Health and aesthetic aspects of water quality ja Water quality control in the networks
-PIPE BIOFILMS-

Pirjo Rantanen, Lic. Tech.

WAT-E2110 - Design and Management of Water and Wastewater Networks

25.1.2017

Parts of this lecture

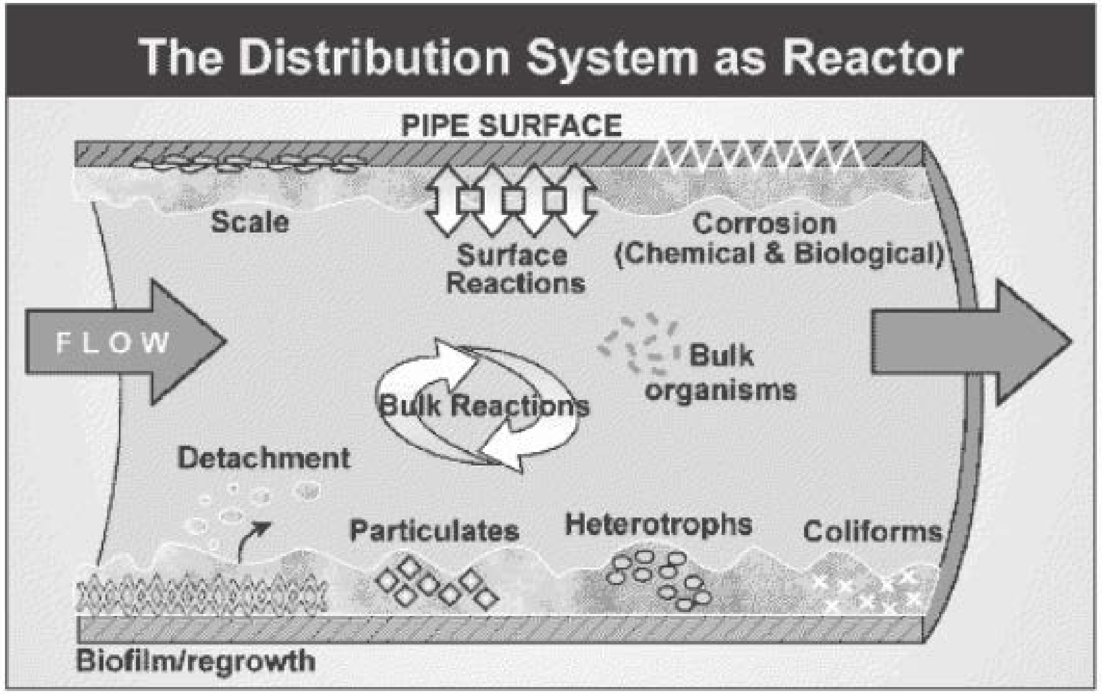
- Distribution pipe biofilms
- General water quality is distribution
- Disinfection in distribution

- Exercise in water quality

Biofilms

- Microbes grow in the inner surfaces of pipes
  - Cannot be prevented!
  - Mostly harmless, but…
  - Biofilm protects microbes, also harmful ones
- Microbially induced corrosion
  - Pitting of copper
  - Iron bacteria growth on pipe surface
- Reactions in biofilm can change the quality of drinking water

Distribution system as ”bioreactor”

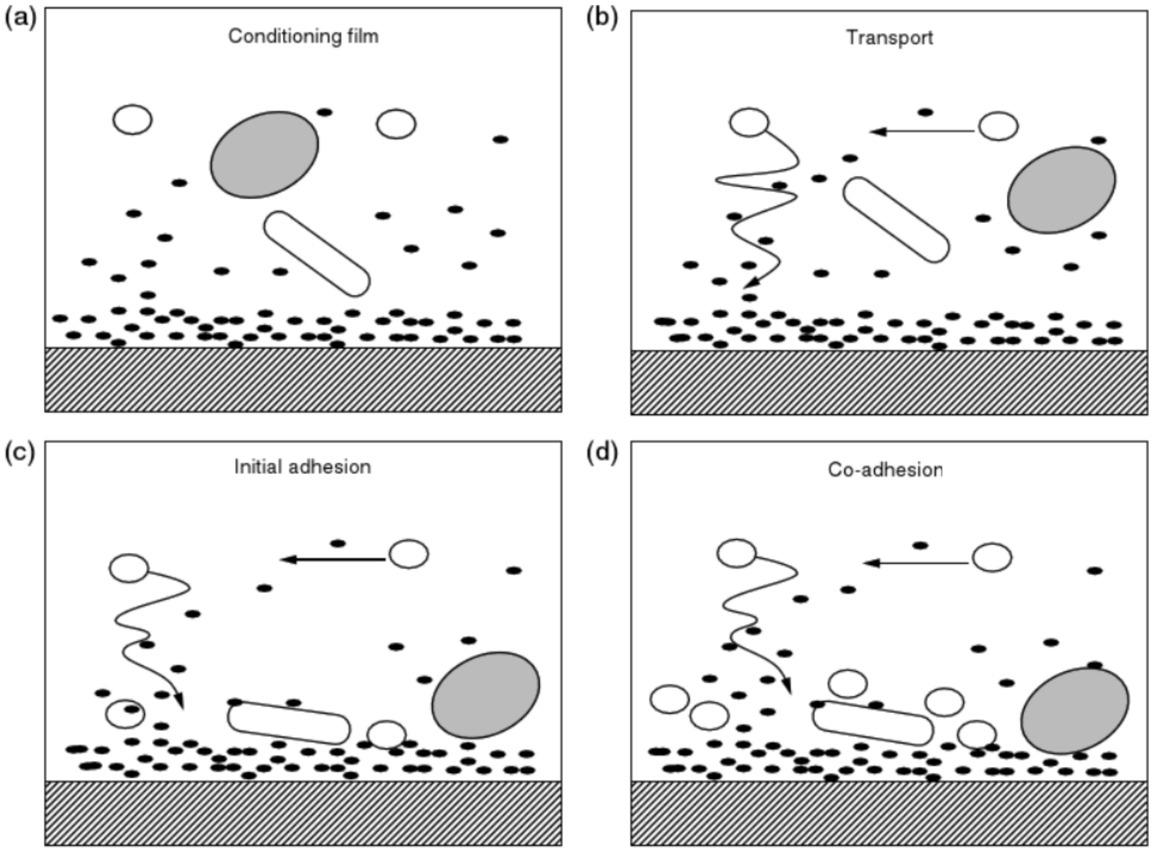


Transformations in the bulk phase and at pipe wall

Clarke, 2011

”The distribution system is a man-made complicated biosphere, buried underground”

Biofilm formation



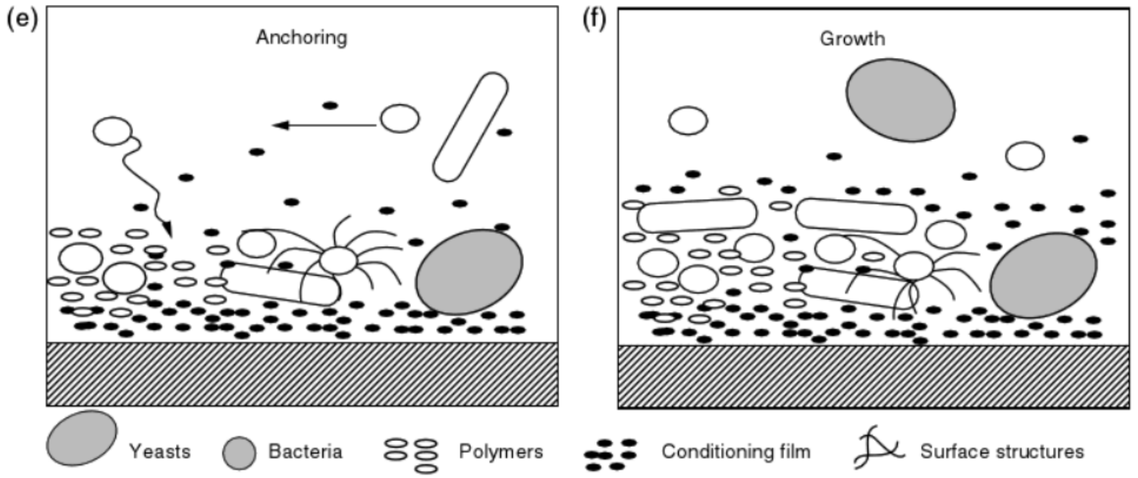
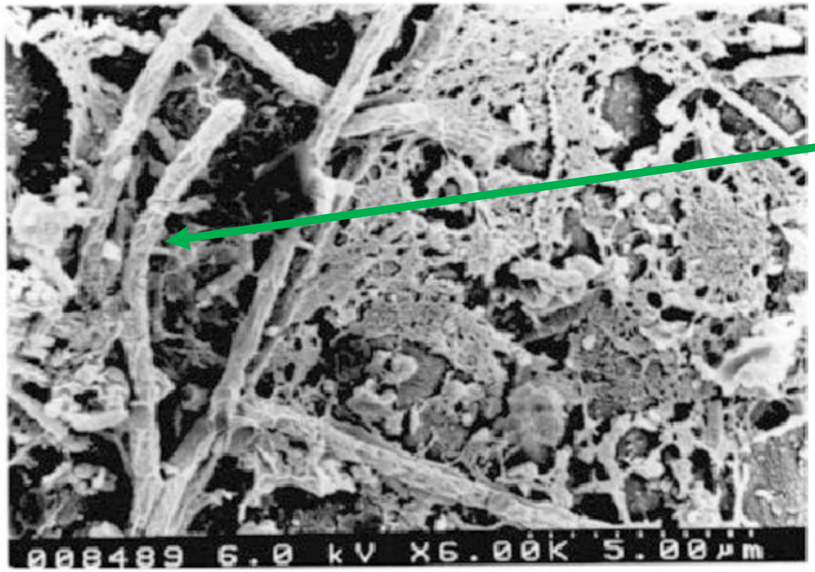
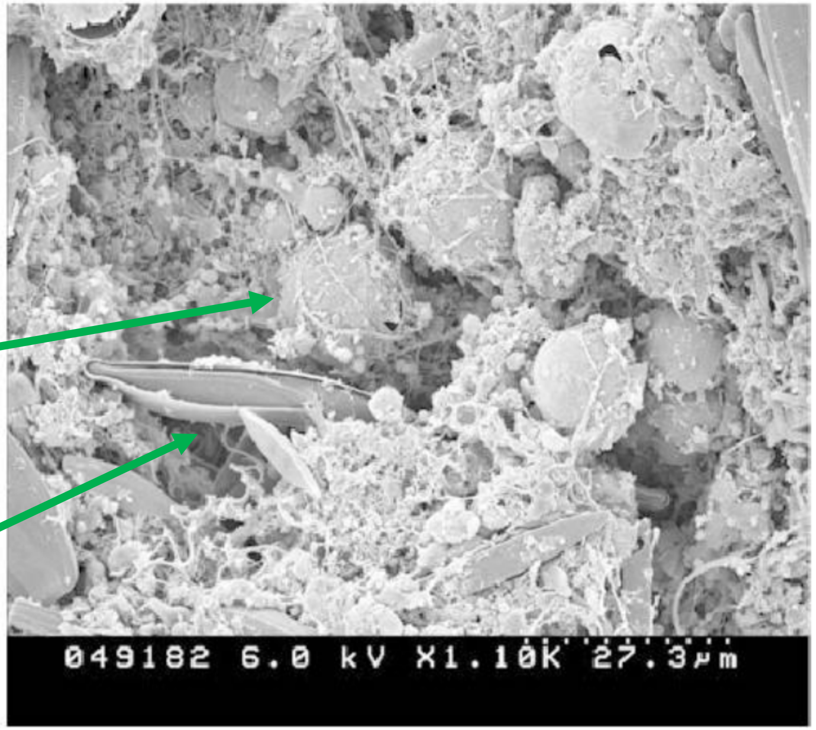


Figure 4.2 Sequence of events in biofilm formation *Source:* Gomez-Suarez et al. (2002). In: *Encyclopedia of Environmental Microbiology*, Gabriel Bitton, editor-in-chief, Wiley-Interscience, N.Y.

a) Surface conditioning
b) Transport of microorganisms to conditioned surfaces
c) -d) Adhesion of microorganisms to surfaces
e) Cell anchoring to surfaces
f) Cell growth and biofilm accumulation

Distribution pipe biofilms





Critical thickness 100-200 µm => nutrient diffusion limitation to growth

Net accumulation of biofilms on surfaces

(Rittmann and Laspidou, 2002).

$$X_f L_f = \frac{YJ}{b + b_{det}}$$

where;

X_f = biomass density (mg biomass/cm^3)
L_f = biofilm thickness (cm)
Y = true yield of biomass (mg biomass/mg substrate)
J = substrate flux (mg substrate/cm^2-day)
b = specific decay rate of biofilm microorganisms (d^{-1})
b_{det} = specific detachment rate (d^{-1})

- Biofilm accumulation increases if
  - Substrate increases
  - Detachment decreases
- In steady state conditions specific growth rate is equal to spefific detachment rate (see Monod equation)

Organic matter

- Names, methods
  - Natural organic matter, NOM
    - Raw water
  - Total organic carbon, TOC
  - Dissolved organic carbon, DOC
  - UV-absorption
  - AOC, assimilable organic carbon
    - Depicts the quality in relation to biofilm regrowth in distribution
    - Biochemical complex method
- Consumes disinfection chemical
- Organic matter enables slime and biofilm growth

TOC analyzer in our lab

Nutrients: Phosphorus

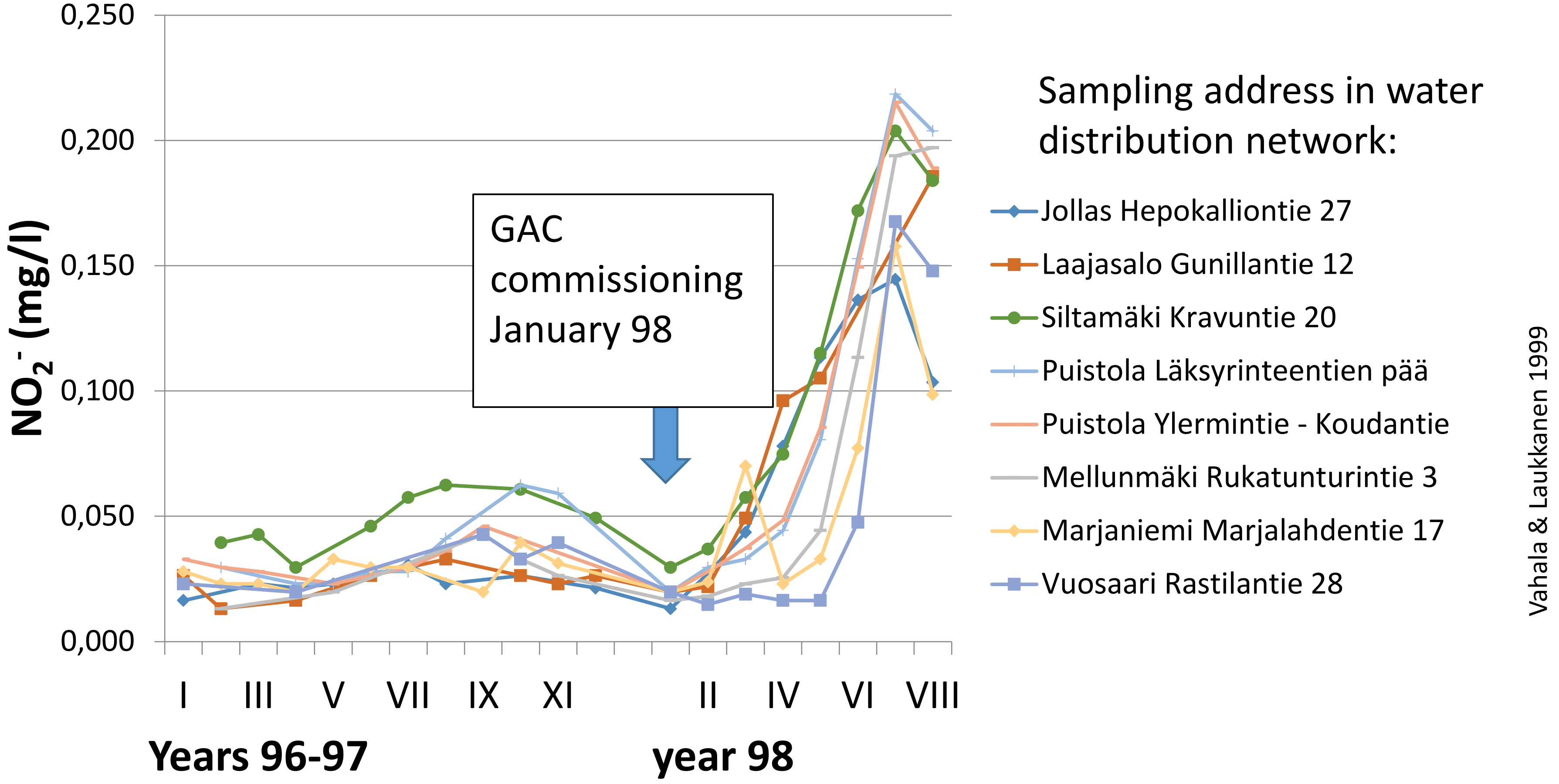
- Usually very low
  - In HSY drinking water total phosphorus 1 µg/l (Lehtinen, 2017)
  - C:N:P ratio in HSY drinking water = 2000:600:1 => limits microbiological growth (Lehtinen, 2017)
- Phosphorus pool at the scale/biofilm/pipe material complex
- Microbially available phosphorus (MAP) depicts biofilm regrowth potential
  - Biochemical complex method
- Sometimes added as corrosion inhibitor at level ~mg/l
  - Not toxic

Nutrients: Nitrogen

- Usually comes from water source
  - Nitrate
  - Sometimes ammonium (poor quality water source)
  - Organic nitrogen from decomposing organic matter
- Ammonium added as chloramine at some WTPs
- Nitrite and nitrate form in nitrification in the biofilm:
  - NH_4^+ -> NO_2^- -> NO_3^-
- Autotrophic bacteria are able to use NH_4^+ and NO_2^- as energy source
- Nitrite and nitrate are harmful in high enough concentrations
  - Nitrite can cause methemoglobinea in infants and some types of cancer

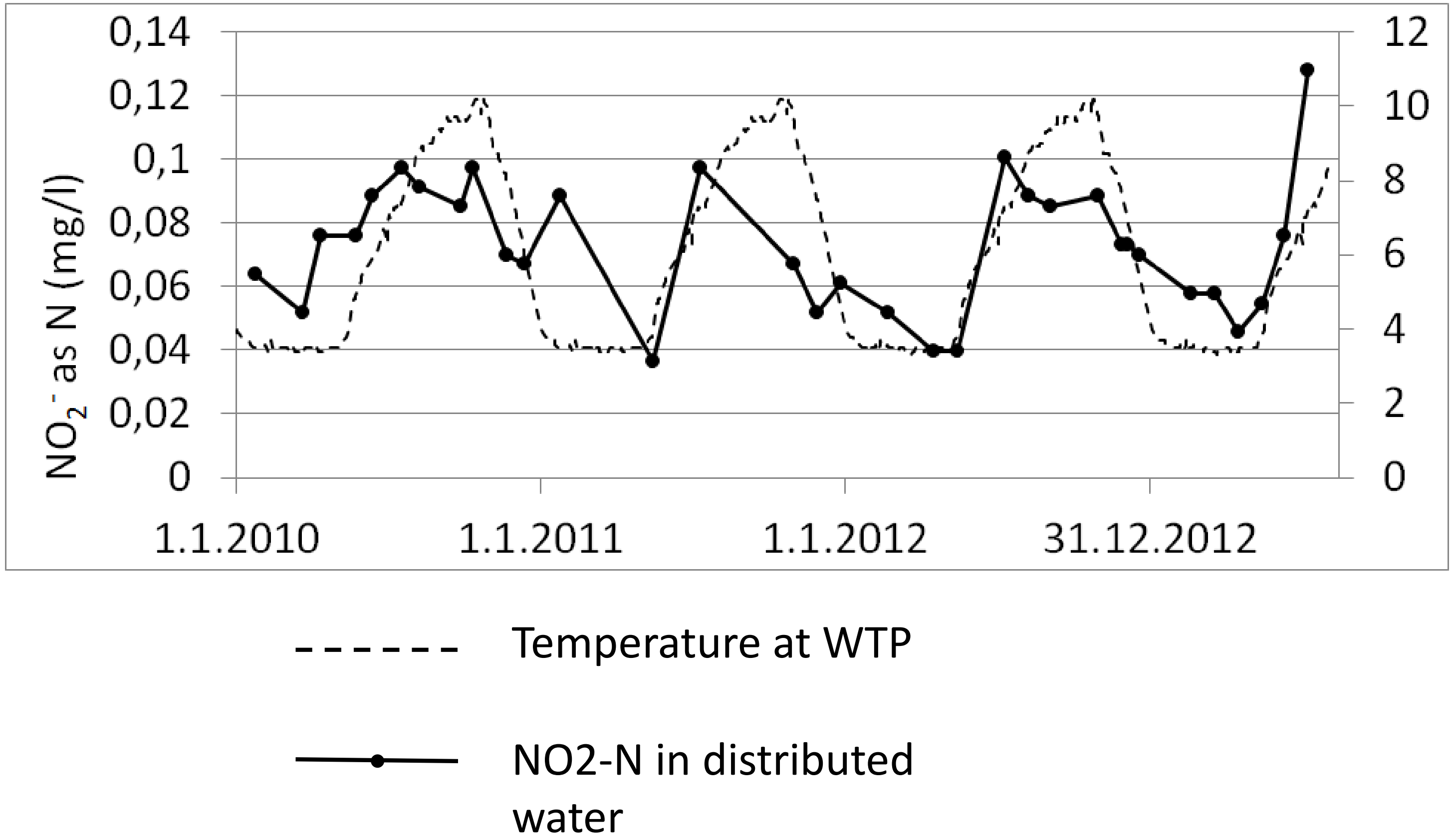
Nitrate and nitrite limits in distributed water

- Maximum levels of nitrate
  - 10 mg/l as N (US and Mexico)
  - 45 mg/l as NO_3^- (Canada)
  - 50 mg/l as NO_3^- (WHO, Denmark, Finland)
- Maximum levels of nitrite
  - 1.0 mg/l as N (US)
  - 0.05 mg/l as N (Mexico)
  - 3 mg/l as NO_2^- (WHO)
  - 0.1 mg/l as NO_3^- (Denmark)
  - 0.5 mg/l as NO_3^- (Finland)



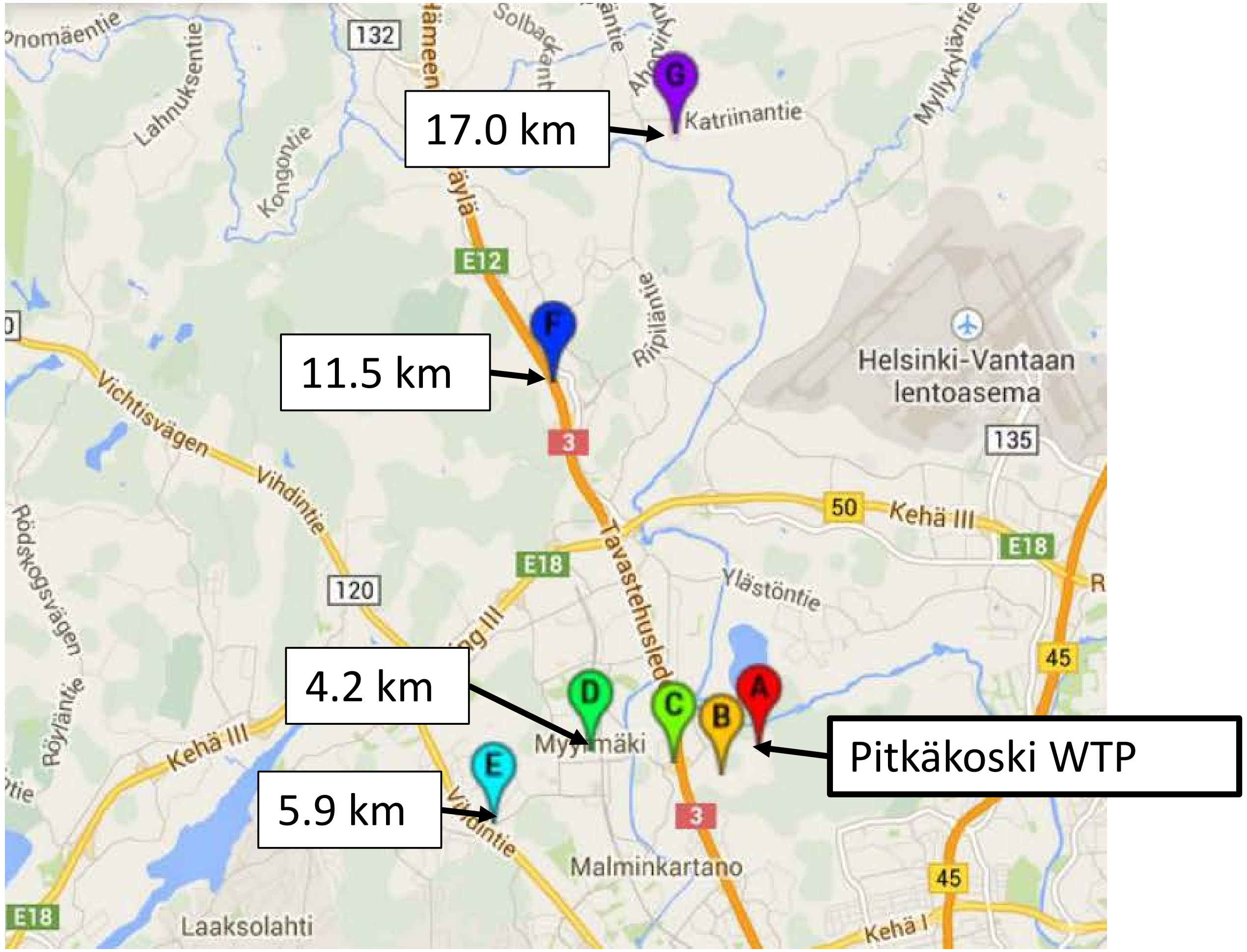
Background: commissioning GAC at WTP in Helsinki in 1998 (Vanhakaupunki WTP)

Temperature effects nitrite accumulation



- Nitrite is formed in the biofilm of distribution pipes from the added chloramine NH_2Cl
- Chloramine decomposes into ammonium
- In higher temperature nitrite concentration was increased

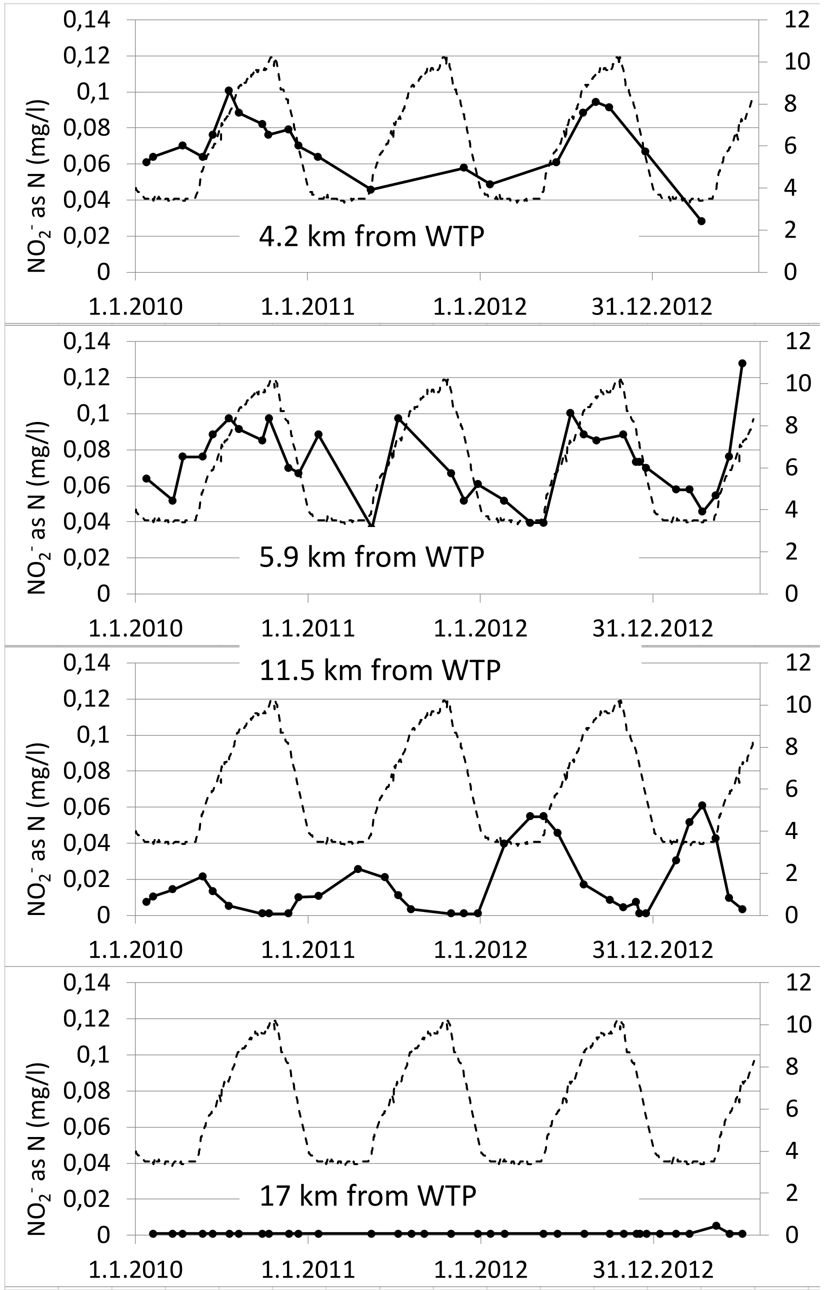
Nitrite formation and depletion in HSY network



- Next slide has nitrite concentrations at the marked sites
- Distances are measures as shortest distance via network

Nitrification reaction progresses in distribution

- At WTP there is no nitrite in water
  - Nitrite is formed in distribution pipes
- Distributed water samples (see previous slide)
- More nitrite is formed in warm temperature
- High nitrites occurred at 11.5 km in winter. *Why?*
- At 17 km nitrite is depleted throughout the year. *Why?*



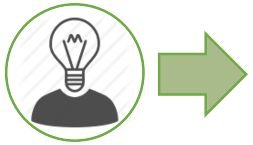
Obligatory monitoring data

Nitrification in distribution systems is limited by

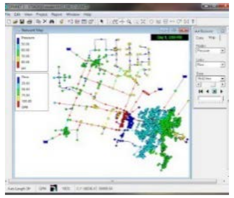
- Total nitrogen in drinking water
  - NH_4^+ and compounds that produce NH_4^+ when decomposing
- In Helsinki are the limiting factor is added NH_2Cl
  - Target concentration 0.35 – 0.4 mg/l residual total chlorine
- In US NH_2Cl target concentration is often 1 - 3 mg/l residual total chlorine
  - => nitrification episodes, where nitrite can raise upto 1 mg/l NO_2-N
- High chlorine concentrations can be used to control nitrification
  - Short periods only (customer complaints)

Sign explanations

= The material is useful to remember during the workday of a water engineer



= You should remember this fact when woken 3 o’clock am and understand during the working day (☺)



= Material concerning the topic of exercise