7.1 Introduction

Water quality will change over time, albeit improvement or deterioration. Passage through the transport and distribution system alters and mostly deteriorates the water quality. The deterioration is a time dependant process. The longer the retention time in the network, the more serious the deterioration will be.

In the Netherlands about 110.000 km pipes is used to transport the water from the treatment plant to the customer. The average residence time amounts to 14 hour (see text box), but can vary between several hours to days in specific areas in the periphery of networks.

Average residence time in the Network.

In the Netherlands 110.000 km pipe is used for the drinking water system. The larger part of the diameters used is smaller than150 mm. If we assume 150 mm. to be the average diameter, the total content of the network is

$$\text{Content network} = \frac{1}{4}\pi D^2 \cdot 1{,}1 \cdot 10^8 m^3$$

$$= \frac{1}{4}\pi \left(0{,}15\right)^2 \cdot 1{,}1 \cdot 10^8 \approx 1.9 \cdot 10^6 \ m^3$$

The yearly production of drinking water amounts roughly to 1,2 billion cubic meters: 1,2 $*10^9$ m^3. Average daily consumption is than

$$\frac{1{,}2 \cdot 10^9}{365} = 3{,}3 \cdot 10^6 \ \text{m}^3/\text{day}$$

This gives an average residence time of about 14 hour.

The materials the network is composed of are roughly Cast Iron, Asbestos Cement and PVC (see figure 7.1 and 7.2).

The interaction between the water and the materials will influence the water quality. Also prolonged treatment processes influence the water quality. The treatment of water to drinking water is a chemical, physical and biological process that doesn't stop when the water enters the network. Apart from the residence time also the hydraulic circumstances influence the

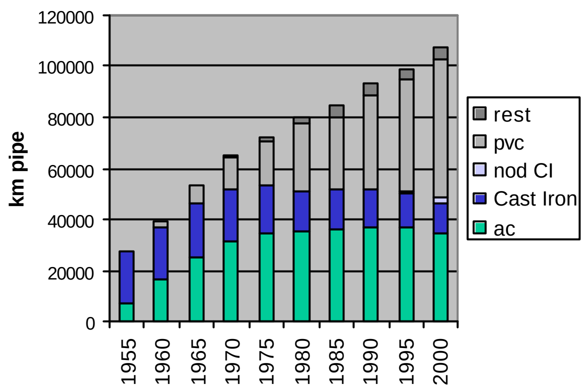


Fig. 7.1 - Material composition of network

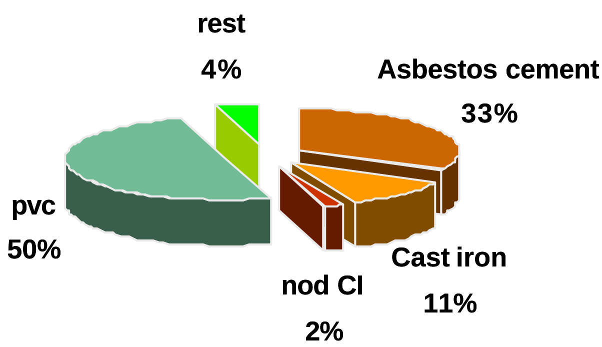


Fig. 7.2 - 2001 material composition of Dutch drinking water systems (110.000 km)

water quality in the network.

Processes that influence the water quality can roughly be divided in:

- Biological
- Chemical
- Physical

Within the framework of this college, the emphasis is on the understanding and controlling of the physical processes that affect the water quality. These processes mainly concern the settling, accumulation and resuspending of discrete particles in the network. Main problem is the resuspension, which causes discoloration of the water that leads to customer complaints. Moreover there are increasing leads indicating that there is a relation between bacteriological problems and accumulated sediment in the network.

The biological processes will cause bacteria to regrow or to develop when the network is infected. This process is mainly governed by the amount of nutrients that is available for bacteria to grow. Growth is in other ways limited by adding disinfectants to the water. Basic control mechanism is to treat the water to socalled biological stable water. This means that the biological regrowth potential of the water is minimized by good treatment.

Chemical processes primarily impact the interaction between the pipe material and the water quality. Corrosion of Cast Iron, lead and copper and leaching of calcium from cementitious materials are the main processes that affect the water quality. Condition the chemical properties of the water by careful choosing of source and softening will control this as much as possible.
Control of water quality changes, starts with an adequate water quality at the pumping station. In the Netherlands this is reached with extensive treatment because no source for drinking water is so good that treatment can be left out. In other parts of the world sources can be so good (or standards to the water so low) that treatment is not necessary.

7.2 Physical processes in the network and discoloration

The nature of the physical processes in the network is sedimentation, accumulation and possible resuspention of discrete particles. The problems that will cause this are divers. The sedimentary deposit can be a source for biofilm formation leading to regrowth or other bacteriological adverse effects. Also the accumulated sediment can whirl up or resuspend due to sudden changing velocities in the network, causing the water to discolor, which can lead to complaints.
Actually discoloration of the water is the largest source for customer complaints. (Apart from complaints concerning the bill of course.)
The last ten years the problem of discolored water has become more important, leading to more research and a better understanding of the driving mechanisms. But still a lot has to be dissolved.

> **Number of water companies in the Netherlands**
> Historically water companies were municipal companies serving the municipality they were part of. This led to a total of over 200 water companies in 1946. With the Water Act that was passed through Parliament in 1964 the process of merging of companies towards larger provincial companies was started. This resulted in a process that led in 2002 to a total number of 17 companies. It is estimated that this number will further decrease to 5 to 6 companies in total.

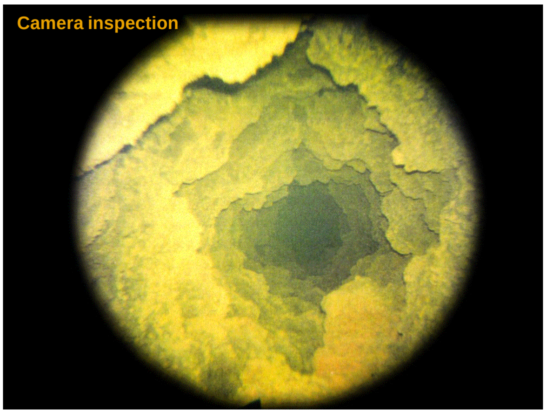


Fig. 7.3 - Encrusted cast iron

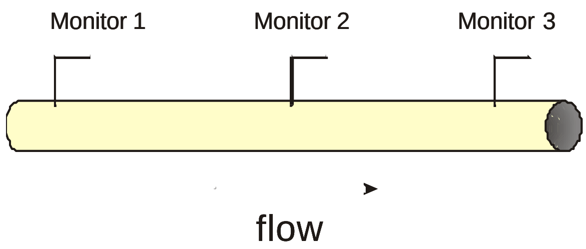
In the early 90's of last century the topic was put on the agenda of the water companies because of several reasons.
The first reason is that the number of complaints unexpectedly increased. An explanation for this was that customers became more critical towards the water quality they experienced.
A second reason was that water companies started with more professional registration of complaints. With the increase of the size of the company, it was possible to have a 24-hour telephone service for registration. (see text box)

Concurrently with the rise in number of complaints the amount of cast iron was decreased. Rehabilitation of old cast iron pipes was the main cause for this decrease. Cast iron was traditionally considered to be the most important reason for discoloration complaints. This is substantiated by the condition of some old cast iron pipes, as is shown in figure 7.3.

Besides the rehabilitation of the cast iron, water companies also performed large cleaning programs to remove the sediment from the network and apparently this was not effective enough.
These observations encouraged research towards to cause and nature of discoloration of drinking water.

7.3 Continuous monitoring of water quality

The continuous monitoring of water quality in a network gives information about the actual changes of the water quality during transport and distribution. The principle of continuous monitoring is given in figure 7.4.



- pH
- Oxygen
- Turbidity
- Temperature
- Conductivity
- Pressure
- (Velocity)

Fig. 7.4 - Principle of continuous monitoring

The first monitor will record the initial water quality, for instance at the treatment plant or a location in the trunk mains. The following monitors will record the water quality downstream of the first monitor, which allows for analysis of changes. The parameters that can be recorded are limited, because they must be measurable with relative simple instruments that can record on line the specific parameters. Examples of those parameters are pH, conductivity, Oxygen content, turbidity, temperature and pressure. Parameters as iron concentration and biological properties are much more difficult to record, because they cannot be monitored on line.

The equipment used is compact and can be put anywhere in the network. Figure 7.5 shows a picture of such a monitoring unit.
An example of the results of continuous monitoring is given in figure 7.6.

In this figure the turbidity of the water is given in three places consecutive in the network. At the first location the turbidity at the treatment plant is given.

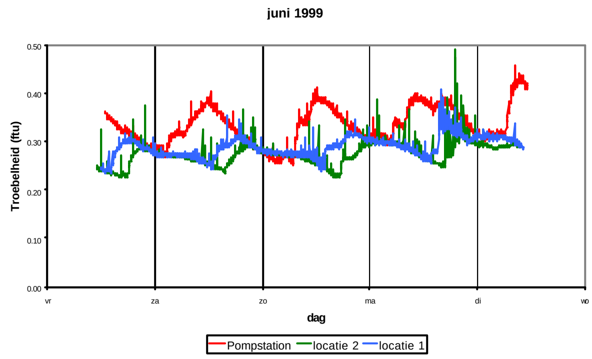


Fig. 7.6 - Continuous monitoring of turbidity

It shows a pattern of turbidity that varies slightly over the day. Probably this has to do with the hydraulic load of the treatment process.
In a location downstream (location 1 the blue line) the pattern of turbidity can be recognized, but the level is lower. The peaks in the turbidity can be identified as the same 'plug' of water. This firstly indicates the retention or travel time between the treatment plant and the first location. In this case this is about 8 hours. Secondly the turbidity has significantly dropped: from 0,4 FTU to 0,31 ftu a drop of almost 25%. This quantifies the change in water quality. The second location in the network represented in the green line, is a bit further downstream and shows again the same pattern with a slightly lowered peak concentration of turbidity.

Continuous monitoring is necessary when evaluating changes in water quality. Most important reason being the possibility of actual identifying plugs of water and following them during the passage through the network. Using grab samples at several points will easily lead to other conclusions. This will also be demonstrated in the next paragraph.

Fig. 7.5 - Monitoring units

7.4 Cause and nature of discoloration

The main cause for discoloration of drinking water is the sudden whirling up or resuspention of accumulated sediments in the network. In figure 7.7 is the turbidity pattern of a typical discoloration incident given.

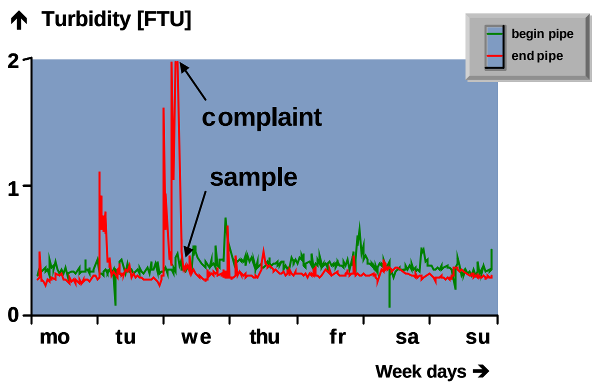


Fig. 7.7 - Typical discoloration incident

This turbidity pattern shows also that it is virtual impossible to 'catch' a discoloration incident with a grab sample. The figure shows the turbidity pattern at two points in the network: one at the beginning of the pipe, the green line, and one at the end, the red line. At the end of the pipe at two times the turbidity is very high and doesn't have a pattern relation with the upstream turbidity. Analysis of the supply pattern at the end of the pipe revealed that at the time of the high turbidity level an extraordinary supply took place, because a fire hydrant was used.

Schematically the sediment balance in a network is given in figure 7.8. This model is generally used to provide an overview of these processes. Discolored water occurs if the outgoing turbidity C_{out} becomes too high.

The processes involved in the generation of discolored water are:

- o processes leading to particles entering the distribution system:
  - o directly from the treatment plant;
  - o from corrosion of water mains or domestic installations;
  - o from inadequate installation or maintenance work;
- o processes leading to particle formation within the distribution system by physical, chemical and biological processes (ongoing coagulation, formation and abrasion of biofilm);

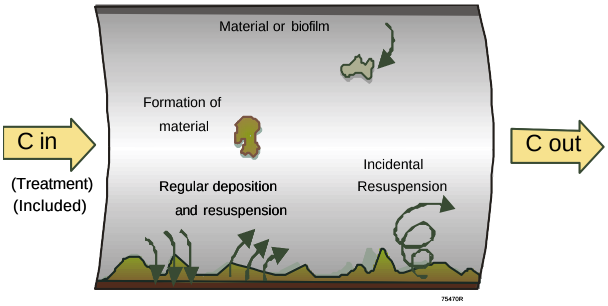


Fig. 7.8 - Sediment balance in a network

- o hydraulic processes leading to accumulation and resuspension of particles.

The dominant cause for discoloration is the resuspention of sediment. The resuspention is the result of a sudden change in velocity in the network, for instance the use of a fire hydrant or another large demand. Also the failure of pipes will induce a sudden change in velocity because of the large water loss or as a result of a different supply pattern when the broken pipe is isolated and flows go another way. Hydraulically the solution to the problem can be threefold:

- o Avoid sudden changes in velocity
- o Remove accumulated sediment regularly.
- o Prevent sediment from settling and accumulating

7.4.1 Avoid sudden changes in velocoties

This is a measure that has limited possibilities. Sudden changes in velocities as a result of pipe failure realistically cannot be influenced. Changes in velocities as result of an extraordinary supply, for instance

Fig. 7.9 - Use of hydrants other then fire fighting

when fire hydrant are used can be controlled partly. Fire hydrants used to be used by others than the fire department as well. For instance contractors that need large quantities of water to pave streets or municipal workmen using fire hydrants to fill tanks for watering gardens or cleaning sewers.

Most water companies in the Netherlands now have a policy of prohibiting the unauthorized use of fire hydrants.

7.4.2 Remove accumulated sediment regularly

To remove sediment and slime that accumulated on the walls of pipes in distribution networks the pipes are cleaned. A high velocity that is generated along the pipe wall, thereby producing a wall shear stress sufficient to loosen sediment and biofilm from the pipe wall, achieves the cleaning effect. The flowing water transports the loose sediment. Various methods are commonly used for this, namely:

- o scouring with water;
- o scouring with water and air;
- o swabbing (using pigs).

Scouring with water is the most simple and effective method. Opening a fire hydrant or a dedicated flushing point inflicts a high water velocity and the volume flow removes the resuspended sediment.

In scouring with water and air, compressed air is introduced into the pipe concurrent with opening a flushing point (hydrant or dedicated point). The injected air forms large bubbles in the pipe that are separated by very turbulent plugs. In this turbulence extra sediment will be resuspended and removed with the water flow.

Fig. 7.10 - Dedicated flushing point

Fig. 7.11 - Foam pigs to clean water pipes

In the case of swabbing, a plastic pig is transported through the pipe. Because the pig has a slightly larger diameter than the pipe's internal diameter, the sediment is scraped from the wall and pushed along in front of the pig.

Flushing or scouring with water is most effective when carried out using what is known as a clean water front. This means that water used for cleaning the pipes is only supplied through sections that are supposed to be clean. The section may be the pumping station, or a large trunk main. Whether or not a trunk main can be used as a clean water front generally has to be determined by measurement. The clean water front follows the flow direction of the network. Working according to this concept maximizes assurances that recently cleaned areas will not be refouled by hydraulic disturbances in the network.
The clean water front has to be defined after information on the pipelines has been collected. The sequence of distribution areas to be cleaned is then determined. Finally, calculations are made to determine where flushing points can be located. Flushing points must be selected so that they can be easily and safely accessed and so that there are adequate drainage possibilities.

A secondary result of meticulous flushing plans is that a great deal of information on the mains system is generated. This information can be used for the system's systematic management. Every cleaning program will yield new information on the quality of the water mains system, which relates to matters such as how easy shut-off valves are to operate, and the degree of corrosion and biofilm formation. The information can be used, for example, for establishing priorities in the renovation of cast iron, restyling diameter transitions, and for adequately monitoring shut-off valves and fire hydrants.

7.4.3 Prevent sediment from settling and accumulating

Sediment can only whirl up when it is accumulated in some quantities in the network. The primary requirement for accumulation is a low scouring impact on settled sediment. To avoid accumulation then obviously requires a certain scouring impact on settled material. Given the natural variation in the demand pattern, during the night hours of low consumption the impact will be low. At that time the accumulation will be large.

At the natural high demand hours, the impact can be higher when pipes are not too large. Traditionally pipes are dimensioned with a large safety margin towards the maximum flow that has to be carried through the pipe. In the next chapter more detail on dimensioning a network will be given.

Fig. 7.12 - Foam pig leaving a pipe