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Hygienic drinking water quality – an ongoing issue

Or: Why do we have to address an issue which we considered to be solved yesterday (i.e. >100 years ago)?

- enhancements of modern drinking water plumbing systems
- New utilisations (showers, whirl pools, ACs)
- in particular: domestic hot water
- changing user profiles, risk groups
- advanced methods of investigation
- new systematic insights concerning the hygiene of drinking water

Principles of drinking water hygiene

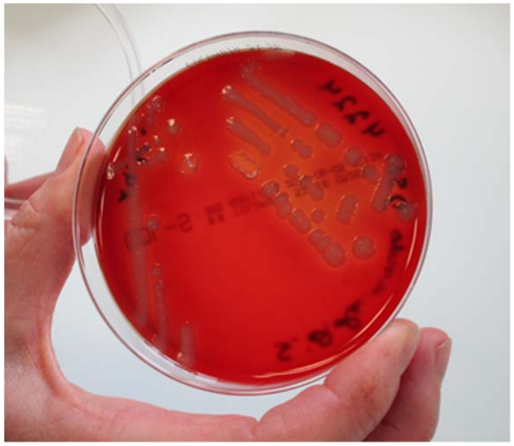
- Drinking water is NOT sterile – not achievable
- Therefore: *Drinking water may not contain pathogens in concentrations which may impair human health.* (German Drinking Water Ordinance § 5,1)
- three criteria to assess health impact of pathogens:
  - Qualitative: **pathogenicity**
  - Quantitative: **concentration**
  - **Transmissibility** through water
- The microorganism needs to reach the drinking water, needs to be able to survive, and needs to be able to reach a human organ from the water which is sensitive to infection
- Drinking water may deteriorate in plumbing systems

Microorganisms multiply in water!

- Drinking water plumbing systems are inhospitable environments
- However even in these aquatic milieus an autochthonous microflora exists
- Including some potentially harmful microorganisms: Legionella, *Pseudomonas aeruginosa*, MOTT (mycobacteria other than tuberculosis)
- Things become more tricky – not sufficient to control microbial pollution entering from outside

Microorganisms multiply in water!

- The indicator principle (*E. coli* etc.) fails!
- A new question arises: Which **ecological conditions** favour survival and growth of these pathogens in DWPS?
  - Temperature, time, nutrients, …?
- Which survival forms are micro-organisms able to develop?
- Does this change their pathogenicity?



Legionella spec.

- Lq#4<:9#4;3#rxw#ri#7/733#sduwlflsdqw#ri#d# yhwhudqvÑ#p hhwlqj#lq#Sklodghoskld#ihoo#vlfn#z lwk# vhyhuh#sqhxp rqld>#5<#ri#wkhp #ghfd|hg
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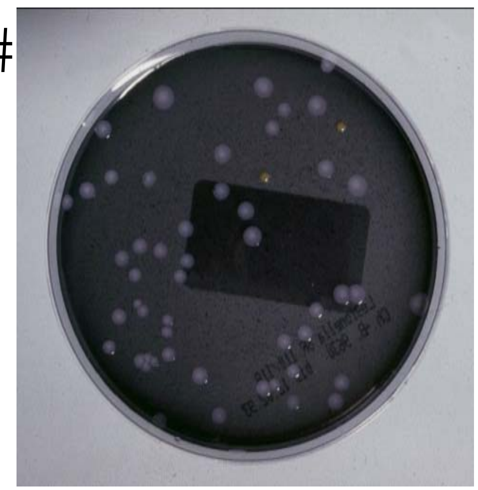

Legionella spec.

- 53/333063/333#dqqxdo#fdvhv#ri#Ohjlrqqdluh´v# glvhdvh#lq#Jhup dq| +lqihfwlrq#udwh=#607#fdvhv#2#433/333#shuvrqv,
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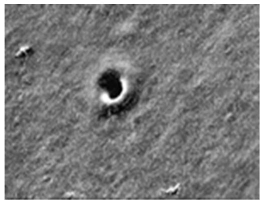
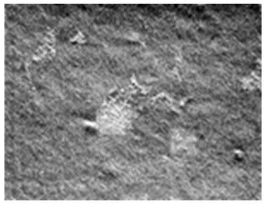
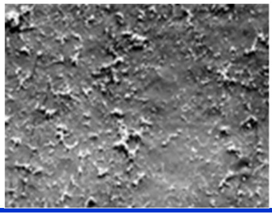
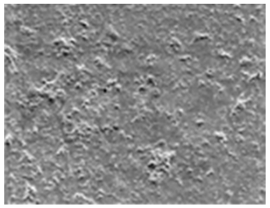
- Whfkqlfdo#Dfwlrq#Ydoxh#+WDY,=#¹433#NEH2433p o

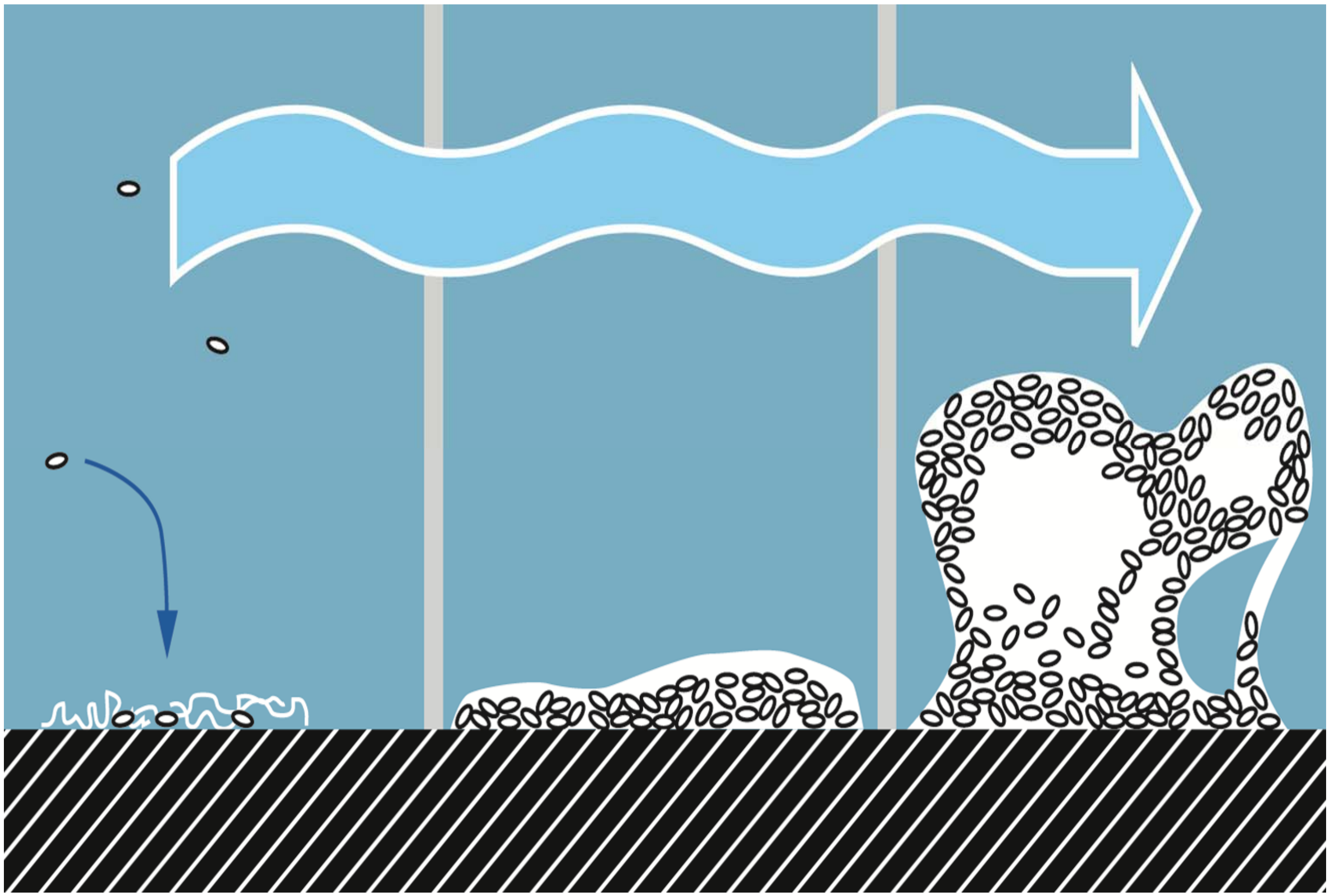
Biofilms

- slime layers upon surfaces in regular contact with water
- contain microorganisms
- old and successful survival strategy of microorganisms
- Biofilm does not require much:
  microorganisms, water, some nutrient, a surface
- frame is made of extrapolymere substances (EPS)
  which are produced by the microorganisms themselves
- organic and inorganic molecules are embedded (liquid, solid, gaseous)
- extremely heterogeneous environment (pH, O_2, nutrients, …)
- cell density exceeds density in the liquid phase (1:10,000)
- 95 % of DWPS microorganisms within the biofilm

Dynamics of biofilms

- Macromolecules attach at the boundary layer and form an initial rough coat – ‚conditioning film'
- autochthonous microorganisms attach at the conditioning film, multiply, form and extracellular polymeric substances (EPS) – „the house of biofilm cells"
- Microorganisms grow together and form macro-colonies
- Steady state: decease and multiplication, dynamic exchange
- Increased exchange during transformation periods of physical and/or chemical conditions: nutrients, temperature, pH, toxic substances …

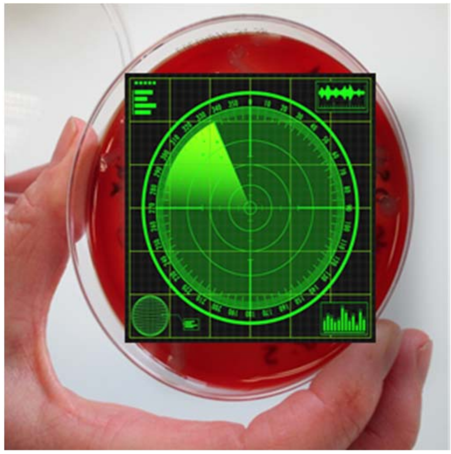


Pathogens in biofilms!

- **Quality of materials substantially influences density of microorganisms (Flemming et al 2010)**
- **Typical biofilm flora is aquatic and not pathogenic, but:**
- **Availability of nutrients enhances microbiological mass, diversity, probability of pathogens to nest**
- **pathogens in DWPS biofilms:**
  - **Faecal pathogens (e.g. Salmonella)**
  - **Legionella – even outside of amoebae = extracellular**
  - **Pseudomonas: pioneer settler**
  - **MOTT: pioneer settler, can always be isolated**

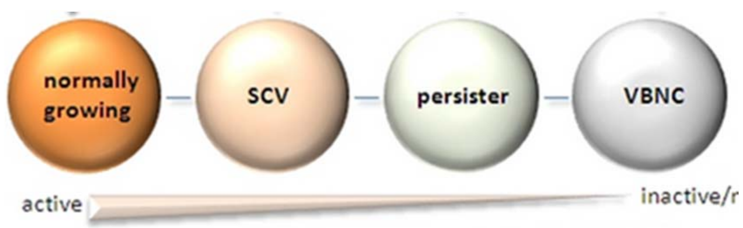
Bacteria disappear from the radar

- Under stress, bacteria loose their ability to multiply, but remain alive, keep their cellular structure, may recover
- ‚Viable but not culturable‘
- Stressors: lack of nutritients, osmotic pressure, O_2 pressure, pH, radiation, toxic substances, predators
- Reduced metabolic activity reduces sensitivity against external stressors
- Cultivable microbes: less than 1 %
- VBNC is the normal form of life for the aquatic flora
- amount of VBNC higher in biofilm



VBNC pathogens in DWPS

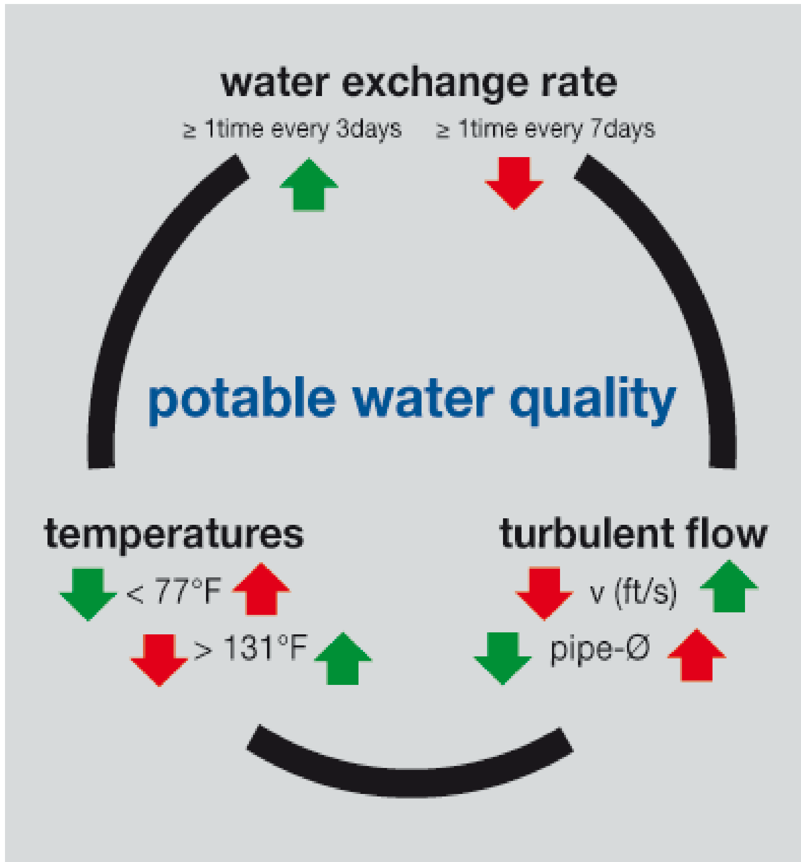
- *Legionella* are able to migrate into the VBNC status
- Prompted by copper stress, lack of nutrient, …
- Consequence: cell concentration of pathogens in DWPS is systematically underestimated
- VBNC pathogens can be found also in biofilms
- VBNC is reversible also for pathogens
- VBNC is an important refuge for pathogens



Practical consequences

- Consider ecological aspects already when planning a DWPS
- Avoid temperature optimum of human pathogens (75-130° F) (see WHO GDWQ)
- Ensure water dynamics: water exchange + flow
  - Water exchange controls time for multiplication
  - Turbulent flow reduces laminar boundary layer
    - Enhanced diffusion between biofilm and water
    - Enhanced shearing forces which negatively affects biofilms
- low stagnation, high water exchange!

„Triangle of effects“ for DW quality



Microbiological requirements for DW

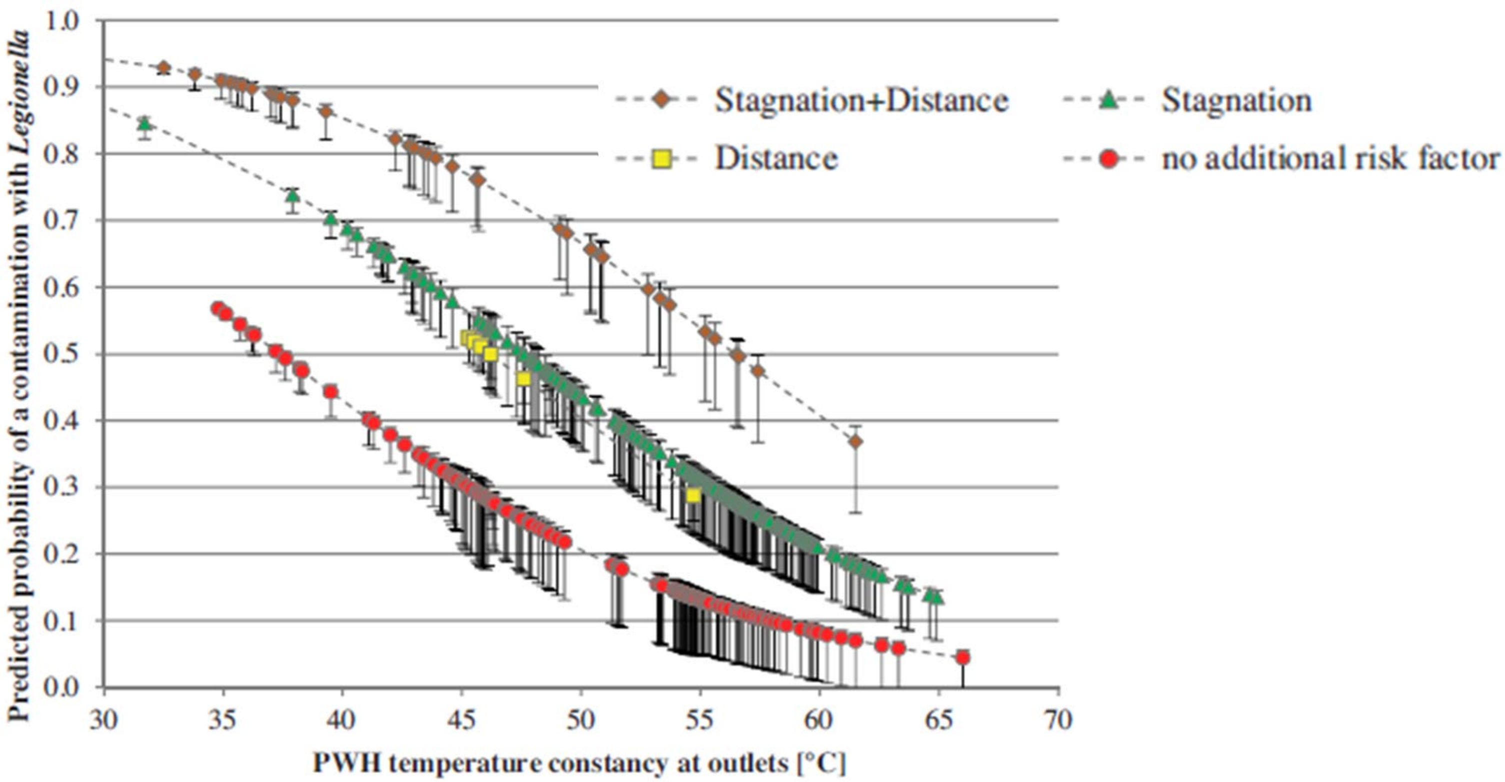
- According to German Drinking Water Ordinance
- Pathogens below concentrations which impair human health
- Proof traditionally through investigation of indicator bacteria: *E. coli*, enterococci, coliform bacteria, *Clostridium perfringens*
- Reliable, but not comprehensive!
- Further microbiological routine parameters:
  - heterotrophic plate counts (HPC) 72° F, 97° F (regrowth)
  - *Legionella* spec. („Technical Action Value“)
- Additionally and equally ranking: commonly accepted technical standards (CATS) have to be fulfilled

The Biofilm Management Project

Research Question:

**Which outlet specific parameters are pertinent for
an early prediction of the risk of Legionella contamination above the Technical Action Value (TAV) at single outlets?**

Influence of temperature and other risk factors (Logistic Regression)



Consequences

- GZSV#@#hfrorjlfdo#v|vwhp >#
  hdfk#rxwohw#@#hfrorjlfdo#qlfkh
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  - orqj#glvwdqfhv
  - whpshudwxuh
  - qxwulhqw#+soxpelqj#pdwhuldo/#zdwhu#txdolw|,
- udwkhu#txdolw|#frqwuro#ri#surfhvvhv#
  wkdq#txdolw|#frqwuro#ri#wkh#surgxfw#dw#srlqw#ri#xvh

Critical dimensions for DWPS planning

- ‚Room book‘:
  - complete description of DWPS
  - characterisation of drinking water outlets (place, type, use)
  - exact description of the intended use of the DWPS
  - measures of maintenance
  - qualification of operator
  - temperature regimes (PWC, PWH)
- Temperature: avoid critical range which is preferred by most pathogens (77°F – 131°F): colder or warmer!
- Water dynamics: water exchange and water flow are critical for drinking water quality!
- Nutrients: avoid plumbing materials dispensing organic substances (TOC, DOC, AOC) into the drinking water

Critical dimensions for DWPS constructing

- Protection of surfaces which will be in contact with drinking water against any contamination
- This applies for production, product control, packing, stocking, transport, and processing
- Visual control for contamination
- Basic rules of hand hygiene need to be respected at the construction site
- Operating supplies (for sealing, gliding, cutting, adhering) are potential nutrients
- These substances have to be non-hazardous concerning health, flavour and smell

Critical dimensions for DWPS implementing

- Testing of tightness by use of air or inert gases
- Water may be applied for testing of tightness only if
  - water is filtered
  - water is free of *Pseudomonas aeruginosa*
  - normal operation starts immediately after testing
  - not in buildings with specific hygienic requirements
- Charging = implementing!
- Flushing should be processed and documented
- Hygienic-microbiological controls of representative sample sites immediately after implementing
- Check compliance with temperature limits

Critical dimensions for DWPS operation

- Preconditions for normal operation:
  - maintenance
  - fittings for reflux prevention
  - no connection to Non-DW plumbing systems
  - compliance with temperature limits
  - prevention of stagnation > 3 days
- Measures in case of interruption of operation
  < 4 weeks: complete exchange of water
  < 6 months: additionally cut-off of DWPS areas
  > 6 months: + hygienic-microbiological controls
  > 12 months: complete cut-off of DWPS

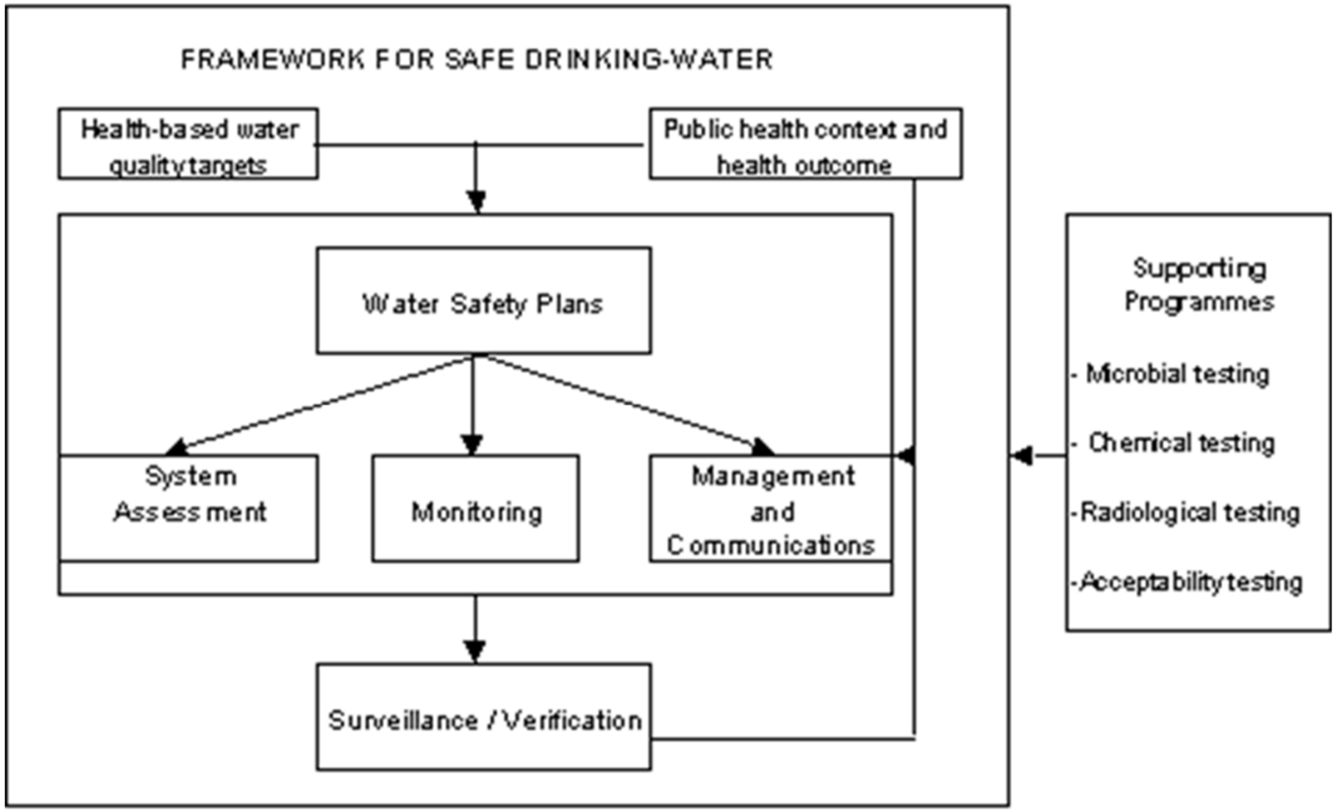
Critical dimensions for DWPS maintenance

- Operation instructions and maintenance plans have to be part of detailed engineering
- Intervention types within maintenance:
  - preventive service
  - inspections
  - repairs
  - improvements
- Classes of maintenance:
  - A parameter monitoring and repair when defect
  - B regular inspection
  - C regular service

Water Safety Plan

- for principal reasons, **end point control is not sufficient** for quality management of DWPS
- WHO: it is more productive to apply the HACCP concept of food production to drinking
- from source to tap, critical control points need to be defined and surveyed
- process control replaces product control
- new paradigm of WHO for safe drinking water
- the quality targets are health-based
- implementation requires team work

Water Safety Plan



Water Safety Plans for Buildings

- The last meters (= DWPS in buildings) are critical concerning drinking water quality!
- But very often CATS are not completely implemented
- Strong analogies between the German system of technical standards and the concept of WSP
- WSP for buildings follow the common rules of procedure of an iterative process:
  description – assessment – management – monitoring – verification
- WSPs for Buildings: an organizational frame for the implementation of the system of technical standards

Resume and perspectives

- Human health is the top priority objective
- In order to maintain the high standard of drinking water quality in buildings, the principles of drinking water hygiene need to be adapted and improved
- Thorough planning, constructing, implementing, operating and maintaining of DWPS is critical
- The adjusting screws of the water quality circle: (temperature, water exchange, water flow, nutrients)
- it is not possible to run a DWPS with a zero risk
- The WSP concept provides an appropriate framework to ensure drinking water of high quality