11 SURFACE WATER TREATMENT IN ZURICH (SWITZERLAND)

PËRPUNIMI I UJËRAVE SIPËRFAQËSORE NË ZYRI (ZVICËR)*

H. P. Kaiser**

Përmbledhje

Ujësjellësi i Zyriut (WSZ) siguron ujë të pijshëm për rreth 800'000 banorë të qytetit të Zyriut dhe 67 bashkive në zonën e Zyriut. 70% e ujit të pijshëm të Zyriut merret nga uji i liqenit i përpunuar. Këtu është zbatuar parimi i pengesave të shumfishta për të furnizuar me ujë të pijshëm, të sigurt, në çdo kohë. Mbrojtja e mirë e vendburimeve të pellgut ujëmbledhës përbën masën e parë; dy ozonime dhe tre filtrime të mëtejshme janë masat e mëtejshme për mbrojtjen e cilësisë së ujit të pijshëm. Masat e kontrollit mbështeten në konceptin HACCP (*Hazard Analysis and Critical Control Points* / Analiza e Lëndëve të Dëmshme dhe Kontrolli i Pikave Kritike). Mbështetur në analizën e lëndëve të dëmshme në cilësinë e ujit të liqenit ndiqet aftësia e largimit të këtyre lëndëve gjatë hapave përpunues. Ndjekja e dy hapave të ozonimit mbështetet në një kod kompiuterik të bashkërenduar me një reaktor hidraulik me reaksion kimik dhe kinetikë disinfektuese, që llogarisin çaktivizimin e mikroorganizmave dhe shpërbërjen e ndotësave kimikë. Për t'u siguruar në veprimin e dëshiruar përpunues, në çdo kohë bëhet kontrolli gjatë pikave kritike. Për parametra kritikë janë vendosur kufij të përshtatshëm. Kur një nga parametrat është jashtë kufirit, një seri e paracaktuar veprimesh korrektuese siguron që procesi kontrollues të jetë nën kontroll në çdo kohë.

Abstract

Water Supply Zurich (WSZ) supplies drinking water to about 800'000 inhabitants in the City of Zurich and in 67 communities in the Zurich area. 70 % of Zurich's drinking water is treated lake water. The multiple barrier principle is applied to ensure safe drinking water at any time. Effective resource protection of the catchment area provides the first barrier, two ozonations and three filtrations further barriers for protection of drinking water quality. Control measures are based on the HACCP-concept (Hazard Analysis and Critical Control Points). Based on hazard analysis for lake water quality the effectiveness for eliminating those hazards in the treatment steps was validated. The validation of the two ozonations steps was based on a computer code combining reactor hydraulics with chemical reaction and disinfection kinetics to calculate the inactivation of microorganism and the degradation of chemical contaminants. To assure the desired effect of the treatment at any time critical control points were defined. Appropriate limits for critical parameters are set. When a critical parameter is out of limit, a predefined catalogue of corrective actions assures the treatment process is under control at any time.

Keywords: Degradation, HACCP, Inactivation, Microorganisms, Micropollutants, Lake Zurich, Surface Water Treatment, Zurich-Lengg, Zurich Water Supply

* *Translation parts in Albanian language by prof. A. Miho, Tirana University*

** *Water Supply Zurich, Hardhof 9, CH-8023 Zürich, Switzerland, e-mail: hans-peter.kaiser@zuerich.ch*

11.1. Introduction

Water Supply Zurich (WSZ) is the largest water supply company in Switzerland and supplies drinking water to approximately 800'000 inhabitants in the city of Zurich and in 67 communities around Zurich. WSZ is part of the Industrial Utilities of the city of Zurich and has 280 employees responsible for drinking water supply in sufficient quantity, with adequate pressure and in an excellent quality. WSZ has a turnover of 126 Mio sFr. per year (2005) and produces approximately 60 million m^3/year of drinking water.

70% of drinking water is treated lake water from the lake water plant Zurich-Lengg and Zurich-Moos, 15% ground water from the ground water plant Zurich-Hardhof and 15% spring water from the valleys of the river Sihl and Lorze (*see* Fig. 11-1). The largest plant is Zurich-Lengg with a capacity of 250'000 m^3/day followed by the ground water plant Zurich-Hardhof with 150'000 m^3/day. The lake water plant Zurich-Moos is the oldest plant of WVZ, built in 1912 and has a capacity of 80'000 m^3/day. In the lake water treatment plant Zurich-Moos spring water is mixed with lake water and partly treated together with lake water.

Spring water is also used as emergency water supply for the city of Zurich. A completely separated distribution system (the old drinking water distribution network of the city of Zurich) is used to distribute spring water to about 100 emergency water wells in the city. The springs are located in the hills around Zurich, therefore no pumping and no electricity is necessary to distribute spring water.

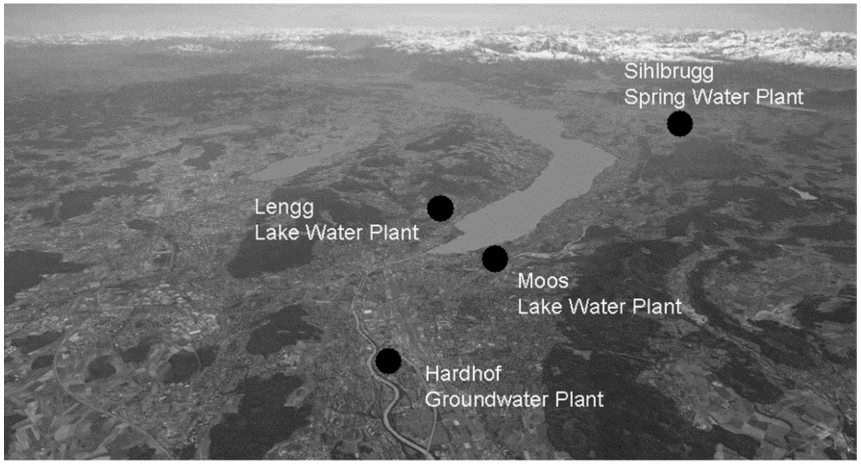


Figure 11-1. Water treatment plants of Water Supply Zurich (WSZ). / Impiantet e përpunimit të ujit të pijshëm të Ujësjellësit të Zyriut (WSZ)

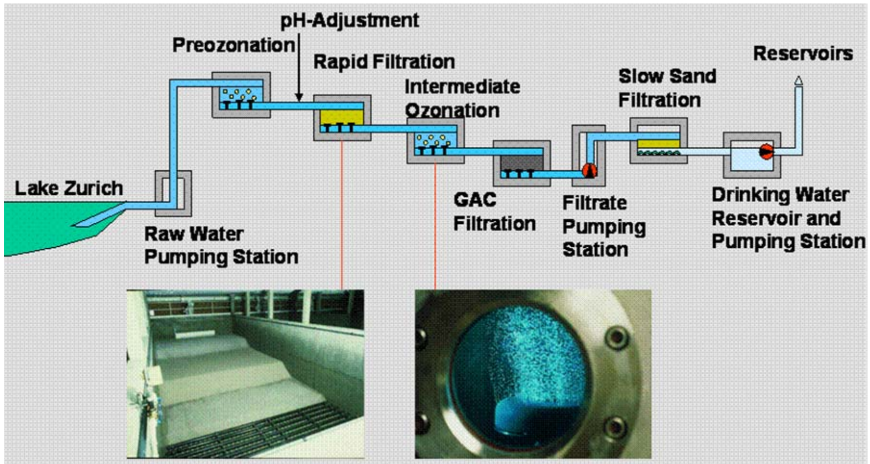


Figure 11-2. Lake Water treatment plant Zurich-Lengg. / Impianti i përpunimi të ujit të liqenit në Zurich-Lengg.

The lake water treatment plant Zurich-Lengg is located on the right side of Lake Zurich. Raw water is collected in a depth of 32 m about 620 m from the lakeshores. The raw water pumping station pumps the raw water from the lake to the treatment plant Zurich-Lengg. The treatment is a six step multiple barrier treatment with preozonation, pH-adjustment, rapid filtration, main ozonation, granulated activated carbon filtration and slow sand filtration (Fig. 11-2).

The treatment in the lake water plant Zurich-Moos is in principle the same as in the Zurich-Lengg plant except for the first treatment step. Instead of the preozonation, chlorination with a mixture of chlorine/chlorine dioxide provides the first oxidation and disinfection of lake water.

11.2. The HACCP Quality assurance concept

In Switzerland, the quality of drinking water is regulated by food law and several food related ordinances. The same legal requirements are applicable for Drinking Water and other foodstuff. Drinking Water has to meet the legal requirements at any time and producers are liable for drinking water related health problems. To meet these requirements, Water Supply Zurich (WSZ) has implemented from 1999 to 2003 the Hazard Analysis and Critical Control Point (HACCP) concept (Pierson & Corlett, 1995). A similar approach to assure drinking water safety is the Water Safety Plan of the World Healthy Organisation (WHO, 2005).

One important motivation for the HACCP project was the fact, that drinking water is consumed before all analytical test results are available and that end product testing provides nothing than an “it’s already too late” approach to assuring safety. Furthermore, only a very small volume of the distributed water volume is tested. The likeliness of detecting a temporary contamination is therefore statistically very low. This is a major difference to other industries, where the product is released for sale only after complete testing. Legally, drinking water regulations in Switzerland require the application of HACCP principles. WSZ is convinced that it is better to control the processes than to test the product and that quality is produced and not tested.

WSZ introduced a management system with the processes ‘Management’, ‘Personnel’, ‘Finance’, ‘Production’, ‘Distribution’ and ‘Quality control’ in the early nineties, certified by ISO-9001 and for the laboratory by ISO-17025. The management system was extremely useful for the realisation of the HACCP system. Many important aspects i.e. directives for personnel and training, production procedures and testing procedures were already in place.

HACCP is a system which identifies specific hazards (biological, chemical, physical and radiological properties that adversely affects the safety of the food) and preventive measures for their control. In Switzerland, a federal and cantonal organization treats radiological risks for drinking water. They are therefore not included in the present study. Beside possible health effects, WSZ included also aspects with severe consequences for the reputation of the company (i.e. colour, taste and odour). The system consists of the following 7 principles:

- Identification of potential hazards and risk assessment from raw water to the point of drinking water consumption
- Determine the critical points, procedures, operational steps that can be controlled to eliminate the hazard (Critical Control Points (CCP))
- Establish target levels and tolerances which must be met to ensure the CCP is under control
- Establish a monitoring system to ensure control of the CCP
- Establish corrective action to be taken when monitoring indicates that a particular CCP is not under control.
- Establish verification procedures to confirm that HACCP is working effectively.
- Establish documentation concerning all procedures and records appropriate to these principles and their application.

In order to get a systematic approach for the hazard analysis, the production process from source to the tap was divided in the 4 subgroups Treatment, Transport, Storage and Distribution (Fig. 11-3). The subgroups were validated separately. In this paper the subgroups raw water and treatment are discussed.

The hazards were categorized in 4 groups: Men, Material, Machinery, and Methodology (the so called 4 M rule).

Men involved in the water treatment process are an important, often underestimated risk for product safety. Many process failures are do to human errors or a lack of understanding the critical points of the treatment process. WSZ has therefore established an extensive training program for new employees and regular training for the whole staff.

The HACCP concept for materials (i.e. raw water), machinery (equipment, buildings, materials) and methodology will be discussed below for the surface water treatment plant Zurich Lengg.

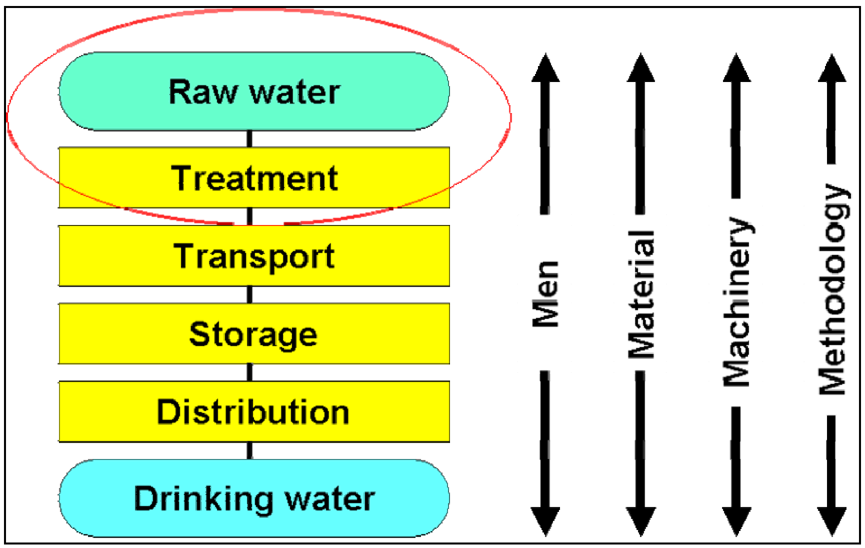


Figure 11-3. General scheme for hazard analysis based on the 4M rule. / Skemë e përgjithshme për analizën e lëndëve të dëmshme mbështetur në rregullin 4M (*Men, Material, Machinery and Methodology /* Njeriu, Lënda, Makina dhe Metoda).

11.3. Lake water treatment in the Zurich-Lengg Plant

Figure 11-4 shows the flow diagram and the treatment chemicals and materials used for the lake water treatment plant Zurich-Lengg. After preozonation the pH is adjusted from about 7.7 to 8.2 to reduce corrosion in

the distribution system and the house installations. Solid materials as algae and particulate matter are removed by a double layer filtration (pumice stone and quartz sand). The main disinfection step is the ozonation followed by activated carbon filtration. The activated carbon filters are used as a biological filtration step. Adsorption of contaminants is not a primary goal. Therefore activated carbon is replaced only in an interval of about 25 years. Activated carbon reduces residual ozone to oxygen and partially eliminates Natural Organic Matter (NOM). The final treatment step is a biological slow sand filtration giving biologically stable water, distributed to the consumers without a final addition of chlorine.

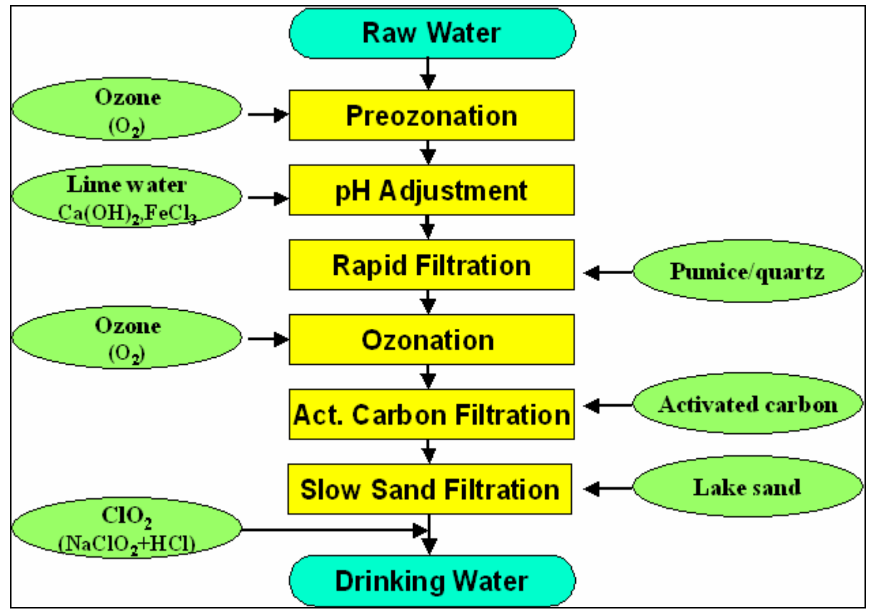


Figure 11-4. The flow diagram and the treatment chemicals and materials used for the lake water treatment plant Zurich-Lengg. / Diagrami rrjedhës, lëndët kimike përpunuese dhe materialet që përdoren nga impianti i përpuminimt të ujit të liqenit në Zurich-Lengg.

The treatment chemicals are used only after an incoming control. They are released for use by the quality control department. Ozone is produced from liquid oxygen. Clear limewater for pH adjustment is made from calciumhydroxide by flocculation with iron(III)-chloride as flocculent and prästol as flocculation aid followed by sedimentation. 1993 the addition of chlorine dioxide to drinking water as network protection was stopped. Nevertheless, for safety reasons the chlorinedioxide production is still in place to be operated within hours in case of a microbiological contamination of the distribution network. Chlorinedioxide is produced from sodiumhypochlorite and hydrochloric acid. Finally aluminiumsulfate is applied for the flocculation of the filter backwash water. After flocculation, the filter backwash water is clarified in a sedimentation tank, then filtered on a sand filter and reused as raw water.

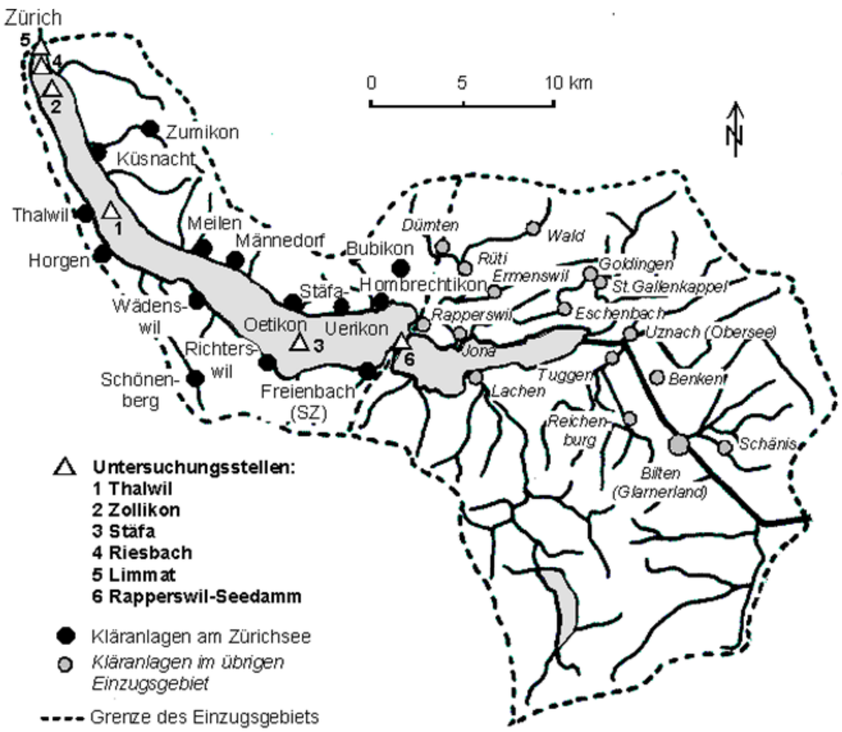


Figure 11-5. Catchment area of Lake Zurich. *Black lines, rivers; black points, WWTP (Waste Water Treatment Plants) discharging directly to the lake; grey points, other sewage plants in the catchment area; triangles, sampling locations of WSZ. I* Hapësira e pellgut ujëmbledhës të Liqenit të Zyriut. *Vijat e zeza, lumenjtë; pikat e zeza, WWTP (Impiante Pastrimi Ujërash të Zeza) që shkarkojnë drejtëpërdrejtë në liqen; pika gri, impiante të tjera në hapësirën e pellgut; trekëndësha, stacione kampionimi të Ujësjellësit të Zyriut (WSZ).*

11.4. Raw Water

The most important raw material for Zurich's drinking water production is Lake Zurich water. Lake Zurich is a deep, prealpine lake with a maximum depth of 136 m, an area of 65 km^2 and an average outflow of 89 m^3/s. The population density around the lake is rather high, reflected in the density of Waste Water Treatment Plants (WWTP) in the catchment area (Fig. 11-5).

Agriculture in the catchment area and therefore contamination of the lake by diffuse sources with pesticides and pharmaceutical animal care products is of minor importance.

Hazards for Lake Zurich are inputs of nutrients (C, N, and P), micro pollutants and pathogens from many WWTP, from drainage canals and from diffuse sources. The phosphorous concentration in lake Zurich reached its maximum in the early 1970s (Fig. 11-6). Since then, over 90 % of the population have been connected to WWTP's with enhanced phosphate removal. Since then Lake Zurich returned from a eutrophic to a mesotrophic state. This is a good example of a successful environmental protective action. Nitrate (Fig. 11-6) showed a large increase between 1950 and 1980 of 200 µg/L to 800 µg/L Nitrate-N. Since the 1990's it seems to be stabilized on a value of 700 to 800 µg/L.

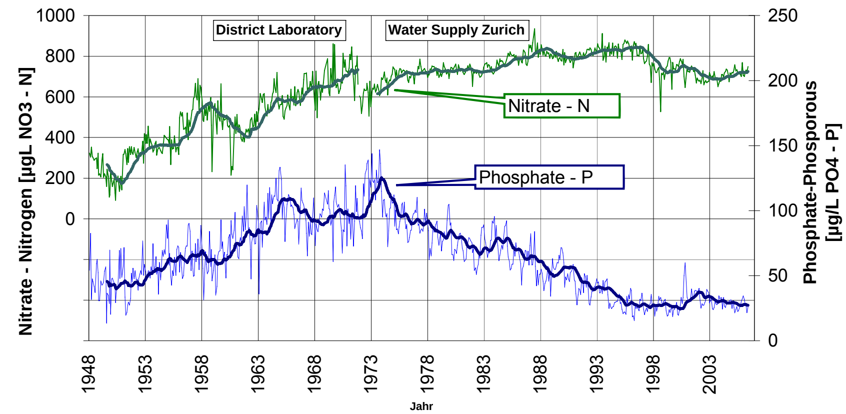


Figure 11-6. Phosphate-P and Nitrite-N in Lake Zurich 1948 to 2005. / P-Fosfatet dhe N-Nitritet në Liqenin e Zyriut gjatë periudhës 1948 deri 2005.

The concentrations of water relevant micropollutants in the effluents of the wastewater plants along Lake Zurich are measured periodically. Random samples but also 24h mixed samples were analyzed. Table 11-1 shows the minimum and maximum concentrations found in the effluents. The complexing agents EDTA and NTA were found in concentrations up to 239 µg/L and 60 µg/L respectively. The heavily biologically degradable x-ray contrast agent iopromide was detected in concentrations up to 38 µg/L. The anticorrosive agent benzotriazole was also found in high concentration with up to 14 µg/L. Compounds indicated in bold letters are detected also in raw water of the lake water treatment plant Zurich-Lengg.

Table 11-1. Micropollutants in the effluents of WWTP's, minimal and maximal concentrations found. / Mikrondotësit në ujërat e shkarkimit të WWT-ve, përqëndrimet minimale dhe maksimale të vrojtuara.

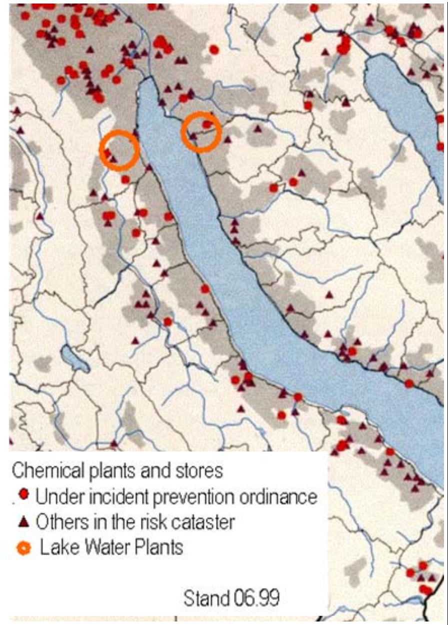
Mikrondotësit	Min – max, µg/L
dichlormethane	<0.1 – 1.2
MTBE	0.1 – 5.30
benzotriazole	7.0 – 14.0
methylbenzotriazole	0.4 – 2.5
NTA	1.6 – 60.2
EDTA	12.7 – 239
diclofenac	0.38 – 1.7
carbamazepine	0.12 – 1.6
atenolol	0.4 – 1.3
iopamidol	< 0.1 – 4.2
iopromide	< 0.1 – 38
ioxitalamic acid	< 0.1 – 3.8
ioxaglinic acid	< 0.1 – 4.0
bisphenol A	< 0.05–1.0
4-nonylphenol	< 0.5 – 2.1

The environmental protection agency of the canton of Zurich is responsible for the strict compliance of lake water with the Swiss federal water protection laws and regulations. Except for pathogens, limits are set by the federal regulations. Monitoring and control of the sewage plants and the diffuse sources is made by the canton itself and for the lake by WSZ (in order of the canton). Sampling of lake water is made twice a month on several distinct places from the bottom to the ground. This organisation allows WSZ to monitor changes in water quality very closely and to take corrective actions together with the canton of Zurich.

WSZ monitored the lake water quality for many years. The level of permanent contamination of the raw water by complexing agents, benzotriazole, pesticides (atrazine and many others), pharmaceuticals, gasoline components (MTBE) and endocrine disrupters (bisphenol A, 4-nonylphenol) is far below the limits for drinking water.

Important hazards for the lake water quality are chemicals stored and transported on streets and rail in the catchment area. After the huge chemical accident at Schweizerhalle, Switzerland in the year 1986 an incident prevention ordinance and a Swiss federal chemical risk register was established. These risk register contains all the chemicals stored and transported in the catchment area (type and quantity of chemicals). Important hazards for Zurich's drinking water quality from stored chemicals are oil, gasoline, halogenated solvents, aluminiumsulfate, and cyanide (Fig. 11-7).

In the last view years also the risks from transportation of chemicals on streets and by railway were evaluated. While on the railway line on the right side of the lake (Fig. 11-8) only minor amounts of hazardous compounds are transported, the railway line on the left side is in case of an accident a mayor risk for lake water quality. Figure 11-8 shows the quantity and type of hazardous chemicals transported on this railway line. Important risks are again oil and gasoline and organic solvents but also phenol and sodiumchlorate.



Chemicals	Quantity, t
Oil, Diesel	4800
Gasoline	740
Organic solvents	250
Halogenated solvents	6.7
Cyanide	4.5
Tensides	3.8
Acids/bases	1000
Aluminiumsulfate/ Diammonsulfate	3700
Phenol (in the past)	-
Pesticides	-
Radiological agents	-
Liquid chlorine	
Ammunition from waste disposal in the lake	?
Tar from waste disposal in the lake (PAK)	?

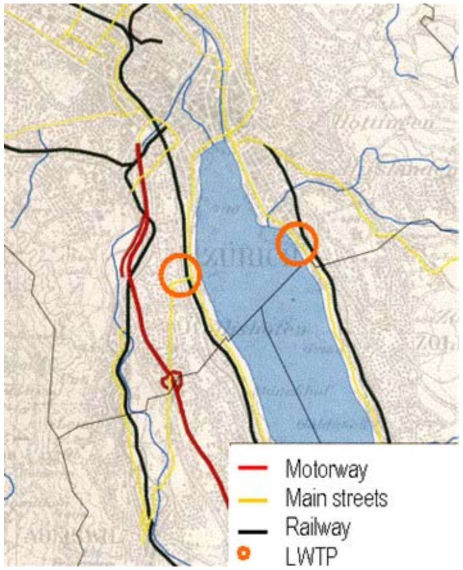
Figure 11-7. Swiss federal risk register and quantities of stored chemicals in the catchment area. / Regjistri i rrezikut federal zviceran dhe sasitë e lëndëve kimike të vlerësuara për pellgun ujëmbledhës.

A 24h alarm organization together with the canton of Zurich and the lake police allows immediate response after chemical accidents in the catchment area.

Beside hazardous chemical compounds, pathogenic bacteria, viruses and protozoa (*Cryptosporidia* and *Giardia*) are a risk for drinking water quality. Pathogens are not easily detectable in the lake water. Contaminations by pathogens, mainly from WWTP's may vary significantly in concentration. Periodic laboratory measurements are not a reliable tool to detect worst-case concentrations. Monitoring for pathogens is based on the indicator organisms as *E. coli* and *Enterococci*.

Algal toxins (i.e. *Microcystine*) after cyanobacterial blooms are a further hazard for drinking water quality.

Based on the hazards for raw water, worst-case scenarios were formulated and the efficiency of the treatment for these scenarios was evaluated.



Chemicals	Quantity
Oil, Diesel	**147196 t**
Gasoline, kerosene	**61800 t**
Organic Solvents	**11900 t**
Sodium chlorate	14575 t
Hydrogen peroxide stab.	2452 t
Epichlorohydrin	2396 t
Formaldehyde sol. 25%	2556 t
Phenol	1841 t
Sodium hydroxide sol.	5610 t
Sulfuric / hydrochloric acids	1700 t
Ammonia 100 %	1050 t
Iron(III)-chloride sol.	1125 t
Liquid gas (hydrocarbons)	4187 t
Chlorine liquid	114 t
Clinical waste	1096 t
Explosives and munitions	1000 t

Figure 11-8. Federal risk register for rail transports in the catchment area. *LWTP, Lake Water Treatment Plant.* / Regjistri federal zviceran për transportin hekurudhur në pellgun ujëmbledhës. *LWTP, Impianti i Trajtimit të Ujit të Liqenit.*

11.5. Chemicals and materials for the water treatment process

Chemicals and materials used (*see* Fig. 11-4) can also present an important hazard for drinking water quality. Therefore, for each chemical and material, a specification was established. The incoming control of WSZ tests all the chemicals and materials according to a written specification. Chemicals and materials not meeting the specification are shipped back to the supplier. For materials as activated carbon, lake sand, quartz sand and pumice stone mainly technical parameters are specified. Granular activated carbon is used as a biological carrier material and not for the adsorption of contaminants. Therefore the last reactivation was made more than twenty years ago.

11.6. Machinery, equipment, constructional design

The filters of the Zurich-Lengg plant are constructed in concrete. No topcoat is used on concrete. No quality problems were be detected related to materials in contact with drinking water. All new materials in contact with

drinking water are tested according Swiss national and European directives (Swiss plastic regulation, DVGW W-270 and KTW-recommendations, etc.).

Preventive maintenance minimizes the risk of equipment failure. A computer based maintenance program allows proper timing and control of the scheduled tasks. Standard operating procedures for plant and equipment start up and cleaning and disinfection of installations and equipments are useful tools to avoid negative impacts on drinking water quality.

A strict access control to the plant and the facilities and other safety measures minimize the risk of unauthorized access.

Knowledge of the hydraulics in the treatment plant (*see* Fig. 11-9) allows the calculation of the residence times of the water in the treatment steps. The hydraulic characteristics in the ozonation reactors (data not shown) are used for the quantification of chemical degradations of micro pollutants and inactivation of microorganisms (*see* below).

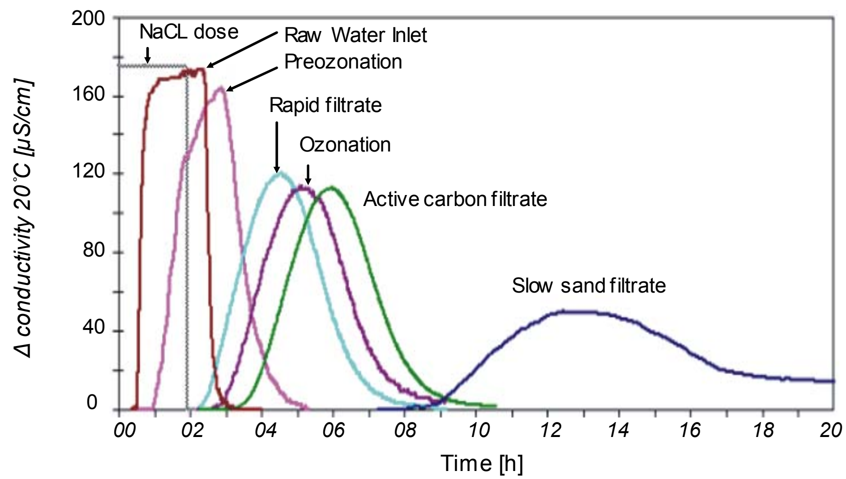


Figure 11-9. Hydraulics in the Zurich-Lengg Plant / Hidraulika në Impiantin Zurich-Lengg

11.7. Methodology of treatment

A risk for drinking water quality is a hazard ore worst-case situation not properly reduced or managed by the treatment. The hazards given above were therefore analyzed quantitatively for all treatment steps (Fig. 11-10).

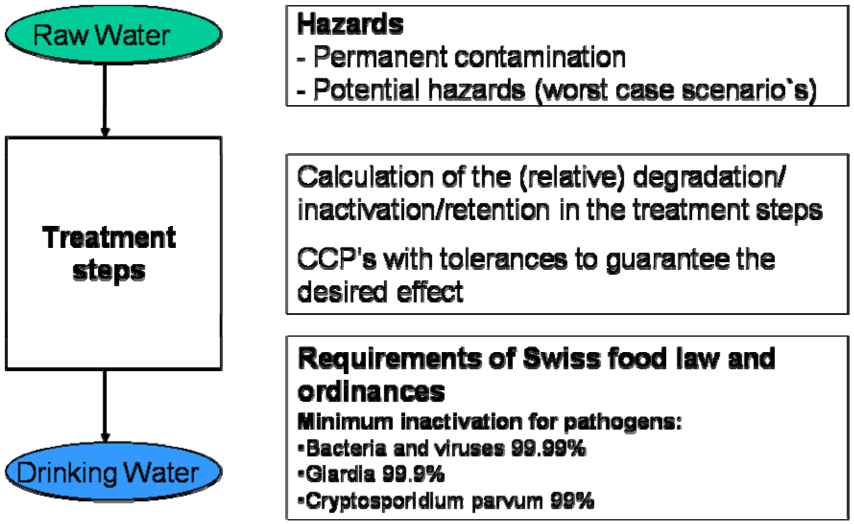


Figure 11-10. Evaluation of the efficiency of the treatment steps. / Vlerësimi shkallës pastruese të hapave përpunues.

The estimation of initial concentrations in the raw water for worst-case situations was in practice found to be difficult and for pathogens even impossible. In the WSZ approach the relative inactivation or removal of microorganisms and the relative degradation of micro pollutants were used. For pathogens, the EPA (1989) treatment goals of 4 log's removal for bacteria's and viruses, and 3 logs removal for Giardia were applied.

The critical treatment steps to remove organic hazardous compounds in the Zurich-Lengg plant are the two ozonations. The carbon filters after many years without reactivation are saturated with organics and no longer a barrier against them. Therefore the ozonation step has to be quantified with regard to microorganism and chemical compounds for disinfection and oxidation efficiency. To achieve this goal, a kinetic approach is necessary.

The WSZ approach consists of three principal steps proposed by von Gunten *et al.* (1997; 1999) and can be summarized as follows:

- Literature search for rate constants for the oxidation of the chemical compound by ozone and OH radicals. Many constants for water relevant chemical compounds are reviewed (von Gunten, 2003)
- Characterisation of the hydraulics in the ozonation chamber with a conservative tracer (i.e. sodiumchloride). With the computer code Aquasim developed by Reichert (Reichert, 1994) the hydraulics was modelled.

- Coupling of the reactor hydraulics with chemical kinetics. Aquasim allows coupling of hydraulic data with chemical kinetic data for inactivation of microorganisms and for degradation of chemical substances.

In case of a permanent or accidental contamination, the known relative degradations are used to estimate if the treatment is able to reduce the contamination to an acceptable level. If not, the plant has to be stopped. Table 11-2 shows exemplarily the results for some of the important hazards for lake water.

Table 11-2. Predicted relative degradation of selected compounds in the two ozonations Zurich-Lengg. / Parashikimi i shpërbërjes relative të lëndëve të caktuara gjatë dy ozonimeve në Zurich-Lengg.

Compounds	**Relative degradation C/Co in the two ozonations of the Zurich-Lengg plant**
Easily degradable:	
Nitrite, Phenol, Cyanide	$< 1 \times 10^{-6}$
Microcystin (toxin from blue green algae)	$< 1 \times 10^{-6}$
Diclofenac	$< 1 \times 10^{-6}$
Carbamazepin	$< 1 \times 10^{-6}$
Atenolol	$< 1 \times 10^{-6}$
17-α-Ethinylestradiol	$< 1 \times 10^{-6}$
Bisphenol A	$< 1 \times 10^{-6}$
4-Nonylphenol	$< 1 \times 10^{-6}$
Benzotriazole	5.4×10^{-5}
Methyl-benzotriazole	3.0×10^{-3}
Fe(III)-EDTA	1.4×10^{-3}
Trimethylbenzene / Xylene	0.1 / 0.2
Heavily degradable:	
Benzene	0.37
Atrazine	0.53
Trichloroethene	0.60
Iopromide	0.65
Tetrachloroethene	0.72
MTBE	0.80

The calculation of inactivation of *Cryptosporidium parvum* in the two ozonation was based on published inactivation data (Drieger *et al*., 2000). For *Enteric viruses* (polio virus) the inactivation rate constant was estimated from data published by the EPA (US EPA, 1989).

The chemical disinfection of microorganisms is supported by the retention of microorganism on rapid and slow sand filters. Quantification of filter retention efficiency on rapid filters was based on data from EPA (EPA, 1989). In a conservative approach 1 log removal was accounted for *Cryptosporidium parvum* and *Giardia lamblia*. For retention of microorganisms on slow sand filters the following log removals were reported: 4 log removal for viruses (Walter, 2000), 2 log removal for bacteria (Huisman *et al.,* 1974), 4 log removal for Cryptosporidia (Timms *et al.,* 1995). In the approach shown in figure 11-11 three log removals were accounted for *Cryptosporidium parvum*, *Giardia lamblia* and Enteric viruses.

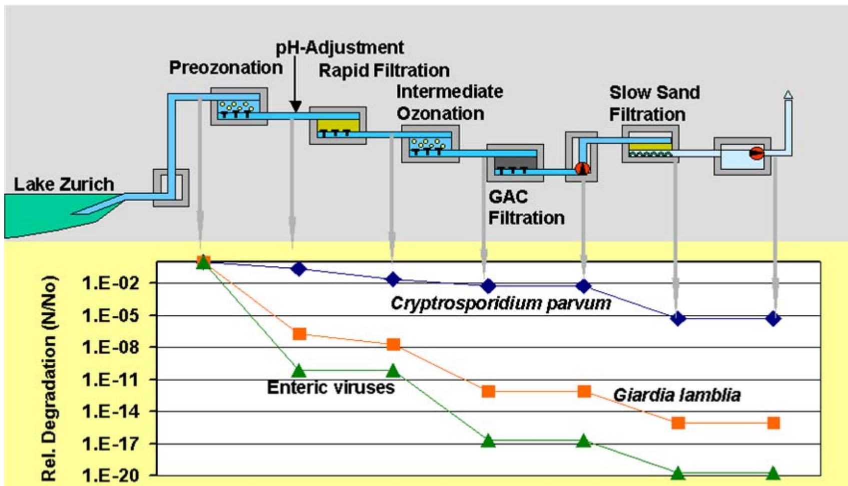


Figure 11-11. Predicted inactivation of selected microorganisms in the lake water treatment Lengg based on published inactivation data (references *see* text). / Parashikimi i çaktivizimit të mikororganizmave të caktuara gjatë përpunimit të ujit të liqenit në Lengg, mbështetur në të dhënat çaktivizuese të publikuara (për sqarimet *shih* tekstin).

Figure 11-12 shows the predicted degradation of benzene, atrazine and p-xylene in the treatment calculated with the Aquasim code (Reichert, 1994). The fuel component MTBE is anti-knock agent. It is found in Lake Zurich in concentrations up to 0.35 μg/L in warm summers with intensive boat traffic on the lake. MTBE is heavily biodegradable. In the ozonation it reacts with OH radicals and not with ozone (Acero, 2001).

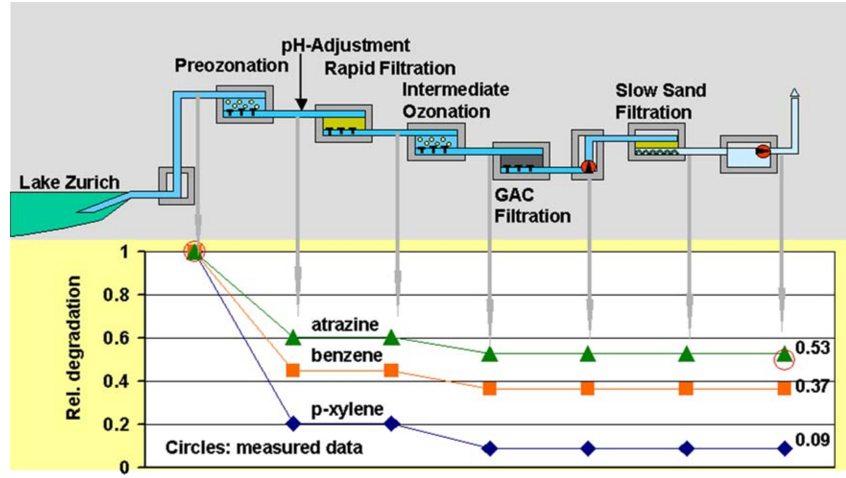


Figure 11-12. Predicted degradation of atrazine, benzene and p-xylene by the lake water treatment. *Circles*: measured data for atrazine. / Parashikimi I shpërbërjes së atrazinës, benzenit dhe p-xilenit gjatë përpunimit të ujit të liqenit. *Me rreth*: të dhënat e matura për atrazinën.

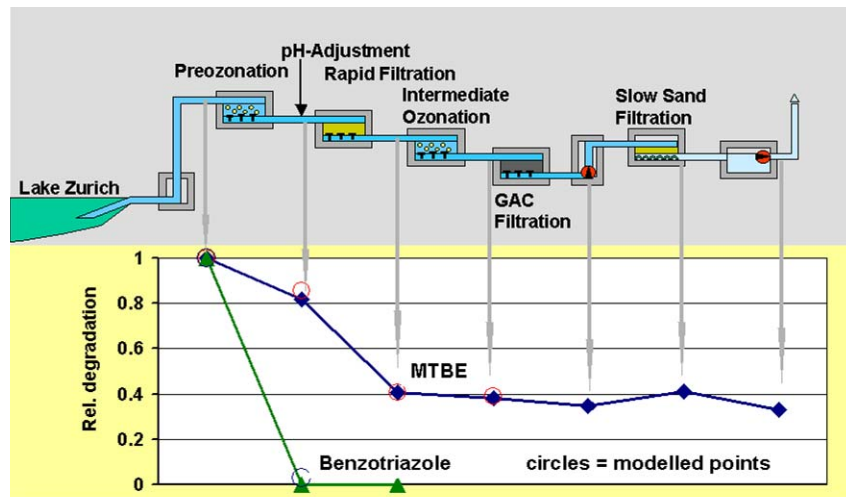


Figure 11-13. Measured data for MTBE (diamonds) and Benzotriazole (triangles). Circles: Corresponding modelled data for the ozonations by Aquasim. / Të dhëna të matura për MTBE (me rombe) dhe Benzotriazole (trekëndsha). Me rrathë: Të dhëna korresponduese të modeluara për ozonimin me Aquasim (Reichert, 1994).

Therefore the degradation is more important in the preozonation where substantially more OH radicals are formed. The calculated relative degradations in the two ozonations fits well with the measured data (Fig. 11-13). For the unexpected degradation in the rapid filters no simple explanation is available so far.

The anticorrosive benzotriazole (von Gunten *et al.,* 2005) is more effectively degraded by ozone. It can be quantitatively removed in the two ozonation steps

11.8. Critical control points and emergency measures

The shown degradations for micropollutants and microorganisms apply when the ozone exposure in the reactors is stable. Therefore the critical control point for these reactions is the residual ozone concentration at the reactor outlet. This illustrates the importance of defining critical control points and emergency measures.

WSZ has defined CCP's and alarm limits for online quality control and for laboratory analysis to assure the treatment step has the desired effectiveness at anytime. WSZ has installed a SCADA–system (Supervisory Control and Data Acquisition) with all the online data and alarms available immediately in the Control Centre. CCP's in the alarm status (i.e. residual ozone concentration below 0.15 mg/L) require an immediate response by the dispatcher on a 24 h base. The quality control department checks all other critical online control points and critical lab results on each working day on behalf of a daily computer based list of values in the warning or alarming status. The warning limits are set close to the desired values to detect trends in water quality on time.

Conclusions

The HACCP concept is a useful tool to assure drinking water safety. WSZ applied this concept successfully for raw water and the surface water treatment.

Catchment and source water protection is an important issue of surface water treatment. A close collaboration with the responsible authorities is inevitable. The water quality of Lake Zurich could be improved significantly in the last decades. Monitoring of WWTP's for micropollutants and the Swiss federal risk register gave important information for potential hazards for lake water. The effectiveness for eliminating these hazards in the treatment steps was validated. The validation of the two ozonation steps was based on a computer code combining reactor hydraulics with chemical reaction and disinfection kinetics to calculate the inactivation of microorganisms and the degradation of

chemical contaminants. To assure the desired effect of the treatment at any time critical control points were defined. Appropriate limits for critical parameters are set. When a critical parameter is out of limit, a predefined catalogue of corrective actions assures the treatment process is under control at any time.

Within practical limits, WSZ is able to demonstrate that it consistently supplies safe drinking water to the population of Zurich.

Literature

Acero J.L., Schmidt T., Haderlein S., Suter M., von Gunten U. (2001): MTBE oxidation by conventional ozonation and the combination of ozone/hydrogen peroxide: efficiency and bromate formation. Environ. Sci. Technol. 35: 4252-4259

Driedger A., Rennecker J.L., Marinas B. (2000): Sequential inactivation of *Cryptosporidium parvum* oocysts with ozone and free chlorine. Wat. Res. 14, 3591-3597.

Huisman L., Wood W.E. (1974): Slow sand filtration, WHO Geneva, p 20ff, 27ff.

Pierson M.D., Corlett D.A. (1995): HACCP – Grundlagen der produkt- und prozessspezifischen Risikoanalyse, Editor: Behrs Verlag.

Reichert P. (1994): Concepts underlying a computer program for the identification and simulation of aquatic systems. Schriftenreihe der EAWAG No. 7. Swiss federal Institute for Environmental Science and Technology (EAWAG), Dübendorf, Switzerland.

Timms S. (1995): Removal of Cryptosporidium by slow sand filtration, Wat. Sci. Tech. 31: 81-84

US EPA (Ed.) (1989): National primary drinking water regulations, Final rule, Federal register, 54 (124): 27485-27541

von Gunten U. (2003): Review Ozonation of drinking water: Part I. Oxidation kinetics and product formation. Wat. Res. 37: 1443-1467

von Gunten U., Elovitz M.S., Kaiser H.P. (1997): Characterisation of ozonation processes with conservative and reactive tracers: prediction of the degradation of micropollutants. Anal. Mag. 25: 29-31

von Gunten U., Elovitz M.S., Kaiser H.P. (1999): Calibration of full-scale ozonation systems with conservative and reactive tracers. J. Wat. Suppl.: Res. & Technol.- Aqua, 48: 250-256

von Gunten U., Giger W., Lutze H. (2005): Unpublished data from the Swiss federal Institute for Environmental Science and Technology (EAWAG), Dübendorf, Switzerland.

Walter R. (2000): Umweltbiologie, Springer Berlin (an cited references).

WHO (Ed.) (2005): Water safety plans: Managing drinking-water quality from catchment to consumer. World Health Organization (WHO).