REDUCTION IN ORGANIC LEVELS AND DISINFECTANT DEMAND BY SLOW SAND FILTRATION IN WESTERN EUROPE

by

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ABSTRACT

Slow sand filtration, the original method of surface water treatment, is still in use in a number of Western European countries, often as part of a more sophisticated treatment process. Slow filtration has an important role to play in current treatment and can provide excellent reductions in the level of organic substances, thereby reducing disinfectant demand and associated by-product formation. Because of its simplicity, slow sand filtration can be considered a viable treatment option for small Canadian communities. At this scale, the principal drawbacks of slow sand filtration, namely high land and labour requirements, are likely to be less important.

This paper presents information obtained during site visits to a number of European waterworks in 1987. The performance data obtained during these visits is not available for small slow sand filters operating in Canada, but yet can give a good indication of the reduction in organic levels which could be achieved by these small units. The paper discusses the performance of specific installations in four Western European countries and concludes with a brief discussion of the applicability of this process to small Canadian systems.

INTRODUCTION

This paper is based on information obtained during site visits conducted in 1987 as part of a review of the use of biological processes in drinking water treatment in Western Europe (Huck, 1987). Facilities in the following countries were visited: West Germany, The Netherlands, Switzerland, the United Kingdom and France. Although all of the treatment plants visited represented what could be termed advanced drinking water treatment technology, in a number of cases slow sand filtration, perhaps including subsequent infiltration and underground passage, was included within the treatment train. In all but one of these plants slow sand filtration represented the original treatment process which was retained in subsequent upgrading of the treatment system. For a number of the plants visited data were available on the performance of each treatment process, including slow sand filtration.

Although all of the slow sand filtration facilities visited were relatively large, this technology is probably more applicable nowadays to small treatment systems than to large ones. The two principal drawbacks of slow sand filtration, namely high land and labour requirements, are less important at smaller scale. Further, slow sand filtration is a simple process which does not require skilled operator attention. The comprehensive data which were obtained for the European slow sand filtration installations are simply not available for small slow sand filters which may be operating in Canada. Because performance of a slow sand filter can be expected to be independent of scale, the information contained in this paper should be valuable in indicating the performance which could be expected of small slow sand filters.

The focus of this paper is on the reduction in total organic carbon levels, including the easily biodegradable fraction of this carbon, achievable by slow sand filtration and the infiltration step which sometimes follows. These removals can significantly reduce the disinfectant demand of the finished water. A reduced disinfectant demand will of course result in a lower level of by-product formation.

The paper describes several facilities visited in each country, and discusses their performance. It concludes with a brief discussion of the application of the results to small Canadian systems.

WEST GERMANY

The West German waterworks discussed are located along the Ruhr River. Although the Ruhr lends its name to a heavily industrialized area, most of the population and industry is located north of the actual Ruhr River drainage basin. The Ruhr itself is used as a major source of drinking water for the region but most municipal and almost all industrial waste is discharged into other river systems. Therefore, although the Ruhr receives significant loadings of biodegradable organic carbon and ammonia its quality is much better than that of the Rhine with respect to synthetic organic chemicals.

The major waterworks along the Ruhr were developed in the late 19th century. Originally groundwater was pumped from the rather shallow (less than 8 m) gravel layer which underlies a clay layer approximately 1 m deep along the whole Ruhr valley. Later the water obtained came to include bank filtrate from wells located relatively close to the river. Still later, as demand rose, the groundwater supply was augmented by river water pumped to infiltration basins which function as slow sand filters.

Treatment continued in this way until after the Second World War with final disinfection being added sooner or later in all cases. However, because of deteriorating water quality in the river, run times of the slow filters had decreased in the post-war period to as low as 4 weeks at some waterworks (Kötter, 1987). Pre-treatment therefore began to be installed, but initially only to increase the capacity of the slow filters. Considerable improvements were obtained, with run times being extended to 4 to 6 months in some cases (Kötter, 1987). Later, the process sequence for pre-treatment was selected to also provide quality improvements, and in instances where post-treatment was installed it was for reasons of quality improvement.

To-day, the main treatment step at all Ruhr waterworks remains slow sand filtration/ground passage, whose working is principally biological. All works provide some form of either pre-treatment or post-treatment and some provide both.

Dortmund

The Dortmunder Stadtwerke AG provides drinking water to approximately 600,000 persons in the city of Dortmund and surrounding communities. The average daily production is 260,000 m^3, consisting of approximately 40% bank filtrate and 60% ground water from artificial recharge.

A summary of raw water quality in Table 1 shows values which are generally similar to other waterworks on the Ruhr.

A schematic diagram of the treatment process is shown in Figure 1 and process details are given in Table 2. Dortmund is unique in that its pre-treatment utilizes only physical and biological processes and no chemical steps.

The pre-filters, which were added in the 1950's, support significant biological activity. They are run intermittently to minimize algae growth. Such growth is undesirable: although it would provide both physical and (temporarily) biological adsorption, it would lead to blocking of the filters,

Table 1 - Raw and Finished Water Quality for Dortmund (Selected Parameters)[a]

Parameter	Units	Raw Water[a]	Finished Water[b]
Turbidity	FTU	3.6	0.22
pH		7.65	7.65
Total Hardness	°dH	1.31[c]	8.7
Dissolved Oxygen	mg/L	10.0	5.2
Ammonium (NH_4+)	mg/L	0.69	<0.03
Total Phosphorus (P)	mg/L	0.38	0.18
DOC	mg/L	3.4	1.7
COD (total as O_2)	mg/L	9.2	-[d]
$KMnO_4$ Demand (as O_2)	mg/L	-	0.9
UV Extinction (254 nm)	m^{-1}	5.87	1.65
THMs	µg/L	2.6	2.6
Chlorine (free)	mg/L	-	0.22
Total Iron	mg/L	0.183	0.009
Total Manganese	mg/L	0.066	0.0012

[a] 1985 data - arithmetic mean of geometric means for following three stations: Hengsen Obergrab, Stau Villigst and Westhofen WW (Annual Report, Ruhrverband, 1985)

[b] 1986 average - Dortmunder Stadtwerke AG

[c] mmol/L

[d] not measured

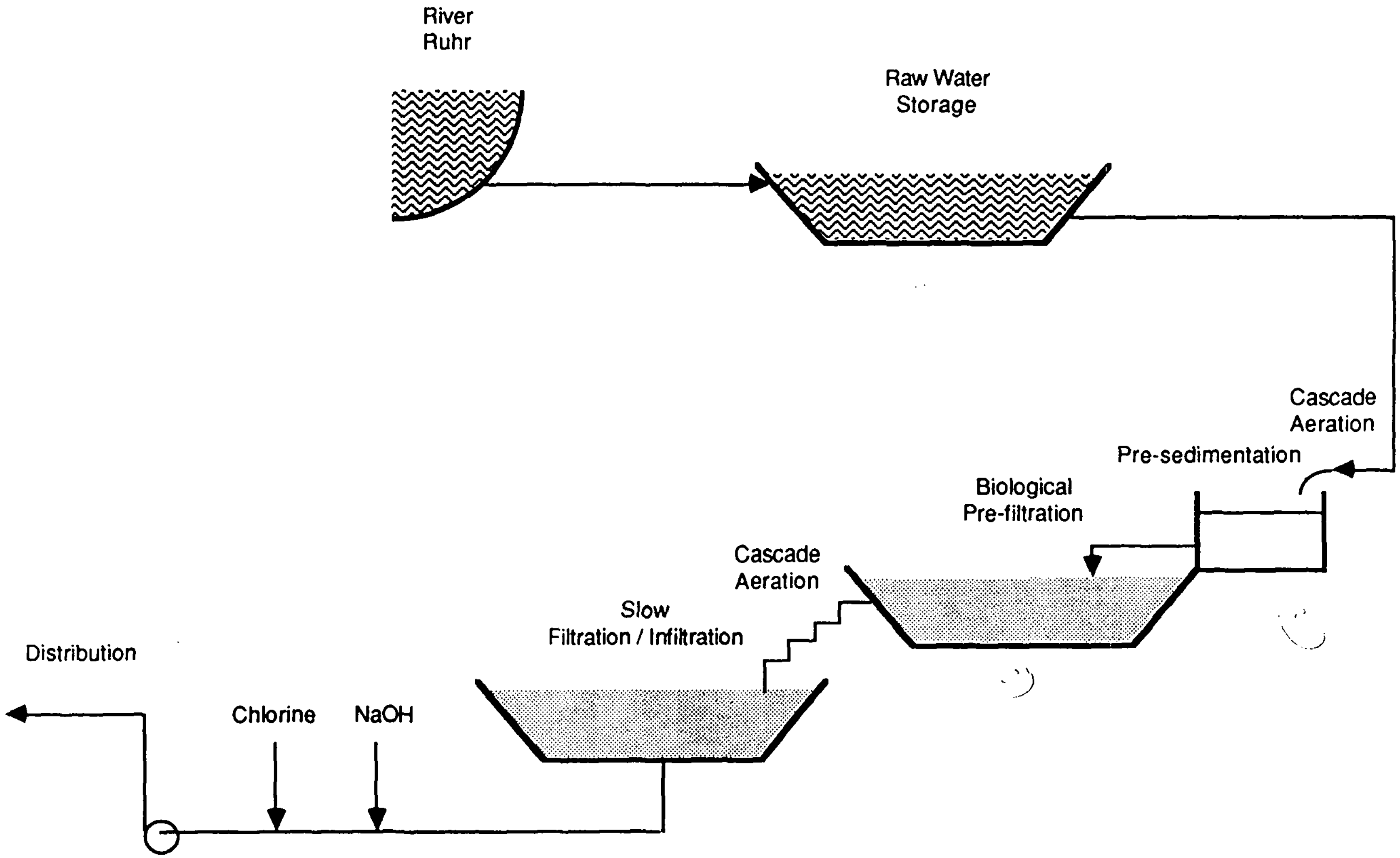


Figure 1. Process Schematic - Dortmund

Table 2 - Process Details (Dortmund)

Treatment Step	**Conditions**	**Remarks**
Raw water storage basin	Detention time several hours	Allows sedimentation. Intake can be closed to avoid pollution incidents.
Aeration	Cascade	Occurs at entry to pre-filter.
Biological pre-filter	30 cm coarse sand on 1.3-1.5 m gravel (5-10 cm diameter)	Pre-sedimentation chamber provided. Not run flooded.
Aeration	Cascade	Occurs at entry to slow sand filters.
Slow sand filters	30-50 cm of sand (0.2-2 mm diameter)	Not run flooded.
pH correction	Sodium hydroxide	In service for last 10-12 years.
Disinfection (chlorine)	Normal dosage 0.3 mg/L. Residual 0.2 mg/L	Higher doses required in winter because of ammonia.

would increase the DOC levels and could produce taste- and odour-causing substances.The practice is to operate the pre-filters for 3 or 4 days and then take them out of service for several days. Providing the weather is suitable, this kills the algae by drying. As a further measure to control the algae, the filters are run in an unflooded condition when they do operate. This however means that the filtration velocity cannot be easily calculated. Water percolates through only part of the surface and at different velocities: the velocity is lowest close to the inlet where biological growth on the surface is greatest.

Although some raking of the surface is performed periodically, actual cleaning of the filters is only required at intervals which can be as long as 8 years. The complete depth is then washed mechanically in-situ.

Aeration following the pre-filters restores the oxygen consumed in the biological process and strips out carbon dioxide.

The slow sand filters are also operated in an unflooded condition in order to provide more oxygen and minimize algae growth. If they were run flooded the velocity would be approximately 10 cm/h, but the actual velocity is much higher because only part of the surface is used. As with the pre-filters there is a range of velocities and residence times. The net effect of operating in an unflooded condition is an improved treatment despite the higher velocities. As with the pre-filters operation is intermittent (several days in service, several days out of service) as another step to minimize algae growth. Measurements have shown that most organic removal occurs in the top 10 or 20 cm of the filters. Although organics and bacteria penetrate deeper into the filter when it is restarted each time, the buffering capacity of the rest of the filter and the underground passage mean that there is no effect detected in the finished water.

On average the filters are cleaned about once per year. As in other locations this involves removal of a 3 to 5 cm sand layer and eventual rebuilding of the filter when the sand depth becomes too low. The sand is not cleaned and placed back in the filters - it is desired to remove any attached organic and inorganic matter from the treatment system.

Following a 12 to 24 h ground passage the water is withdrawn and pH correction with sodium hydroxide is provided.

The final treatment step is disinfection with chlorine. As with other Ruhr waterworks, ammonia levels can be a problem in winter. A period of 3 weeks with water temperatures below 3°C leads to incomplete nitrification in the river and the filters. Final ammonia levels can reach 0.15 mg/L, necessitating a chlorine dose of approximately 1 mg/L, which is considered unusually high in Germany. On occasions the limit of 0.6 mg/L total chlorine residual stipulated in the German water treatment regulations has been exceeded. Other problems associated with the presence of ammonia are a chloramine odour and possible difficulties for dialysis patients. Dortmund is therefore considering a switch to chlorine dioxide for final disinfection. Waterworks staff note that this would also have the advantage of reducing haloforms levels, although these are now only a few micrograms per litre.

Data showing removals throughout the treatment process were not available at the time of the visit. However data for finished water quality are available. Table 1 shows values for selected parameters for 1986. The average turbidity of 0.22 FTU is higher than at some other Ruhr waterworks with either rapid filters or a longer ground passage time. Levels for iron, manganese and ammonia are very low. The average DOC of 1.7 mg/L represents a removal of approximately 50%. It is estimated that approximately 30% of the DOC is removed in the pre-filters. The finished water trihalomethane levels of approximately 3 μg/L are very low.

Over the years much research has been conducted at Dortmund on the functioning of slow sand filters. A number of publications are available, mostly in German.

Gelsenwasser AG

The water supply utility titled Gelsenwasser AG is located in Gelsenkirchen and serves a total population of approximately 3 million. Gelsenwasser AG operates a number of treatment plants along the Ruhr, and the Haltern plant near the Lippe River. The water extracted by the Ruhr plants consists of less than 10% natural groundwater and greater than 90% bank filtrate and artificially augmented groundwater.

This section describes two of the waterworks operated by Gelsenwasser AG: the Haltern plant and the Witten plant, which is on the Ruhr.

Haltern Waterworks

The general arrangement of this waterworks is shown in Figure 2.

Originally groundwater was the supply at Haltern. When this became inadequate, surface water from two small rivers was used for groundwater augmentation. Water for treatment is obtained from reservoirs which impound the flow of the rivers, and flows through the South Basin as the first treatment step. Since high levels of algae occur in the reservoirs, a flocculation step using either aluminum or iron is provided at the entrance to the South Basin.

From this basin the water is directed to a number of slow sand filtration / infiltration basins. Each of these has an area of 12,000 m^2 and operates with a water depth of 1.5 m and a hydraulic loading of 1.25 m^3 per m^2. day.

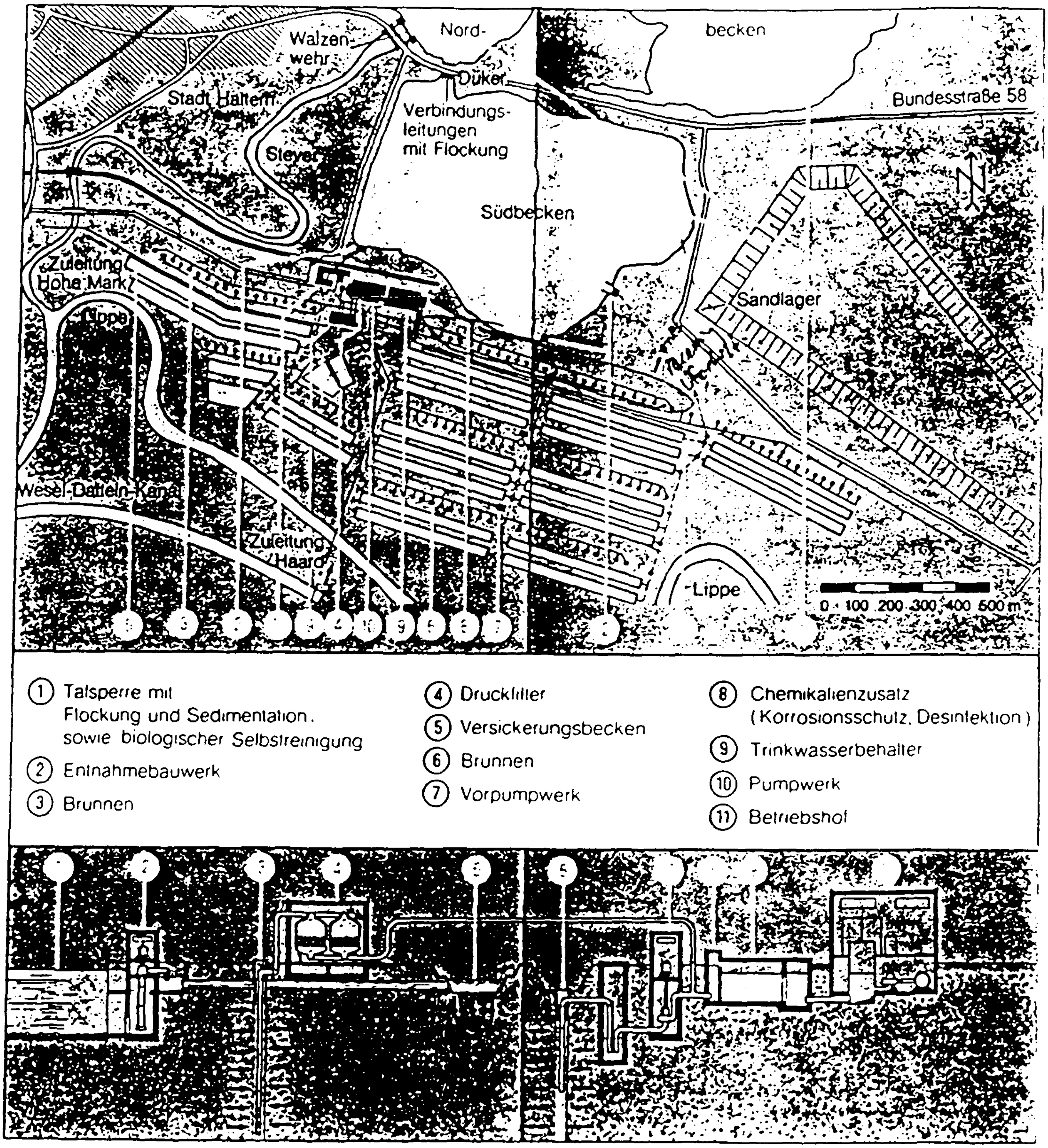


Figure 2

(will be translated and redrawn, similar to Fig. 3)

Although the average filter run time is 160 to 170 days, run times can be as short as 14 days in early spring. During good weather periods in early spring diatoms can develop but their predators do not, leading to blocking of the filters.

The best treatment with the filters is obtained in summer. Despite the algae blooms which occur then, midge fly larvae consume the bacteria and algae (Pätsch, 1987). This shows the importance of the ecosystem in a slow sand filter.

Although 2 cm of sand are removed at each filter cleaning, the biological activity occurs primarily in the top 8 to 10 mm (Pätsch, 1987).

Following a 6 to 8 week ground passage, the water flows by gravity through collection galleries, from whence it is pumped to a central mixing reservoir.

Water from two of the collection galleries is treated in a manganese removal step prior to being sent to the mixing reservoir. The galleries involved are those which receive bank filtrate from the South Basin. Manganese removal is a biological process which occurs in pressure filters (Huck, 1987).

The total production at the Haltern works in 1986 was 110 x 10^6 m^3. Twenty-seven per cent of this was natural groundwater which is pumped directly to the mixing reservoir. The remaining 73% was enriched groundwater from the slow filter / infiltration basins.

Until 1969 the water was distributed without chlorination. Now a dosage of 0.2 mg/L is provided. This is done for several reasons:

1. To keep the chlorine facility in operation. Since this plant serves approximately 1 million persons with a long distribution system, there is a desire to be able to respond quickly with a high disinfectant dosage if

a problem should arise in the distribution system.

2. As the law is written, if an unsatisfactory bacteriological test result were obtained the treatment plant would have to be shut down.

Process performance for the works is shown in Table 3 for selected parameters. Following ground passage the water is of excellent bacteriological quality, and very low in turbidity. Infiltration/ground passage produces a reduction of approximately 60 per cent in DOC and oxidizability and 50 per cent in UV extinction, based on the concentrations at the exit from the South Basin. The low chlorine dose (0.2 mg/L) is able to produce a detectable residual and very low levels of trihalomethanes.

Witten Waterworks

The Witten waterworks has an annual production of 30 x 10^6 m^3. In this waterworks the additional treatment has been placed after the slow filtration / ground passage, although flocculation is practised for part of the time prior to the slow filters. The current process is shown schematically in Figure 3.

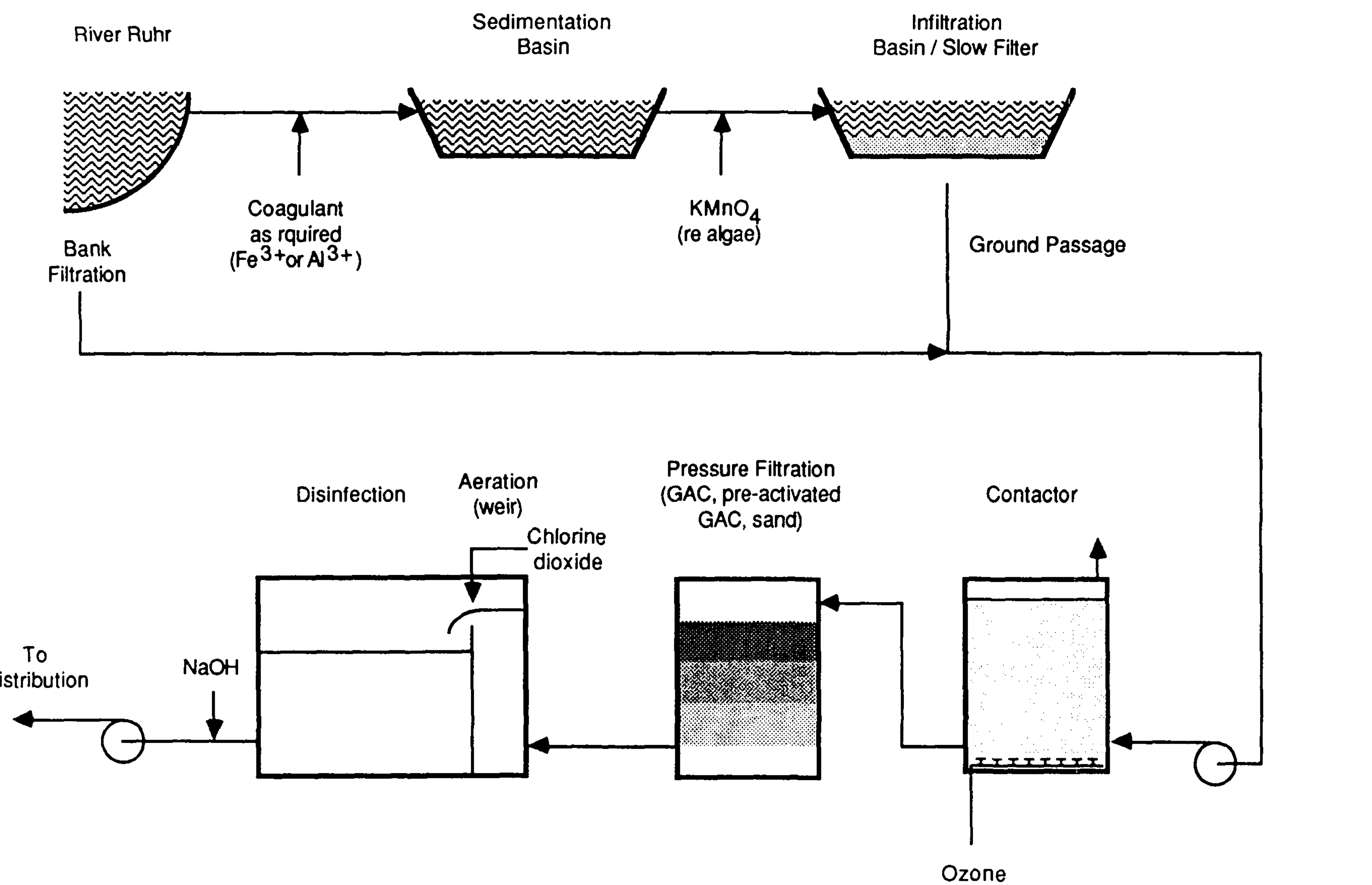
The historical practice at Witten had been to operate the infiltration basins at an initial velocity of 1.5 m/d. This gradually decreased as the sand became clogged and when it reached 0.5 m/d the filter was removed from service and cleaned. The process was basically surface filtration with most of the biological activity taking place in the top 2 cm or less (Kötter, 1987). With each cleaning, 2 cm was removed from the filter. The filters were rebuilt when a significant proportion of the original sand layer had been removed.

A problem faced by all Ruhr waterworks is the growth of algae on the open slow sand filter basins. There are two types of algae: the diatoms, which

Table 3 - Process Performance (Selected Parameters) - Haltern[a]

Parameter	Units	Treatment Step			
		Exit from North Basin	Exit from South Basin	Following Filtration/ Ground Passage[b]	Finished Water
Turbidity	FTU	3.5	0.7	0.08	0.08
pH		7.85	7.49	7.36	7.29
Total Hardness	mmol/L	2.27	2.33	2.41	2.23
Dissolved Oxygen	mg/L	10.4	10.6	4.1	5.7
Ammonium (NH_4^+)	mg/L	0.51	0.31	0.01	0.02
Phosphorus (P)	mg/L	0.15	0.02	0.04	0.16
DOC	mg/L	7.2	5.8	2.4	2.3
$KMnO_4$ Demand (O_2)	mg/L	6.4	4.6	1.7	1.8
UV Extinction (254 nm)	m^{-1}	17.8	11.7	6.0	5.1
AOX (Cl)	µg/L	22	17	-[c]	27
THMs	µg/L	0.2	<0.2	<0.2	2.2
Chlorine (free)	mg/L	-	-	-	0.03
Colony count (20°C)	per mL	2723	544	0	0

[a] 1986 data - geometric means (provided by Gelsenwasser AG)
[b] Recovery wells in row G2 (typical of overall quality)
[c] Not measured



Gelsenwasser-Witten

Figure 3

are free swimming, and the type which float at the water's surface. The latter appear unsightly but cause no real problems in operation. The former contribute of course to filter plugging. The means used by Gelsenwasser and other waterworks to combat the algae is to add potassium permanganate ($KMnO_4$) prior to the filter basins. This must be done prophyllactically, beginning in March - it will not work if the bloom has become established. It is believed that the color provided by the potassium permanganate restricts the light sufficiently that the algae from the sand surface cannot grow.

The statement that most treatment occurs within the top 2 cm of sand is based on the fact that the remaining sand is very clean when the top 2 cm has been removed. At an approach velocity of 4 cm per hour, which is approximately that used, the "empty bed" contact time in this zone would be 30 minutes. The actual contact time would be less than half that since the volume occupied by the sand grains themselves would be greater than 50%. It is felt that an important purpose of the underlying sand is to have a bacterial inoculum present for the re-development of biological activity when the top layer is removed (Kötter, 1987).

At Witten the post-treatment was provided because of the need to reduce manganese concentrations in the finished water. It was therefore necessary to use ozone for oxidation and since ozone was being provided, it was decided to include other new process technologies as well. The Biological Activated Carbon process (ozonation followed by GAC) was added, although as discussed below, it is not really required. Chlorine dioxide was provided instead of chlorine to reduce trihalomethanes - approximately 5 to 10 µg/L would have been produced by chlorination following ground passage.

Table 4 shows percentage removals through the complete process for ammonia, DOC, $KMnO_4$ and UV absorbance (254 nm). It is evident that much more

Table 4 Process Performance for Selected Parameters (Gelsenwasser - Witten)[a]

Treatment Step	Parameter			
	Ammonia	**DOC**	**$KMnO_4$ Demand (as O_2)**	**UV Extinction (254 nm)**
Raw water	(0.40 mg/L)	(3.3 mg/L)	(3.1 mg/L)	(6.2 m^{-1})
Flocculation and floc separation	0	18	26	42
$KMnO_4$, infiltration and ground passage	92	42	36	14
Addition of groundwater of different quality	3	0	(3)	(3)
Oxidation with ozone	0	0	0	18
Flocculation, filtration with biological activated carbon	0	6	6	0
Gas exchange (weir), disinfection	3	0	0	0
pH adjustment with NaOH	0	0	0	0
Cumulative	98	66	65	71
Finished water level	0.01 mg/L	1.1 mg/L	1.1 mg/L	1.8 m^{-1}

[a] Values shown are percentage reduction (increase) with respect to initial value, for each treatment step (based on geometric means).

After Gelsenwasser AG (1984)

is accomplished by slow filtration / ground passage than by the complete treatment sequence which follows. For example, both DOC and $KMnO_4$ demand are reduced by approximately 40 per cent during infiltration and ground passage, and only 6 per cent by the step which includes biological activated carbon.

THE NETHERLANDS

In the Netherlands the City of Amsterdam has retained slow sand filters as part of present day multi-step treatment processes. Amsterdam is served by two waterworks, the older Leiduin plant located west of the city and the Weesperkarspel plant located southeast of the city. The Leiduin plant has retained original slow sand filters and added additional units to increase the capacity of this treatment step. The Weesperkarspel plant is a totally new facility which was placed in operation in 1976. After long discussions slow sand filters were included when the plant was built, as an added precautionary step (Graveland, 1987). In both the plants the slow sand filters are covered.

At both Leiduin and Weesperkarspel the water is pre-treated before arriving at the plant, and the slow filters are the last step in a multi-step treatment process. Because of this, data available (Huck, 1987) do not show measurable changes in most chemical parameters across the slow filters. However, the slow filters are important in reducing the levels of easily biodegradable or Assimilable Organic Carbon (AOC) levels to very low values (Schellart, 1987).

In 1983 final chlorination of the water was stopped in Amsterdam. Although one special feature which allows this is the fact that all connections to the distribution system are provided with some type of backflow prevention device (van der Kooij, 1987) it is the opinion of waterworks staff that it is only the presence of the covered slow sand filters which allowed this step to be taken.

Of interest from an operational point of view is the fact that mechanical cleaning devices have been developed for the newer slow sand filters.

SWITZERLAND

Of the five facilities visited in Switzerland, two cities (Zurich and St. Gallen) have retained slow sand filtration as part of their current treatment sequence.

Zurich

Zurich is served by three sources of water: Lake Zurich, groundwater and spring water. The lake water, which provides approximately 70% of the total supply, is provided by two treatment plants (the Lengg and the Moos) located on opposite banks of the lake. Both of these plants originally had rapid filtration followed by slow filtration and both have undergone upgrading over the years to achieve their current multi-step treatment sequence. The current process in both plants is generally similar and that for the Lengg is shown schematically in Figure 4.

Slow sand filters have been retained in the treatment process because of a reluctance to eliminate a possibly important treatment step. Their main purpose is biological treatment (Aeppli, 1987). Prior to an upgrading at Lengg it was shown that the filtration velocity could be increased without a deterioration in particulate removal efficiency. The maximum velocities used in the slow filters (16 m/d at Lengg and 9 m/d at Moos) place these units in the category of "rapid" slow sand filters. The flexibility exists at both plants to place the slow filters directly after the rapid filters rather than

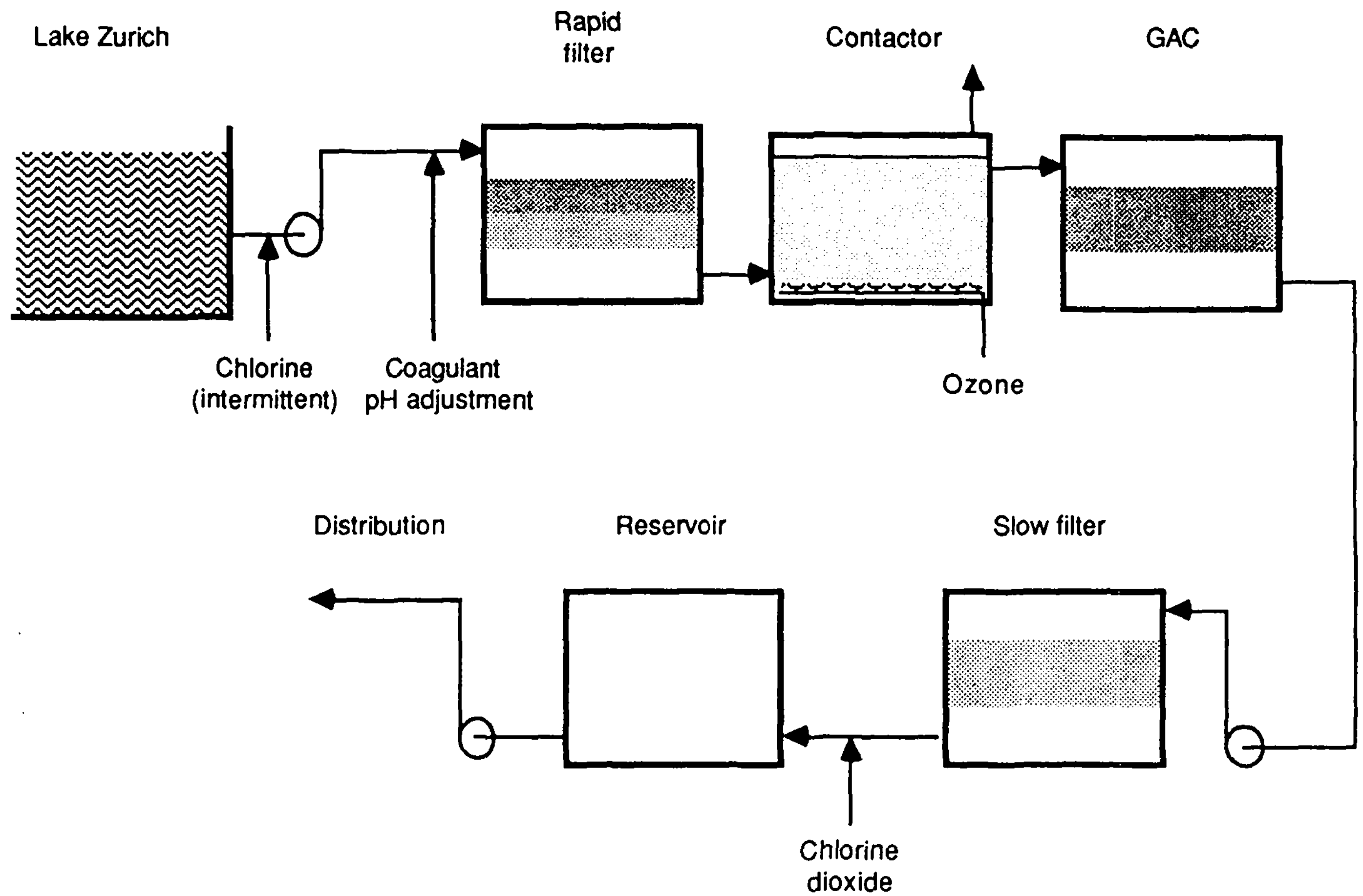


Figure 4

Zurich-Lengg

after the GAC step as at present, and this is being considered for the future.

Process performance for selected parameters for the Lengg plant is shown in Table 5. The raw water is of quite good quality and because of the preceding treatment steps little measurable removal is evident in the slow filters.

Additional data obtained as part of a doctoral research project (Jägqi, 1986) show the removal of Assimilable Organic Carbon in the various treatment steps at the Lengg plant. These measurements were carried out using the method of van der Kooij (van der Kooij et al., 1982). The basis of the method is to monitor the growth of a specific strain of bacteria (Pseudomonas P-17) inoculated into the sample of interest. The maximum number of colonies formed by this bacterium per microgram of the easily-biodegradable organic substrate acetate is quantitatively known. Bacterial growth measurements obtained with the sample can then be converted to a concentration of Assimilable Organic Carbon, expressed as acetate equivalents.

The data in Table 6 were measured over a six week period in the late fall of 1984. The results must be interpreted with caution because there is a considerable amount of scatter in the data, and on some dates AOC values following a biological treatment step were higher than prior to that step (Jäggi, 1986). The general trend however shows low values in the raw water, an increase following chlorination and a subsequent reduction attributable to biological activity during rapid filtration. A considerable increase is obtained following ozonation but much of this additional AOC is removed in the subsequent GAC filters. The slow filters provide some additional removal and a reduction in the standard deviation of the measurements compared to those in the GAC effluent. The finished water values are below the 10 µg/L level

Table 5 - Process Performance for Selected Parameters[a] (Zurich - Lengg)

Parameter	Treatment Step						
	Raw Water (unchlorinated)	Raw Water (chlorinated)	Following Rapid Filtration	Following Ozonation	Following Activated Carbon	Following Slow Filtration	Finished Water
Turbidity, FTU	-[b]	0.28	0.06	-	0.04	-	-
DOC, mg/L	1.20	1.20	1.20	1.15	0.95	0.80	0.85
$KMnO_4$ demand, mg/L	1.1	0.9	0.9	0.8	0.6	0.6	0.6
UV extinct. m^{-1} (254 nm)	3.0	2.6	2.3	1.1	1.1	1.1	1.0
AOX, µg/L	15	46	-	-	-	-	21
TTHMs, µg/L	<0.1	5.1	-	-	-	-	5.2

[a] 1985 averages (Annual Report, Wasserversorgung Zurich)
[b] Not measured

Table 6 - Assimilable Organic Carbon (AOC) Determinations (Lengg Plant)[a]

Sample Point	AOC (µg acetate-carbon/L)		
	Mean	Standard Deviation	Geometric Mean
Raw water	13.7	6.9	12.3
Chlorinated raw water	19.4	9.5	17.6
Rapid filter effluent[b]	12.9	6.6	10.2
Following ozonation	31.6	6.8	31.0
GAC effluent	17.0	18.8	11.3
Slow filter effluent	12.5	8.3	10.6
Finished water (following ClO_2)	9.6	7.7	5.3

a from Jäggi (1986). Seven samples, taken between October 29 and December 10, 1984.

b Only six samples.

recommended by van der Kooij (1987) for the avoidance of bacterial regrowth problems in distribution systems.

St. Gallen

St. Gallen is a city of approximately 70,000 population located in northeastern Switzerland. Almost all of its drinking water is provided from Lake Constance (Bodensee). The treatment plant at Lake Constance began operation in 1985 when the lake was still oligotrophic. The original treatment consisted of only slow sand filtration. The plant has undergone various upgradings and expansions since.

The current process is shown schematically in Figure 5. The slow filters operate in a velocity range from 7 to 21 m/d and therefore function partly as depth filters. They are cleaned by hand twice per year, with 5 cm being removed and are fully rebuilt every 10 years. The filters are enclosed. It should be noted that no oxidant is added to the water until after the slow filtration step.

Process performance data for selected parameters are shown in Table 7. While some removals of organic parameters are seen in the slow filtration step, the most impressive results for this step are the reduction in bacterial numbers.

The role of the slow filters in the removal of Assimilable Organic Carbon is not clear. In a recent survey of four Lake Constance waterworks, the bacterial growth rate measured in the finished water at St. Gallen was usually the second lowest of the four plants (Werner and Hambsch, 1986). St. Gallen is the only one of these plants to have slow filters.

Trihalomethane analyses are performed periodically and show values to be always below 4 µg/L in the finished water. Such a low value would not be

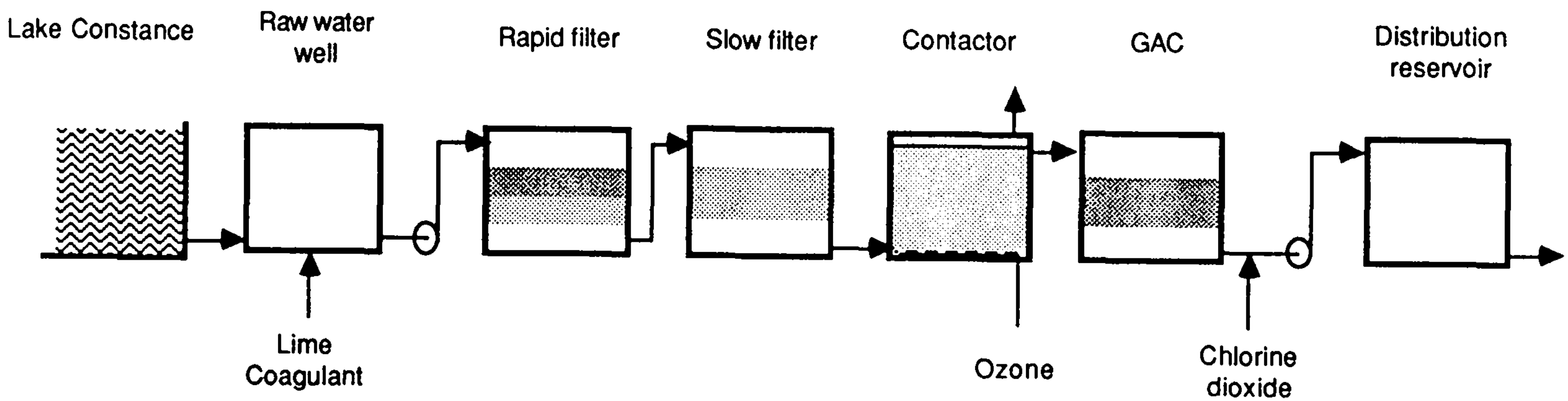


Figure 5

St. Gallen

Table 7 - Process Performance for Selected Parameters[a] (St. Gallen)

Parameter	Units	Treatment Step					
		Raw Water	Following Rapid Filtration	Following Slow Filtration	Following Ozonation	Following Activated Carbon	Finished Water
Turbidity	FTU						
DOC	mg/L	1.3	1.2	1.1	1.0	0.8	0.9
$KMnO_4$ demand	mg/L	4.4	4.1	3.9	3.2	2.5	2.6
UV extinction (255 nm)[b]	m^{-1}	2.7	2.6	2.4	1.5	1.0	1.3
Colony count[c] (20°C)	per mL	230	79	2	2	4	1
Suspended solids[d]	mg/L	1.0-1.2	0.2-0.4	>0.1-0.1	<0.1-0.2		

a 1986 arithmetic means (data provided by St. Gallen Stadtwerke)
b Wavelength used since 1973; values considered equivalent to measurements made at 254 nm (Henauer, 1987)
c Geometric means. Some variation in individual filters reported.
d Range of annual averages for years 1971-1974.

unexpected given the low DOC levels in the raw water, the multi-step treatment process and the use of chlorine dioxide (at a dosage of 0.12 to 0.15 mg/L) for final disinfection.

UNITED KINGDOM

In the United Kingdom slow sand filters are used by Thames Water, the Water Authority which provides drinking water to the several million inhabitants of the Greater London area.

Most of the drinking water supply is obtained from the river Thames. After abstraction from the river the water is stored in a number of large reservoirs. In all but one treatment plant the reservoirs are followed by rapid filtration. The next step in all cases is slow filtration. This step of course provides biological removal of organic matter and also has the goal of producing bacteriologically acceptable water without chlorination, although chlorination is practised in all cases.

Ammonia levels are typically 0.05 to 0.1 mg/L after slow filtration. Raw water TOC levels of 4 to 6 mg/L are reduced to 2 to 4 mg/L by the end of the treatment process. The run length of the slow filters is based on measurements of particulate organic carbon and chlorophyll a, and on bacteriological determinations.

Over the past few years a considerable research effort has been carried out by Thames Water, much of it in cooperation with the Water Research Centre. The basic aim of this work has been to increase the operating rate of the slow sand filters. The principal options investigated have been:

(1) Improvements to algae removal by the rapid filters through either coagulation or ozonation or the use of dual media.

(2) Use of ozone ahead of the slow filters or shading of the filters themselves, to reduce in-filter algae growth. (During the summer this in-filter growth is the major blocking mechanism.)

Long term investigations are focusing on the use of man-made non-woven fabrics as either alternatives or additions to slow sand filters. These have shown promising results at small scale but give rise to very serious handling problems in the large filters operated by Thames Water.

APPLICATION TO SMALL SYSTEMS IN CANADA

It is evident that slow sand filtration can provide considerable reduction in organic levels and therefore in the disinfectant demand and disinfectant by-product level in the finished water. Slow sand filters should therefore be considered as a treatment option for small Canadian communities. They are simple to operate and land requirements should not be a problem in these situations.

If maximum benefits are to be obtained from this technology it will likely be necessary that these units be covered. While this would certainly increase their cost, it should be possible to provide some type of inexpensive enclosure since the main reason for covering would be to prevent freezing in winter and algal growth in summer.

Additional investigations need to be performed to assess the level of organic removals achievable under Canadian conditions, where organic matter may not be as biodegradable as in European rivers and where water temperatures are lower in winter. Investigations should also proceed into the use of the principle of slow sand filtration in modified configurations which might eliminate the large space requirements and simplify cleaning of the filters.

This latter point is important since it is doubtful whether mechanical cleaning would be feasible for small systems.

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