopwatch procedure), but elsewhere it may prove difficult to obtain more than rough estimates based on the use of hoses.

Nevertheless, it is preferable to be armed with rough estimates rather than no data at all, and with this supplementary information it is feasible to compare the proportions of "recorded" and "unrecorded" water consumption. This will prevent any excessive unrecorded consumption going unnoticed, and the identification of areas requiring further investigation will be faciliated by this auditing procedure.

II. TARGET FIGURES FOR WATER CONSUMPTION

Alternative sources of target information

Two different sources may be consulted for water consumption targets; one, data compiled from measurements at a number of works and the other, figures derived from theoretical and experimental studies of the processes involved. Each has its advantages and disadvantages, although works' data will perhaps have a more practical appeal, since these are derived from measurements made under conditions of normal works' practice. Indeed, it is important that such works' data should represent simply an examination of works' practice without any attempt to impose constraints on the conditions employed, whether or not the examiner (who may well have his own prejudices) considers them wasteful.

Collected in this way, works' data display the pattern of water consumption of a number of finishing establishments; they can provide worthwhile targets only if they are sufficiently extensive to include a number of careful users, and they can only indicate target consumption by comparison of these lower values with the remainder. The target values indicated cannot therefore be absolute ones.

The alternative of deriving target values from the theoretical analysis of water-using operations has the advantage that the results produced are independent of current operating practice. Furthermore, since the analysis must be based on certain, defined assumptions, it is immediately apparent what must be done to achieve the target figure. It follows, therefore, that care must be taken to ensure that the assumptions represent realistic operating conditions achievable in practice.

Targets from works' data

Numerous authors have published water consumption figures in articles dealing with water consumption or water conservation. At the level of unit processing operations detailed results have been presented by Burford and others [10] and Gopujkar [11], and particularly extensive lists are given in a series of articles by Jaeckel, Knight and Pyle on batch dyeing processes [12], by Little [1] and in the publication The Use of Water by the Textile Industry [13]

It is immediately apparent from these surveys that even at the level of unit operations a remarkably wide range of specific water consumption is obtained. In The Use of Water by the Textile Industry a comparison is given of data collected in India, the United Kingdom of Great Britain and Northern Ireland, and the United States of America (table 2). Although there are some interesting differences in average water consumption, the most noticeable features are the wide ranges of variation, rarely less than 4 : 1.

Table 2. Comparison of water consumption figures

	Specific water consumption (l/kg)					
	India [a]		UK [b]		USA [c]	
Process	Average	Range	Average	Range	Average	Range
Desizing and washing	11		26	1-47	21	17-25
Kier boiling and washing	24	22-25	25	5-46	68	24-111
Hypochlorite bleaching and washing	11		68	21-173	310	276-343
Continuous peroxide bleaching			38	13-64	90	
Mercerizing	60	27-92	26	11-57	77	
Jig dyeing (vat)	35		82	38-196	102	
Continuous dyeing			38	9-63	32	17-50

[a] Gopujkar [11].

[b] Textile Research Council [13].

[c] Burford and others [10].

This wide variability is characteristic of virtually all measurements quoted, and is caused mainly by differences in water consumption (a) on different types of machine; (b) for dyestuffs, related to their processing requirements; (c) between chemical baths and rinses; and (d) according to the effects of machine loading.

A number of examples are given below to illustrate these points, using mainly data taken from The Use of Water in the Textile Industry.

The influence of machine type is illustrated in table 3 for a variety of fabric preparation and dyeing processes. In each instance the data from a large number of processing operations have been combined; for example, the results for dyeing relate to a variety of fibres and of dyestuffs.

Table 3. Effect of machine type on water consumption

Process	Processing method	Specific water consumption (l/kg)	
		Average	Range
Scouring	Continuous	30	3-94
	Jig	18	2-48
	Winch	73	41-146
Peroxide bleaching	Continuous	33	13-64
	Jig	41	8-80
	Winch	57	54-60
Dyeing	Continuous	38	10-63
	Jig	77	5-300
	Winch	183	28-540
	Beam	92	31-166
Washing	Continuous	19	3-60
	Jig	52	2-220
	Winch	81	41-195
	Beam	35	23-89

Continuous (with an average water consumption ranging from 20 to 40 l/kg) and jig (20-80 l/kg) use less water on average than beam (35-90 l/kg) or winch (60-90 l/kg) processing, but this difference results primarily from a difference at the bottom end, rather than the whole, of of the range. Both continuous and jig processing show low water consumption, but these low values are never obtained on the winch or the beam machine. At the top end of the ranges the differences between the machines are not pronounced.

Very large water consumption must result mainly from the user's choice, and it is apparent that on each of these machines some users are prepared to employ large quantities of water. On the other hand, however, the user can only be as economical as the machine allows, and it is apparent from these figures that very low water consumption cannot be obtained on winch or beam machines.

An indication of the "best" value attainable with each type of machine may be the averages of the lowest values (table 3):

	l/kg
Continuous	7
Jig	4
Winch	41
Beam	27

There are large differences in the amounts of water employed for different dye stuffs in jig dyeing (table 4), for which the complexity of processing is primarily responsible. Thus, in azoic dyeing the development of the colour may be done in from three to five steps with intermediate rinses, whereas a direct or disperse dye might be applied in one process followed by a single wash.

Table 4. Effect of dyestuff in jig dyeing

Dyestuff	Specific water consumption (l/kg)	
	Average	Range
Azoic	153	
Sulphur	136	44-297
Soluble vat	118	
Reactive	93	56-133
Vat	82	38-196
Acid	44	41-48
Direct	34	5-99
Disperse	6	4-9

Variations in washing practice exist, however. Although the more complex processes use a greater number of washes, the use of a running wash in others may increase the water consumption greatly, and one such running wash may consume more water than a number of single static washes. This effect is responsible, for instance, for the very wide range of values recorded for direct dyeing; in some works only one or two static washes are employed, with total water consumption less than 20 l/kg; in others, running washes increased the total water consumption considerably. Very low values are only possible when the number of individual steps is few.

When comparison is made between the water consumption in processing baths and washing, it is apparent that washing is responsible for the major part of the water consumption (table 5).

Table 5. Distribution of water consumption between processing baths and washing

Processing method	Average specific water consumption (l/kg)			Wash as percentage of total
	Process	Wash	Total	
Continuous:				
Scouring (kier and rope washer)	4	22	26	85
Scouring (kier and open-width washers)	5	25	30	83
Peroxide bleaching	1	12	13	92
Dyeing	9	25	34	74
Jig:				
Scouring	3	10	13	77
Peroxide bleaching	2	44	46	96
Dyeing	7	70	77	91
Winch:				
Scouring	22	56	78	72
Peroxide bleaching	26	64	90	71
Dyeing	55	126	181	70
Beam:				
Dyeing	14	36	50	72
Package machine:				
Scouring	10	19	29	66

Some interesting differences between processing methods can be seen from table 5. In winch processing the washing operations consistently require approximately 70 per cent of the total water consumption; in jig processing the percentage is higher and in two instances is over 90 per cent. Continuous processing also uses a higher percentage of water for washing.

The reason for these differences is to be found in the inherent characteristics of the machines and the attitude towards water consumption in chemical baths and in washing operations. On the jig, for example, it is perfectly feasible to use small quantities of water, and water consumption in chemical baths tends to be held down by the constraint imposed by chemical consumption. In washing, where this constraint does not apply, less effect is likely to be made to keep the water consumption to the lowest practicable level; as a result, proportionately much more water will be employed in the washing stages. Generally similar considerations apply in continuous processing, but on the winch it is just not feasible to use very little water, even for chemical baths. Therefore, although a generous attitude may still prevail to the use of wash water, the difference is not so marked.

Values quoted for ranges of specific water consumption represent a wide variety of operating practices and inevitably include results of differences in machine loading. In virtually every instance a reduction in machine loading is accompanied by an increase in specific water consumption. This is unavoidable in batch processing on machines that must hold a fixed volume of water, when any load less than the maximum that the machine will accept must increase the specific water consumption each time the vessel is filled, but in practice the effect is observed also on machines where the water volume can be altered and on continuous-processing machines.

In jig dyeing, for instance, there is a tendency to use a fixed length of fabric, so that the time of treatment for each end is constant. This gives a variation in batch weight proportional to the fabric weight per unit length and correspondingly higher water consumption for the lighter fabrics if the volume of liquor is not altered. In one works studied, the specific water consumption increased from 21 l/kg to 84 l/kg as the batch weight was reduced from 240 to 60 kg. The same effect is observed in winch processing where again there is a tendency not to alter the water volume as the batch weight varies.

In continuous washing operations there is a tendency to run a given machine with a fixed water through-flow rate, but little effort is made to adjust processing speeds to achieve a constant mass throughput rate of fabric. Most often, perhaps, a machine is run at a constant speed or the speed may be reduced slightly for heavier fabrics. As a result there must be a higher specific water consumption on lighter materials, since in effect the machine loading is reduced in these circumstances.

Therefore, the lowest values in any quoted ranges of water consumption generally relate to conditions of maximum machine loading. If these lowest values are to be employed as target figures, this point must be borne in mind and the possible adverse effects of underloading recognized. In some circumstances it may be possible to achieve optimum water consumption on an underloaded machine (for example, on a washing range by reducing the water flow or on a jig by reducing the volume), but in others (for example, pack, beam or jet dyers) it may prove virtually impossible.

Targets from theoretical analysis

Theoretical analyses bearing directly on water consumption have in the main dealt with washing processes. Bonkalo [14] and a little later Parish [15], pointed out that the performance obtained from a continuous washing range could be described in terms of only two independent parameters, one related to water consumption and the other to the efficiency of interchange of impurity between the goods being washed and the wash water. Experimental work showed that the efficiency parameter could be derived, with an accuracy sufficient for all practical purposes, by assuming the process to be governed by simple diffusion or mass-transfer relations.

A little later Morton [16] applied a similar theoretical treatment to batchwise washing on a jig, and Parish [17] has shown that the same basic principles apply to washing on a perforated beam.

The essential features of these analyses in the context of water consumption are that they deal with efficiency in the washing process, and specifically with the quantity of wash water it is reasonable to use. Subsequent investigations have considered in detail the efficiency factor, with a view to defining the influence of process variables on it, but without altering the validity of the general conclusions from the original analyses.

The function of any washing process is to transfer an impurity from the textile material to the wash water. The effectiveness with which this is done, called the washing performance P, is defined as the ratio of the amount of impurity removed from the textile material to the amount initially present.

The washing performance of a process, whether it operates batchwise or continuously, is determined by the relative amount of water used and the number of stages in the process (in batch operation the number times the vessel is drained and refilled, in continuous operation the number of compartments in the machine).

The relative amount of water used is expressed in theoretical analyses as the water factor F, defined as the ratio of the volume (or flow rate) of wash water to the volume (or flow rate) of water retained by the textile material at the end of the stage. It differs from conventional measures of relative water consumption in that it is dimensionless, i.e., it is not given as so many litres per kilogram of material, but as so many litres per litre of wash water retained by the material.

The efficiency of each process stage is the measure of how closely the real process approaches an ideal one operating with the same water factor. The ideal process cannot remove all the impurity from the goods, because the contamination in the wash water limits the cleanliness achievable; the goods cannot be relatively cleaner than the wash water they retain. The efficiency E of a real system may then be defined by the ratio of the amount of impurity removed by the real process stage to the amount of impurity removed when the goods are brought into equilibrium with the wash water.

The equations that relate P,E, and F to each other will be found in the publications referred to above. For the present purpose it is sufficient to note one important conclusion that follows from them: Optimum washing conditions are represented by a balance between efficiency and water consumption in each washing stage. It is unprofitable to operate with these factors out of balance and, in particular, with a water factor that is too large for the efficiency. It is possible to determine the optimum value of F to achieve a given washing performance. By way of illustration, optimum conditions for achieving a P of 95 per cent are presented in table 6.

It has been assumed in deriving these figures that continuous washing employs a counterflow of wash water; the water factor F for each stage is therefore the same as the total water factor F_t. In batchwise washing on a machine where the water volume can be adjusted, three washing stages (as on the continuous machine) are optimum. With a filling of fresh water each time, it is possible to achieve the same performance as on the continuous machine, and with the same efficiency and a slightly smaller value of F, but F_t is now three times the value for one stage.

A batch-processing machine of fixed volume is assumed to prohibit the use of an F-value less than 8. It is then uneconomical to use three washing stages. Two will suffice if the efficiency is increased (for example by increasing the washing time per stage) to keep E and F in balance.

The above remarks refer only to the water consumption as defined by F. Between this factor and the conventional measure of water consumption there are significant differences between continuous and batch-processing machines. On a continuous washing range the mangle squeeze between stages reduces the water content of the fabric to a value that makes the corresponding specific water consumption U_t numerically similar to F_t, typically (as shown in table 6) approximately twice as large.

Table 6. Optimum washing conditions to produce a washing performance of 95 per cent

	Washing parameters (per stage)		Number of stages	Total water factor F_t	Corresponding specific water consumption U_t (l/kg)
	Efficiency E (%)	Water factor F			
Continuous	80	4	3	4	5
Batch, adjustable volume	80	3	3	9	18
Batch, fixed volume	88	8	2	16	30

In general, continuous washing can be particularly economical because, with counterflow, it makes repeated use of the same water and because the mangle nips help to keep U_t numerically similar to F_t. Batch processes are inherently more water-intensive because they use the water once only and there is no inter-stage squeeze.

The figures in the last column of table 6 represent theoretical target figures for washing to a specified performance level. Similar calculations may be made for other assumed values of washing performance, and when this is done it is found that the optimum way to obtain significantly different values of performance is to vary the number of washing stages, without much change required in either the efficiency or the water consumption per stage. These figures may then be translated into general-purpose target figures, as follows:

Continuous washing	5 l/kg, with counterflow
Batch washing, adjustable volume	6 l/kg per stage
Batch washing, fixed volume	15 l/kg per stage

Comparison of target values

Theoretical considerations can provide target values for water consumption per process stage, but they cannot define the number of stages required in batch processing without reference to the complexity of the operation and the severity required of the washing treatments. It is therefore instructive to compare the above theoretical values with the lowest values observed in works processing (table 7).

Table 7. Comparison of target values

	Specific water consumption (l/kg)			
	Theoretical		Practical	
Continuous	5	with counterflow	7	
Batch (adjustable volume)	6	per stage	4	Jig
Batch (fixed volume)	15	per stage	27	Beam
			41	Winch

For continuous processing, where the number of stages is unimportant (if counterflow is used), the agreement is very good. The beam and winch data also are consistent with the theoretical figure for fixed volume batch processing; the pratical results represent the water consumption to be expected from one chemical bath followed by one or two rinses, which is a likely minimum processing sequence. It is only for the jig that the practical figure is lower than the value to be expected on theoretical grounds. A value as low as 4 l/kg can only be explained if it corresponds to only a single processing stage.

The theoretical figures then may be used with some confidence as target values for the water consumption in each processing stage. It remains necessary for the user to make his own decision regarding the number of stages he requires.

III. WATER CONSERVATION MEASURES

In view of the widespread current interest in this subject it is not surprising that over the past few years many authors have made reference to some aspects of water conservation or water recycling. A useful summary of practical suggestions for conservation has recently been published by a Working Party of the Society of Dyers and Colourists [13], and this article also contains a substantial list of references. Many suggestions are also discussed in a review article on energy conservation by Wyles [19].

One feature of many published articles is that the authors make no obvious distinction between conservation measures directed towards reducing process demand and those effecting saving by water reuse. These alternatives, as has been pointed out, represent quite different approaches to the problem and it is preferable to discuss them separately.

Conservation by reducing process demand

Water consumption target figures relate directly to process consumption and therefore act primarily as a stimulus to savings by reducing process demand. The methods by which such savings may be achieved are rather varied, but may conveniently be described as (a) good-housekeeping measures; (b) savings on existing machines and processes; (c) savings by machinery changes; and (d) savings by process changes. Within this listing there are really two distinct categories, represented respectively by those measures that require only a change in operator practice and those that require some physical alteration to be made to a machine or some other discrete change. In a general way, (a) and (b) come into the first category, (c) and (d) into the second.

Savings brought about by instructing an operator to perform (or not to perform) some action are represented, for example, by a decision to fill jigs only to some specified level or to dispense with overflow rinsing. Such measures are easy to initiate and, very usefully, may be introduced in small steps; however, they may be difficult to maintain.

Savings brought about by making some discrete change to the machine or the process are represented, for example, by the introduction of counterflow on a washing range or a decision to alter a processing sequence. These measures are likely to be somewhat more difficult to initiate and may involve some capital expenditure; they can probably only be introduced as substantial step changes, but once introduced should be self-maintaining.

Good-housekeeping measures

Although no general guidelines can be given for the identification of good-housekeeping measures, opportunities for savings can be picked up by a critical eye in the course of a water-auditing exercise. Examples are taps and hoses left running when not in use, valves that do not shut properly, and leaks. Individually such sources of waste may be relatively trivial, but corrective measures can collectively produce substantial savings. In addition, the attitude towards waste of this nature can have a strong influence on general attitudes to water consumption; a tightening-up here will serve to emphasize the importance of conservation elsewhere.

Savings on existing machines and processes

Comparisons of actual water consumption data with target figures indicate the magnitude of savings that may be achieved simply by using less water and without changing machines or processing procedures in any way. Savings of this nature are likely to be more available in washing operations than in chemical baths.

On continuous washing ranges counterflow of wash water is the single most important factor. The benefit in terms of washing performance from running fresh water into each tank is very small and the extra water and steam requirement is considerable. There are virtually no circumstances under which it is necessary to introduce any substantial fractions of the fresh water input part way along the range; apart from a possible small water consumption in nip-sprays, all the water should be fed into the last unit in the range and all the effluent discharged from the first. Even when the range contains an intermediate, standing chemical tank it may be possible to carry the counterflow round this unit, although in some circumstances it is preferable to treat the two washing sections separately.

Most modern machines are, of course, arranged to permit counterflow by gravity from one tank to the next, and this facility should be used wherever possible. Where it is not provided it is well worth introducing some suitable arrangement, if necessary pumping the liquor between compartments.

In terms of washing performance the use of a single supply of fresh water and counterflow must give a result somewhat inferior to that provided by individual water supplies with the same flow rate per stage. Theoretically, therefore, some slight increase in the throughflow rate should be employed with counterflow. However, under most practical conditions the required increase will be quite negligible, and even in the least favourable circumstances will not exceed 25 per cent. It is this fact that makes counterflow so desirable.

For example, a four compartment range producing a satisfactory result with a feed of fresh water into each compartment at 100 l/minute would have a total water usage of 400 l/minute. If the machine were converted to counterflow with a single supply at 100 l/minute it is most unlikely that there would be any detectable deterioration in performance, but to be assured of the same result this single flow might be increased to 125 l/minute. This still represents a substantial reduction of nearly 70 per cent in the original water consumption.

Second in importance to the introduction of counterflow is reduction in the actual water-flow rate. For most purposes, as already discussed, a specific water consumption in excess of about 5 l/kg cannot readily be justified. Exceptions may, however, occur in the washing of printed goods where a low impurity concentration in the wash water is necessary to prevent deposits on white parts of the pattern, although the contaminated water may still have ample "washing capacity" for the coloured parts; this may also apply, for a different reason, in the washing of highly fibre-substantive impurities, where the substantivity requires a higher water consumption to achieve the desired washing effect. Even in these circumstances, however, a consumption of more than 12 l/kg is hardly likely to be worthwhile.

When a target value is set for the water consumption on a washing range in terms of litres of water per kilogram of fabric, it implies that the actual water-flow rate should be adjusted to suit the throughput rate of different fabrics. If this is not done, the likely effect will be unnecessarily high water consumption with lighter-weight goods. However, to arrange an operating procedure that would take account of every possible fabric quality that might be processed on one machine could be extremely difficult unless the water flow is controlled automatically. With wholly manual control it is generally practicable to define no more than two or three flows and some means must be provided to indicate the rate of flow; the instrument used must be of the type that provides a direct reading of flow rate. In any event, if an attempt is to be made to reduce the water consumption it is desirable to incorporate a flowmeter in order to check that the specified flow is in fact being used.

The target figure for water consumption in continuous washing processes may be much lower than the value a finisher has measured on his own equipment. Although accepting the general validity of target data, he may be reluctant to make such a large change in a single step. It is therefore a valuable feature of simple water-flow reduction that changes may be made as gradually as desired. It would be perfectly reasonable, for example, to reduce the water flow in steps of 10 or 20 per cent, ensuring that there was no deterioration in product quality before proceeding to the next step. Indeed, it would be quite feasible for a user to determine his own limit in this way, reducing consumption until some deterioration was observed (it would be unlikely to be serious with small step changes) and then reverting to the next higher flow-rate.

If the water is used counterflow and its flowrate is trimmed to a modest value, there is little more that can, or need, be done while the machine is running. However, it is important to ensure that the flow is switched off when the machine stops; there is no advantage in maintaining the water flow with the machine stationary.

The direct reduction of the specific water consumption in batchwise processing operations (without change in the machine or operating procedure) can be achieved only by reducing the amount of water added each time the machine is filled or increasing the load of textile material, or both.

Any batch machine in effect sets two limits to the specific water consumption; one by virtue of its inherent liquor-to-goods ratio, the other by the minimum water volume it can employ. Although in many instances these are not absolutely fixed values, each machine or machine type has its characteristic liquor ratio, below which it is impracticable or at least undesirable to operate, and its minimum volume requirement, below which it would be considered impossible to run. These are both lower limits, and machines can be, and frequently are, operated with ratios higher than their nominal values.

The minimum volume determines the minimum load of textile material that allows the (minimum) liquor ratio to be employed; for any smaller load the liquor ratio will be greater than its optimum value. Underloading should therefore be avoided if at all possible, but this does not necessarily mean that the machine should always carry the maximum load it can hold. If the water volume can be reduced in proportion to the reduction in load, the liquor-to-goods ratio may be kept at its optimum value until the limit on liquor volume is reached. It is only beyond this point that underloading really occurs.

Water conservation measures should therefore be directed towards achieving the optimum liquor ratio as consistently as possible. On closed machines holding a fixed volume of liquor this can only be done by keeping the load as close as possible to the maximum value; on open vessels where the water volume is adjustable the problem is most conveniently dealt with by control of the water level. Over-filling and, in particular, the use of running rinses should be avoided at all costs.

As in the corresponding situation on continuous machines, the ideal of a water level precisely matched to the requirements of each particular load would be virtually impossible to supervise, and the use of two or three set levels is likely to be all that is practicable. Automatic level controls can be used for this purpose, or a single control might be used as an upper, safety limit.

Savings by machinery changes

The direct replacement of an old machine by a new one of the same general type is likely to lead to water savings, since machinery manufacturers are increasingly aware of the energy and water consumption of their products and strive to produce designs that are more economical in both respects.

Although processing requirements must be the main criteria when contemplating machinery replacement, the opportunity for improving water consumption should always be borne in mind. However, it is unreasonable to leave this aspect entirely to the machinery manufacturer and to expect to find conservation automatically built into the new machine. Modern designs permit lower water consumption and generally make it easier to achieve, but they can rarely automatically guarantee it. The user must still use his judgement and control of operating procedures to ensure that the full potential of the machine is realized.

The effects of machinery replacement on water consumption are perhaps likely to be more apparent in batchwise than in continuous processing. In particular, the introduction of a machine capable of operating at low liquor ratios will provide a dramatic reduction in water demand in comparison with the high-liquor-ratio machine it replaces. In this respect the latest generation of jet-dyeing machines offer significant advantages over both winches and earlier jet-dyers.

The same principle can be put into practice among the existing machines in a works by arranging as far as practicable to process on machines offering the lowest liquor ratios. So far as production requirements permit work should be distributed between machines of different capacity so as to maximize the machine loadings.

The opportunities for the introduction of water-saving changes into existing machines are relatively few. In one sense, the addition of a counterflow system to a continuous washing range could be put into this category, but more relevant are suggestions for reducing the volume of water in batch-processing machines by the introduction of "volume-filling" inserts into spaces normally occupied by water that is not directly contributing to the processing effect. Squire [20] has suggested fitting inserts of this type into winches and into beam-dyeing machines.

Savings by process changes

This category of conservation measures includes savings achieved either by altering the processing sequence on a given machine or by processing on an entirely different type of machine. Although substantial savings can be made in these ways, the changes involved are more intimately associated with processing requirements than any of those discussed previously. There is therefore more scope for individual choice and more likelihood of disagreement as to which measures are or are nor practicable. In presenting a summary of the very large number of conservation measures that have been proposed it is recognized that many finishers will consider some to be inappropriate to their individual circumstances and requirements.

Since batch processes are inherently more water intensive than continuous processes, conservation measures most commonly depend on either restricting a batch-processing sequence or replacing batch processing by continuous or semi-continuous operation. The simplest form of restriction is to eliminate one or more rinsing baths or to combine chemical treatment baths. Under these circumstances the water savings are normally directly proportional to the number of stages involved, for example, the compression of the sequence scour-rinse-dye-rinse-rinse to scour-dye-rinse-rinse reduces the water consumption by 40 per cent, and the elimination of the final rinse by a further 20 per cent.

The ability to make changes of this nature may be facilitated by the use of additional or alternative chemical products, such as specific dye-bath auxiliaries or water-soluble spinning lubricants, and as a consequence many suggestions for conservation by sequence-restriction are related to the use of modified chemical processes.

Conservation achieved by changing to an entirely different type of processing requires the most serious consideration of production requirements, and in general production demands rather than water conservation must be the primary consideration. Nevertheless, water savings have prompted a number of suggestions for changes of this nature and low water (and energy) consumption is a major factor in some developments. Thus, it has been suggested in yarn dyeing that package processing should be employed wherever possible to replace hank processing because of its lower liquor-to-goods ratio, and padding techniques have been employed to replace winch processing of knitted cotton goods. However, such a change may cause problems; for instance, it is reported [13] that one processor, although using a padding procedure, continues to wash-off in the winch, feeling that this is necessary to achieve the handle he requires. Under these circumstances, although the procedure may be advantageous in other respects the water savings will be small.

The use of very low liquor ratios in batchwise dyeing, typified by the Sancowad system [21] and processes related to it [22], enables the dyeing operation itself, on certain classes of goods, to be performed with a specific water consumption of from 1 to 1.5 l/kg, a figure not much greater than that required in padding. However, although fabric dyeing by this technique was originally tried with a water consumption in this range, the figure was subsequently increased to 4 or 5 l/kg, to facilitate handling of the material. It is interesting to note that these figures are close to the target values quoted in table 7 for batch processing in machines allowing choice of water volume.

Conservation by water reuse

The main attraction of conservation measures based on water reuse is that they treat water as a service to the works and make no specific demands on the processing requirements. So long as water quality is not impaired to a significant extent by recycling, the processing operations can continue free from worries about the adverse effects of reduced water quantity and the problems of implementing and maintaining direct economy measures.

Although it is true few users would prescribe to this extreme view and expect to make savings solely by recycling, it is equally true that most would expect, or hope, to be able to supplement direct process savings by some use of recycled water, and thereby avoid or postpone taking the direct savings to their extreme limits. Certainly, suggestions for conservation by recycling abound in the literature and investigations of recycling schemes have been reported for several years, but there is still no evidence that on average the direct process demand has been reduced to anything approaching the limits attainable.

The main problems of recycling concern the quality of the water and any necessary treatment of it. The important distinction is between water that can be reused without any treatment and that which requires some treatment, rather than between different degrees of treatment. Whether the recycled water is suitable for all purposes or should be restricted to specific processes only must then be decided. In principle, there are four categories of water conserved for reuse, but in practice it is convenient to consider all waste-water treatment systems as one group, and to restrict the categories to three:

Untreated, for general purposes
Untreated, for specific purposes
Treated

Before discussing these categories, the requirements for process-water quality in the context of water reuse should be considered.

A list of the suggested limits for water contaminants is given in table 1. These contaminants, however, may be found in natural waters and are not necessarily representative of those present in water that has been used in textile processing. Organic matter (measured, for example, by chemical oxygen demand, or COD) does not appear in table 1 since it is not normally a significant factor in raw waters although it is a major factor in textile effluents. Also important is the fact that the acceptable colour levels quoted relate to natural colouring matters and not specifically to the colour resulting from textile dyestuffs.

A recent study on water quality conducted by three research associations in the United Kingdom of Great Britain and Northern Ireland [2] was concerned in part with an examination of this problem (table 8). Measurements were made of the actual levels of contaminants in the waters employed for processing in a variety of works, and experiments were performed on the effects in fabric preparation and dyeing operations of specific contaminants, including those to be found in waste-waters in a form of residual dyestuffs and organic matter.

Table 8. Comparison of water quality data

Property or impurity		Suggested limits	Works' process waters average values	Experimental data (Tolerable values) White fabric	Experimental data (Tolerable values) Medium dye shade
Colour	(Absorbance	-	-	0.0003	0.005
	(Hazen	5-25	10	1	20
		mg/l			
	(Fe	0.05-0.3	0.1	0.2	0.35
Metals	(Cu	0.01	0.05	0.2	0.4
	(Al	0.25 a/	-	n.d. b/	0.5
Organic matter (COD)				500	150
Inorganic salts) Dissolved salts)		150-500	200-1000	1200	1000
Hardness (as $CaCO_3$)		15-100	50-80	n.d. b/	(50)

a/ Value from Little [2]; other values from table 1.

b/ n.d. = not determined.

The suggested limits (table 1) are compared with average values for works' process waters (or ranges, where a single average does not appear appropriate), and these figures are then compared with two sets of experimental results, referring respectively to preparatory processes (white fabric) and to dyeing in a medium shade. The experimental results are expressed in terms of "tolerable values", which indicate those concentrations producing a specific but tolerable variation in the product, usually a small shade variation.

Three significant points emerge from these comparisons. First, the average quality of works' process waters is generally within or close to the range presented by the suggested limits. Secondly, in all respects but that of colour, the experimentally determined tolerable values, although generally somewhat higher than the suggested limits, are not so much higher as to indicate that process waters can tolerate much additional contamination. Thirdly, in respect to colour the experimental results show a significantly higher sensitivity in preparatory processes that is indicated either by the suggested limits or the works' measurements; for some operations, at least, a very strict limit must be set when dyestuffs are the source of colouration.

General reuse without treatment

Water reused without treatment for general purposes is returned to the works' central water-storage system and must introduce no contaminant at such a concentration that, after dilution with the fresh supply water, it is present at an unacceptable level. The quality requirements discussed above indicate that only small increases in most contaminants are permissible and dyestuff concentrations must be kept to a particularly low level.

For assuredly safe results, the recycled water must be substantially as clean as the normal incoming water supply. The only used water that really meets this requirement is cooling water. This stands little chance of being contaminated in use and there can be no objection to returning it to storage for process use; the heat it contains is generally beneficial rather than otherwise.

In some, perhaps in many, instances it would also be possible to reuse clean rinse waters in the same way, but the recovery system must incorporate safety measures to ensure that more contaminated waste-waters cannot get through, or must be provided with equipment to monitor the water quality before it is returned and to accept or reject as appropriate. In view of these uncertainties and complications many users may be reluctant to contemplate general purpose reuse for even the cleanest rinse waters, preferring instead to employ specific reuse procedures where the problems may be less severe.

Specific reuse without treatment

Water reused without treatment for specific purposes is employed for one or two processes only. It is usually, although not always, necessary to store the water for subsequent use, and considerations of cost and convenience dictate that this form of recycling is most manageable when restricted to a single area of the works and, preferably, to a group of similar machines or to an individual machine.

Specific reuse measures are likely to be particularly applicable to batchwise processing (on a continuous machine reuse is practised automatically in the safest and most convenient manner when counterflow is employed). The most obvious procedures involve the storage of clean rinse waters for reuse either in rinsing or in the preparation of chemical baths. Since the water is reused for processes similar to its first use, the problems are not so severe as when general reuse is in question. Furthermore, any catastrophies (resulting, for example, from collection in error of a dirty rinse bath) will not be so farreaching.

The same principle can be applied to the reuse of chemical baths and in particular of dyebaths. It is necessary to ensure that the bath is reused for the same or a deeper shade and, although it would be possible to pump liquors between adjacent machines, it is generally more convenient to retain the dye liquor in one vessel and remove the goods for subsequent processing on another machine. By using one machine in this way, allocating to it a series of dyeings of the same colour or a progression from light to heavy shades, the frequency of machine cleaning can also be reduced.

The reuse of chemical baths automatically leads to the reuse of those chemicals present that have not been removed by the textile material or destroyed in the chemical operation. However, advantage can be taken of this - by using less chemicals when the second bath is prepared - only if suitable means are employed to determine the residual concentrations of the chemicals concerned (or, less satisfactorily, by making estimates of these concentrations). It is quite practicable, under appropriate circumstances, to treat reused chemical baths as though they were clean water and to prepare repeat baths using the standard quantities of the chemicals involved. On the other hand, it is equally practicably, when conditions are suitable, to allow for the residual chemicals by simple, direct measurements, such as pH or solution conductivity [23]. In these circumstances the benefits from chemical savings may, in financial terms, be appreciably greater than those from water savings.

The general reuse of chemicals in this way is hindered by the complexity of the chemical baths involved and the number of parameters that may need to be measured in order to define the composition. The reuse of dyebaths and other chemical baths in some batch processes appears to be one of the few instances in which, at the present time, it is reasonable to look for chemical recovery associated with water reuse. Those instances where chemical recovery is the primary incentive (recovery of sizing agents or of caustic soda after mercerizing) are characterized by the chemical of interest being the only, or much the largest, constituent of the liquor.

Treatment for reuse

Water contaminated to any significant extent is not suitable for general-purpose reuse without some form of treatment; the brief discussion of quality requirements earlier in this section indicates the level of purity required.

There is no doubt that it is technically feasible to purify waste-waters (either the wastes from individual machines or processes or the total mixed effluent from a works) to this level, and a very large number of experimental and pilot-scale studies have been reported. However, the successful treatments appear to require tailoring to suit particular conditions, and at present there is no single procedure that stands out as the obvious choice for all circumstances. Furthermore, although treatment costs are often difficult to assess, the general impression is that these costs are such that they would only be justified in exceptional circumstances.

There is so much that can be done at the present time to conserve water by its direct reduction in processing and by reuse without treatment of clean waste-waters that it seems premature for the majority of users seriously to contemplate waste-water recycling schemes. The explanation for the considerable effort currently being expended on such schemes, and for the widespread interest in the subject, may lie in the obligation, increasingly being imposed, to treat effluents before discharge back to the environment. The fact that a water stream is required to be purified before being thrown away leads to the feeling that the purified water should be put to some more practical use. However, the quality requirements for discharge and recycling are substantially different (a comparison of the processing requirements listed in table 8 with any effluent-discharge conditions will show this) and it follows that the conventional methods employed to treat effluents for discharge do not produce a water quality generally suitable for recycling. This explains the wide variety of alternative treatments that have been employed in recycling studies and the fact that, to be successful, they must be more severe (and are therefore likely to be more costly) than conventional treatment.

The tendency is for the conditions imposed on discharged effluents to become more demanding. Increasingly this must reduce the difference between discharge and recycling, both in respect of quality standards and of treatment costs. In the medium-or long-term it seems that the arguments in favour of recycling must become more pressing than they are at present, and more promising treatments therefore deserve mention.

Of the treatments that have been employed to enable waste-waters to be reused, most frequently mentioned are adsorption on activated carbon [24, 25] and reverse osmosis [26]. Alone, these processes are unlikely generally to be satisfactory and each benefits from some pretreatment of the waste. This may take the form of a conventional biological plant or of a sequence of flocculation and filtration or flotation. Other processes that have been employed include adsorption on other materials than carbon, electrodialysis and catalytic oxidation. Each of these processes has its virtues and each can make a significant contribution to purification in appropriate circumstances, but in general it appears that a sequence of processes must be employed for consistently satisfactory results. The most promising sequences seem to be those incorporating flocculation and carbon-adsorption or flocculation and reverse osmosis.

A recent innovation, the IBK system of high-pressure, multiple-effect evaporation [27], offers the prospect of a single treatment that is capable of producing water of very high quality. In this system the functions of effluent treatment and steam raising are intimately related and it is therefore perhaps easier to envisage the system as a part of the services in a completely new plant rather than as an accessory or replacement in a works with an existing boiler and effluent-disposal system.

In the IBK system useful steam is generated by the evaporation of waste-water and the number of stages in the evaporation process determines (and is numerically equal to) the ratio of water treated to steam produced. Temperature and pressure limitations are likely to restrict the realistic number of stages to three, whereas the overall water/steam ratio in a typical textile works is closer to five. Although this is to the disadvantage of the evaporation system as a solution to effluent disposal problems, it does not preclude its use for the purpose of water recovery since only three fifths of the effluent needs to be treated and this would make a substantial contribution to water saving.

The extensive use of direct water conservation measures might alter the picture somewhat, but probably not to a dramatic degree, since to a considerable extent water and steam savings proceed together. In terms, however, of the actual capacity of equipment required any water conservation measures must be beneficial. This also applies to any effluent treatment system and is a further reason for regarding direct water savings as the first requirement.

Water savings by substitution

Water savings were once claimed as a major benefit of the substitution of organic solvents for aqueous processing. However, the success of any alternative procedure mainly depends on the technical advantages it offers, and increasing costs of solvents make it less reasonable at present.

Work on solvent-processing systems continues, for sound technical reasons, although it is generally recognized that very efficient solvent recovery must be achieved to keep costs competitive with aqueous systems. Where solvent processing can be justified on technical grounds, the consequent reduction in water consumption is perhaps best regarded as wholly incidental.

Summary of conservation measures

Use less		Reuse
	General-purpose savings	
Good housekeeping	2	Cooling water, possibly clean rinses: 1 (Effluent treatment for recycling: 4)
	On continuous machines	
Measure	Savings index	
Counterflow	4	(Rarely applicable; reuse is automatic if counterflow employed)
Reduce flow rate	3	
Match flow rate to fabric	2	
Turn off flow when machine stopped	1	
Replace old machine	3	

On batch-processing machines

Avoid underloading	2	Rinse baths	3
Avoid over-filling and running rinses	3	Dyebaths etc.	3
Match filling to load where possible	2		
Reduce number of process stages	4		
Transfer process to more economical machine	4		
Replace old machine	3		

This summary includes estimates of the savings that might be achieved by each of the measures listed. It is assumed that average, "uncontrolled" conditions are employed before the conservation measure is introduced, and the savings indicated relate specifically to the consumption on the relevant machine or process. Thus, for example, if good housekeeping practices are not already in force it is estimated that they can effect a moderate saving in the total water consumption at the works. The introduction of counterflow on a continuous washing range might reasonably be expected to make a large saving in the consumption on the machine; replacing an old machine of this type by a new one could produce a significant saving in all processes involved, and so on.

Such estimates of savings are only approximate, but they may be of assistance as a guide to the relative importance of alternative procedures, particularly if read in conjunction with target and actual figures for water consumption.

IV. CONSEQUENCES OF WATER CONSERVATION

Characteristics of textile effluents

The net effluent flow from a textile dyeworks or printworks is typically 10 per cent lower than the fresh-water inflow, and the effluent discharges from the works most of the processing chemicals used plus any impurities extracted from the textile material in the processes of desizing, scouring and bleaching. Of the total mass of chemicals employed in processing, the only items that do not pass through to the effluent are those deliberately applied to the textile (dyes, finishing agents) and small quantities that escape rinsing processes or are lost in other ways.

Although textile effluents are notoriously variable, both in flow rate and composition, in the short-term, the long-term average composition may be derived with reasonable precision from a knowledge of the total effluent flow, the total chemical consumption and the impurity loss from the textile material. With the exception of raw wool, which is particularly heavily contaminated and requires special treatment, natural fibres may be expected to carry 5-10 per cent of their weight in the form of impurities. The amount removed in finishing depends on the severity required in the preparatory processes and is typically 3-10 per cent. Synthetic fibres are less contaminated, so the overall range of impurity loss, depending on the fibre types involved, may be 7-10 per cent. This material is mainly organic, of natural or synthetic origin.

The consumption of process chemicals depends greatly on the actual operations performed, but a typical figure for all the processes in a dyeworks or printworks is in the range of 8-20 per cent of the weight of textile material, of which perhaps one quarter is organic chemicals.

The total load discharged in the effluent is therefore between 10 and 30 per cent, or, 100-300 g/kg of textile material. Of this load 40-150 g represents organic matter. With an average water consumption in the region of 100 l/kg of textile, the effluent composition is total solids 1,000-3,000 mg/l and organic matter 400-1,500 mg/l. When allowance is made for the different levels of degradability of different organic products in terms of the parameters normally applied to effluents (chemical oxygen demand (COD) and 5-day biochemical oxygen demand (BOD)) for the acidity and alkalinity of the inorganic materials and for the properties of suspended and dissolved matter), these figures translate into the following typical effluent characteristics:

pH	4 to 12
	mg/l
COD	200-1,500
BOD	100-600
Suspended solids	50-200
Total solids	1,000-3,000

The BOD level is much too high to be generally acceptable for discharge untreated into a stream or river, and this factor has been the major influence in determining the form of treatment most widely employed at the present time. After neutralization (and possibly the addition of suitable nutrients), textile effluents are amenable to treatment by the conventional biological methods, employing percolating-filter or activated-sludge systems in their various forms. Treated in this way, textile effluents, alone or in admixture with domestic sewage, can be purified to an acceptable level, represented, say, by the widely-used requirement of BOD 20 mg/l, suspended solids 30 mg/l.

Biological treatment brings out a large reduction in the concentration of biodegradable organic substances and a substantial reduction in the suspended matter, but has little effect on the other characteristics of the waste. The treated effluent may then be low in BOD, but its COD may be reduced only to 100-200 mg/l; the total concentration of solids is reduced only by the elimination of some of the organic chemicals and is still likely to be in the range 800-2,000 mg/l, the major components being sodium chloride and sulphate ions.

Although the parameters of BOD and suspended solids concentration are the ones most frequently quoted in relation to effluent purification, restrictions may be placed on several other impurities or properties. Thus it is common to find pH and temperature limits imposed, and limits may also be placed on nitrogen (for instance, as ammonia), on heavy metals, on sulphide and cyanide and on specific organic substances, such as oil or phenols. Where there is concern about the salinity of the receiving water a limit may be imposed on total solids, and a limit on sulphate may be imposed for the protection of sewer pipes and sewerage systems. Overall there is likely to be a limit on the flow rate of discharge, probably in the form of a maximum average rate and a maximum peak rate.

These limitations are imposed for the protection of the environment and are, in principle, determined by the capacity of the receiving water (stream, river, lake or estuary) to absorb each particular impurity without its quality being significantly impaired. This capacity is defined primarily by the flow rate or volume of the receiving water, by its condition before the waste is discharged into it and by the quantity of impurity discharged. As far as the discharger is concerned this quantity is controlled by the permissible volume of discharge and the permissible concentration of the impurity in question, but it is common to find these two limits treated as though they were independent. Thus, for example, a permissible peak flow rate of 100 m^3/h and a BOD limit of 20 mg/l together define an acceptable BOD discharge rate of 2 kg/h, and it must be assumed that the receiving river is able to assimilate BOD at this rate. However, the use of a fixed BOD concentration limit arbitrarily restricts the quantity discharged when the flow rate is less than its peak value.

One exception occurs when the effluent flow rate is comparable to the river flow rate upstream of the point of discharge. In this case, it may be reasonable to impose impurity concentration limits independently of the effluent flow rate, but in all other instances the use of independent limits may not only seem unfair, but may also act as a positive disincentive to conservation, although their administrative convenience is obvious.

Effects of conservation measures

Generally, all measures directed towards the reduction in process demand or the reuse without treatment of clean waste-waters are not expected to reduce to any significant extent the quantity of impurities discharged, and hence will increase impurity concentrations in direct proportion to the volume reduction. This is not quite true when the conservation measures take the form of a process change to utilize a machine with a lower liquor-to-goods ratio and hence permit lower quantities of chemicals to be employed. The reuse of chemical baths may also permit chemical consumption to be reduced and restrict the quantity of impurity extracted from the textile material [23]. Nevertheless, the changes resulting from the adoption of all measures but those involving waste-water treatment are represented by a volume reduction accompanied by a proportionate increase in impurity concentrations.

These changes are apparent in the first place in the raw effluent, and their consequences depend on the treatment given and, to some extent, on whether this treatment is applied on-site to the textile effluent alone or at a sewage works to the textile effluent in admixture with other wastes.

If the effluent is treated on-site the reduced volume flow-rate increases the contact time in the treatment plant and it may be possible to reduce the BOD and suspended solids to their previous discharge concentrations. At the sewage works the volume change will be less apparent, but again the increased contact time may be beneficial.

However, this refers only to those impurities removed by the treatment. The increased concentration of some other impurities may be harmful to the operation of the treatment plant and cause a serious problem. More commonly, however, the important feature is that many impurities, and particularly the inorganic constituents, pass through treatment at their increased concentrations. Therefore concentration limits may be exceeded.

Many users, although they do not discharge the maximum volume of effluent to which they are entitled, value this entitlement as a safeguard for future expansion in activity and would be reluctant to reduce it. However, where conservation measures have produced a substantial, consistent reduction in flow accompanied by high impurity concentrations it would be reasonable to accept a reduction in the volume entitlement in exchange for increases in the concentration limits which recognize that the total impurity discharge is unchanged.

Where effluent treatment for recycling is concerned the situation is less clear-cut. These treatments vary appreciably in the extent to which they achieve separation of water from the solid residue. The specialized treatments designed for chemical recovery (for example, of sizing agents or caustic soda) reclaim the material in the most convenient form, typically as a concentrated solution, but of the general treatments some (e.g. carbon adsorption and multiple-effect evaporation) produce at most a dry residue; others (e.g. flocculation) produce a sludge; and others (e.g. reverse osmosis) produce only a concentrated liquor. The nature of this residue, in which the water impurities are concentrated, determines the influence of the process on overall effluent characteristics.

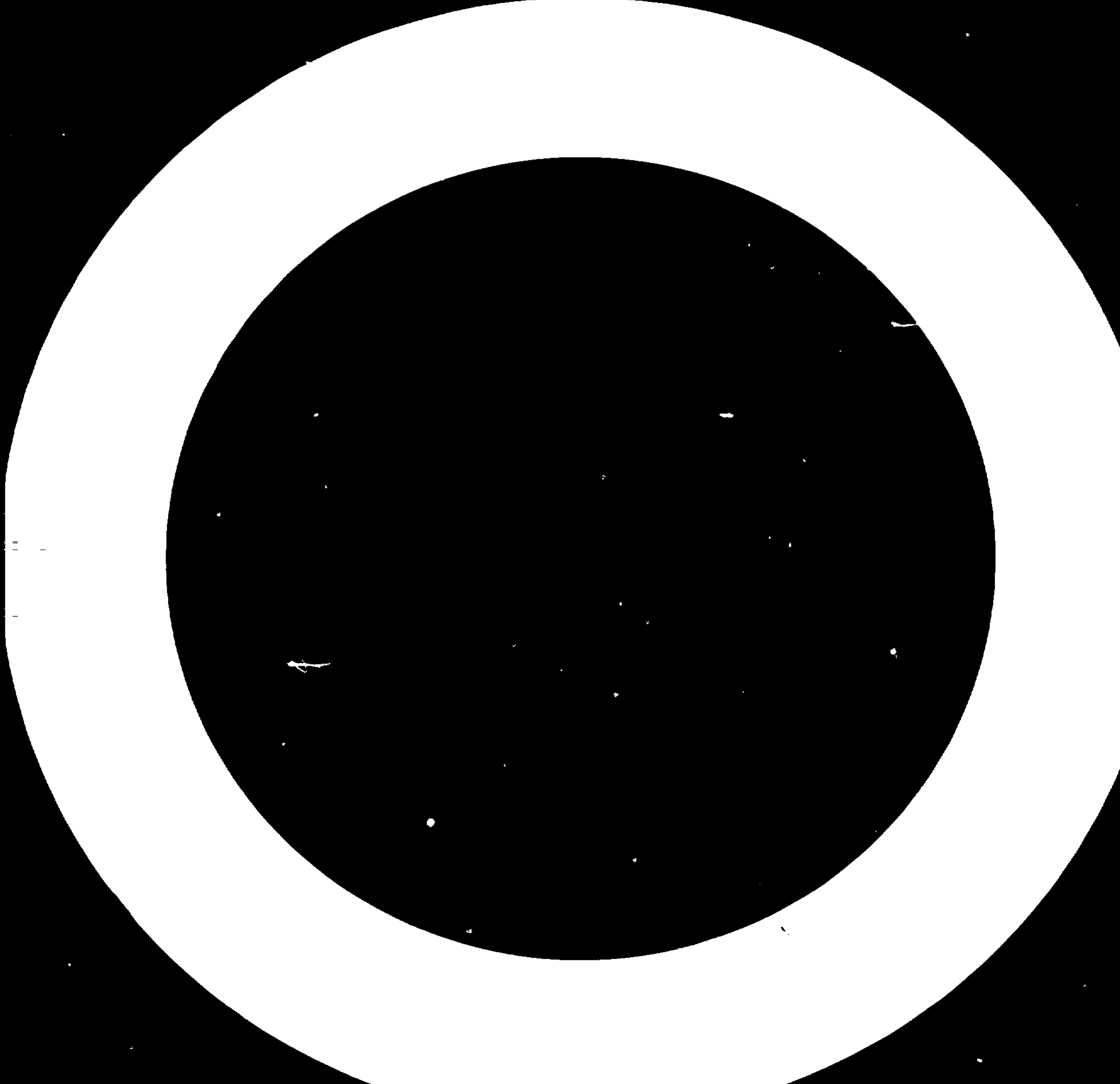
Most processes for effluent treatment and recycling are described and discussed in relation to their ability to solve an effluent disposal problem as well as to produce reusable water. In view of their cost it is essential to pay due regard to this dual function in any consideration of this form of water conservation.

V. CONCLUSION

The topics discussed in this monograph can be summarized by a description of the steps leading to the introduction of simple conservation measures at a printworks; this is done in the annex. In the example given there, the measurements and data analysis were mostly performed by staff members of the Shirley Institute, but could equally well have been made by the works' staff, following the guidelines indicated in this monograph. The conservation measures were introduced by the works' staff.

Many works are already extensively employing the conservation measures described above, but the average situation is still that of a works where the water consumption could be substantially reduced by restricting process consumption and reusing clean waste-waters. In the short term (the next four or five years), it is reasonable to expect that a more widespread adoption of these measures will lead to a fall in average water consumption of perhaps 30 per cent.

In the long term, by taking advantage of developments in machinery and control systems that must surely occur, but without recourse to the widespread use of effluent treatment and recycling systems, the average consumption may fall to 40 or 50 per cent of present values. However, it is difficult to envisage the **actual** processing requirements being, on average, capable of reduction to much below these figures. Only if it becomes generally necessary or economical to employ treatment and recycling will the average consumption be reduced much further. The practical situation might then approach very closely the limit set by the water loss by evaporation. This too must be expected to be reduced by technological developments (because of its high energy consumption), and the limit may well be as little as 6 or 7 per cent of the present water consumption. This would be achieved, for example, by cutting the actual process demand to 50 per cent of the present level and recycling 90 or 95 per cent of the resulting effluent.



Annex

AN ILLUSTRATIVE EXAMPLE

Background. The works in question performs fabric preparation, printing and finishing, mainly on continuous machinery. The investigation was undertaken because the works' management wished to examine the possibility of using simple means to reduce water and steam consumption, not because of any external pressures on water supplies.

Data collection. The works already had the following information available, expressed as average daily values: total water consumption; boiler feed-water consumption; total steam consumption; and, for individual machines, fabric throughput (in kilograms) and duration of operation (in hours).

Examination of processing schedules and observation of the machines concerned indicated that the major use of process water occurred on a rope washing range used in fabric preparation and on four open-width washing machines, and measurements of water consumption were made only on these machines.

The rope washer used only cold water, but the open-width machines had unheated compartments and three or four compartments with the water steam-heated; it was observed that fresh water was fed into each one, although the individual water-flow rates appeared to be carefully controlled by the machine operator.

Measurements of water flow into the rope washer and into each compartment of the open-width machines were made by the bucket-and-stopwatch method. In addition, tank temperatures were measured as appropriate.

Data analysis. The daily water consumptions on the washing machines were calculated from the measured flow rates and the average operating hours. These figures were assembled with the known boiler feed-water consumption and estimates of consumption elsewhere to produce a water audit for the works. The important features are presented by expressing the measured water consumptions as percentages of the total works' water consumption:

		Per cent
Four open-width washers:	hot	32
	cold	7
Rope washer		34
Boiler feed water		12
		85

The balance is readily accounted for by estimates made of the consumption in the washing of printing blankets, washing-down etc. This estimate confirms the expectation that the washing ranges account for the major part of the total water consumption and shows that no other significant source of consumption has been missed.

Specific water consumptions were calculated from water measurements and production data:

		l/kg
Open-width washers:	hot	24-30
	cold	6
Rope washer		17

Conservation measures. The total water consumption in each of the washing operations was much higher than the target figures for these processes. On the open-width machines this was because no counterflow was employed in the heated sections; the flow into individual compartmemts was close to the target figure at 6-8 l/kg.

The action suggested was to introduce counterflow, maintaining the previous flow through each compartment; and leave the cold-water system unchanged (it would be physically difficult to direct this flow into the heated tanks).

The effect of those changes would be to reduce the total water consumption on the machines by approximately 60 per cent.

On the rope washing range only a single water supply was used, but the flow was excessive.

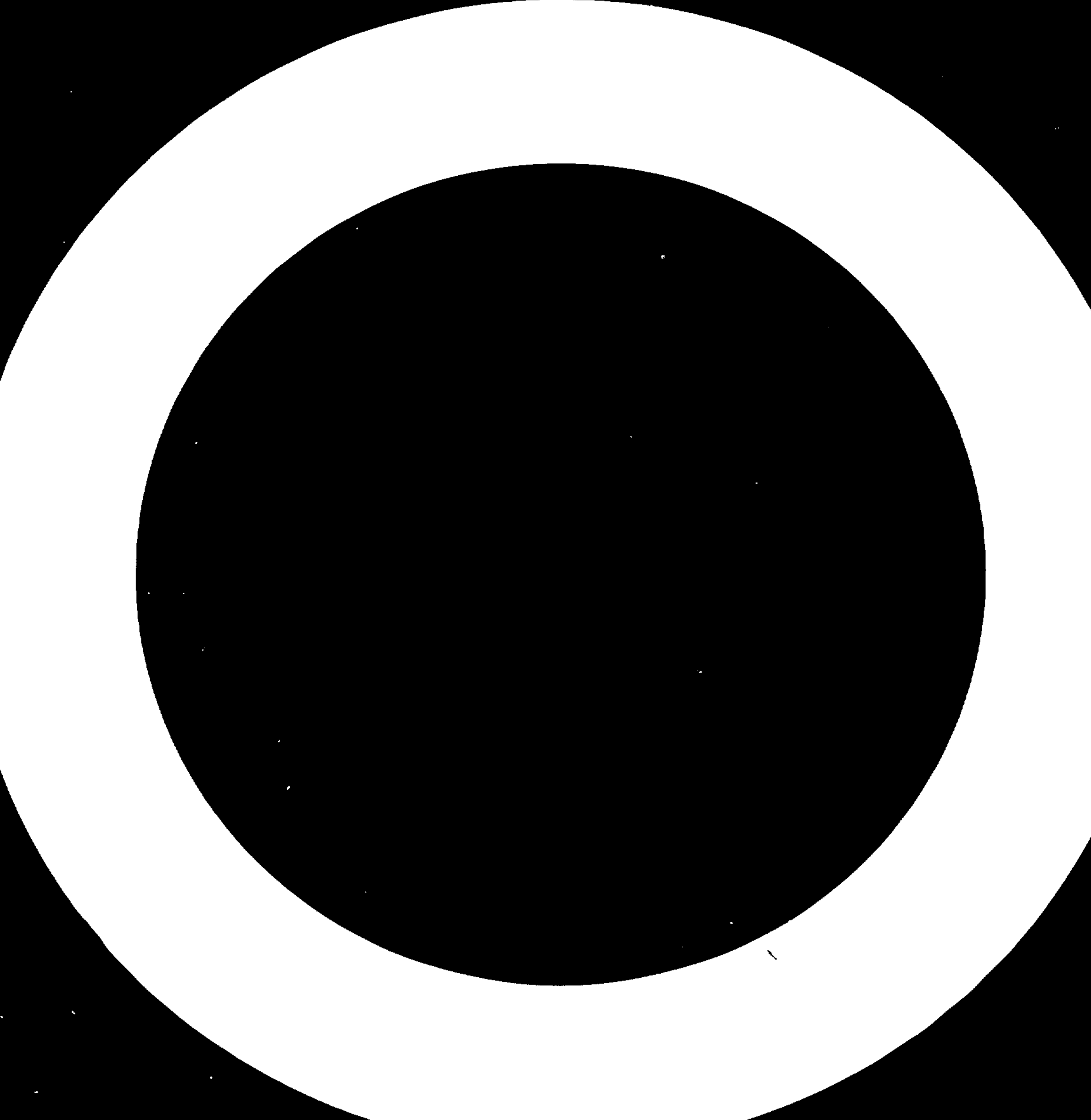
The action suggested was to reduce the flow to about half its previous value.

The steam savings resulting from the water savings on the open-width machines was calculated from the reduction in daily water consumption and the tank temperatures. Expressed in terms of the overall water and steam consumptions in the works the calculated savings were:

	As percentage of total	
	Water	Steam
Counterflow on open-width machines	22	15
Reduced flow on rope washer	17	-

Consequences of conservation. A total water savings of 40 per cent was predicted, but it was ascertained that that would pose no problems in relation to effluent disposal.

Action. The works' management proceeded immediately only with the measures proposed for the open-width machines. After making the necessary modifications and introducing some supplementary changes they were able to show savings, in both water and steam, a little higher than predicted.



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