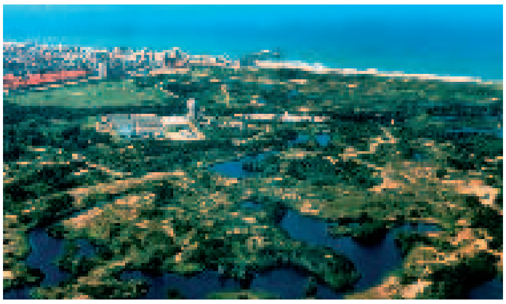
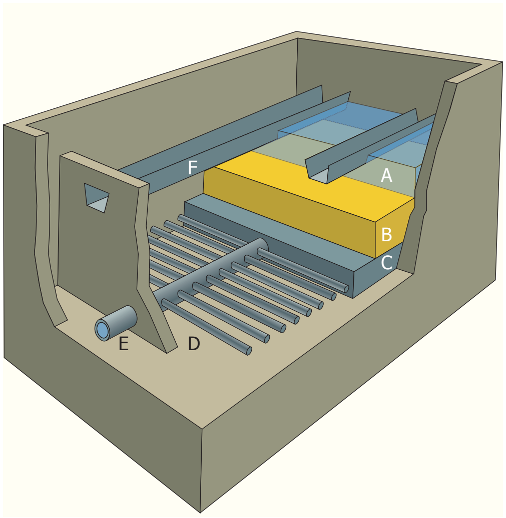
Indirect treatment of surface water via infiltration





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This handout is based on *Drinking Water, Principles and Practices* by de Moel et al.

1. Introduction

The indirect treatment of surface water through infiltration consists of infiltrating pre-treated surface water into the ground, abstracting it and treating it afterwards (post-treatment).

Surface water is characterized by temperature and salinity variation throughout the year, contamination with pathogenic microorganisms, and the fact that, even after treatment, growth and settling of particles in the distribution network may occur.
By infiltrating the surface water into the ground, its quality is improved. This means that the pathogenic microorganisms are degraded and the water is in a better biological and chemical state and thus neither settling nor regrowth occur.
Besides, the temperature changes are levelled. Both the temperature and the salinity are more or less constant.

Water can be infiltrated with open canals and ponds into the phreatic groundwater. When the supply of treated surface water is obstructed somehow (e.g., accident, network repair), it is possible to continue the abstraction for some time. During this time the groundwater level decreases, which is, to some extent, acceptable without damaging the natural biology.

Infiltration projects cover large areas that need to be protected, since they deal with large amounts of water. However, as the infiltration area is always developed as a natural area, it has a high recreational value.

Figure 1 shows an example of an intake stop because of contamination of the surface water by micropollutants. Since the contamination occurred in winter, an intake stop of some weeks could be taken without damaging the environment in the infiltration area.

As an alternative to infiltration water into phreatic groundwater, deep infiltration into a confined aquifer, by means of wells, can also be done. Due to the enclosing clay layers, there is almost no exchange with the phreatic water above, so the

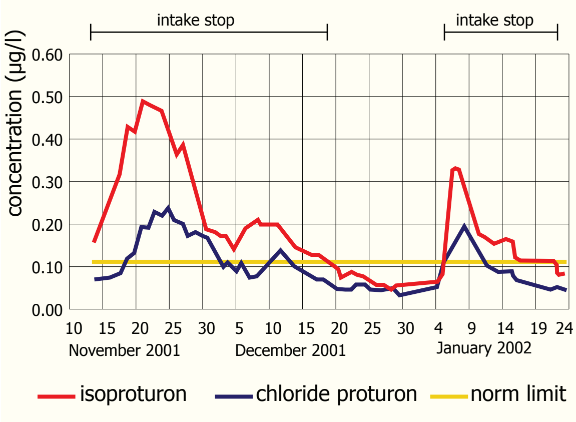

Figure 1- Pollution at the intake point of the WRK Nieuwegein

infiltrated water does not influence the ecosystem. Preliminary treatment should be also considered when using deep filtration. The fewer particles that are present in the water, the smaller the chance that the infiltration wells will clog. Storage in deep infiltration is limited. When extracting water without supplying the necessary water for a long period, the chance of salt water intrusion exists.

2. Pre-treatment

To make the surface water suitable for transport and infiltration, suspended particles need to be removed first.
The standard pre-treatment of surface water (Figure 2) consists of flocculation followed by floc removal and rapid filtration.

With the flocs, substances like heavy metals (being positively charged and adsorbed to the flocs) and microorganisms are removed. The most used coagulants are trivalent metal salts, like iron chloride ($FeCl_3$), iron chloride sulfate, or aluminum sulfate..

At the WRK Nieuwegein production plant (Waternet), coagulation is accomplished with iron chloride, followed by settling in a large sedimentation tank, and rapid filtration (Figure 2 and Table 1).

The quality of surface water varies throughout the year. For example, the turbidity at the Nieuwegein site varies between 5.5 and 25.5 FTU and the tem-

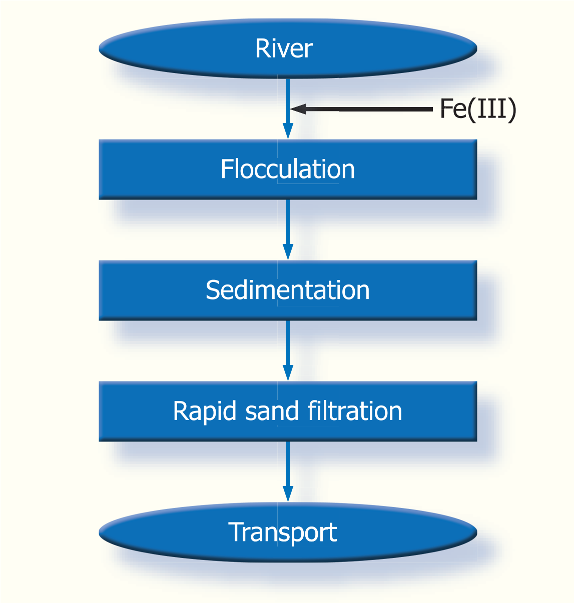

Figure 2- Preliminary treatment of surface water for infiltration

perature between 2 and 23°C. This influences the settling behavior, the filtration, and the biological processes.
During the treatment process the composition of the water changes. The quantity of suspended

Table 1 - Quality data of the raw and treated water at Nieuwegein (Utrecht)

Parameter	Unit	Raw water	Clear water
Temperature	°C	12.5	12.5
pH	-	8	7.8
EC	mS/m	80	80
SI	-	0.4	0.2
Turbidity	FTU	10.4	0.2
Na^+	mg/l	80	81
K^+	mg/l	6	6
Ca^{2+}	mg/l	81	81
Mg^{2+}	mg/l	11	11
Cl^-	mg/l	149	155
HCO_3^-	mg/l	157	156
SO_4^{2-}	mg/l	66	67
NO_3^-	mg/l	4	4
O_2	mg/l	9.2	7.3
CH_4	mg/l	-	-
CO_2	mg/l	2.6	4.4
Fe^{2+}	mg/l	-	-
Mn^{2+}	mg/l	-	-
NH_4^+	mg/l	-	-
DOC	mg/l	3.9	3
E.Coli	n/100 ml	5,000	50
Bentazon	µg/l	0.2	0.2
Chloroform	µg/l	0	0
Bromate	µg/l	< 2.0	< 2.0

solids, the turbidity, the amount of heavy metals, like cadmium and nickel, and the colony count decrease.
By adding iron chloride, the chloride concentration of the water rises. On average 3 mg/l Fe^{3+} is added, implying an increase in the chloride concentration of 5.7 mg/l. The ferric ions form a compound together with the hydroxide ions, thus removing hydroxide ions and reducing the pH value.

The quality standards for infiltration water have become stricter.
Originally, preliminary treatment was performed in order to prevent contamination of the transport pipelines and the clogging of the infiltration ponds. Nowadays, another demand is that no elements foreign to the infiltration environment will accumulate (like organic micropollutants). The standard pre-treatment process for infiltration water does not remove organic micropollutants. This requires the preliminary treatment process to be expanded with activated carbon filtration (Figure 3).

Pre-treatment is usually sited at the intake point of the surface water. This site can be rather remote from the infiltration area, requiring long transport mains. Due to the large size of surface water production plants, these mains have a considerable diameter. Sometimes, a double transport main is constructed in order to improve the reliability of the system in case of breakdown.

3. Infiltration

Figures 4, 5 and 6 show pictures of open infiltration in dune areas.

The pre-treated surface water infiltrates into the soil, which results in a quality improvement, including the levelling of concentrations.
A retention time of two months is deemed enough to make the water microbiologically reliable.

The spatial need for infiltration is easily computed from the desired retention time in the ground:

$$T = V / Q \Rightarrow A = (T^*Q) / D.p$$

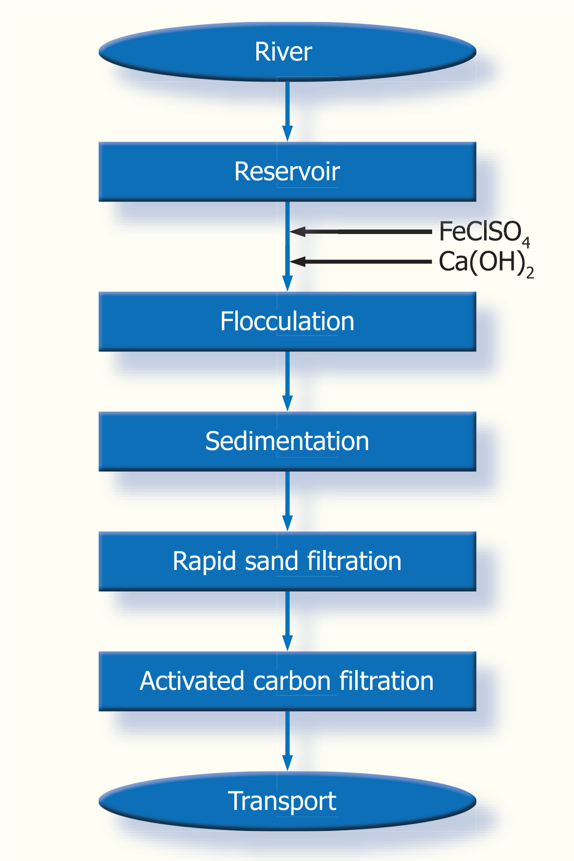

Figure 3 - Treatment scheme of infiltration water where organic micropollutants are removed

where:
T = the average retention time in the ground (s)
V = the volume flowing through (m^3)
Q = the flow through the ground (m^3/s)
D = the thickness of the aquifer (m)
p = the porosity of the ground (-)

With the above equation, the spatial demand for an infiltration of 50 million m^3 per year amounts to 5.6 million square meters, at a retention time

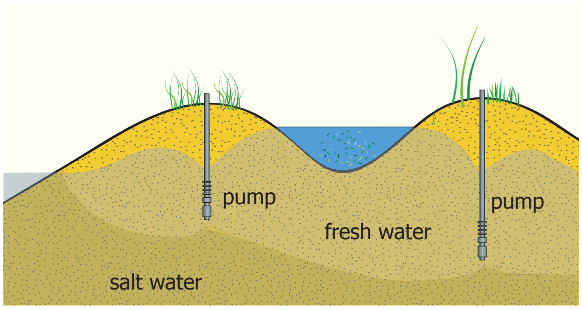

Figure 4 - Infiltration systems in the dunes

Figure 5 - Infiltration pond in the dunes

of two months, an aquifer of 5 m thickness, and a porosity of 0.3. This can be achieved in an area of 1 x 5.6 km.
This spatial demand is equal to a surface load of 8.9 m/y, which is about (8.9 / 0.3 =) 30 times more than the net precipitation (rainfall minus evaporation) of 0.3 m/y.
Within this infiltration area there is thus an abstraction of about (1/30 =) 3.3% rain water, assuming the water balance in the area is closed.

When infiltration is interrupted, it is possible to abstract water for a long time. A delay of a month results in a maximum reduction of the groundwater level with (8.9 / 12 / 0.3) = 2.5 m.

Pre-treated surface water is mainly infiltrated into the dunes by means of open infiltration. In the dunes there is a system of ponds and artificial canals.
An infiltration rate from the infiltration facilities of 2 m/d (730 m/y) appears possible. Therefore, the example above would require an infiltration area of (8.9 / 730 =) 1.2% of the total area necessary for infiltration.

Figure 6 - Infiltration pond (drying up)

Figure 7 - Sludge in infiltration pond

The distance between the infiltration facility and abstraction is determined by the porosity of the ground. A limiting factor is the acceptable reduction of the groundwater level.
The system of infiltration facilities is constructed in such a way that all ponds can be dried separately in order to clean accumulated matter on the bottom. (Figure 7).

The composition of the infiltrated water is different from the composition of the original dune water. This leads to the entrance of nutrients into the normally poor sandy soils, thus changing the vegetation. In this way infiltration can affect natural areas.

The removal of microorganisms from the water is compromised when recontamination occurs after infiltration. Birds and other animals can contaminate the water with their feces. Therefore, most water companies turn towards a system of closed abstraction through wells or drains.
After being abstracted out, the dune water is transported through pipes to the final treatment plant.

4. Post-treatment

The soil passage in the dunes removes microorganisms and, at the same time dissolves iron, manganese, and ammonium ions from the soil. These ions need to be removed from the water. In case the water was not treated with activated carbon before infiltration, organic micropollutants may be present in the water. Those need to be removed as well.

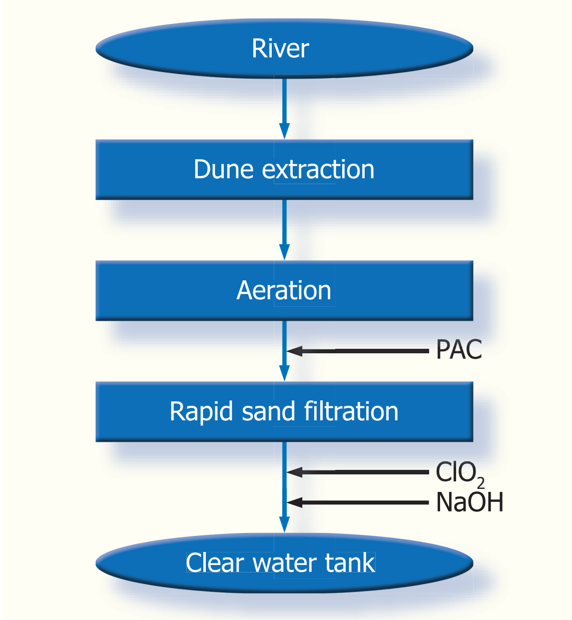

Figure 8- A simple post-treatment scheme of infiltration water

The simplest procedure for the final treatment of infiltration water is similar to a groundwater treatment plant: aeration followed by rapid filtration (Figure 8).
An example of the final treatment of infiltration water is the Bergen plant in Noord-Holland.
Pre-treated water from the IJsselmeer (with activated carbon filtration) is infiltrated into the dunes. Abstraction is done by means of a closed system. The final treatment consists of aeration and rapid filtration.
The abstracted water has a low turbidity because it has been filtered by the dunes (Table 2).
During the retention time in the ground, the oxygen concentration is reduced. During the aeration phase the oxygen rate rises again.

During aeration the iron and manganese ions are oxidized. To remove the iron hydroxide and manganese oxide, rapid filtration is used. The ammonium is transformed into nitrate in the rapid filter.

The concentrations of Bentazon and Diuron (micropollutants) are low when abstracting water from the dunes. This is because of the activated carbon filtration before infiltration. The concentrations are not further reduced during the final treatment phase.

Table 2 - Quality data of the raw and treated water at Bergen treatment plant

Parameter	Unit	Raw water	Clear water
Temperature	°C	11.7	12
pH	-	7.6	7.7
EC	mS/m	86	86
SI	-	0.1	0.0
Turbidity	FTU	-	0.1
Na^+	mg/l	78	78
K^+	mg/l	7	7
Ca^{2+}	mg/l	89	90
Mg^{2+}	mg/l	13	12
Cl^-	mg/l	147	149
HCO_3^-	mg/l	192	198
SO_4^{2-}	mg/l	92	93
NO_3^-	mg/l	1	1
O_2	mg/l	0.2	8
CH_4	mg/l	0	0
CO_2	mg/l	9	7
Fe^{2+}	mg/l	0.6	0.03
Mn^{2+}	mg/l	0.1	< 0.01
NH_4^+	mg/l	0.31	< 0.03
DOC	mg/l	3	3
E.Coli	n/100 ml	0	0
Bentazon	µg/l	< 0.1	< 0.1
Chloroform	µg/l	0	0
Bromate	µg/l	< 2.0	< 2.0

In the past, the, final treatment of infiltrated water consisted of slow sand filtration only. Later, other treatment techniques were added. The slow sand filters are still functional when the abstraction of water is done in an open system. In that case, the slow sand filters remove pathogenic micro-organisms.

Infiltration water from the large rivers and lakes can have a high hardness. Softening with pellet reactors is then undertaken to reduce the hardness to about 1.5 mmol/l. These pellet reactors are used after aeration and before rapid filtration, in order to remove the carry-over.

When they have not been removed during preliminary treatment, organic micropollutants are removed by means of powdered carbon or activated carbon filtration. The addition of powdered carbon is done before (weir) aeration, because that process sufficiently mixes the powder with the water. When activated carbon filtration is used, it is done after rapid filtration.

To improve the removal of organic micropollutants, ozonation can be used. Ozonation oxidizes organic macro-molecules into smaller organic molecules, which can be removed more easily during activated carbon filtration. A disadvantage of the combination of ozonation and activated carbon filtration is the high level of biological activity in the activated carbon filters. This may lead to the growth of microorganisms in the water, which requires disinfection after activated carbon filtration. This disinfection is done in the slow sand filters.