Lecture 4

Drinking water quality

Drinking water regulation (TrinkwV 2001) § 3 Definitions

Leibniz Universität Hannover

According to this regulation

1. Is **„water for the human use“**, “drinking water“ and **“water for food industry companies“**

With it

a) „Drinking water“ as water, in its original state or after purification, that serves for cooking, food preparation and for beverages or specially for the following domestic purposes:

- Personal hygiene,
- Cleaning of objects that come into contact with food,
- Cleaning of objects that come into contact with the human body for an extended period of time.

Drinking water regulation (TrinkwV 2001) § 3 Definitions

This is valid regardless of the water origin, of its physical state and regardless whether it‘s distributed through pipelines, tankers, in bottles or in other types of containers.

b) **„Water for food industry companies“:** it is water, that regardless of its origin and of its physical state, is used in a food industry company for the production, treatment, conservation and for the distribution of products or substances that are meant for the human consumption. This is valid as well as for the cleaning of objects and facilities, that can come into contact with the food.

Drinking water regulation (TrinkwV 2001) § 8 Compliance position

The limit values set in § 5 section 2 as well as the limit values and requirements set in 7 must be fulfilled:

1. with water that is being provided through pipelines to properties or to buildings and watercrafts, aircrafts or ground vehicles, at the point of extraction for human consumption,

2. with water provided through tankers, at the tankers extraction point,

3. with water that is filled into bottles or other containers, at the point of the bottling,

4. with water used in food production facilities, at the point of usage.

Drinking water characteristics

The quality of water subdivides in:

- **Physical** *(physikalisch)* water quality or characteristics
- **Chemical** *(chemisch)* water quality or characteristics
- **Biological** *(biologisch)*, **bacteriological** *(bakteriologisch)* water quality or characteristics

Drinking water requirements in Germany

The quality requirements *(Qualitätsanforderungen)* in Germany are set down in the DIN 2000.

Basic principles according to DIN 2000 are:

- Drinking water must be free of pathogenic germs *(Krankheitserregern)* and must not have any health affecting characteristics
- Drinking water must be germ free *(Keimfrei)*.
- Drinking water must be hygienic and its appearance should animate to consume it. Therefore it should be fresh, clear, cool, odourless and regarding its taste characteristics flawless.
- The content of dissolved substances should be maintained below certain limits. This should be as low as possible with certain specific substances
- Drinking water should cause the smallest possible corrosion *(Korrosion)*.

Drinking water characteristics

- Drinking water should always be available in enough quantities and with sufficient pressure.
- According to the possibilities the raw water to be caught should fulfil the above mentioned requirements in its natural state. Otherwise a water treatment must be planed.
- The qualitative and quantitative preservation of drinking water has the highest priority compared to all the other concurrent interests. Protection zones *(Wasserschutzgebiete)* must be set up for every water catchment facility.
- The water supply facilities must be designed in a way in which the necessary water quantity can be provided and the water during its transport to the consumer does not loose its quality.

Drinking water regulation (TrinkwV 2001)

Bacteriological characteristics:

- Drinking water must be free of pathogenic germs.
- This requirement is fulfilled when 100 ml water do not contain any E. Coli and coliforms in at least 40 tests. The count of colonies in disinfected *(desinfiziert)* water should not exceed the guide value *(Richtwert)* of 20 in every ml.

Chemical characteristics:

- Limit values must be defined so that a lifelong consumption will not lead to any health damages. More rigorous requirements apply to such substances that do not exist in nature, e.g. Pesticides *(Schädlingsbekämpfungsmittel)*.

Additives *(Zusatzstoffe)*:

- During the drinking water treatment additives can be used, e.g. Chlorine for disinfection, Al, Fe.

Supervision of drinking water quality

The drinking water supplier must analyse the water to be delivered on its own or through someone else **(self-monitoring** *(Eigenüberwachung)***)**. The frequency and range of the analysis depends on the delivered quantities. A delivery of 1.000 m³/a up to 1 Mio. m³/a requires :

- Supervision of disinfection once a day, continuous analysis every 30.000 m³ delivery: odour *(Geruch)*, turbidity *(Trübung)*, conductivity *(Leitfähigkeit)*, chlorine, E. coli, coliforms, counts of colonies
- Periodical analysis: pH-value once weekly, substances according to Appendix 2 Paragraph 1 and Appendix 3 of the drinking water regulation

The overstepping of the limit values must be reported to the public health department immediately. In addition to the self-monitoring by means of the supplier, the public health department also supervises the water supply facilities through tests and inspections **(third party inspection** *(Fremdüberwachung)***)**.

Water contents of the Hanoverian drinking water, east region

The most important components			
	Mean value Fuhrberg (mg/l)		Limit values TrinkwV (mg/l)
	Before treatment	After treatment	
Calcium *(Calcium)*	72	87	400
Magnesium *(Magnesium)*	4.2	4.2	50
Sodium *(Natrium)*		28	200
Potasium *(Kalium)*		2.5	12
Iron *(Eisen)*	15.0	<0.02	0.2
Manganese *(Mangan)*	1.16	<0.02	0.05
Ammonium *(Ammonium)*	0.75	<0.05	0.5
Nitrite *(Nitrit)*	<0.01	<0.01	0.1
Nitrate *(Nitrat)*	0.5	3	50
Chloride *(Chlorid)*		52	250
Sulfate *(Sulfat)*		113	240
Phosphate *(Phosphat)*		1	6.7
Silicate *(Silikat)*		15,5	40

Drinking water parameters

Total hardness *(Gesamthärte GH)*:

Water hardness is defined through the alkaline earth content.

Measuring units are: 1 mmol/l = 5.6 ° dH

1 ° dH = 10 mg CaO/l

Carbonate hardness (Temporary hardness) *(Karbonathärte (KH))*:

Ca and Mg react with carbonic acid to hydrogen carbonate and carbonate.

Measuring unit acid capacity: until pH 4.3 (KS 4.3)

1 mmol/l KS 4.3 = 2.8 ° dKH

Non-Carbonate-hardness (Permanent hardness) *(Nichtkarbonathärte(NKH))*:

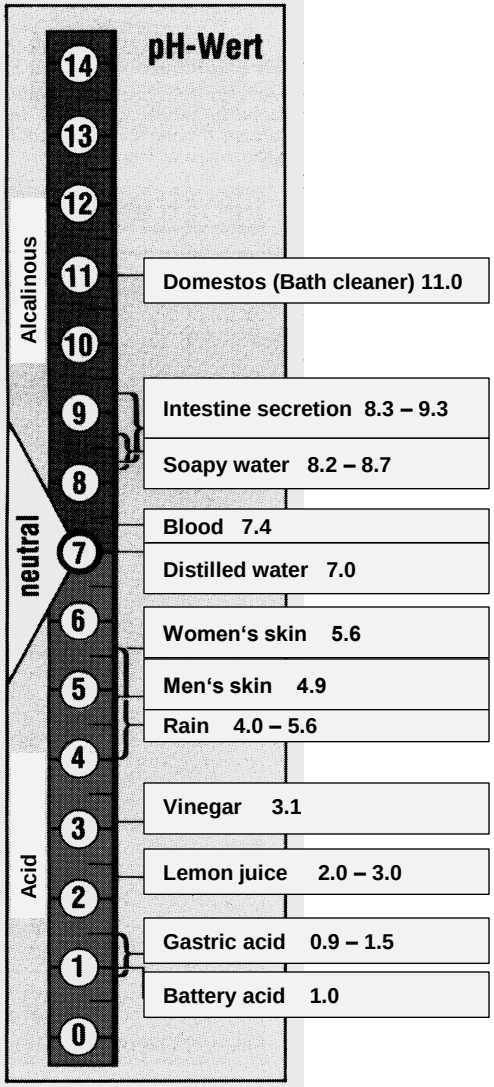
Ca and Mg react with sulphate (CaSO4), nitrate (Ca(NO3)2) or chloride (e.g. CaCl2).

Degree of hardness of drinking water

Degree of hardness (detergent law)	Total hardness ° dH	Alkaline earth mmol/l
1	0 - 7 soft	up to 1.25*
2	7 - 14 middle	up to 2.50**
3	14 - 21 hard	up to 3.75
4	21 - 28 very hard	up to 5.00

* e.g. reservoir water ** e.g. Hanover groundwater

pH-value



pH-value

According to the drinking water regulation the pH-value of the delivered drinking water must be between 6.5 and 9.5 and should not fall below the pH-value of the calcium carbonate saturation *(Calciumkarbonatsättigung).*

This water is in lime-carbonic acid-balance *(Kalk-Kohlensäure-Gleichgewicht)*.

Variations of the pH-value within 0.2 pH-units under the pH-value of the calcium carbonate saturation are not taken into account.

Lime-carbonic acid-balance I

Simplified equation

$CaCO_3 + CO_2 + H_2O \leftrightarrow Ca(HCO_3)_2$

The difference between the real pH-value measured in the water and the theoretical pH-value, in which the water depending on the calcium and hydrogen carbonate content is in the lime-carbonic acid-balance state (pH_L), is called **Saturation Index** *(Sättigungs-Index)*.

SI = pH(measured) – pH_L(pH in lime-carbonic acid-balance)

If the Saturation Index is zero, than the water is in lime-carbonic acid-balance, and therefore in a calcium carbonate saturation state.

A negative Saturation Index shows that the water has a lime-dissolving tendency *(Kalkalösende Tendenz)*.

A positive Saturation Index indicates that water tends to lime deposition*(Kalkabscheidung)*.

Lime-carbonic acid-balance II

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Ca in mg/l	Ca in mmol/l	Upper row: Saturation-pH-value (at 10°C) Lower row: Conductivity in µS/cm (at 10°C) Acid capacity till pH 4,3 (≡ m-value) in mmol/l														
		0,25	0,5	0,75	1	1,25	1,5	2	2,5	3	3,5	4	5	6	7	8
10	0,25	**9,65**	**9,18**	**8,98**	**8,84**											
		54	59	75	91											
20	0,5	**9,28**	**8,88**	**8,69**	**8,54**	**8,44**	**8,36**	**8,24**								
		112	106	104	119	135	150	181								
40	1,0	**9,00**	**8,61**	**8,41**	**8,27**	**8,17**	**8,08**	**7,96**	**7,87**	**7,80**						
		222	216	210	204	198	204	234	264	294						
50	1.25	**8,92**	**8,53**	**8,32**	**8,19**	**8,08**	**8,00**	**7,88**	**7,78**	**7,71**	**7,65**	**7,60**				
		276	270	264	258	252	246	260	290	319	349	379				
60	1,5	**8,85**	**8,46**	**8,26**	**8,12**	**8,02**	**7,93**	**7,81**	**7,71**	**7,64**	**7,58**	**7,52**	**7,44**			
		330	323	317	311	305	299	286	315	345	374	403	461			
80	2,0	**8,74**	**8,36**	**8,16**	**8,02**	**7,92**	**7,83**	**7,70**	**7,61**	**7,53**	**7,47**	**7,41**	**7,33**	**7,26**	**7,20**	
		423	428	422	416	409	403	390	378	394	423	451	509	566	624	
100	2,5	**8,67**	**8,28**	**8,08**	**7,94**	**7,84**	**7,76**	**7,63**	**7,53**	**7,45**	**7,38**	**7,33**	**7,24**	**7,17**	**7,11**	**7,06**
		538	531	525	518	512	505	492	480	467	470	499	556	612	669	725
120	3			**8,02**	**7,88**	**7,78**	**7,70**	**7,57**	**7,47**	**7,39**	**7,32**	**7,26**	**7,17**	**7,10**	**7,04**	**7,00**
				626	619	613	606	593	580	567	554	545	601	657	713	769
160	4				**7,79**	**7,69**	**7,60**	**7,47**	**7,37**	**7,29**	**7,23**	**7,17**	**7,07**	**7,00**	**6,94**	**6,89**
					818	811	805	791	778	765	751	738	711	745	801	856
200	5						**7,53**	**7,40**	**7,30**	**7,22**	**7,16**	**7,10**	**7,00**	**6,92**	**6,86**	**6,81**
							999	986	972	958	945	931	904	877	885	940
280	7								**7,20**	**7,12**	**7,05**	**7,00**	**690**	**6,82**	**6,75**	**6,70**
									1351	1337	1323	1308	1280	1252	1224	1196

Lime-carbonic acid-balance III

Carbonic acid

Carbon dioxide in water

Free carbonic acid

Bound carbonic acid

Associated carbonic acid (harmles s for pipelines and concrete)

Excess carbonic acid (aggressive)

Totally bounded Carbonic acid

Half bounded

e.g. $CaCO_3$ in carbonates

Hydrogen carbonate e.g. $Ca(HCO_3)_2$

Total surplus

inhibiting rust-protective layer;

destruction of pipes

Partial surplus (concrete and lime aggressive)

not aggressive

Water contents

- Dissolved gases *(Gelöste Gase)*
- Dissolved metals *(Gelöste Metalle)*
- Salts *(Salze)*
- Organic compounds *(Organische Verbindungen)*
- Microbiological parameters *(Mikrobiologische Parameter)*

Daily requirement values of a human being

• **Calcium** 1000 mg:	for bones, teeth
• **Chlorine** 830 mg:	for gastric acid, digestion
• **Iron** M 10 mg, W 15 mg:	blood cells, O_2-Tr
• **Fluoride** M 3,8, W 3,1 mg:	dental enamel
• **Iodine** 180 microgram:	thyroid gland, growth
• **Potassium** 2 g:	muscles, nerves, enzymes
• **Magnesium** M 350, W 300 mg:	nerve impulses, enzymes
• **Sodium** 550 mg:	water balance in body
• **Phosphorus** 700 mg:	bones, teeth, enzymes, DANN
• **Zinc** M 10, W 7 mg:	cell division, wound healing, growth

Source: D.A.CH- Reference values for nutrition 2000 *(Referenzwerte for Nährstoffzufuhr 2000)*

Daily requirement of different trace elements for an adult

Name	TDaily dosis (estimate)	Food (example)
Arsenic	12,5 - 25 µg	Cereals
Chlorine	200 – 830 mg	Common salt
Chrome	20 – 100 µg	Beer yeast, liver
Iron	8 – 15 mg	Caviar, meat, beans, peas
Fluorine	0,25 – 4 mg	Water, black tea, saltwater fish
Iodine	40 – 260 µg	Saltwater fish, iodized common salt
Potassium	400 – 2000 mg	bananas, spinach
Calcium	220 – 1200 mg	Milk products
Cobalt	0,2 – 0,4 µg	Spinach, tomatoes, fish
Copper	0,2 – 1,5 mg	Crustacean, cocoa
Lithium	3 – 10 mg	Eggs, milk, butter, meat
Magnesium	60 – 400 mg	Cocoa, nuts
Manganese	0,6 – 5 mg	Green leafy vegetables, oatmeal
Molybdenum	20 – 100 µg	Rice, parsely, whole grain products
Sodium	100 – 550 mg	Common salt
Nickel	150 – zu 800 µg	Cocoa, tea
Phosphorus	120 – 1250 mg	Wheat germ, cheese
Selenium	10 – 70 µg	Fish, meat
Silicon	5 – zu 40 mg	Potatoes
Vanadium	15 – 30 µg	Vegetable oil
Zinc	1 – 11 mg	Oyster, eggs, oatmeal

Dissolved gases

Oxygen (O_2)

High content of free, dissolved oxygen shows a high hygienic water quality.

- Limit value: at least 6 mg/l.
- Enrichment procedures: rainfall *(freier Regenfall)*, spraying *(Rieselung)*, cascade aeration *(Kaskadenbelüftung)*, propeller and pressure ventilation *(Propeller- und Druckbelüftung)*, O_2-dosage *(O_2-Dosierung)*

Hydrogen sulfide (H_2S)

H2S is toxic.

- Limit value: < 0.1 mg/l
- Treatment: Gas stripping (gassing, gaseous interchange during open aeration, oxidation)

Dissolved Substances

Carbon dioxide (CO_2)

In general water with an excess of aggressive carbonic acid does not implicate a health concern. Although in order to avoid technical problems the excess of carbonic acid must be removed.

- Limit value: Water must be in lime-carbonic acid-balance (balance-pH-value).
- Physical procedures: Gaseous exchange *(Gasaustausch)*, de-acidification, *(Entsäuerung)* (stripping, etc.)
- Chemical procedures: Binding of the carbonic acid with lime (marble-filter *(Marmorfilter)*, filter with half-burned dolomite, lime dosage *(Kalkdosierung)*)

Dissolved Metals

Iron (Fe)

Because of its negative effect on piping systems and installations the iron value should be maintained wide below the limit value. Fe produces brown stains on clothes. The taste limit is between 2 - 3 mg/l. There are no concerns regarding the health because of elevated iron contents.

- Limit value: < 0.2 mg/l, when possible to maintain: < 0.05 mg/l
- Procedures: Oxidation of the soluble Fe^{2+}- compounds into insoluble Fe^{3+}, afterwards removal through filtration.

Manganese (Mn)

In normal concentrations it is not dangerous to health. The taste limit is around 0.5 mg/l. Mn produces small black stains on clothes.

- Limit value: 0.05 mg/l, when possible to maintain: < 0.01 mg/l
- Procedures: Conversion into insoluble form through oxidation, afterwards rapid sand filtration *(Schnellsandfiltration)*.

Dissolved Metals

Magnesium (Mg)

Normally there is no need to remove magnesium.

- Limit value: 50 mg/l
- Procedures: Rapid-decarbonization *(Schnellentkarbonatisierung)*, „amorphous decarbonization“ (lime-soda-process, phosphate-process)

Arsenic (As)

Metallic arsenic is relatively not toxic, but turns quickly into toxic oxide.

- Limit value: 0.04 mg/l
- Procedures: Flocculation, oxidation of trivalent arsenic, precipitation with iron salts and aluminium salts *(Aluminiumsalze)*.

Dissolved Metals

Lead (Pb) (similar data in preparation by UBA for Uranium 2010)

Signs of poisoning paleness, colics and cramps.

- Limit value: 0.04 mg/l
- Procedures: Precipitation *(Fällung)*, flocculation, ion-exchange *(Ionenaustausch)*, adsorption on active carbon *(Aktivkohleadsorption)*.

Cadmium (Cd)

Toxic effect, specially for the kidneys (long biological half-life period).

- Limit value: 0.005 mg/l
- Procedures: Flocculation *(Flockung)*, slow sand filtration and bank filtration *(Uferfiltration)*.

Aluminium (Al)

Through elevated absorption possibly lung damage.

- Limit value: 0.2 mg/l
- Procedures: Flocculation, filtration.

Salts

Nitrate (NO_3)

Elevated contents of nitrate mainly through agricultural over fertilization.

- Limit value: 50 mg/l (standard value 25 mg/l)
- Procedures: Ion exchange, reverse osmosis *(Umkehrosmose)*, electro dialysis or biological drinking water denitrification *(Denitrifikation)* with addition of nutrients *(Nährstoffe)*.

Nitrite (NO_2)

Not very stable in water because of its quick oxidability. Toxic for fishes.

- Limit value: 0.1 mg/l
- Procedures: Oxidation by chlorination *(Chlorung)*, ozonisation *(Ozonung)*, partially in biological rapid sand filter.

Salts

Ammonium (NH_4)

In general Ammonium is not primarily contained in water but will be introduced through fertilizers or leaky sewers. The transformation in ammonia (toxic for fishes) depends on the pH-value.

- Limit value: 0.5 mg/l
- Procedure: Biological drinking water denitrification in filters.

Chloride (Cl^-)

Water contains Chloride frequently in form of common salt (NaCl). Standard values are around 25 mg/l. The taste limit is around 250 mg/l.

- Limit value: no limit value, up to now only a European Union reference value of 25 mg/l
- Procedures: Ion exchange, reverse osmosis, distillation *(Destillation)*, membrane technology.

Salts

Sulphate (SO_4^{2-})

Elevated sulphate content lead to corrosion, concrete destruction at concentrations > 300 mg/L „laxing„ effect.

- Limit value: 240 mg/l (under geogenic conditions up to 500 mg/l)
- Procedures: Ion exchange, reverse osmosis or distillation.

Phosphate (PO_4^{3-})

High amounts of phosphates reach the water through the sewage water, specially with high animal waste amounts (liquid manure) *(Jauche)*. An elevated phosphate content leads to protective coating formations in piping systems. Phosphate coating is therefore applied as a corrosions-inhibiting measure.

- Limit value: 6.7 mg/l
- Procedure: Flocculation filtration

Organic Compounds

Polycyclic aromatic hydrocarbon (PAK)

Through traffic emissions, heating systems as well as industry firing.

- Limit value: 0.0002 mg/l
- Procedures: active carbon filtration and ion exchange, membrane technology

1,1,1 Trichlorethane

Through discharge of industrial waste water. Inhalation has a narcotic effect.

- Limit value: 0.01 mg/l, every single component < 0.0001 mg/l, Temperature: limit value 25° C.
- Procedures: Aeration *(Belüftung)*, active carbon, stripping

Microbiological Parameters

Bacteria

Each body of water contains bacteria and specially superficial waters. Bacteria must be differentiated between pathogenic and harmless types. For drinking water are particularly coli, Salmonellae (typhoid) and Shigella (dysentery) of great importance.

- Limit value: 100 ml water should not contain any E. Coli and coliforms in at least 40 tests. The count of colonies in disinfected water should not exceed the reference value of 20 in every ml
- Procedures: Chlorination, ozonisation *(Ozonung)*, UV irradiation *(UV-Bestrahlung)*, boiling *(Abkochen)*, slow sand filtration

Virus

Virus are even smaller as bacteria (difficult to detect) and are only able to reproduce in living cells.

- Limit value: not any.
- Procedures: Disinfection, see Bacteria