STATE-OF-THE-ART IN DRINKING WATER TREATMENT IN GERMANY

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ABSTRACT

Due to increasing raw water pollution in the fifties, sixties and seventies, drinking water technology became very developed and a lot of new processes were installed. The main raw water source in Germany is groundwater, however also rivers, riverbank filtrate, reservoirs, lakes and other surface water sources are used. In the history of drinking water treatment, slow sandfiltration, chlorination, flocculation and filtration were the first processes. Today, modern oxidation processes like ozonation and advanced oxidation (AOP), adsorption technologies like activated carbon, new disinfection means, like chlorine dioxide and UV are state-of-the-art. Membranes are used more and more, specially for particle removal, the control of microorganisms and the reuse of backwash waters. A lot of research is done to optimize existing processes and to optimize them for the needs of today and the future. Cost is playing an important role, so cost effective technologies and optimization processes are developed. The general philosophy for the production of a safe and healthy drinking water is the use of a multiple barrier system. This multiple barrier safety system starts already with the protection of the raw water source. A good raw water quality ensures already a good product quality. Not just one specific technology, but the combination of different treatment steps are used. The range of possible hazards is wide, so a system of different acting processes may cover the problems, which may even include unknown risks. The multiple barrier approach guarantees a high quality and safe drinking water to our people.

KEYWORDS

Drinking water treatment, bank filtration, particle removal, disinfection, distribution system

INTRODUCTION

About two thirds of Germanys drinking water is produced from protected deep groundwater. Other raw water sources for waterworks are bankfiltrate (16 %), dam-water (9 %) and spring water (8%). The direct use of river water and other sources is limited to approximately 3 % of the total drinking water production (Fig. 1). The annual production of the German waterworks reach nearly 5 billion m^3. The mean drinking water consumption is 128 L/consumer/day. Drinking water sales are going back since ten years, due to measures in the industry (recycling etc.) and due to the savings in private households.

The quality of drinking water is regulated by the drinking water guideline of the European Union (1998), which was transferred in to national right by the German Drinking Water Guideline (2003). The German guideline includes a list of registered additives, which are allowed for use in drinking water treatment. Technical rules for water treatment are issued by the DVGW, the German Gas and Waterworks Association. The technical equipment may follow the rules of the DIN, the German Institute for Standardization. The Federal Environment Agency (UBA) recommends quality targets for raw, treated and finished water.

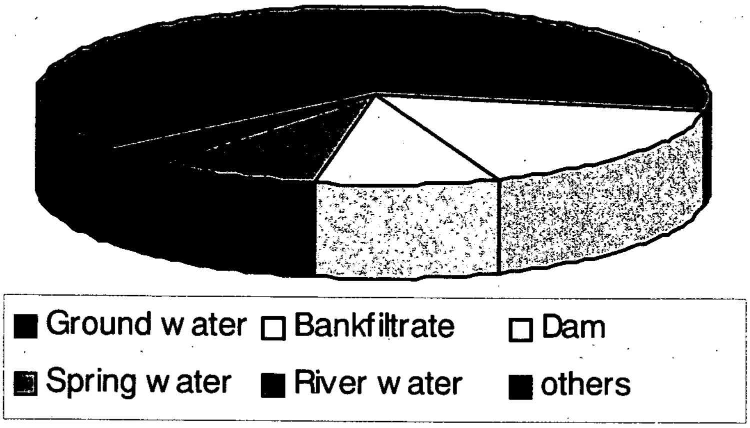

Figure 1: Sources for drinking water production in Germany (BGW, 2002)

Focussing the treatment technology, higher quality standards lead to a more and more sophisticated and sometimes expensive treatment. Nevertheless, the market forces the water works to look for economic solutions. Therefore, the treatment technology in a waterworks should be focussed on site specific problems, the raw water quality and the possible risk potential of the raw water source.

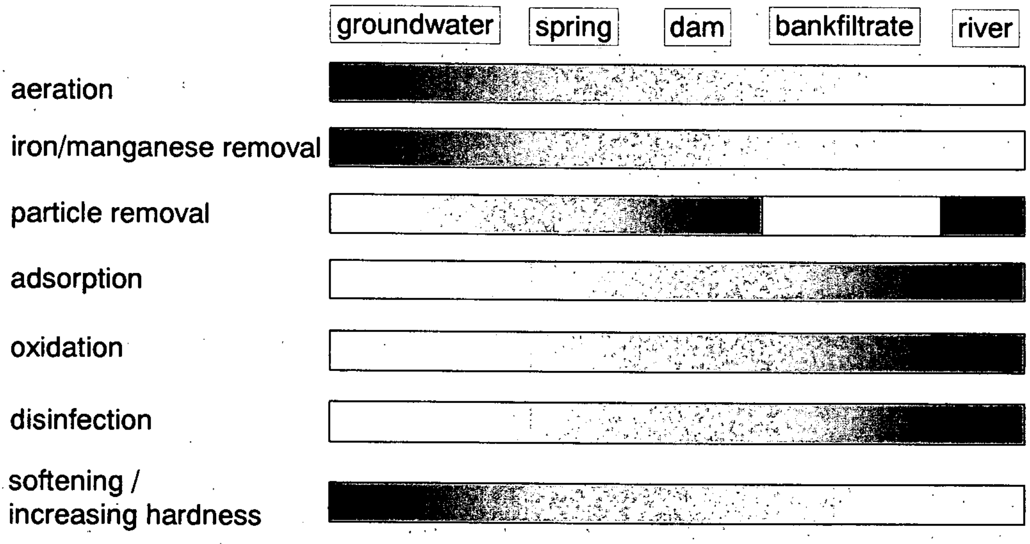

Figure 2: Origin of raw water and applied treatment technology

As Fig. 2 shows groundwaterworks use mostly aeration, rapid filters to remove iron and manganese and sometimes technologies for water softening. Only in cases of special hazards (e.g. farming (pestizides, nitrates), pollution) additional treatment is used. In general, a removal step for micropollutants or a disinfection is not required for groundwaterworks due to a careful protection of the catchment area. Water treatment, which means in Germany a multiple barrier system, starts with the protection of the raw water source. Waterworks using surface water focus their treatment on removal of particles, micropollutants and microbiological risks.

BANKFILTRATION – A PROCESS CLOSE TO NATURE

Waterworks using river water favor the bankfiltration or infiltration as the first treatment step (Fig. 3). Bank filtrate is river water, passed through the river banks. The infiltration is often characterized by pretreatment of the river water, e.g. by flocculation, followed by trickling in certain basins in the underground to enrich the groundwater. Bank filtrate and infiltrate are collected from the underground by wells, followed by a further treatment in a waterworks. Infiltration is often applied, if the quantity of water provided by bank filtration is too low, or bank filtration is impossible due to the geological conditions. Both processes show, that the German treatment philosophy likes to include a very natural step, like an underground passage (Kuehn and Mueller, 2000).

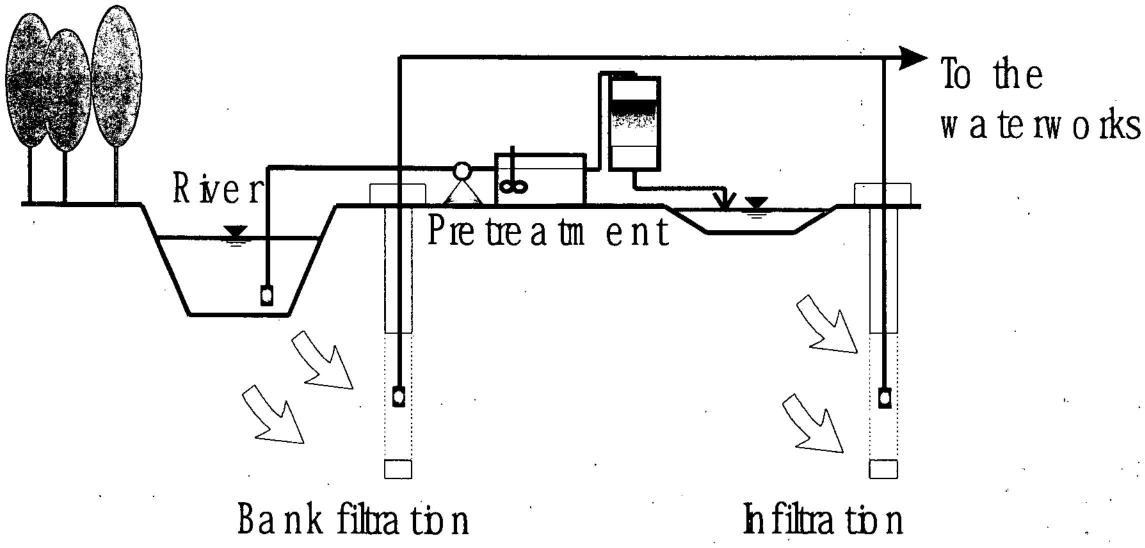

Figure 3: Principle of bankfiltration and infiltration

In recent years the importance of the underground passage grew worldwide, nevertheless the bank filtration has a long tradition in Germany. This is due to several advantages of the underground passage. First of all the underground passage is a natural process. The underground passage removes particles, bacteria, viruses, parasites and the whole spectrum of biodegradable compounds. It is well known, that a river water is characterized by extreme varying concentrations, depending on the water flow, seasonal effects, emissions by municipal and industrial sewage, runoff etc. However, these concentration peaks are compensated and blended during an underground passage.

Important reasons for this concentration compensation are the different retention time, required for a water particle to flow from the river bottom through the underground to a well or the different porosity of the soil. Therefore, the underground passage acts as a barrier against shock loads, caused e.g. from emergency situations such as defects in industrial wastewater plants as shown in Figure 4. The compensation of temperature peaks will improve the water quality, too. The bank filtration has no effect on recalcitrant substances. Therefore the treatment of bankfiltrate often includes granular activated carbon filters.

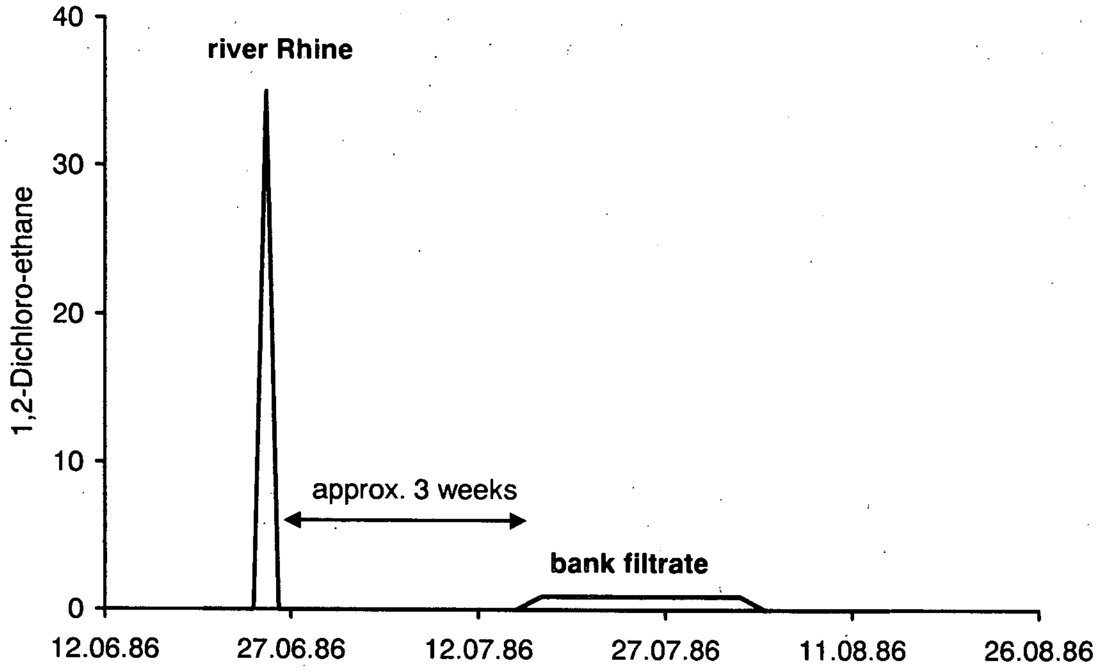

Figure 4: Protection against shock loads during bank filtration (Sontheimer, 1991)

Some examples demonstrate the effect of bankfiltration of the river Rhine in Germany. Figure 5 compares DOC-concentrations in the river water and in the bank filtrate for a waterworks in the central Rhine area in recent 25 years.

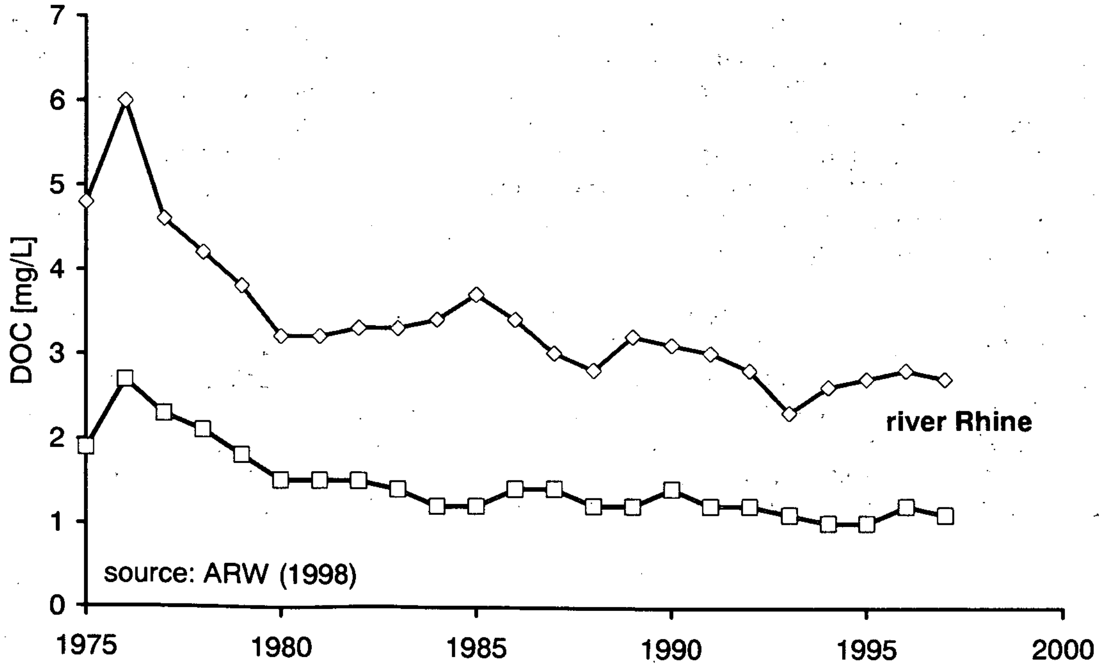

Figure 5: Long term behavior of organic carbon removal while bankfiltration at the Rhine river (Denecke et al., 1998)

Between 1975 and 1997 the DOC-concentration in the river dropped from approximately 5 mg/L to 3 mg/L. A similar decrease of the DOC-concentration was found in the bankfiltrate. The results indicate, that the underground passage has a nearly constant efficiency to remove biodegradable substances dissolved in the river water. Regarding biodegradable compounds, 70 to 100 percent of the removal is done in the underground passage. A reliable and also cheap process.

Even for some micropollutants the underground passage acts as a barrier. An example is given with Fig. 6, demonstrating concentrations of various pharmaceutical compounds in the Rhine river, the bank filtrate and in the drinking water. Some pharmaceuticals such as sotalol or diclofenac were completely removed by bank filtration. Some other pharmaceuticals, e.g. carbamacepine or amidotrizoic acid, pass the underground. Therefore it is necessary to remove these recalcitrant substances in further treatment steps in the waterworks by ozone and activated carbon, whatever process is necessary for the given compound.

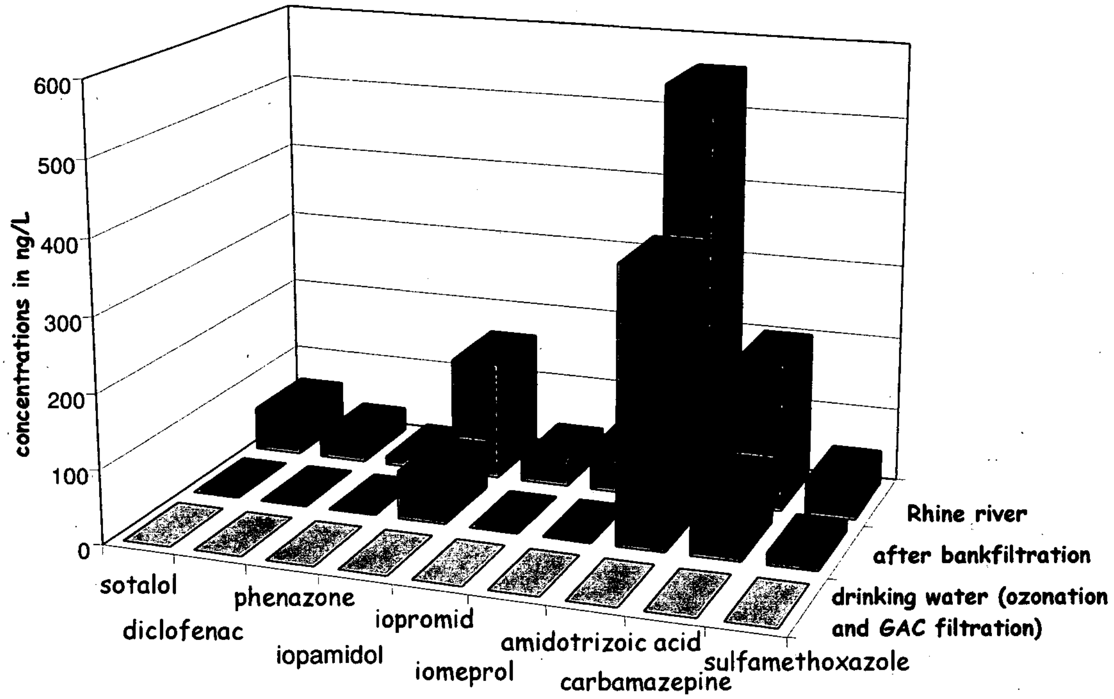

Figure 6: Influence of bank filtration and treatment in the waterworks on removal of pharmaceuticals (Sacher, 2002)

PARTICLE REMOVAL

A sampling campaign was conducted to quantify the occurrence of parasites in surface waters and in waters under influence of surface water. 13 reservoirs and 19 springs were evaluated. Nevertheless, the campaign is not representative for the general raw water situation in Germany, it allows an first indication about the requirements on the waterworks for particle removal. As Fig. 7 shows, in 26 % of the samples collected in dams no Cryptosporidium were detected. In about 60 % of the samples less than 1 Cryptosporidium in 100 L were found. Approximately 70 % of the samples from spring waters showed negative findings for parasites. This campaign indicated, that the parasite concentration in raw waters used for drinking water treatment is relatively low, showing the success of protection measures in the catchment areas.

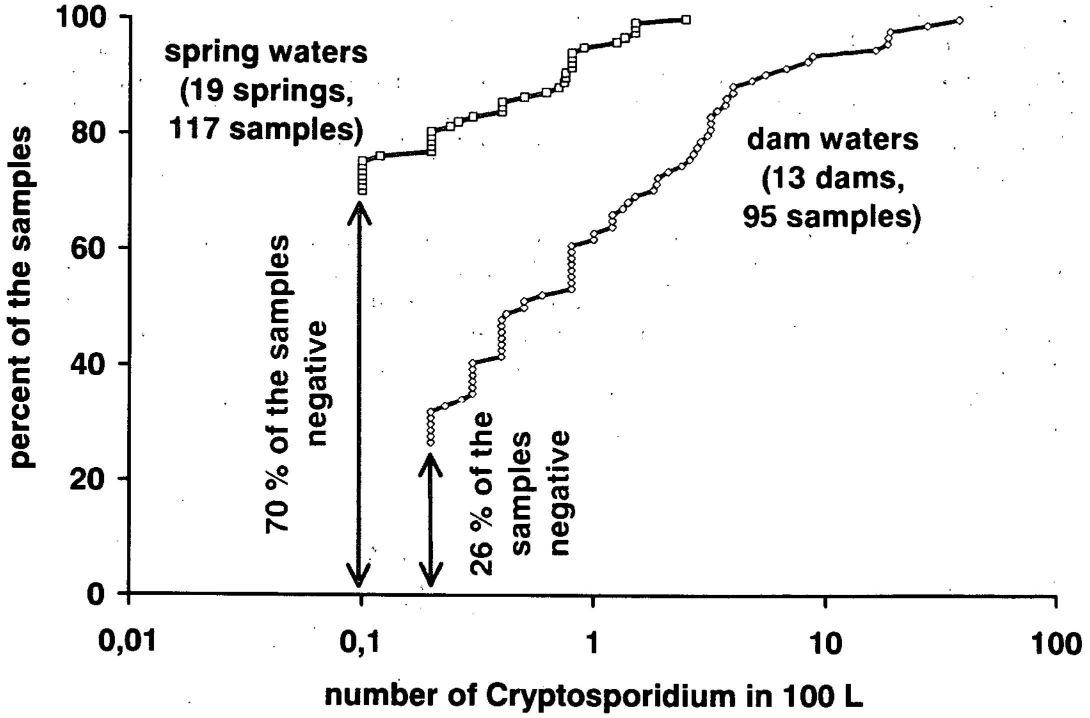

Figure 7: Screening on Cryptosporidium in dam and spring waters

Table 1: Overview of MF/UF-plants for drinking water treatment in Germany (8/2003) (Lipp and Baldauf, 2003)

Site	Capacity, m³/h	Source water	Start-up	Membrane type
Neckarburg	70	Carstic spring	9'1998	Aquasource
Hermeskeil	140	Spring + Dam	2'1999	X-Flow
Sundern	250	Sorpe Dam	3'2001	X-Flow
Marmagen	45	Carstic spring	3'2001	ZENON
Denkingen	15	Carstic spring	6'2001	X-Flow
Neustadt / Saale	70	River	7'2001	X-Flow
Olpe	80	Well	8'2001	X-Flow
Calw	50	Spring	2'2002	X-Flow
Jachenhausen	72	Carstic spring	8'2002	Inge
Olef	600	Olef Dam	1'2003	X-Flow
Regnitzlosau	27	Well	1'2003	ZENON
Bad Herrenalb	36	Spring	2'2003	X-Flow
Miltenberg	80	Well	5'2003	ZENON
Kandern	50	Spring	3'2002	X-Flow
Lauterhofen	90	Well	5'2003	X-Flow
Waldberg	210	Spring	7'2003	ZENON
Roetgen	150 (pilot)	Dreilägerbach Dam	2'2001	X-Flow
Hof	6000 Pilot phase	River	planned 2001	Not decided yet X-Flow / ZENON

Measuring turbidity and particle counts as well as microbiological indicator parameters may be an excellent tool for the utilities to control and optimize the removal of parasites such as

Cryprosporidium and Giardia during the treatment process.

In Germany membrane filtration is used in public water supply since 1998. Table 1 gives an overview and some technical details about the plants, that have been put in operation since then.

However further research is needed to optimize ultrafiltration. For instance, a case study of the long term behavior of an ultrafiltration plant showed a considerable increase of the transmembrane pressure (TMP) as can be seen in Figure 8. In this case study chemically enhanced backwashes were carried out with hydrogen peroxide every 4 to 8 hours. In time intervals of 4 weeks chlorine has been taken instead. It is planned to change backwash chemicals to acid and base. Nevertheless chlorine is a much stronger oxidant, the application should be minimized, due to the formation of by-products leading to sewage polluted with chlorinated compounds.

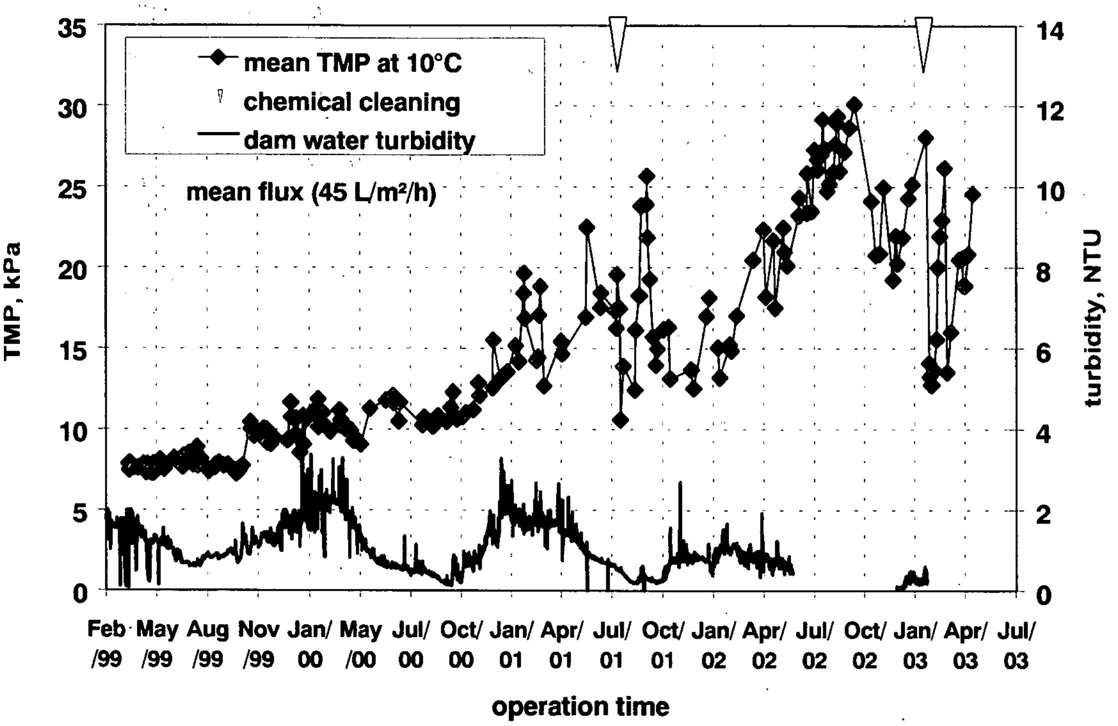

Figure 8: Case study: Increase of TMP versus time (Lipp et al., 2004)

Figure 9 shows results of realized improvements in full scale in five waterworks to enhance particle removal. The success of optimization was measured by particle counts for particle sizes in the 2 to 20 μm range. The particle counts were measured before and after optimization. The interval between both measurements of particle counts was up to 5 years.

The technological changes applied depend on the local situation. Utility 1 used three measures. First, ozonation was optimized to improve the ozone induced microflocculation. Second, to maintain a homogenous filter layer the backwash process was improved. Third, fluctuations in the throughput of the rapid filters were reduced. Utility 2 added a new flocculation and filtration step. Utility 3 replaced the filter material in the rapid filters. Utility 4 installed a direct flocculant dosage in the filter influent. Utility 5 decided to acquire an ultrafiltration. The efficiency for particle removal of the five different works can not be compared directly, since for utility 5 the particle count of the raw water is shown, whereas for utilities 1 to 4 particle counts of already pretreated water are plotted. Otherwise the efficiencies of utilities 1 to 4 would be higher.

As the results show, advanced as well as traditional methods supported the waterworks to enhance the particle removal even under consideration of cost and performance. Since a lot of waterworks are in operation already, optimization of existing processes is often more cost effective than building a whole new plant.

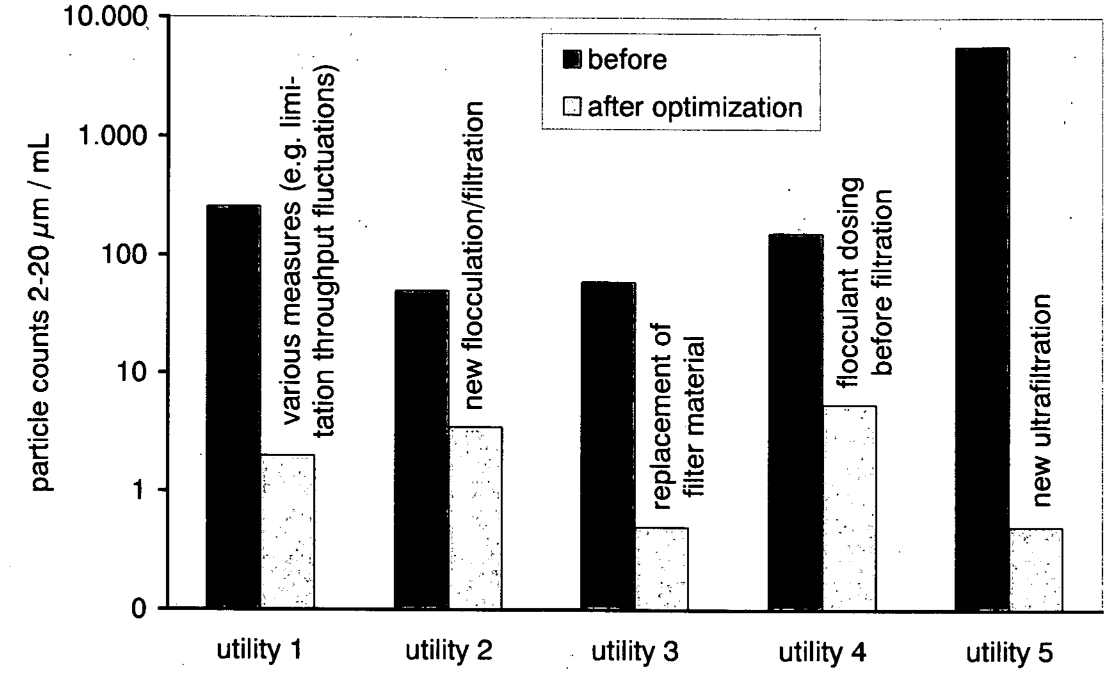

Figure 9: Examples for full scale optimizations to enhance the particle removal

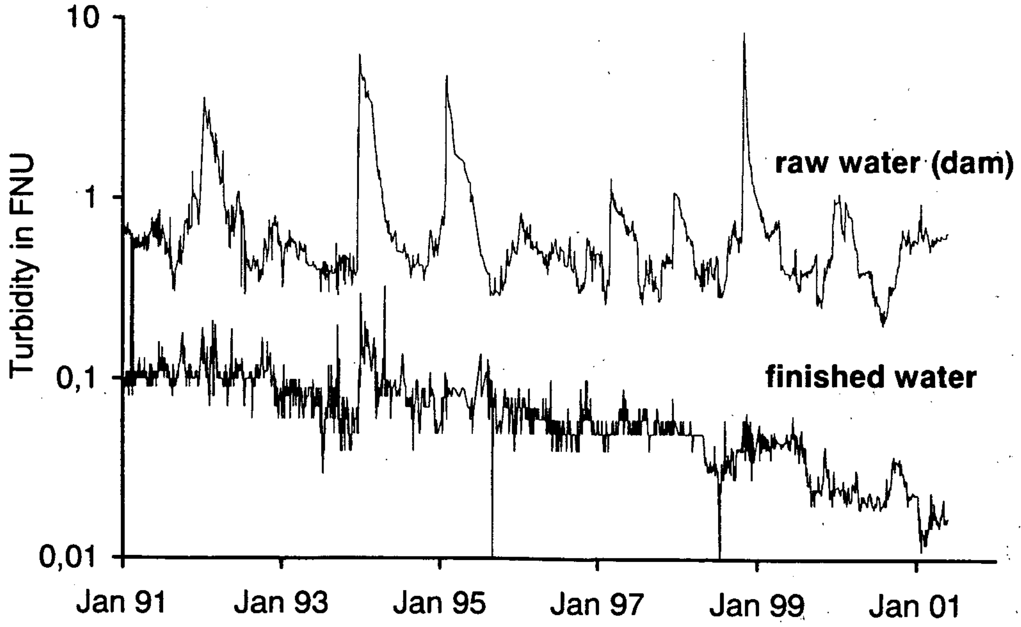

Figure 10: Example for full scale optimization by improving the traditional treatment

Further improvement of particle removal may be achieved in waterworks even at low turbidity as shown in Figure 10. The waterworks for reservoir water treatment uses a traditional treatment consisting of steps to increase the hardness, ozonation, flocculation, rapid sand filtration and disinfection. Optimization of this conventional treatment process led to a drop of turbidity in the finished water from 0.1 FNU to less than 0.05 FNU and showed a more stable and much safer finished water even at high turbidity situations.

DISINFECTION

Due to the protection of the catchment areas many groundwater sources already meet the microbiological requirements of the drinking water standard. This means the water is free from coliforms or other pathogens. Therefore, approximately 60 % of the drinking water in Germany is distributed without disinfection. Waterworks operating with a disinfection step use mostly chlorine. In general, the chlorine dosages in the waterworks is low and range between 0.2 and 0.5 mg/L. A 1999 survey of some 1000 samples taken at 144 sampling points in distribution systems of 23 waterworks showed, that in most samples the THM-concentrations were below 50 μg/L (Fig. 11). A THM-concentration of 50 μg/L, measured at the consumers tap, is the limit of the German Drinking Water Regulation and 100 μg/L the parametric value of the European Union for water intended for human consumption. An increasing part of the waterworks replace chlorine with chlorine dioxide or with UV-irradiation to prevent the THM-formation.

If the groundwater meets the microbiological standards and the distribution system is in a good condition a safety chlorination may be dispensable. An example for switching from a distribution with chlorine residual to a distribution without residuals in full scale is given in Fig. 12. Approximately two weeks after chlorination was stopped, the heterotrophic plate counts (HPC, 20 °C, 2 days) increased. Continuing the water supply without chlorine, the HPC dropped down after approximately one month and remain constant to nearly < 5 cfu/mL. This is due to the formation of a different biofilm in the distribution network.

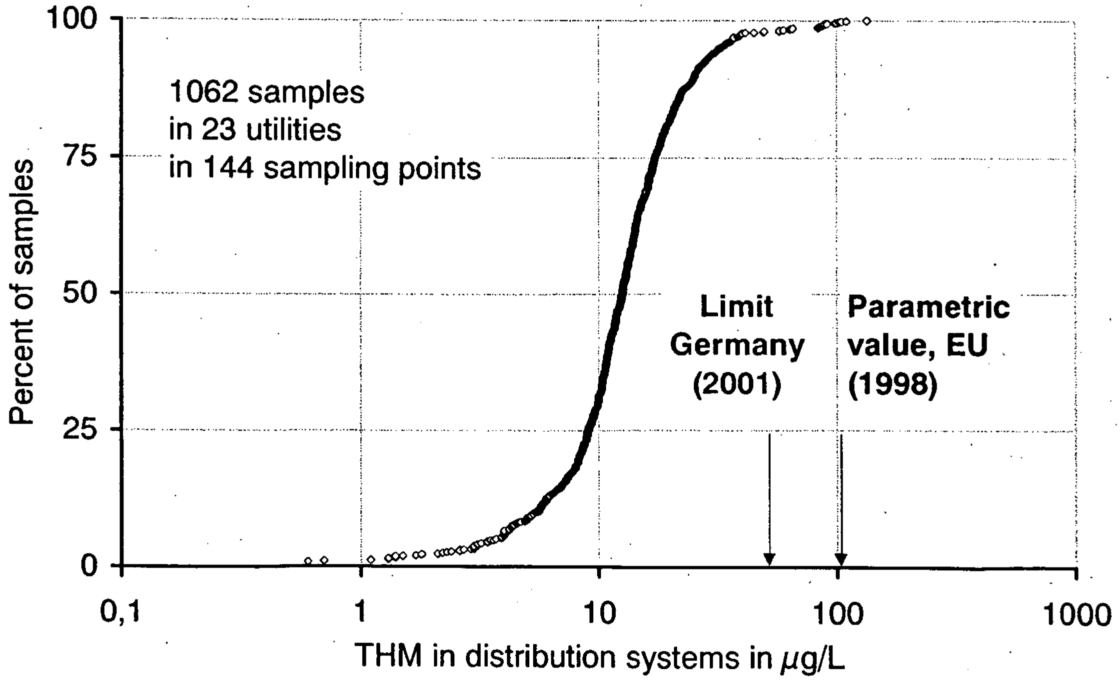

Figure 11: Survey on THM-concentrations in distribution systems

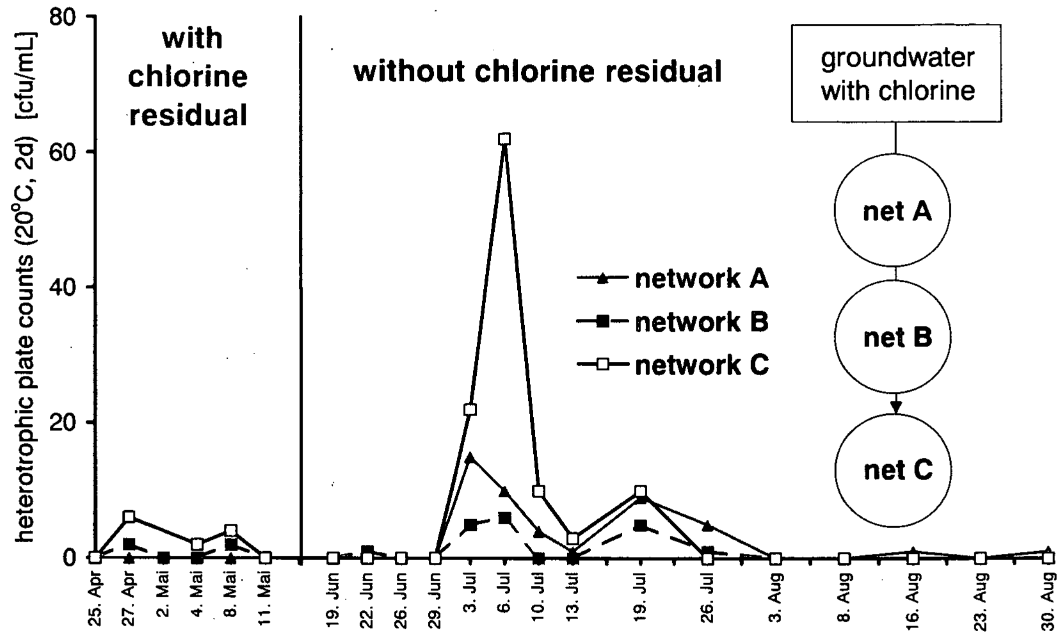

Figure 12: - HPC in distribution systems with and without chlorine residual (Hambsch, 1999)

CONCLUSIONS

The general philosophy for the waterworks in Germany to produce a fresh and safe drinking water is to establish a multiple barrier system. This concept covers three levels. Level one requires the protection of the raw water sources by stringent regulations and their control. On level two the treatment technology and operation should base on a suitable, site specific concept to produce a high quality drinking water even at possible quality changes of the raw water. Level three requires a careful maintenance of the distribution system. Only the consideration of all levels guarantees to supply the consumer with a safe and high quality drinking water.

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