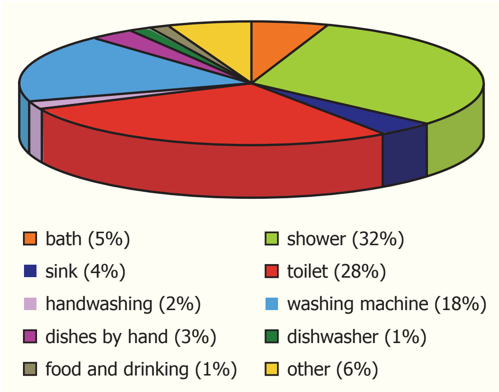
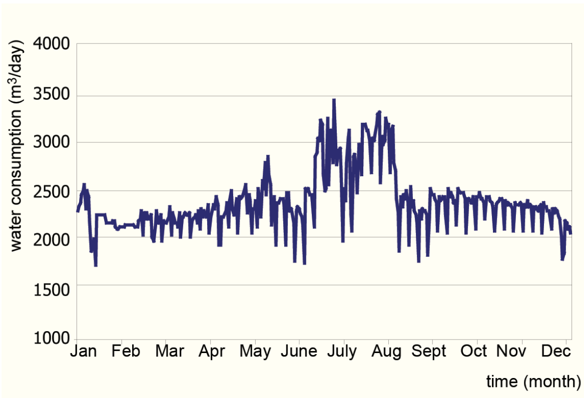
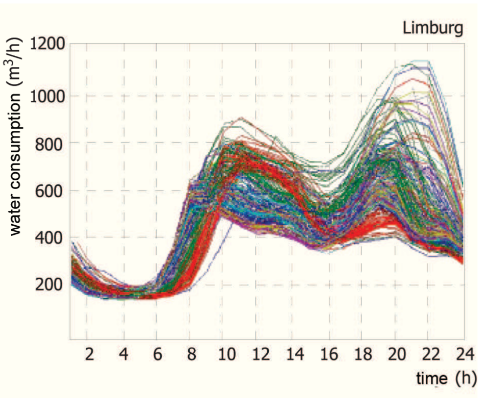
Water consumption







Contents

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

1. Introduction

Water is used for various purposes.
As part of the hydrologic water cycle, water is used for:

- pushing back salt intrusion at river mouths
- replenishing ground- and surface water for water level control (because of "consumption" by evaporation, irrigation, etc.)
- flushing waterways (canals, etc.) for quality control
- private water supplies (private abstraction by the industrial, agricultural, and horticultural sectors and electricity companies)

and

- public water supplies for domestic use and for small businesses and the industrial sector (water companies).

Each public water use requires a different quality but it is not practical nor economical to produce many different types of water. Therefore, there is a clustering of water qualities for multiple uses. Sometimes, water is supplied with a base quality which is later upgraded at the place of use.

The most common types of water uses are named in Table 1. The typical quality characteristics have also been shown. For all the uses, "cleanliness" is a general quality characteristic.

2. Calculation of water demand

Water demand is the volume of water that is attributed to an individual or to an activity per unit of time (m^3/s). The demand has a significant fluctuation over time and it can be expressed in different ways, including the amount that is consumed over an entire year (m^3/y) and the average consumption per day.

Table 1 - Characteristics of different water types

Water type		Characteristics
Drinking water	- household purpose - drinking purpose	Clean + healthy
Cooling water	- once-through - open circulation	Cold, clean + soft/low salt (scaling)
Rinsing water	- cold - warm	Clean + soft (scaling)
Boiler feed water	- low pressure - high pressure	Clean, soft + salt free (scaling)
Greenhouse water	- circulation	Low salt (affect plants)

The demand for public water consists of different end-uses, such as domestic (Qd), public buildings (Qp), small businesses (Qc) or industry (Qi), of which the sum constitutes the actual water demand (Qa) of the system. The total demand (Qtot) is determined by the sum of the actual demand and the losses (Ql)

The losses are normally defined as a percentage of the actual demand: $Ql = \alpha * Qa$

In practice, the water losses are estimated through the difference between the paid water and the produced water, while the volume of the water losses depends on the treatment processes, the transport and distribution of water (including, cleaning and pipe breaks), the efficiency of the water payment system and the control that is done on the distribution network to avoid illegal connections. In developed countries the percentage of water losses in the distribution network is generally low, achieving 5 to 15% of the total consumption (for an old and well maintained network), but in developing countries these percentages can go up to 50 to 100%.

The average demand for domestic water supply depends on certain consumer groups and the size of the served population by the supply system. The water demand per capita attributed to individuals or groups of consumers vary with geographic regions and they are influenced by several factors, such as:

- Water availability (the easier is to obtain water, the easier is to use more water)
- Climate (the hotter, the larger the water demand)
- Water price (the cheaper, the smaller the concern forwater saving)
- Culture (In Africa there are other water habits than in the USA)

Table 2 shows the constituents of domestic water consumption in the Netherlands. The total average domestic water demand of a certain community is

Table 2 - Constituents of domestic water consumption in The Netherlands

Toilet	35 L/d
Personal hygiene	35 L/d
Clothes washing	20 L/d
Dishes washing	15 L/d
Drink/cook	10 L/d
Cars washing	1 L/d
Irrigation / recreation	2 L/d
Total	118 L/d

the sum of the average demands of each population group with a certain water demand per capita:

Q = ∑ (Popi * Capi) (l/d)

Since the water supply systems are designed to cover the situation at present, but also on the long term, the above calculations should be done for both situations.
For the long term situation, it is necessary to consider an additional water demand that results from the improvement of access to potable water (in the case of developing countries) and the expected population growth.

Table 3 shows that water consumption per capita differs greatly throughout the world. Even in the Netherlands, there are still large differences between urban and rural areas, and between water companies with and without water meters.

The water demand for public buildings and small businesses depends on the characteristics of the activities of that city or town. Table 4 shows the values of water demand for several activities.

Table 3 - Water consumption per person in the world

Location	**Consumption per person (l/p/d)**	**Background**
Tanzania (village)	10	Buckets with water from village pump
Maastricht / Tilburg	80	Urban area
Amsterdam / Rotterdam	155	No water meters, big urban area
Zeeland / Drenthe	170	Rural area
Romania	500	No costs, leakage, dissipate
New Mexico (USA)	1,500	Green gardens in desert

Table 4 - Water demand for several public/comercial activities

Schools	15 - 30 L/d
Eldery houses	90 - 140 L/d
Hospitals	220 - 300 L/d
Hotels	90 - 120 L/d
Restaurants	65 - 90 L/d
Motels	25 - 40 L/d
Cinemas	10 - 15 L/d
Offices	24 - 40 L/d
Stations (Buses, trains)	15 - 20 L/d
Cattle	10 - 35 L/d

The total water demand attributed to the public buildings and small businesses of a certain city or town, results from the sum of the individual demands or is calculated by considering it as a percentage of the total demand.

The water demand for industries is influenced by:
- the number of industries
- the type of industrial activity
- production hours
- production volume

The industrial demand is not constant over time and when specific information does not exist, the industrial water demand is usually estimated as a percentage of the total consumption.

3. Fluctuations in water demand

The water used by costumers is decisive for the design of any drinking water supply system. Their use fluctuates widely throughout the day and during the night, there is a relatively low demand. During the early evening hours of summer days, there is a very high demand (watering the garden).

Water demand varies thus according to patterns that occur within the year, the month, the week, the day and even the hour. Such variations are dependent on factors that include weather (e.g. temperature, and occurrence of precipitation), variation of social and economic activities, habits of the customers, size of the community, etc.

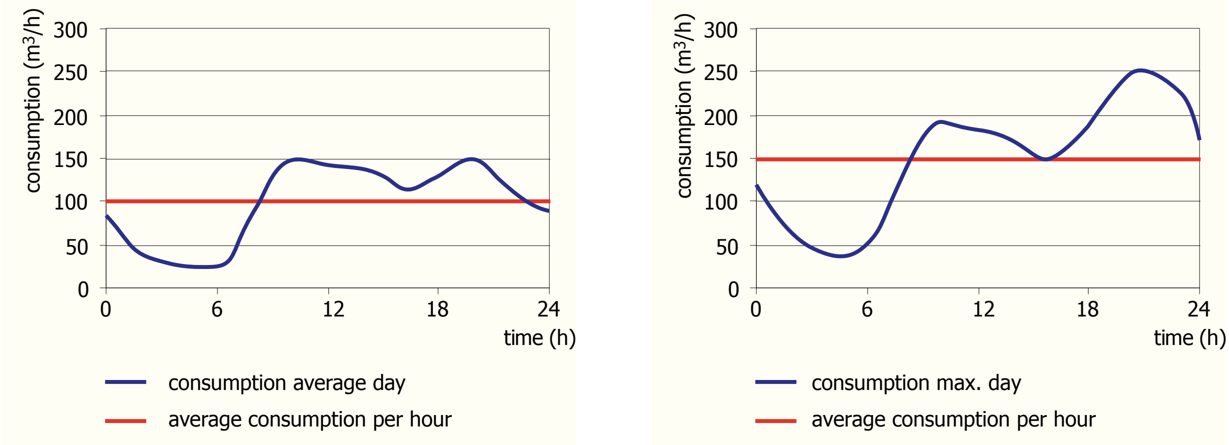


Figure 1- Consumption on an average and maximum day (pattern and average)

These fluctuations lead to demand peaks. A peak factor expresses then the deviation in the demand of a city, town or region, during a certain period in time (day, week, month or year), from the average demand for the same period. The peak factors are used to design the individual water supply sub-systems guaranteeing an efficient functioning of that sub-system. Table 5 provides examples of typical peak factors.

As can be seen in Figure 1, the hour pattern on the maximum day is different from that on the average day. Therefore, it can be concluded that the peak factors are not independent, and, in addition, they differ from country to country, region to region and city to city.

For design purposes, composite peak factors are used. Table 6 shows the general design capacities for the different aspects of a water supply system.

Table 5 - Peak factors per period

Period	Peak factors	Difference in relation to
Year (dry / wet)	0.94 - 1.08	Average year consumption (10 years, excl. autonomous growth)
Half a year (summer/winter)	0.94 - 1.07	Year consumption / 2
Month	0.92 - 1.10	Year consumption / 12
Week	0.70 - 1.25	Year consumption / 52
Day	0.65 - 1.40	Year consumption / 365
Hour	0.25 - 1.80	Day consumption / 24
Minute	0.25 - 1.85	Day consumption / 1,440
Days in a week	0.75 - 1.10	Week consumption /7

Abstraction, treatment and transport are generally based on the demand of the maximum day which occurs once every 10 years. In order to limit the costs of production and transport, storage facilities are designed for dampening the daily fluctuations.. As an example, Figure 2 shows that for an imaginary use pattern, no storage is necessary when production equals the maximum hourly use, and that a storage capacity of 23.3% of the average daily use is required when the production capacity equals the average use calculation.

For the average water demand the following applies: Q0 = average annual demand / (365 • 24)

The average demand on a maximum day in a dry year is, for the given example, then:
Qd= (1.08 • 1.40 =) 1.5 • Q0

Table 6 - Capacity of house connections

Connection type	Number of connections	Capacity per connection (l/h)
Toilet (free fall), washbasin	2	150
Washbasin	2	300
Shower	1	400
Kitchen tap	2	600
Boiler	-	750
Watering of garden	1	1,200
Toilet (pressure)	-	3,000
Total installed capacity	8	3,700
Total simultaneous capacity (by error law)		1,595
Average consumption with 130 l/p/d and 2.5 p/house		14

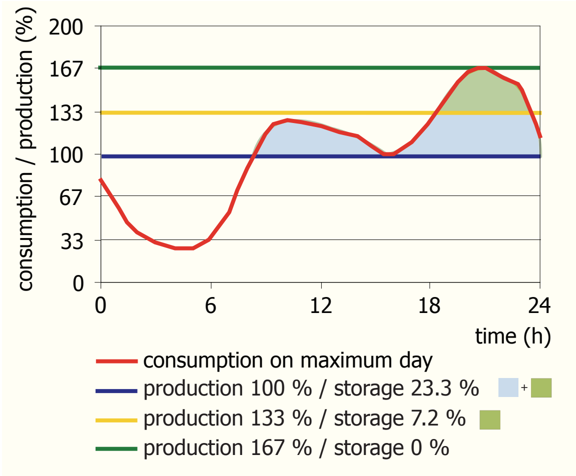


Figure 2- Consideration of production capacity versus storage capacity

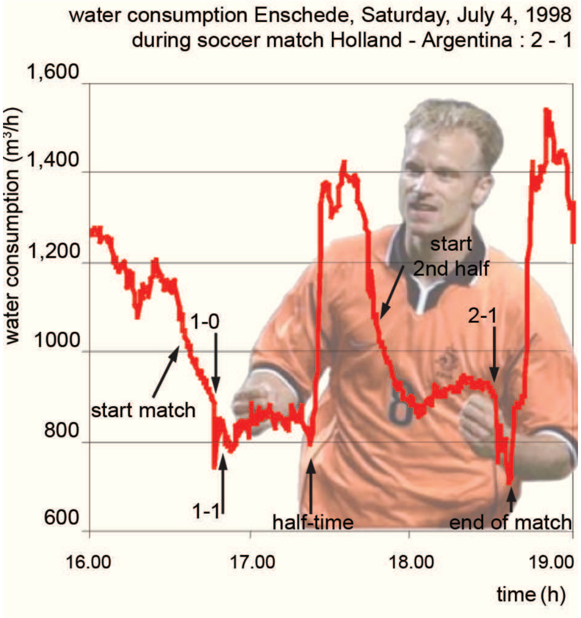


Figure 3- Water consumption in Enschede during a soccer match: Netherlands - Argentina (quarterfinal WC 1998)

Distribution is usually designed for the demand on the maximum hour of the maximum day.

And, the demand of a maximum hour of a maximum day in a dry year is then:

Qm = (1.08 • 1.40 • 1.80 =) 2.7 • Q0

Other peaks can be observed when there is an important football game on TV. At half-time, a lot of people go to the toilet or make a pot of tea or coffee. Also, exciting game moments can be deduced from the water consumption. During the game , less water is used because everyone is glued to the TV, and, the same applies to the end of the game (Figure 3). When Johan Cruyff gives commentary during half-time, we also see a “dip” in water consumption!

Looking at the house level, the water use of an individual house, the one who opens the tap, is extremely erratic. The average consumption of a larger group of consumers is less erratic. Dampening of the peaks occurs, because not everyone uses water at the same time, and both large and small water uses occur simultaneously. In order to determine the dampening of the consumption of an amount of water, statistical analysis provides us with a cumulative error law that can be used. Inside a house, pipe diameters are then chosen based on the maximum tap capacity of the specific taps. The home connection is determined by the maximum instantaneous use by its residents. This is less than the sum of the capacities of the different taps, because it never happens that all taps are in use at the same time

4. Forecasting Water demand

For the planning of new water supply infrastructures , future water demand has to be predicted over a period of 10 to 20 years. For the daily operation of a treatment plant, the water use has to be reasonably well-predicted for the coming hours. The timeframe of a prediction depends, therefore, on what the prediction is used for. Table 7 gives an overview of goals and timeframes of forecasts.

Operational and tactical predictions are based on the consumption patterns described above. The deviations from the basic patterns are especially important for the operational control and management.

Strategic predictions are based on the extrapolation of historical data, requiring the analysis of the developments of the annual water use.

To predict the annual water demand, two different methods can be examined:

Table 7 - Goal and timeframe of forecast

Goal forecast	Timeframe	Aspect
Planning new production sources	Upcoming years	Strategic
Setting up available capacity	Upcoming year	Tactical
Management infiltration / reservoirs	Upcoming month / week	Operational
Management production / clear water reservoir	Upcoming day / days	Operational
Management transport (pumps, etc.)	Upcoming minutes / hours	Operational

- extrapolation of the total water use
- extrapolation and summation of the water uses per consumer group

The second method is more detailed and requires much more data.

Extrapolation is based on the assumption that water demand increases or decreases by a fixed growth factor, as expressed by the following equation:

$$demand_p + n = demand_p \cdot GFn$$

where:
$demand_p$ = demand in period p
$demand_p+n$ = demand in period p+n
n = number of years
GF = Growth factor per year

When planning for future water demand, it is important to determine when the capacity increase is necessary.
Here, the legal supply obligation is important, meaning that the available capacity must always be larger than the demand.
A large over-capacity, however, is expensive. On the one hand, for this reason, expansions are built in phases, and its realization is postponed as long as possible. On the other hand, an over-capacity provides a greater reliability of water supply and a better operational flexibility. With all these uncertainties, the water supply engineer will have to choose between certainty and costs.

Example of the analysis of the drinking water use in the Netherlands

In Figure 4 the history of the drinking water use in the Netherlands is given (m^3 of water supplied to the network per year). Table 8 gives growth factors for the annual water use over decades (C_{1960} = 1.64 C_{1951}). These growth factors can be converted to a growth factor per year ($GF_d = GF_j^{10}$), and expressed as the growth percentage per year (a yearly growth factor of 1.051 equals a yearly growth of 5.1%). The average growth over 50 years amounts to 2.7% per year, with a growth above 5% in the period 1950 to 1970, and even a decrease during the last 10 years. Until 1960 the increase in water use was mainly caused by growth in the population and an increase in the degree of supply (percentage of connected plots). In addition to that, the water use increased because of a growing water civilization (showering, washing, watering the garden), see Figure 5. In the period after 1950 and until the present, two breaks in the trend have been observed. The first was a result of the implementation of the Surface Water Pollution Act (Wet Verontreiniging Oppervlaktewater - WVO) in 1974, which required that people would pay for the treatment of wastewater. The second break was the result of public awareness campaigns for water saving, which started in 1990, and the introduction of a tax on drinking water (eco-tax).

5. Water use in the Netherlands

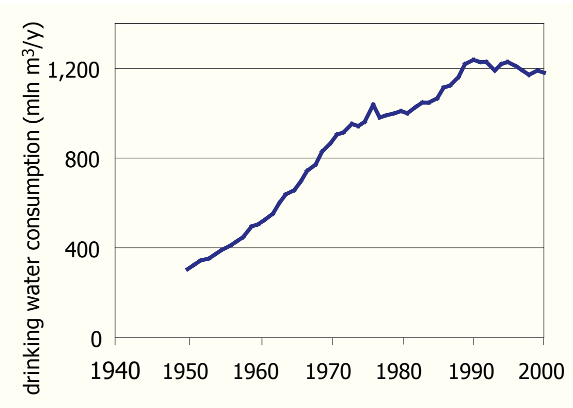


Figure 4 - History of drinking water consumption in the Netherlands (mln m^3/y)

Table 8 - Growth factor per decade and growth per year

	1951 - 1960	1961 - 1970	1971 - 1980	1981 - 1990	1991 - 2000
Growth factor	1.64	1.72	1.16	1.22	0.96
Growth per year	5.1%	5.6%	1.5%	2.0%	-0.4%
Average over:					
Last 50 years	2.7 %	2.7 %	2.7 %	2.7 %	2.7 %
Last 40 years		2.2 %	2.2 %	2.2 %	2.2 %
Last 30 years			1.0 %	1.0 %	1.0 %
Last 20 years				0.8 %	0.8 %
Last 10 years					-0.4 %

In the Netherlands almost 10 billion m^3 of water are used yearly (CBS 1996), not including private abstraction by the agricultural and horticultural sectors (Table 9).

Power stations are the largest water users (63% of the total consumption). This water is used almost entirely for cooling (99.5%) and directly abstracted from surface water. Also, industry is a considerable water user (26% of the total consumption). A large part of this water, mainly abstracted from surface water, is used as cooling water (83.2%) as well. Households use approximately 730 million m^3 of water per year. Small businesses and organizations use, approximately 300 million m^3 per year. Most of the water used by households and small businesses is produced by water companies. These water companies also use water themselves during the production process. Losses during distribution are attributed to the consumers. As shown in Table 10, the amount of water supplied to the network was not exactly equal to the amount used by the customers

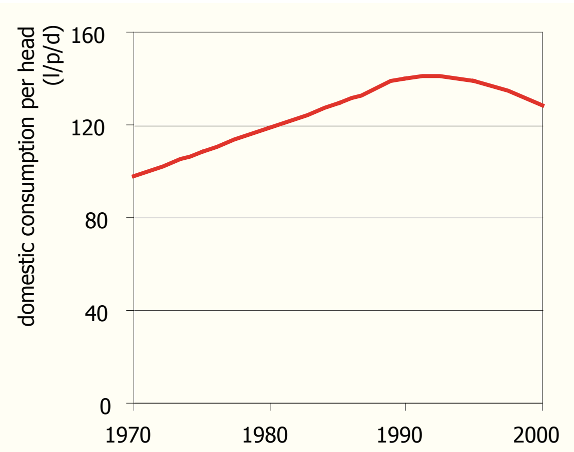


Figure 5 - Trend in water consumption per person for households (l/p/d)

Supply by user category

Households

In the Netherlands, households are water companies' largest users with approximately 740 million m^3/y. The average consumption per person within the household is 128 l/p/d (with 15.8 million inhabitants in the Netherlands). Figure 6 shows how the use of water is divided. Almost 50% of the water is used for activities for which a very good quality is required to avoid direct health risks, being "shower" the most used (32% of total). For flushing the toilet (28%) and washing machines (18%), a less strict quality is sufficient (household water).

Small business consumers

Small business water use can also be indicated as "water use for commerce, services and government" (CSG) or "consumption for commercial, public, agricultural and recreational reasons" (CPAR). The small business water use is about 210 million m^3/y.

In Figure 7 the development of water use by small businesses is plotted.
The increase up until 1990 was caused by an increase in water use for agriculture and horticulture, and by the decrease in large business consumption (classification in another category).

Table 10 - Water supply by drinking water companies (VEWIN 2000)

Kind of water	Own production	Mutual exchange	Supplied to distribution network	
	(mln m^3/y)	(mln m^3/y)	(mln m^3/y)	(%)
Drinking water	1,183	4	1,187	93
Other water	78	7	85	7
Total	1,261	11	1,272	100

Table 9 - Water consumption in the Netherlands (private abstraction by agricultural and horticultural sector not included) (CBS 1996)

	Consumption (mln m^3/y)	Percentage (%)	Percentage cooling water (% of consumption)
Power stations	6,199	63	99.5
Industry, refineries and mining	2,529	26	83.2
Households	733	7	-
Small companies and organizations	297	3	-
Water companies	52	1	-
Total water consumption	9,810	100	84.3

Industry

The industrial sector in the Netherlands uses approximately 170 million m^3 of water per year from the public water supply system. This water is used as a supplement to the sector's own abstraction of groundwater and is used where higher quality water is needed, such as for process water and sanitation. Figure 8 shows the development of public water use for the industrial sector.

The increase in water use until 1990 can be explained by the growth of the industrial sector. Note that suh increase was smaller than the increase in production. The decrease after 1990 is the result of internal water savings..

"Other water"

"Other water" is defined by the supply of water, separated from the public water supply, through a second network. The costs of construction and operation of a second network are so high that it is only profitable in certain situations. Two examples of other types of water are the supply of household water and industrial water.

The idea of providing household water is not to waste expensive drinking water in toilet flushing. The possibility of using less quality or inferior source water for flushing, in order to save treatment costs, led the Netherlands to undertake several dual network projects. However, it was proved that the costs of such projects are too high and that contamination of drinking water, due to cross connections, can create large risks.The total amount of household water in the Netherlands is, consequently, negligible (<0.1 million m^3/y).

The supply of industrial water has steadily increased over the last few years to 85 million m^3/y (as of 2000). An industrial water project is frequently profitable because of the large water use at one location. The costs of constructing an extra pipeline (network) can, more easily be earned back by the savings on the costs of the public water infrastructure. Besides, the risk of cross connections is more easily overcome by the simpler setup. It is possible that industrial water

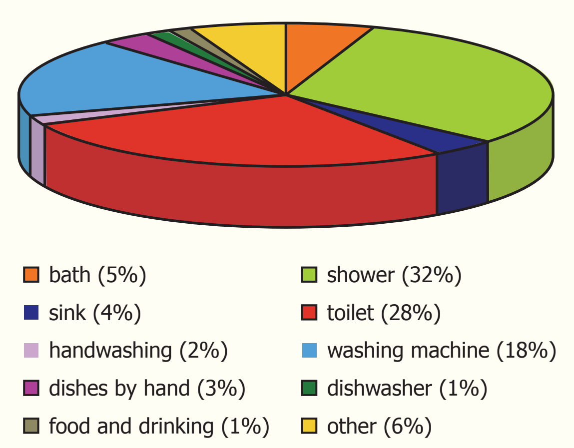


Figure 6 - Average household drinking water consumption (VEWIN 2000)

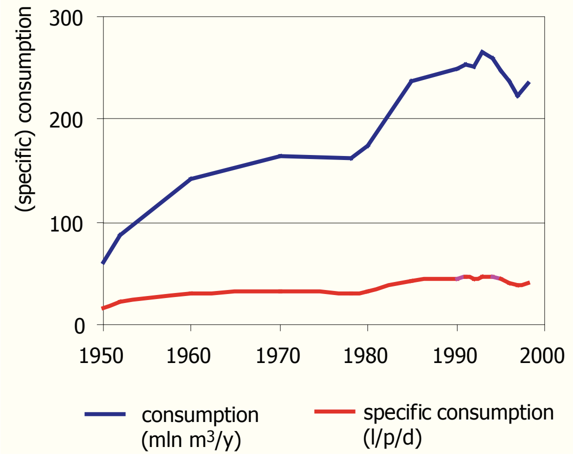


Figure 7 - Trend in water consumption for small business (mln m^3/y and l/p/d)

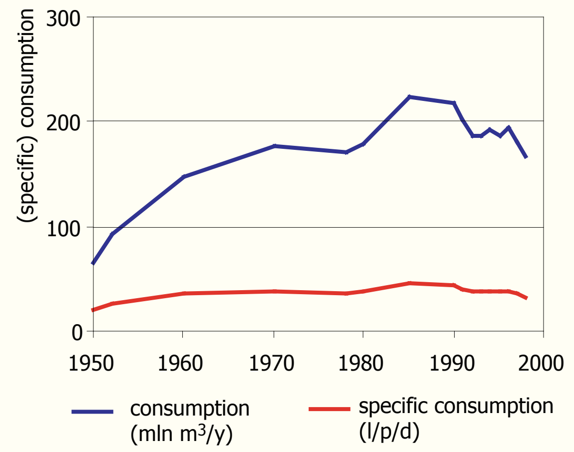


Figure 8 - Trend in reduction of drinking water consumption by the industry (mln m³/y and l/p/d))

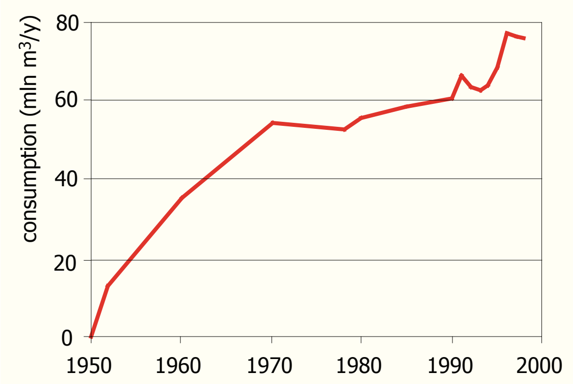


Figure 10 - Trend in delivery of "other water" by drinking water companies (mln m³/y)

has either a higher or lower quality than drinking water, depending on its application in the industry.

Industrial water provided by the water companies is generally supplementary to the industry's own water abstraction. A number of large industries that use industrial water provided by Dutch water companies include:

- Corus IJmuiden (30 million m³/y process and cooling water, from the WRK system)
- AKZO Delfzijl (10 million m³/y injection water for salt extraction, from Veendam (Figure 9)
- CVG Velsen (4 million m³/y process water, from the WRK system)
- DOW Terneuzen (14 million m³/y process water, demineralized water, from the WBB system and from seawater)
- Shell Moerdijk (5 million m³/y process water, from the WBB system via the Zevenbergen pumping station)

Figure 9 - Industrial water project Veendam (Groningen) with anaerobic injection water from surface water

Figure 10 shows the development in the supply of “other” water. The increase results mainly from the growth of water use by Corus (steel industry) and of new industrial water projects.