3 Water, networks and crossings

Contents

3.1 Water balance

3.1.1 Earth

In case all ice would melt

The surface of the Earth is approximately 510,000,000 km² large (see page 23) and there is 1 390 000 000 km^3 water. So, if there were no differences in temperature or ground level and water was equally dispersed over the Earth, the planet would be fully covered by a 2.7km deep ocean (Fig. 352)[82]. The 48m upper layer would be ice.
However, there is 148 900 000 km^2 land and 361 100 000 km^2 water. So, 29% is land. It contains 3% of all existing water, and 2/3 of that part is frozen. If all ice would melt by gobal warming sea level would raise 66m. Water would submerge the most densily populated areas of the Earth. Fortunately the sun still adds snow to the poles.

The case of maximal glaciation

On the other hand, during an age of maximal glaciation the the amount of glacier ice would have been three times larger as the present ice volume. The sea level would have been lowered as much as 140 meters. The continental shelves would have been exposed to the air so man could live there.
The average height of the land is 823 m above sea level. We can calculate the potential mechanical power of the system of the water streaming to the sea over the land. Assuming that 37,000 km³ of runoff water will flow downhill 9 TW (see *Fig. 2* and also *Fig. 16*) would have been produced by the runoff water.

The amounts of water

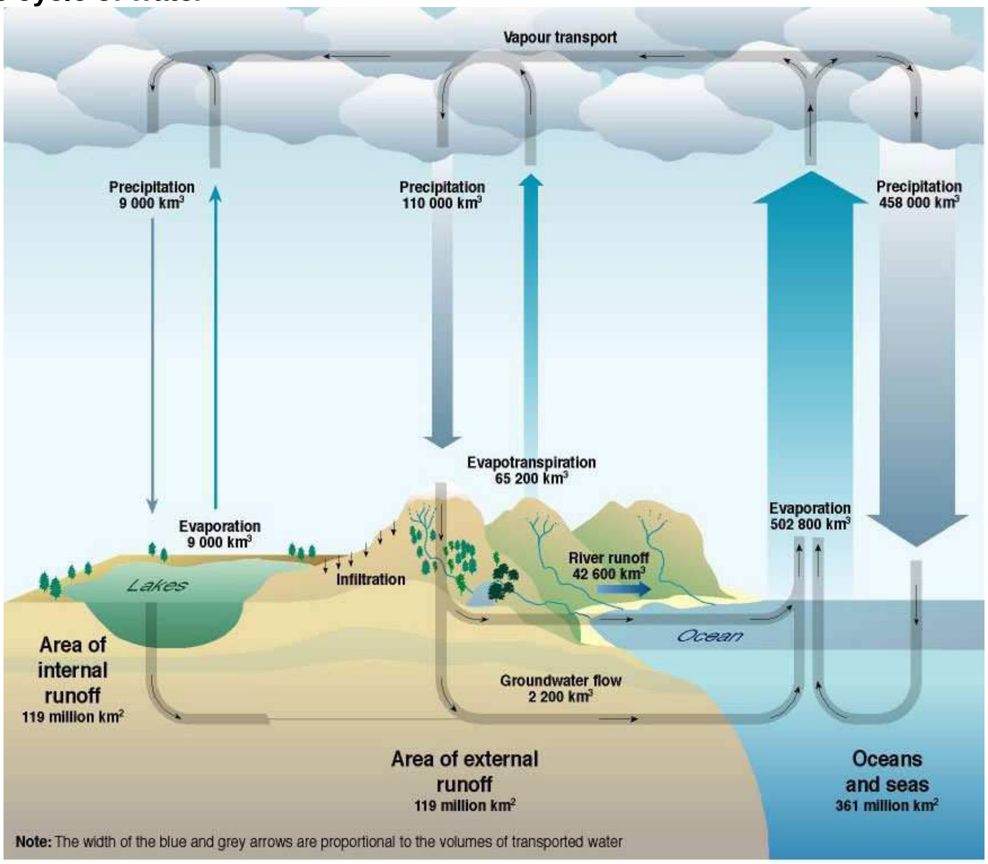
1000 km3	**salt**	**fresh**	**total**	**m3/m2**	**mm**
atmosphere		12,9	12,9	0,025	25
sea	1 338 000		1 338 000	2 624	2 624 021
land, from which	12 957	35 004	47 960	94	94 057
snow and ice		24 364	24 364	48	47 782
subterranean	12 870	10 530	23 400	46	45 891
lakes	85,4	91	176,4	0,346	346
soil moisture		16,5	16,5	0,032	32
swamps		2,1	2,1	0,004	4
life	1,1		1,1	0,002	2
total	1 350 957	35 004	1 385 960	2 718	2 718 079

Fig. 352 *Total amount of water on Earth(see also* ***Error! Reference source not found.****)*

The amounts of water on the Earth are confined in reservoirs of different size and form. In their order of importance these reservoirs are: oceans, glaciers, groundwater, lakes and rivers, atmosphere and biomass (all living matter man included). In actual fact 97% of all surface water is confined in the oceans and most of the other 3% is fixed in glaciers. So, little water is left over for the other reservoirs.

3.1.2 Evaporation and precipitation

The cycle of water



Igor A. Shiklomanov, State Hydrological Institute (SHI, St. Petersburg) and United Nations Educational, Scientific and Cultural Organisation (UNESCO, Paris), 1999; Max Planck, Institute for Meteorology, Hambuirg, 1994, Freeze, Allen, John, Cherry, Groundwater, Prentice-Hall: Englewood Cliffs NJ, 1979.

Fig. 353 The hydrological cycle

Continuously changing the state of water

The sun is the generator or motor of the changes in the state of water. The sun will evaporate water of the oceans and other other water reservoirs to the 100% water vapour saturation of the air. The saturation of the air with water vapour is determined by the temperature. The higher the temperature the more vapour the air can contain. The vapour is perceptible by the clouds in the air because of the always present condensation nuclei .The wind will move the clouds from the oceans to the continents and depending the temperature above the continents will happen nothing (temperature ≥ temperature in the cloud) or it will rain or snow (in both cases is the temperature ≤ temperature in the cloud). Rain, hail and snow is called precipitation.

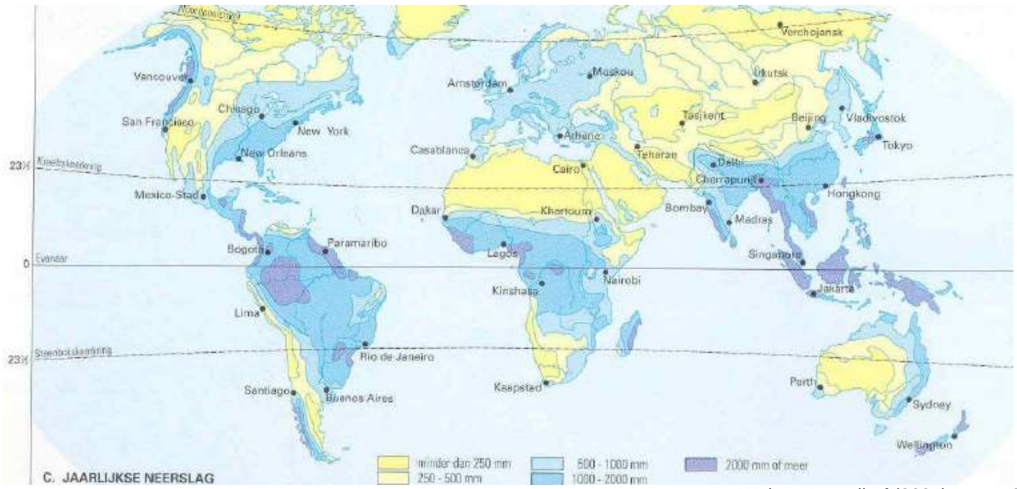
Energy needed for evaporation

You can evaporate $1m^3$ water by 2.26GJ, 2.26GWs, 630kWh or 72Wa (say 72 m^3 natural gas). The Earth's surface receives 81 PW from sun. So the sun could evaporate 1.1 million km^3 per year. Actually less than half is evaporated in unsaturated air only (Fig. 354). It falls down discharging its solar heat in the same time as soon as the air becomes saturated in cooler areas by condensation (precipitation). That is nearly $1m^3/m^2$ or 1m and more precise 957mm (Fig. 354).

	evaporation	**precipitation**	**runoff**	**evaporation**	**precipitation**	**runoff**
	1000 km3/a			**mm/a**		
sea	419	382		1157	1055	
land	69	106	37	467	717	250
total	488	488		957	957	

Fig. 354 *Yearly gobal evaporation, precipitation and runoff*

Areas like deserts receive less than 200mm, areas like tropical rain forests more than 2 000mm average per year (Fig. 355).



Wolters-Noordhof (2001) page 181

Fig. 355 *Global distribution of precipitation*

Europe has the same extremes (Fig. 356).

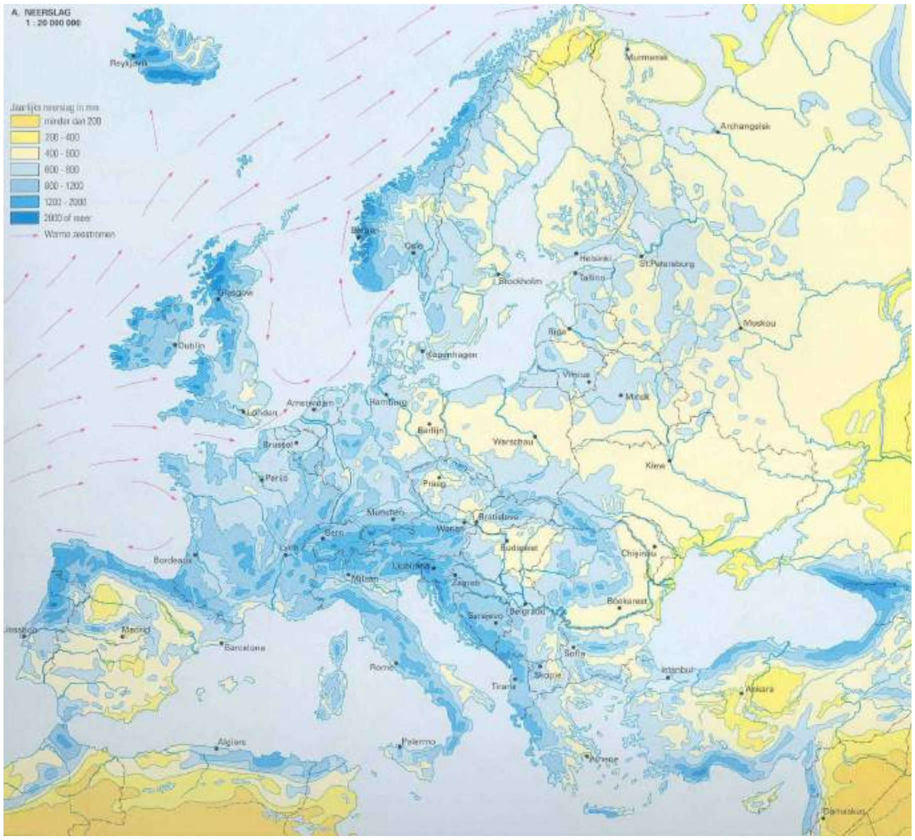
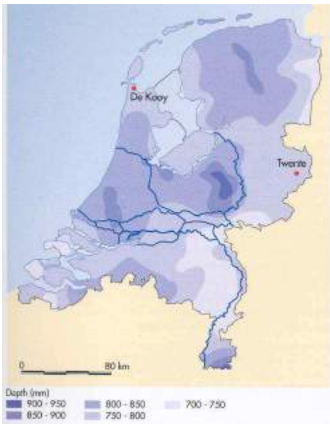


Fig. 356 *European distribution of precipitation* (Wolters-Noordhof (2001) page 61)

3.1.3 Runoff

The Netherlands receives from 700mm in East Brabant to 900mm precipitation in central Veluwe (*Fig. 357*), but there have been years of 400mm and 1200mm precipitation.



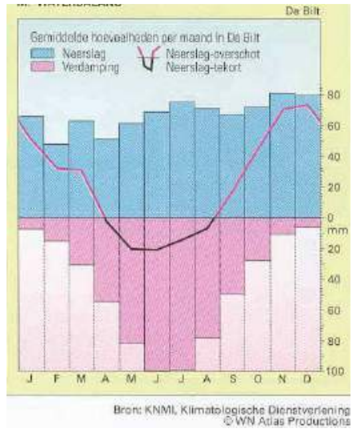


Fig. 357 Distribution of precipitation in the Netherlands (Huisman, Cramer et al., 1998; page 18)

Fig. 358 Precipitation minus evaporation in the Netherlands (Wolters-Noordhof, 2001; page 53)

If precipitation exceeds evaporation lakes and subterranean aquifers fill up. As soon as these cannot be filled up in time, water runs off subterranean or along brooks and rivers (*Fig. 359* and *Fig. 360*).

That part of the precipitation that reaches a stream is called runoff. The water during rainfall will gather into rills and streams down the slope. During and after the rain part of the water will soak into the ground. If the soil is saturated with water the remaining water will stream together in small streams and form a river. The groundwater flows also downhill and where the water bearing layer crops the slope a source will come out. The surface water and the subterranean water feed together a river. When the catchment area is large enough a permanent river will be the result. An estimation is made that ⅛ of the annual runoff will reach directly overland the sea while the remainder part will go underground.

the Netherlands receive runoff from catchment areas of the Rhine (entering the Netherlands in Lobith), Meuse and Scheldt rivers.

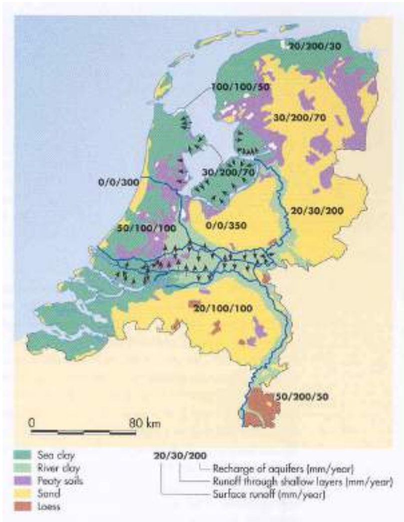


Fig. 359 Major soil types and average annual runoff in the Netherlands (Huisman, Cramer et al., 1998; page 21)

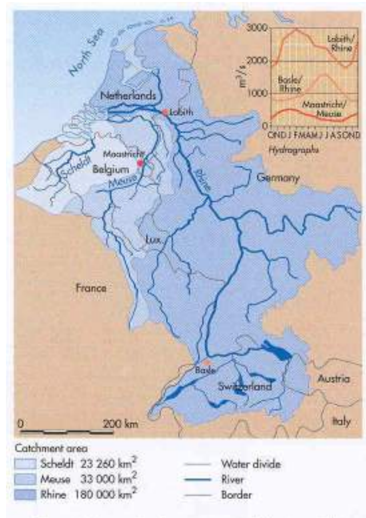


Fig. 360 Received runoff in the Netherlands (Huisman, Cramer et al., 1998; page 13)

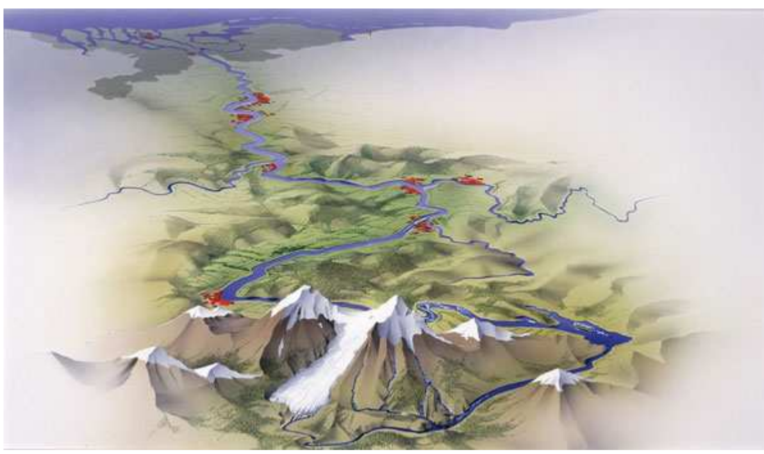


Fig. 361 The river basin of the Rhine (Paul Maas, opdrachtgever: Thieme Meulenhoff)

The river Rhine for example

The river Rhine has a catchment area of 160 000km^2 with an annual average of 1 775mm precipitation minus 1 392mm evaporation in the part of that area as far as Lobith. So, approximately 383mm over an area of 160 000km^2 produces 61km^3/year. So, on average 1942m^3/sec of water should run off and enter at Lobith.

Levelling by seasons

Snow and ice in mountains level out seasonal fluctuations of rivers by storing precipitation in winter, releasing it in summer[83] (see *Fig. 361* and *Fig. 363*).

Fig. 362 Source of the Rhine
(http://www.natuurdichtbij.nl/kennismaken/)

Fig. 363 Precipitation in the basin
(http://www.natuurdichtbij.nl/kennismaken/)

Discharge related to catchment area

In *Fig. 364* a rough approximation of discharge related to catchment area is shown. A big spot indicates the mentioned values of the river Rhine and a line is drawn for any catchment area producing a discharge in the Rhine circumstances. However, if precipitation is more than the average mentioned the line shifts upward, if evaporation or other reductions are more than mentioned, it shifts downward.

As a rule of thumb the m^3/sec of discharge is 1/100 of the km^2 catchment area[84], but any river has its own graph, less regular than suggested here.

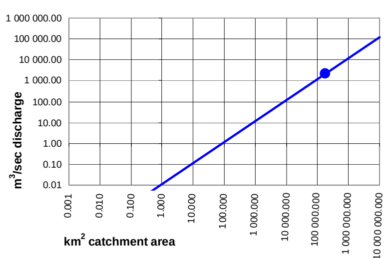


Fig. 364 Discharge Q roughly related to catchment area
(author Jong)

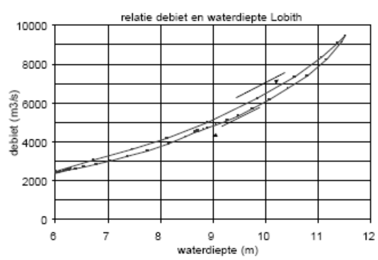


Fig. 365 Discharge Q related to water depth H near Lobith
(http://www.geog.uu.nl/fg/mkleinhans/teaching/tgrs-hw.pdf#search=%22waterdiepte%20Rijn%22)

Discharge related to depth

The relation of discharge to the water level near Lobith in *Fig. 365* is important for the height of dikes and the draught of ships, but it changes in time because of sedimentation and excavation.

Discharges in time

Because precipitation and evaporation differ much per day, the discharge of the Rhine differs daily (see *Fig. 366*), as unpredictably as the weather forecast.

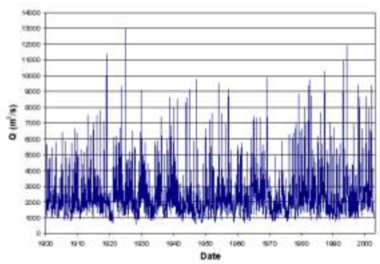


Fig. 366 Daily average discharge of the Rhine at Lobith (Lecture Marc F.P. Bierkens UU Faculty of Geosciences)

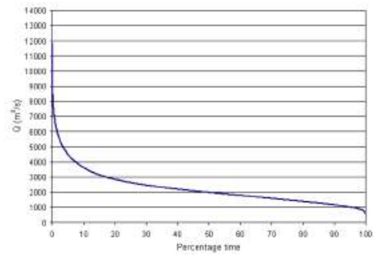


Fig. 367 Duration line of Rhine discharge at Lobith (Lecture Marc F.P. Bierkens UU Faculty of Geosciences)

Ranking *Fig. 366* you can derive a 'duration line' as in *Fig. 367*, indicating how often you can expect a given discharge to be exceeded.[85] From that figure you can conclude that 50% of the time the discharge of the Rhine did not exeed 2000m^3/sec. The mirrored graph gives the percentages of underspending.

Local impact of rain on discharge

The discharge of a river fed by a catchment area increases some time after the first rainfall (see *Fig. 368*) and after the last rainfall it continues some time, depending on the size of the area.

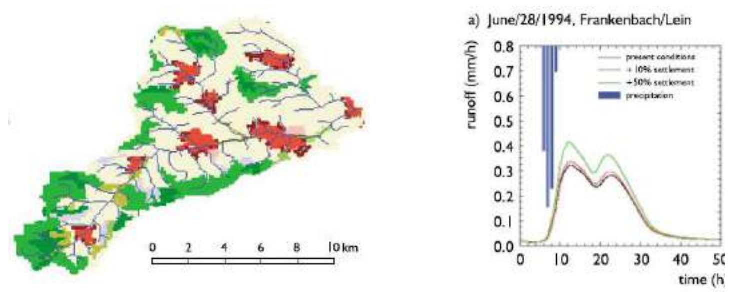


Fig. 368 Local impact of rain in hours R=10km (http://www.ncr-web.org/downloads/NCR18nl-2002.pdf)

Extreme situations

Suppose an unusual system of heavy showers follows the basin around the course of the Rhine and those of its feeding rivers like the Main and Mosel

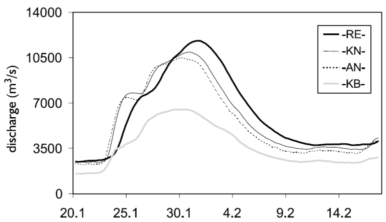


Fig. 369 Flood 1995 (http://www.ncr-web.org/downloads/NCR18nl-2002.pdf)

Fig. 370 Impact of rain in days R=300km (http://www.ncr-web.org/downloads/NCR18nl-2002.pdf)

from Switzerland to Lobith and everywhere in the basin drainage is optimal. A wall of water then nears Lobith. How often will that happen, how long will it last? These are the questions to be answered to calculate risks of flooding.

3.1.4 Static balance

Static forces and the potential energy along a slope

The weight W of a bullet on a slope of α degrees can be resolved in factors perpendicular and parallel to the slope (see *Fig. 372*). The force parallel to the slope equals $W \cdot \sin(\alpha)$.
For example, if $\alpha = 30^o$ that force is ½W, because $\sin(30^o) = ½$.

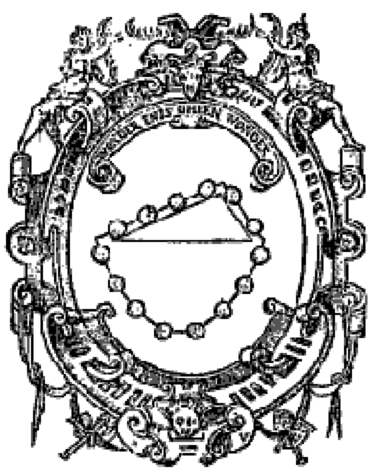


Fig. 371 Stevin: Clootcrans

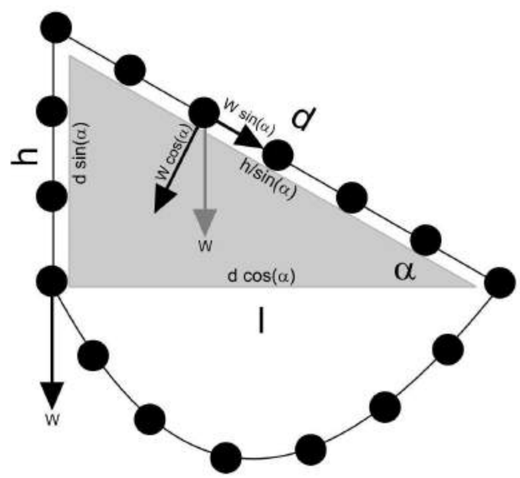


Fig. 372 Balance on different slopes

However, the distance d any bullet has to cover parallel to the slope into the base equals the vertical height *divided* by $\sin(\alpha)$. So, force times distance (potential energy) remains the same at both sides of the summit. For example, if $\alpha = 30^o$, the force is $½ \cdot W$, but the distance d to cover is $2 \cdot h$.
The 'Clootcrans' Stevin used as his logo (see *Fig. 371*) shows the equal potential energy of bullets according to their slope by intuition (count those at the corners in *Fig. 372* half).

Potential acceleration

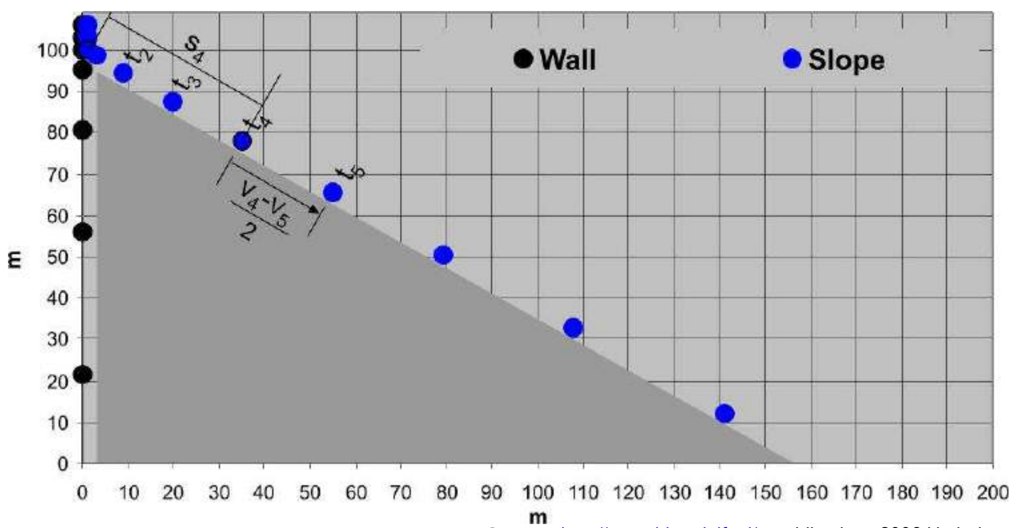
Force is defined as mass times acceleration (F = m·a).
At the vertical wall the potential acceleration equals the gravitational acceleration g = 9.807 m/sec^2.
If the masses of the bullets are the same, but the force F parallel to the slope is reduced by sin(α) then the acceleration 'a' parallel to the slope should be reduced by the same factor.
In case α = 30^o, a = ½·g = 4,904 m/sec^2.

3.1.5 Movement ignoring resistance

Bullets falling or rolling along a slope

Suppose we disconnect all bullets and supply every second a bullet on the summit at both sides.
Acceleration 'a' is defined as velocity v divided by time t (a = v / t).
As long as there is no resistance the velocity v of any bullet will increase constantly with the time t according to v = a· t. But, the covered distance will increase disproportionally, because every next second the bullet has covered a larger distance according to its increased velocity.

So, we can conclude a source distributing an equal amount of bullets per second produces a stream thinning downstream gaining mutual distance by increasing velocity (see *Fig. 373*).



Source: *http://team.bk.tudelft.nl/* > publications 2006 Hydrology.xls

Fig. 373 Bullets falling and rolling along a slope every second with a growing distance and velocity

Calculating increasing velocity v and covered distance s along a slope

The growing velocity v and covered distance s shown in *Fig. 373* are calculated as follows.
Between any two moments t_p and t_q (t_p<t_q) velocity grows from v_p into v_q with a constant acceleration a: $v_q - v_p = a \cdot (t_q - t_p)$. Let the time interval $(t_q - t_p)$ near zero. Then $v_q - v_p = a \cdot t$, or $v_q = v_p + a \cdot t$.
At time t half way any t_p and t_q the mean velocity v_m equals $(v_p+v_q)/2$. Here you can substitute v_q .
So, $v_m=(v_p+v_p+a \cdot t)/2$ or $v_m=v_p+ ½ \cdot a \cdot t$.

The distance s covered at any moment equals $v_m t$ if you take for v_p the velocity v_0 at the beginning.
So, s = (v_0 + ½·a·t)t or s = v_0.t + ½·a·t^2, shortly calculated as a time summing integral of s/t = v = a·t:

$$s = \int a \cdot t \, dt = C + \frac{1}{2} \cdot a \cdot t^2$$

Supposed the bullets start in rest (v_0=0) and then begin to fall or roll without resistance, then s equals ½·a·t^2 without initial C.

The velocity at the end of the slope is reached at slope length d = ½·a·t^2 = ½ ·g·sin(α)·t^2.

And d = h/sin(α) (see *Fig. 372*). So t^2 = (h/sin(α))/(½·g·sin(α)) or 2h/g·sin(α)^2.
So, t_{end} = sin(α)$^{-1}$·√(2·h/g).
At that time v_{end} = a·t_{end} = g·sin(α)·sin(α)$^{-1}$·√(2·h/g) = √(2·g·h).
So, the velocity at the end of the slope is independent from α: it is the same velocity of a falling bullet at the end of the wall. The average velocity along the slope is half of v_{end}: v_m:= ½ √(2·g·h).

Kinetic energy

If a bullet of mass m [kg] hits you with a velocity of v [m/sec], and you resist its force stepping back slower bringing its velocity back to zero, the bullet has lost m·v·(v - 0 m/sec)/2 = ½ m·v^2 energy.
That kinetic energy E_k could have been built up falling or rolling h [m] with an acceleration a [m/sec^2], according to E_p = F·h = m·a·h. Falling or rolling, the bullet lost E_p, gaining E_k, while E_p := E_k at last.
So, the process is described as m·a·h := ½ m·v^2 [joule].

Running water in a pipe

Suppose running water is a stream of more or less cohesive incompressible drops, flowing downstream in a volume per second of Q [m^3/sec] everywhere.
Suppose the bullets of *Fig. 373* are cubic metres water forced in a pipe of minimal cross section.
The average velocity will be the velocity at the end of the natural slope √(2·g·h) divided by two:
v_m = ½·√(2·g·h).
So, the cross section of a pipe with capacity Q should be at least A = Q/v_m = 2·Q/√(2·g·h) [m^2].
Its water content is A·h/sin(α) [m^3]. If the mass m [kg] of water relates to its volume [m^3] as ρ (normally 1000 kg/m^3) its mass equals ρ· A·h/sin(α) [kg].

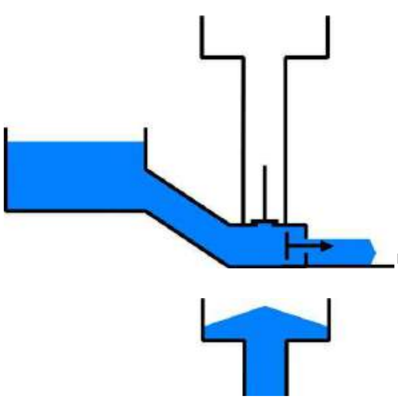
A water ram

A sudden obstacle at the end of the pipe (like a tap closed at once) shows the large amount of energy built up in flowing water. Such an obstacle has to resist a force F_1 equal to the weight of the water column divided by A [newton/m^2] and a force F_2 resulting from kinetic energy E_k = ½·m·v^2 divided by some distance s (braking distance) to get the force (energy is force times distance). If that braking distance is very small F_2 increases into infinity, breaking the water pipe.

A water column of height h on a surface A produces a force F_1 = ρ·h·A·g [newton].
A mass m = ρ·h·A/sin(a) [kg] water with a velocity v = ½·√(2·g·h) [m/sec] reduced to zero over a distance of s metre (braking distance) produces a force F_2 = ½·m·v^2/s:

$$F2 = \frac{1}{2}\cdot\frac{\rho\cdot h\cdot A}{\sin(\alpha)}\cdot\frac{\left(\frac{1}{2}\cdot\sqrt{2\cdot g\cdot h}\right)^2}{s} \quad \text{or} \quad F2 = \frac{1}{4}\cdot\rho\cdot A\cdot\frac{h^2}{\sin(\alpha)}\cdot\frac{g}{s}$$

The kinetic force F_2 is many times larger than F_1 = ρ·h·A·g caused by the weight of the water column (the difference is ¼·h/s·sin(α)). In the example of *Fig. 374* a kinetic force of flowing water is calculated as 500 times the weight of the water column.



slope angle	α	30.0	deg	(Input)		
slope	one to	1.73				
acceleration	a	4.9	m/sec^2			
height summit	h	1.0	m	(Input)		
slope length	d	2.0	m			
time to reach end of slope	t	0.90	sec			
end velocity free flow	v	4.43	m/sec		16	km/hr
average velocity	v_m	2.21	m/sec		8	km/hr
discharge	Q	1	m^3/sec	(Input)		
min. sectional plane of pipe	A	0.4516	m^2			
radius of pipe	r	37.9	cm	diameter	75.8	cm
content of pipe	C	0.90	m^3			
density of water	ρ	1000	kg/m^3			

braking distance	s	0.001	m	(Input)			
force by weight	F_1	4429	newton	452	kgf		
kinetic force	F_2	2213997	newton	225757	kgf	226	ton
proportion	F_2/F_1	500					
pressure at tap	p	4912447	newton/m^2	500912	kgf/m2	501	ton/m2
m height of rise		501	m				

Source: *http://team.bk.tudelft.nl/* > publications 2006 Hydrology.xls

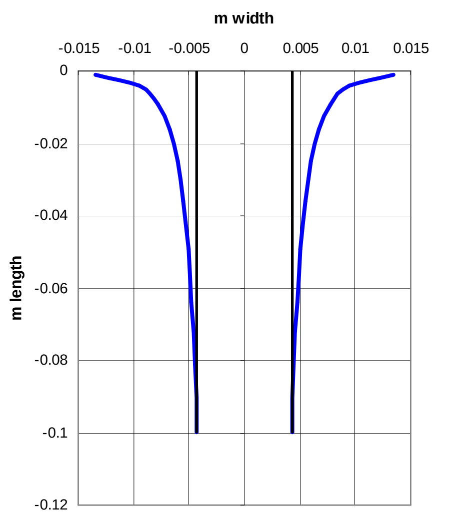
Fig. 374 Water ram

That force is utilised in a pumping device called 'water ram'. The pressure p built up in the water ram by suddenly closing the tap braking the flow to yield its kinetic force is utilised to push up the water through a valve. Theoretically the water column can be built up until 500 m. However, the pressure falls away shortly after the valve opens, so the procedure has to be repeated often to near that theoretical value.

Free flow

The cross section of a free flow A = Q/v will be smaller downstream according to its increasing local velocity v = ½ ·a·t (if there are no other sources feeding the stream).
You can see that decreasing width already on the tap (see *Fig. 375*).
Since $s = ½·a·t^2$ or $t = \sqrt{(2·s/a)}$ and consequently $v = s/\sqrt{(2·s/a)} = \sqrt{(s·a/2)}$, the cross section on any distance from the source will be $A = Q/\sqrt{(s·a/2)}$.

Fig. 375 Water flowing from the tap



Source: *http://team.bk.tudelft.nl/* > publications 2006 Hydrology.xls

Fig. 376 Simulation of 0.00004 m3/sec falling water

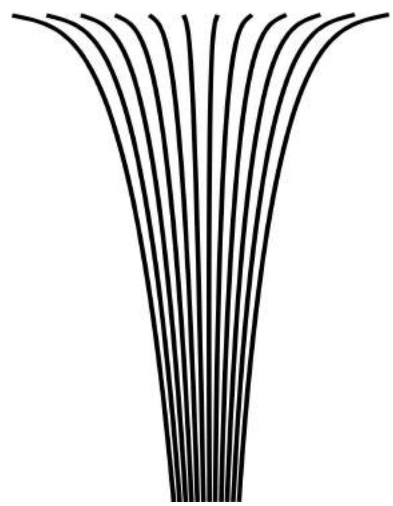


Fig. 377 A river stemming from different separate streams

However, what you see is the diameter, 2·r. And $A = \pi·r^2$. So, $2·r = 2·\sqrt{(A/\pi.)}$
In *Fig. 375*, the water from the tap has an intial velocity, perhaps comparable with the 0.02m level of the falling water in *Fig. 376*. As soon as a critical velocity is passed a continuous flow is falling apart in drops like rain. It shows the limits of water cohesion.

A river

A river, stemming from different separate streams with smaller cross sections (see *Fig. 377*) will end up flowing faster in the end. Moreover, its resistance reduces because of less contact with its bed, becoming more and more smooth (less rocky) downstream. However, its slope reduces also coming closer to the sea. How do these circumstances balance locally?

3.1.6 Resistance

Until now, we supposed flows, running without resistance.
But, any liquid flowing along a surface encounters a shearing force in the opposite direction dependent on its roughness. That force causes deceleraton or even partially flowing back (turbulence).
Force is mass times acceleration. If mass remains the same, the accelerations 'a' of previous paragraph 3.1.5 should be reduced. How much is that reduction in a stream flowing through a landscape?

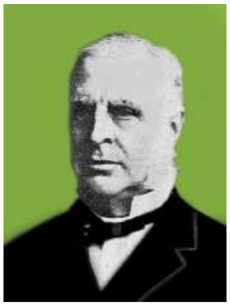
Many parameters play a role, but the result mainly will be that shearing stress reduces the force of water and consequently its acceleration and velocity substantially only if the water level is less than 2m to bottom. However, it always plays an important role in transporting sediments.

So, a river can not adapt its discharge, but rather its form to bring the water most efficiently to the sea. However, that search for the most efficient course may take a very long time, sometimes waiting for a year of extreme rainfall to improve the course, clearing up bottle necks, looking for steeper slopes lessening its tress.

Shearing stress

Manning[a] created the formula of *Fig. 378* to calculate the force τ every square metre wetted surface exerts [newton/m^2] in opposite direction of the flow ('shearing stress').

[a] *http://64.233.183.104/search?q=cache:2qsQymRjhqcJ:manning.sdsu.edu/+Manning+hydrology&hl=nl&gl=nl&ct=clnk&cd=1*



$$\tau = \rho \cdot v^2 \cdot \frac{n^2 \cdot a}{R^{\frac{1}{3}}}$$

Fig. 378 Robert Manning and one of his formulas

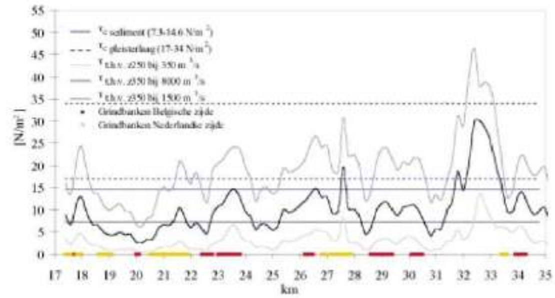


Fig. 379 Shearing stress τ due to different discharge suppositions and local roughnesses and bed forms along 17.5 km of the river Meuse (Grensmaas)[a]

Fig. 379 shows τ for different circumstances a part of the river Meuse (Grensmaas) ranging from 1 to 50 newton/m². *Fig. 382* shows the studied part in *Fig. 379*, folded along the boundary of The Netherlands and Belgium within its winter dikes.

The river Meuse for example

Fig. 380 shows a cross section of a river like the river Meuse approximately half way of its 925 kilometres course. Suppose the surface of its cross section A = 300m² and its discharge Q = 600m³/sec (often in winter). In that case its water level is 5.7m and it transports a mass m = 600 000kg of water per second over 2 metre (so, velocity v = 2m/sec or 7.2km/hr). That represents E_k = 1.2 million joule kinetic energy over 2 m, and a force F_2 = 600 000 newton equivalent to a weight of approximately 60 tons.

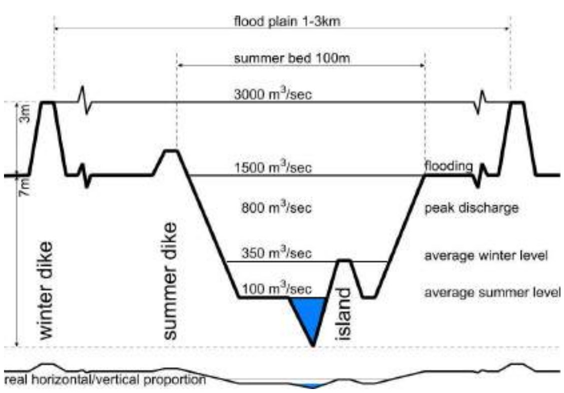


Fig. 380 Typical cross section and wetted surface of a river like the Meuse half way (Grensmaas)[b]

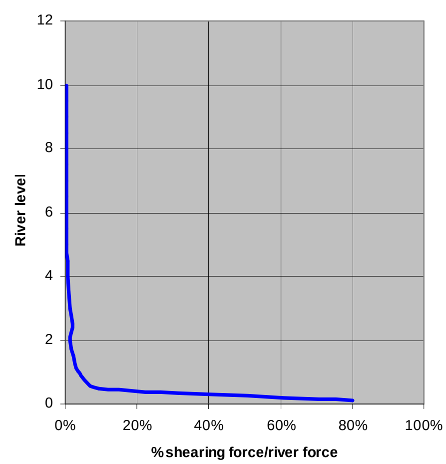


Fig. 381The influence of shearing force by different water levels in Fig. 380[c]

According to Mannings formula in this circumstances the shearing stress τ would be 10 newton/m². If it shears over the river bed taking 100 m in the cross section ('wetted contour'), then perpendicular to that cross section in 1sec over a length of 2m the river has to overcome 2 000 newton resistance. That is only 0.3% of the local force of the river. And in this two metres we did not even count the pushing power of many kilometres moving water coming down upstream.

[a] http://viwc.lin.vlaanderen.be/water/ts2003_09_grensmaas.pdf
[b] http://viwc.lin.vlaanderen.be/water/ts2003_09_grensmaas.pdf
[c] http://team.bk.tudelft.nl/ > publications 2006 Hydrodynamics.xls

Low shearing stress

So, the influence of the shearing stress τ on velocity and acceleration on a water level of 5.7m is negligible, but in many centuries it has given the actual form to the river by loosening material from the bed. Water with a velocity of 2m/sec could even move stones of 0.5kg, but at the bottom a shearing stress of 10newton/m^2 will only move some smaller sediment.

High shearing stress

However, at water levels in the same circumstances lower than 2m, τ becomes more than 1%, increasing into 80% on very low water levels (see *Fig. 381*). You can calculate it yourself for different circumstances downloading *http://team.bk.tudelft.nl/* > publications 2006 Hydrodynamics.xls.
So, in small brooks τ will play an important role on the resultant force, acceleration, velocity and kinetic energy.

Kinetic energy per m3 water ½ $\rho \cdot v^2$

In Mannings formula ρ is the mass of 1m^3 water (mainly 1000 kg/m^3). The kinetic energy reduced by roughness like earlier shown by the water ram (see page 176) is ½ $m \cdot v^2$ (see page 176).
So, $\rho \cdot v^2$ in the formula represents twice the kinetic energy per m^3 water.
You can measure the velocity v [m/sec] on different spots in the cross section to calculate the average velocity (see Fig. 423).
Kinetic energy [newton·m] per m^3 is the same as force per m^2 like τ [newton/m^2].
So, the rest of the formula is a dimensionless factor, but how to calculate it?

Roughness n

The roughness of river beds is expressed in a roughness factor n [sec/$m^{1/3}$] shown Fig. 432, ranging from 0.01 for very smooth concrete until 0.1 sec/$m^{1/3}$ for flooded tight forest.[a]

Hydrolic radius R

R [m] in Mannings formula is the 'hydrolic radius', the wet surface 'A' of the cross section divided by the length of its wetted contour 'P' (R = A/P). The larger 'A' is (for example increasing by a larger discharge (see *Fig. 380*) the less influence the wetted contour has.

The surface/contour proportion is an important factor in many physical phenomena like roads around an urban island (public investment), volume/surface of buildings or growing animals (insolation). If a volume increases by a third power of distance, a minimal surface containing that volume increases quadratically (slower), while the minimum contour (a circle) containing a surface increases in the same time linear (again slower).
A 'wetted contour' of a river is not a circle, but it increases slower than the contained cross sectional surface also because the horizontal upper surface is ignored.

Fall and acceleration a

Most difficult to estimate is local 'a' in Mannings formula. The total acceleration of a river can be calculated according to page 175 and reduced by varying shearing stress, but that average is locally changed by varying slopes and forced by water masses upstream into increased acceleration in narrow cross sections, partly compensated by higher water levels storing potential energy for accelerations later.

Reduction of acceleration

The part of the river Meuse studied, falls 10m (from 40 to 30 above sea level) over 17.5km length with varying resistance (see *Fig. 383*). However, the total fall of the river Meuse from source to sea is 409m over 925km. That is the tangent of α = 0.0253 degree. So, you could expect an average acceleration of $a = g \cdot \sin(\alpha) = 9.807 \cdot \sin(0.0253) = 0.004$ m/sec^2, partly reduced by a substantial τ in the many feeding brooks at the boundary of the basin (see *Fig. 385*).

[a] *http://www.fhwa.dot.gov/bridge/wsp2339.pdf*

Fig. 382 17.5km of Meuse (Grensmaas)[a]

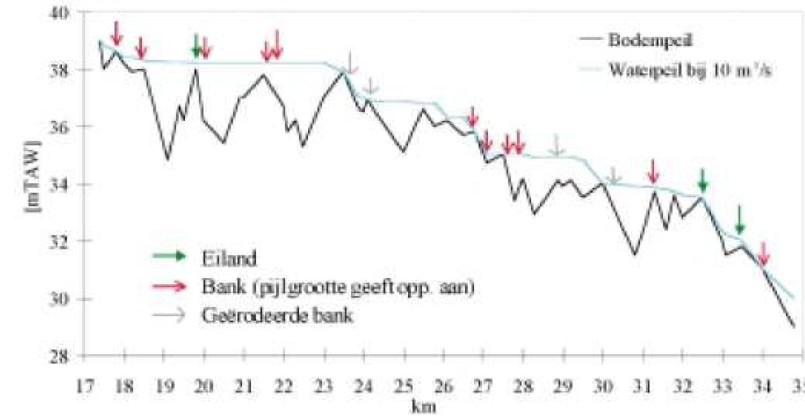


Fig. 383 A fall of 10m along 17.5 km of the river Meuse (Grensmaas)[b]

Because v = a·t and consequently t = v/a, the distance covered $s = a \cdot t^2/2 = a \cdot (v/a)^2/2$.
So, at distance s = 500km from source the velocity should be $v = \sqrt{(2 \cdot a \cdot s)}$ = 66m/sec.
However, we counted v = 2m/sec, to reach Q = 600m^3/sec through a cross section (wetted surface) of 300m^2. So the reduction by τ in all upstream shallow brooks and small rivers of the basin together should be 97%!

Discharge

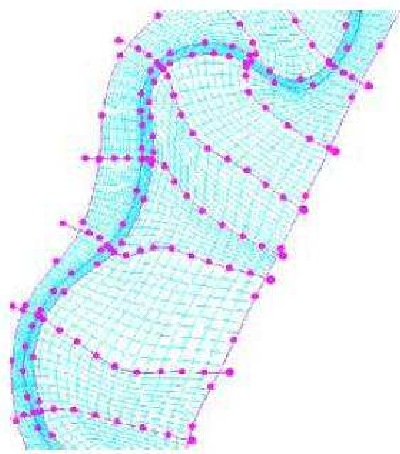


Fig. 384 Successive SOBEK cross-section trajects along the Grensmaas

Fig. 385 Meuse river basin of 36 000 km^2 through France, Belgium, Germany and The Netherlands

If you measure the cross section 'A' [m^2] of a stream and the velocity v [m/sec], the discharge Q = A·v. However, you also can measure the rainfall of the Meuse river basin in Belgium and France (23 500km^2)[c]. If in that area at average in a year 1000mm rain has fallen of which 200mm is evaporated or temporarily sunken down into the earth, then Q = 800mm·23500km^2/yr. That is 600 m3/sec of water coming into the Netherlands at the boundary of Belgium averaged over a year (see *Fig. 385*).

[a] *http://viwc.lin.vlaanderen.be/water/ts2003_09_grensmaas.pdf*
[b] The Belgian standard TAW in *Fig. 383* means 'above average sea level at ebb-tide on Ostende, 2.426m higher than NAP, the Dutch standard for measuring heights.
[c] *http://nl.wikipedia.org/wiki/Stroomgebied_van_de_Maas*

However, in a a concurrence of circumstances like in january 1995, there can be more rainfall (up to 350mm *per day*), less evaporation, no storage in a saturated earth, faster discharge because that earth is frozen, but starting to melt, delivering previously fallen water in the same time.
In such a case you can expect floodings.

Velocity and discharge

A river has its largest velocity on its surface, decreasing into the bottom.
The average velocity v is often measured at 0.4·h (see *Fig. 386*). However, the velocity distribuition over the cross section varies substantially (see *Fig. 387*).

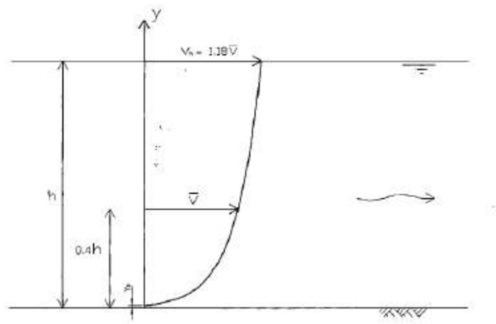


Fig. 386 Velocity in a longitudinal cross section[a]

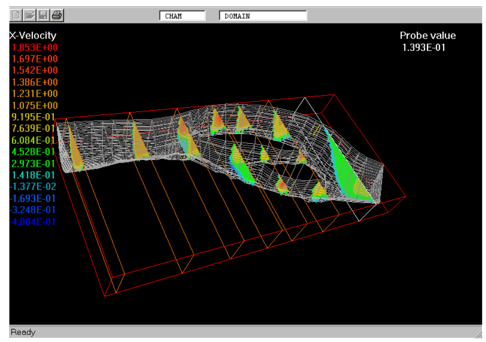


Fig. 387 River cross sections with simulation of velocity profiles[b]

Many rivers have a relation $v = k \cdot Q^m$, but 'k' and 'm' differ from river to river (in Fig. 388 Bovenrijn and Waal obey approcimately to $v = Q^{0.3}$).

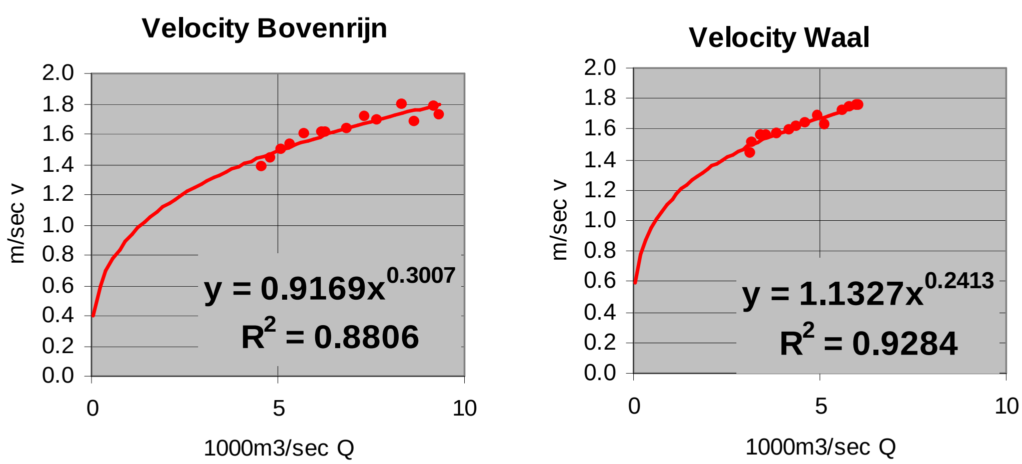


Fig. 388 Flood and velocity in Bovenrijn and Waal[c]

Different sensibility of velocity for discharge

Fig. 389 shows that relation for two extremely different American rivers. In a logarithmic representation the measurements fit very well a straight line. An increasing factor 'k' shifts the whole line up, an increasing exponent 'm' makes it steeper (v more sensitive for Q). If the line is horizontal (m = 0), there

[a] Huub Savenije (2001) Stroming *7* Nummer 4 TU Delft, *hsa@ihe.nl*
[b] *http://www.simuserve.com/cfd-shop/uslibr/vrgeom/vrg4.htm*
[c] Derived from *http://www.engr.colostate.edu/~pierre/ce_old/Projects/Paperspdf/Julien-Klaassenet%20alASCE2002.pdf#search=%22river%20Rhine%20cross%20sections%20Lobith%22*

is no relation between v and Q whatsoever. Even if the discharge increases, the velocity will not. These are stoic rivers having other possibilities to give space to their discharge, for example in the lowlands. The steep liners are nerveous ones, apparently limited in their cross sections in the highlands.

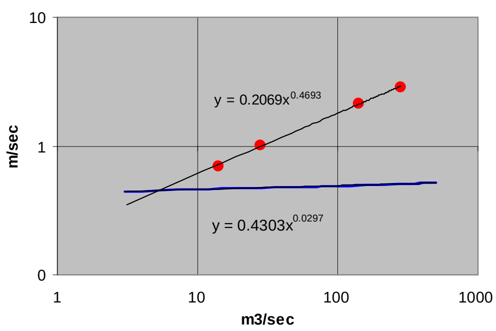


Fig. 389 Different relations between velocity and discharge[a]

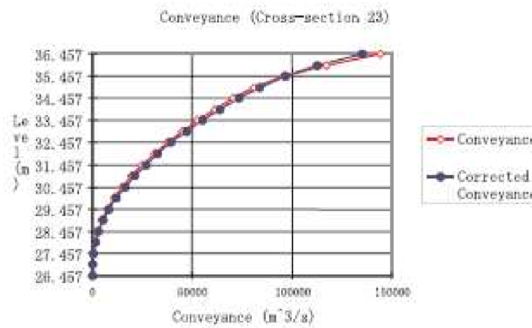


Fig. 390 SOBEK simulation of level related to discharge processed with correction for spatial variations between successive crosssections of Fig. 384[b]

Depth related to discharge

Many rivers have a relation depth $D = c \cdot Q^f$, but 'c' and 'f' differ from river to river (in *Fig. 391* Bovenrijn and Waal obey approcimately to $D = 5 \cdot Q^{0.4}$).

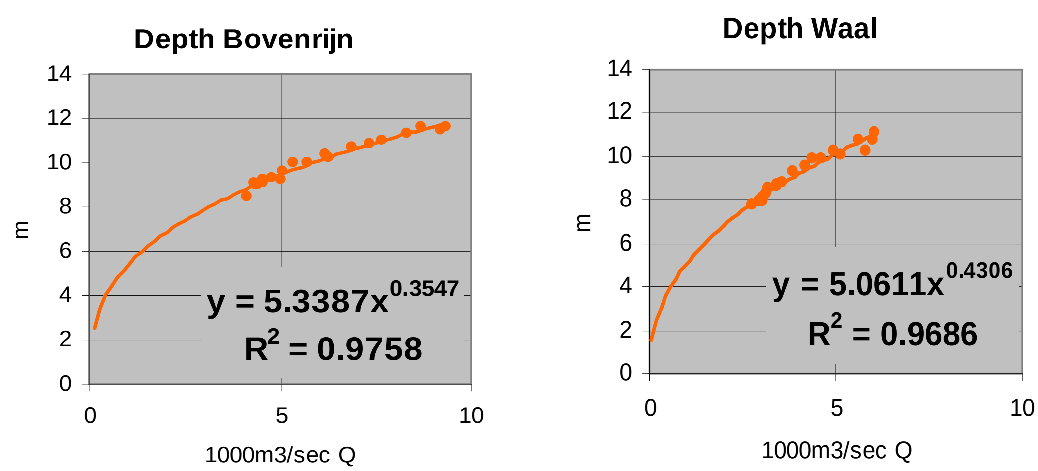


Fig. 391 Depth related to discharge in Bovenrijn and Waal[c]

[a] Leopold *http://eps.berkeley.edu/people/lunaleopold/(043)%20Downstream%20Change%20of%20Velocity%20in%20Rivers.pdf#search=%22velocity%20rivers%22*
[b] *http://www.wldelft.nl/rnd/pdf/rnd2001.pdf#search=%22river%20Rhine%20cross%20sections%20Lobith%22*
[c] *http://www.engr.colostate.edu/~pierre/ce_old/Projects/Paperspdf/Julien-Klaassenet%20alASCE2002.pdf#search=%22river%20Rhine%20cross%20sections%20Lobith%22*

Width related to discharge

Many rivers can be simulated by an ellipsoid cross section (see).

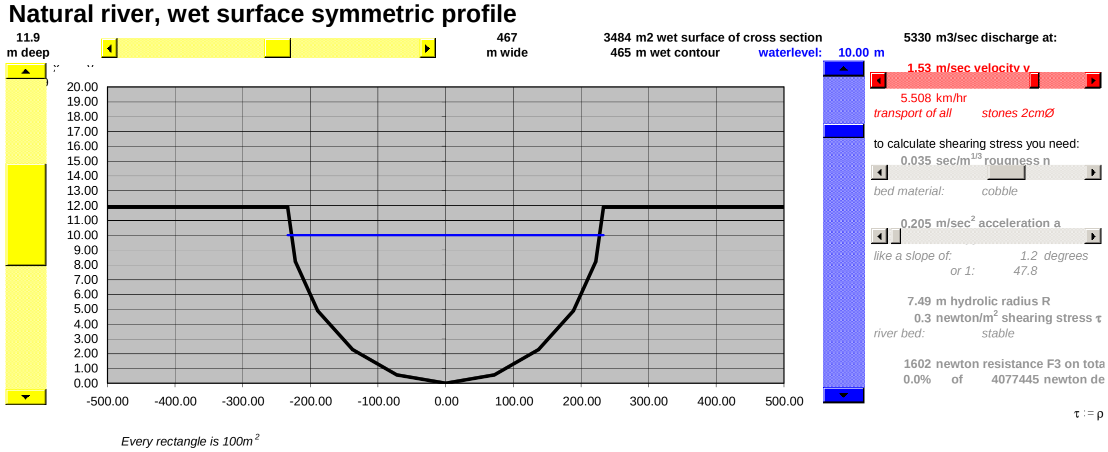


Fig. 392 Simulation of an ellipsoid cross section[a]

For a river in weak soil (not forced by artificial measures) it is easier to find space in width than in depth, because sedimentation reduces depth.

3.1.7 Erosion and sedimentation

Material from the river bed (silk, sand and gravel) is transported dependent from the velocity of water.

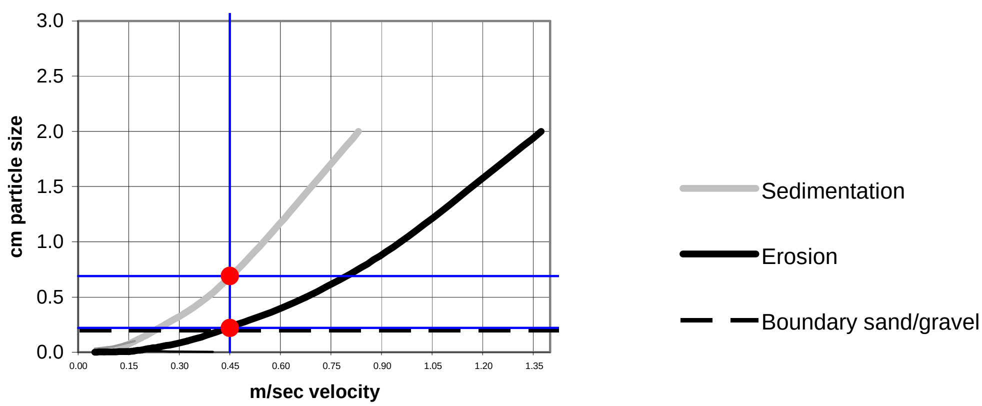


Fig. 393 Erosion and sedimentation dependent from the velocity of water[b]

From >0.2 cm particle size we call it gravel (see *Fig. 393*).
Until <0.2 cm it is named sand or silk (see *Fig. 394*, an enlargement of *Fig. 393*).

[a] http://team.bk.tudelft.nl/ > Publications 2006 > Hydrodynamics .xls
[b] redrawn according to Pannekoek ( ) Algemene geologie ( ) pag. 225

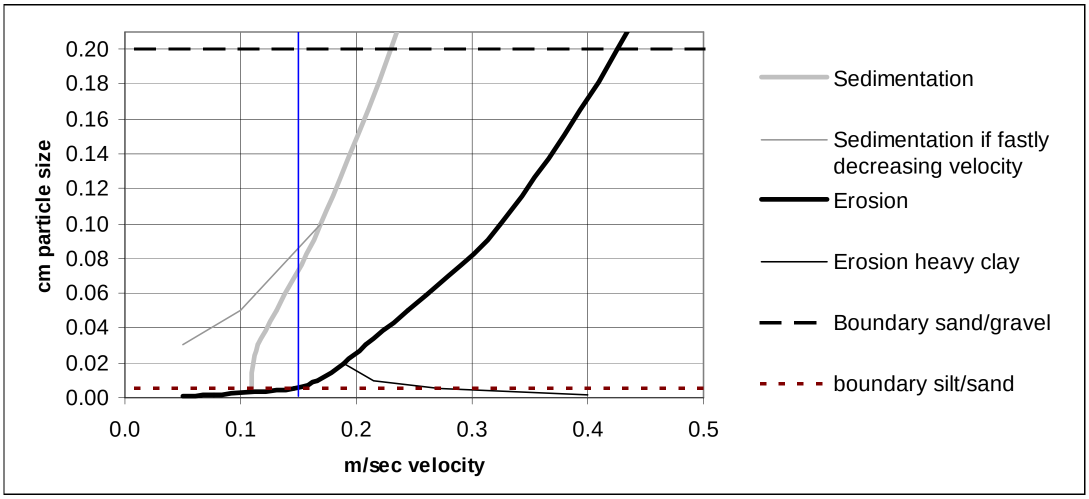


Fig. 394 Erosion and sedimentation at the boundary of silk < 0.0.005 cm and sand >0.005cm dependent from velocity of water, detail from Fig. 393[a]

In *Fig. 394* until **0.05m/sec** you can conclude that the river bed is stable. Or the reverse: if you see a stable bed, the velocity should be less than 0.05m/sec.

Silt

From a velocity **0.15m/sec** all loose silt is moving. So, if you see silt on the bottom, the velocity of the water should be usually less than 0.15/sec. If you do not see silt, it should usually be more. However, heavy clay densified into a cohesive plaster layer needs a higher velocity to erode than you would expect from their particle size.

Sand

From **0.45m/sec** (ample 1.5km/hr, slowly walking) onwards all sand is moved. So, if you do not see sand, the velocity will be probably more than 0.45m/sec.

Gravel and stones

At higer velocities you have to look at gravel and stones in to estimate the water velocity (see *Fig. 393*). From **1m/sec** (3.6km/hr) you see stones of 1cm diameter rolling, from **1.45m/sec** (5km/hr) stones of 2cm, from **1.7m/sec** (6km/hr) stones of 3cm, from **1.95m/sec** (7km/hr) stones of 4cm. On that level the diameter of stones moved grows approximately parabolically with the square of velocity. So, stone diameter $\approx v^2$ like $1 \approx 1^2$, $2 \approx 1.45^2$, $3 \approx 1.7^2$ and $4 \approx 2^2$. That seems logical, because according to page 176 the kinetic energy of running water ($½\, m \cdot v^2$) is proportional to the square of velocity.

Higher velocities widen passages, lower velocities narrow them.

At the long term wider passages of a river with lower velocities will be filled up with sedimentation and narrow passages with high velocities will be widened by erosion or floodings. So, by an equal discharge Q in older natural rivers the velocity v is equalised as well. However we have artificially narrowed our rivers to save land and to make them deeper for ships.

[a] redrawn according to Pannekoek ( ) Algemene geologie ( ) pag. 225

3.1.8 Hydraulic geometry of stream channels

Width (w), depth (d) and stream velocity (v)

The study of the changes of channel width (w) and depth (d), stream velocity (v) and suspended load with a discharge Q = w·d·v is the next step for a better understanding of the behaviour in a landscape. Channel width, depth and current velocity increase during rising water. This is no surprise to anyone familiar with the regime of rivers, but the regular change of each separately is amazing.

With the help of a wide range of streaming conditions it was found experimentally (Leopold and Maddock, 1953) that width, depth, velocity and load increase as simple power functions of discharge. This can be translated in the following equations:

$w = aQ^b$ $d = cQ^f$ $v = kQ^m$ (see page 182)

The numerical values of the arithmetic constants a, c and k are not significant for the hydraulic geometry of streams. On the other hand the numerical values p,q and r are very important. All these values are found by measurements. Leopold and Maddock found that the average for some 20 more or less comparable stations in the United States gave the following values:

b = 0.26 f = 0.40 m = 0.34

In these cases during a flood the *width* of a channel at a specific cross-section will increase slowest ($w = aQ^{0.26}$), the *depth* (level) fastest ($d = cQ^{0.4}$) and the *velocity* in between ($v = kQ^{0.34}$).

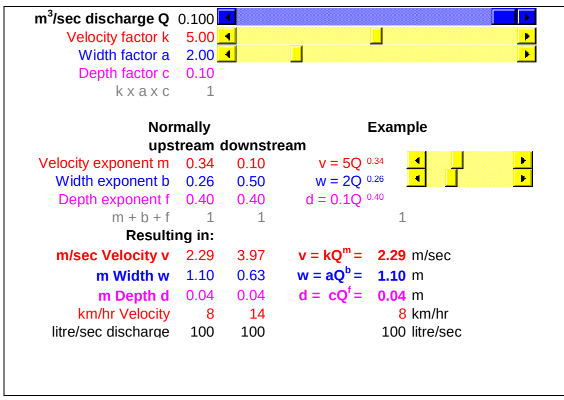


Fig. 395 Calculating v, w and d

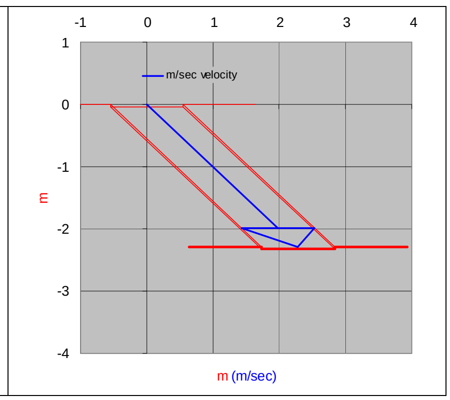


Fig. 396 The geometry of the stream[a]

Comparing measurements of channel shape and stream velocity in a downstream direction gives surprising results. Normally the discharge of a river downstream increases. The same equations are found to apply at the different downstream cross-sections. Research and measurements proved that:

Width, depth *and* velocity increase downstream.

According to *Fig. 373* this empirical results also reject the idea that streams in the mountains flow wildly and more rapidly than downstream.[86] These higher streams are characterized by a flow in circulair eddies with almost as much backward as forward motion.

The numerical value of the exponents b and m from the equations above are not the same for changes downstream as for changes with discharge passing an upstream cross-section.
In the downstream direction the average values for the exponents become:

b = 0.5 f = 0.4 m = 0.1

[a] *http://team.bk.tudelft.nl/* > Publications 2006 > experiments: Hydrology *.xls*

Downstream, the *width* of the channel will increase most rapidly, the *depth* a little bit less rapidly, but the mean *velocity* will increase only slightly.

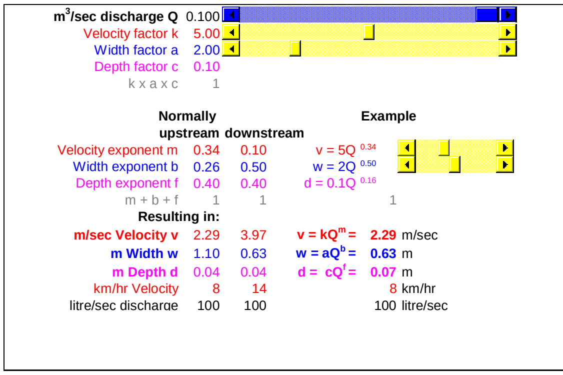


Fig. 397 Calculating v, w and d

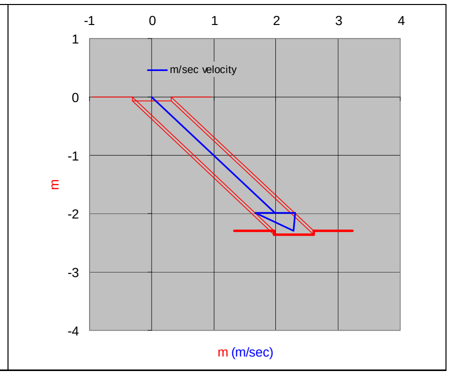


Fig. 398 The geometry of the stream[a]

It is believed that the increasing depth downwards permits a more efficient flow in a river and so overcompensates the decreasing slope. As a result a slight net increase in velocity at mean annual discharge will take place.

Further mathematical calculations of the hydraulic geometry equations suggests useful applications of the principles.

The discharge is defined as $Q = wdv$

and if $w = aQ^b$ $d = cQ^f$ $v = kQ^m$

then by substitution: $Q = (aQ^b)(cQ^f)(kQ^m)$

or: $Q = ackQ^{b+f+m}$

it follows that: $a \times c \times k = 1.0$ and $b + f + m = 1.0$

As is stated above the arithmic constants a, c and k are not important. But it is interesting that for all the made measurements and calculations for the different cross-section b + f + m =1.0 agree.

3.1.9 River morphology

The morphology of a river system depends mainly on climate, gravity, height, slope, bedrock, soil type and vegetation. Human impact on the system cannot be neglected and especially not downstreams with all artfiicial interventions varying from storage reservoirs both for the generation of electricity and for storage purposes of water and for alterations in the system itself and dumping of materials in the system.

[a] *http://team.bk.tudelft.nl/* > Publications 2006 > experiments: Hydrology *.xls*

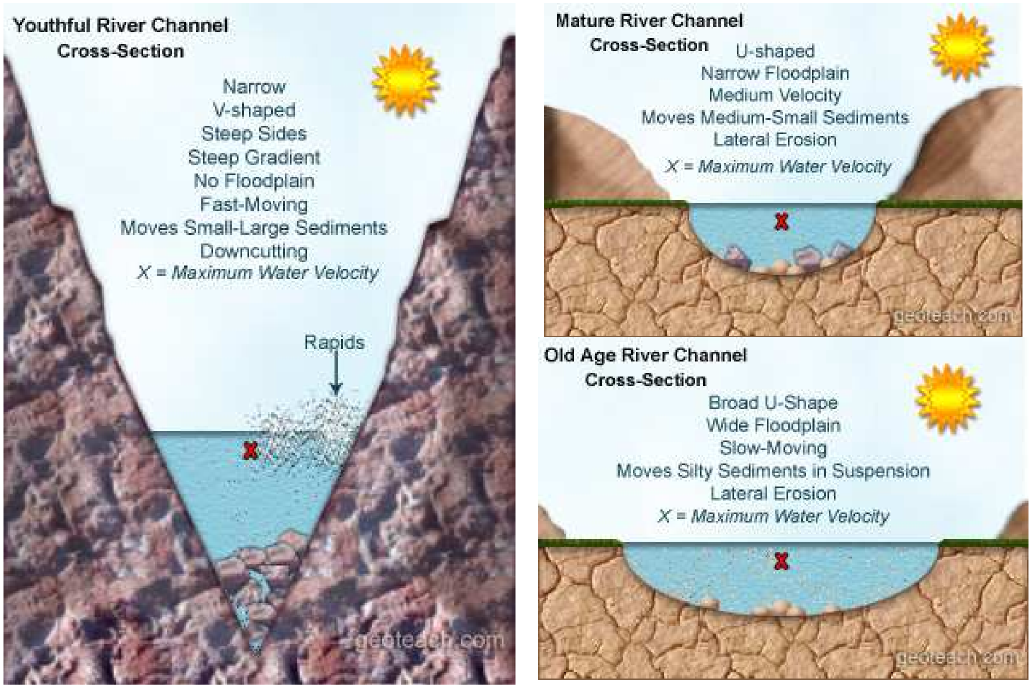


Fig. 399 Development of river beds[a]

[a] *http://geolor.com/geoteach/rivers/Three_Stages_of_River_Development-geoteach.htm*

3.1.10 Simulating a simple drainage system

Wind, water and traffic flow along the earth´s surface. Some of these flows collect into streams.

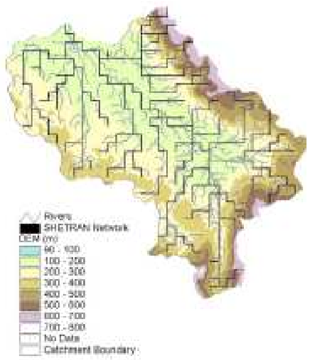


Fig. 400 Schematic of SHETRAN model setup.

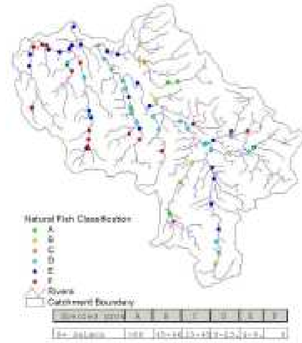


Fig. 401 Salmon Abundance across the Eden catchment[a]

Fig. 402 shows a landscape with 24 x 24 squares (sloped mountain areas or a polder with outlets) with 4 possible drainage directions, producing a converging feather or tree like drainage system. Computer programme Jong (2003) '*river(drainage.exe)*' (see *http://team.bk.tudelft.nl/* publications 2003), made from the 'random walk' example of Leopold and Wolman cited by Zonneveld (1981), arouses such random landscapes producing drainage systems. The image is built up in columns from upper left to down below. The programme prevents convergent arrows and smallest circuits by changing lowest arrow 90^o into right or downward if they occur. So, the runoff tends towards 'South East' as if the landscape has a main slope or a mein drainage outlet. Watersheds become visible separating catchment areas. Why do they concentrate into separate basins and converge into main streams?

[a] *http://www.ncl.ac.uk/swurve/downloads/2002Synthesis.pdf#search=%22river%20Rhine%20cross%20sections%20Lobith%22*

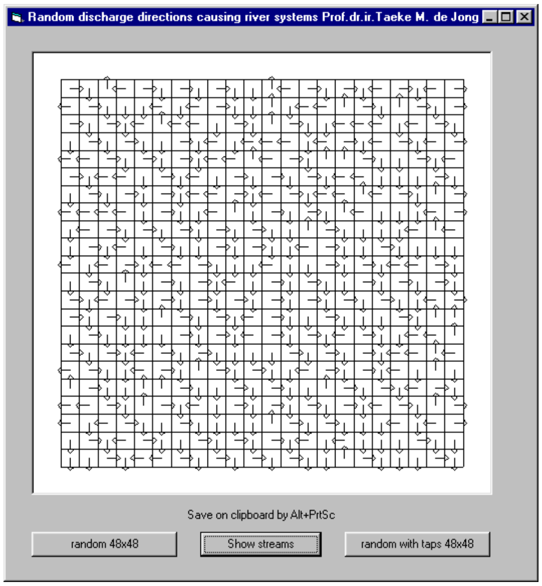


Fig. 402 Directions of drainage in a landscape

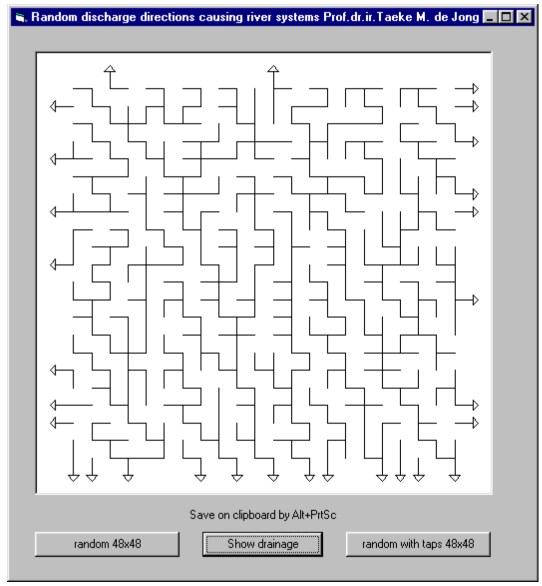


Fig. 403 Surface streams caused by Fig. 402[a]

Getting a feeling for runoff calculations

Run the program or take Fig. 403, draw the catchment basin of an outlet and calculate the discharge Q for one hour taking arbitrary European precipitation and evaporation values into account. Neglect subterranian flows, width and depth of streams, obstacles or retardatons. Suppose surfaces and altitudes, draw the altitude lines and estimate velocities. An exercise like that makes you understand the problems elaborated in next sections.

Truncation orders in river systems

You can divide a river system in different truncation orders from source to the mouth of the system. *Fig. 404* shows four methods. All the ordering systems are more or less based on a method starting with the source and going downstream. The first order is called a source river without any tributaries and so on. The differences are more determined by the nomination of the different tributaries than by the diffences in system. Strahler (above right) considers small source brooks without tributaries above as first order. Streams collecting water from first order rivers are second order rivers and so on. Try to divide Fig. 403 in such an order system[b].

[a] Zonneveld (1981)
[b] Mail pattern and calculation to T.M.deJong@bk.tudelft.nl

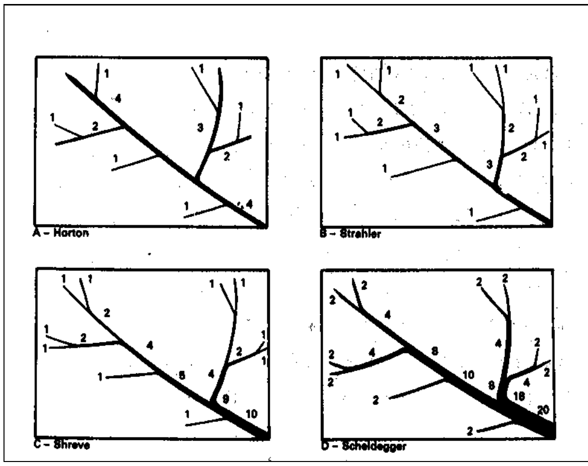


Fig. 404 Four methods to distinguish 'orders' in a feather like drainage pattern[a]

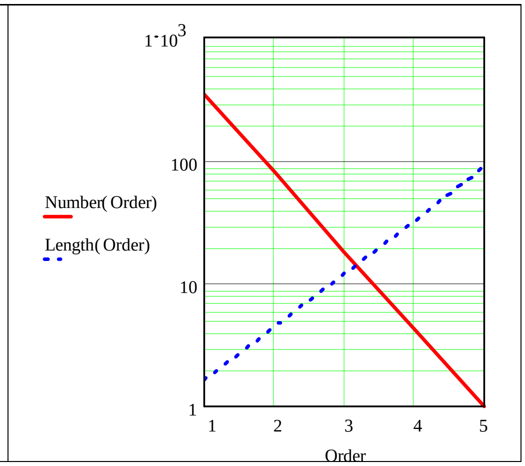


Fig. 405 Average number and length of orders in 'random walk rivers'[b]

Leopold and Wolman calculated that random rivers have 4.4 upstream branchings of lower Strahler orders according to Strahlers method at average. In practice it varies between 2 and 5. The longer a river is the more orders can be distinguished.

3.1.11 Bifurcation or trunking in traffic networks

This 'bifurcation ratio' plays a rôle in traffic as well, though street patterns and artificial drainage systems in flat lands are not like a tree but like a grid (compare Alexander (1966))[87]. If there are 20km streets per km^2, you can raise some 7km of them into the order of neighbourhood roads with a higher capacity and transform 2km into district ways with an even higher capacity. So, the optimal proportion between the density of ways and sideways in a grid seems to be approximately a factor three. Do not take it for granted, it is an easy rule of thumb, based on calculations of Nes and Zijpp (2000) indicating factors 2 and 4 are suboptimal in three different types of calculation.

Density of roads and orders of roads

Suppose a metropolis of 30km radius has 60 x 60 = 3600km^2 surface with 2km/km^2 district roads (see Fig. 498). There should be 7200km district roads in a grid of average 1x1km. To calculate density from the grid mesh bordered by 4km district roads, you have to count them half because they serve adjacent meshes as well. Many of them would be overloaded by through traffic when you would not raise 1/3 of them into city highways (2400km in a grid of 3x3km, 0.67km/km^2) with a capacity of 3000 mv/h and less exits. However, on their turn they would be overloaded. So, this argument produces a semi logaritmic range of orders (Fig. 406).

	km nominal mesh	km/metropolis	km/km^2 inclusive density	exclusive	mv/h
district roads	1	72000	2,00	1,33	1000
city highways	3	24000	0,67	0,47	3000
local highways	10	7200	0,20	0,13	10000
regional highways	30	2400	0,07	0,05	30000
national highways	100	720	0,02	0,02	100000
and so on			nearly 3.00	2.00total	

Fig. 406 *Theoretical* orders *of urban traffic infrastructure*

The total density of ways is 2km/km^2. One third of them we have transformed into highways of several orders. So, the density of ways includes the highways. Exclusing highways, there are 1.33km/km^2

[a] Zonneveld (1981) page 179
[b] After Zonneveld (1981) page 183

small district ways left. If we would like to reduce the amount of exits of local highways to save velocity, we have to disconnect district ways into dead ends. If we like to connect them mutually with extra parallel service roads along side the city highway we need the inclusive density at least.

If we try to draw a system of highways in a square of 60x60km we firstly draw a grid of 10x10km. There are 14 local highways of 60km, but 6 of them we transform into a higher order. So, their exclusive density is 8x60/3600=0.13 indeed. However, we can not fill 10km space between local highways with 3.3 city highways. So we choose 3 highways lowering the inclusive density from 0.67 into 0.60km/km2. This causes a raise of exclusive district way density from 1.33 into 1.40, but on this scale we can not draw them anyhow.

Comparing truncing in rivers and roads

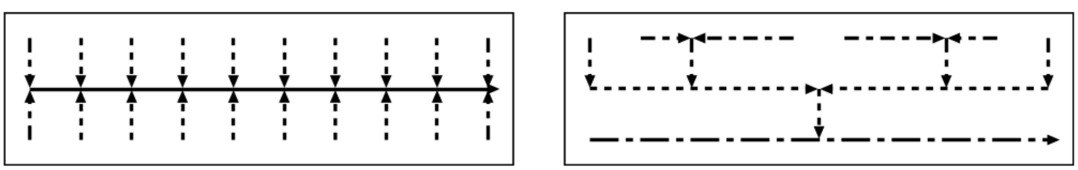
For wet connections the same applies when we call city highways supply channels, local highways brooks and regional highways rivers. In Dutch such orders of water ways can be named more precise than in English.

Riviersystems		**Road systems**	
Dutch	English	Dutch	English
hoofdrivier	mainriver	hoofdweg	highway
hoofdader	trunk stream	wijkverzamelweg	trunkroad
zijrivier	tributary	zijweg	sideroad
aftakking	distributary	zijweg	secundary road
beek	brook	buurtweg	tertiairy road
geul	channel	woonstraat	residential road
geultje	rill	woonerf	residential area

Fig. 407 Naming orders of river and road systems according to Moens

Bifurcation ratio, orders and network density

In Fig. 408 left, the bifurcation ratio of brooks before meeting a river is 20.
However, the same network density could be reached with a bifurcation ratio 2 and 5 orders (Fig. 408 right).

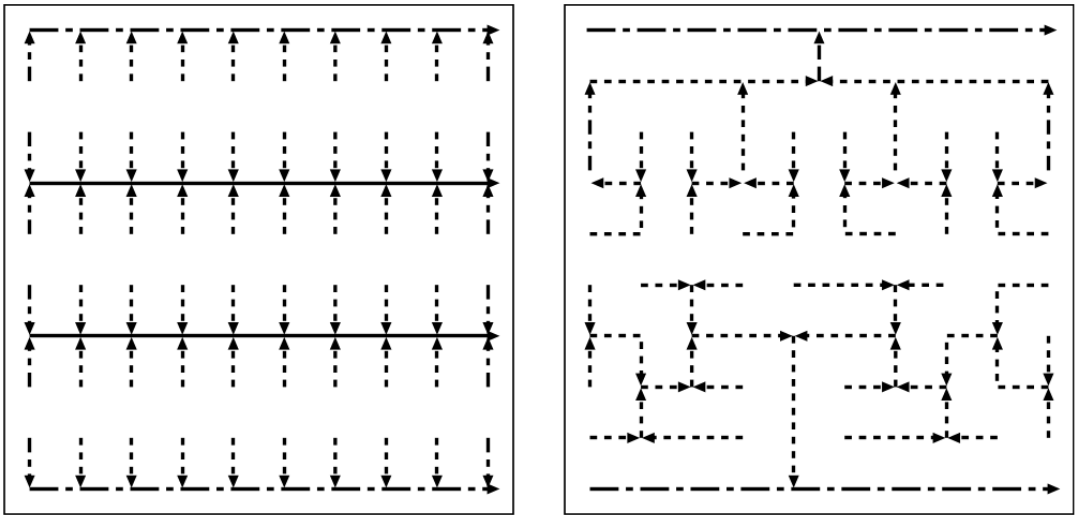


	Feather like	*Tree like*
density	29 sections	29 sections
bifurcation ratio	18	2
number of 'orders'	2	5

Fig. 408 *Feather and tree -like connection patterns*

Multiplying and extending these patterns into square surfaces (Fig. 409) tree like connection patterns seem to require a little higher density to open up all parts and consequenly higher costs when restricted to bifurcation ratio 2.[a] I do not understand why. Is halving the number of outlets responsible for a higher density? If somebody can design a lower density within this boundary conditions or prove its possibility mathematically I will publish it next time.
On the other hand, tree like opening up every point of the area makes many variants and greater diversity of locations possible when you have more space to lay out (Fig. 409).

[a] Perhaps because this restriction combined with mirroring vertically and horizontally has used all possibilities of external connection by two axes (above and below) counting half. So, vertically opening up the whole area makes more vertical sections necessary.



	Feather like	Tree like
density	96 sections	98 sections
bifurcation ratio	20	2
number of 'orders'	2	6 or 9

Fig. 409 *Feather and tree like connection patterns opening up a square*

Perhaps opening up a square in a tree-like way with bifurcation ratio 3 could reach the same or even lower densities and consequently lower costs. Try it. Does it result in less nodes and longer sections, a better readability of the area? The number and characteristics of nodes and the length of sections are important for spatial quality. Which rôle does the length of individual *sections* L play instead of total length per order in *Fig. 405*?

3.1.12 Catchment area and river length

The average length L of a random walk river *section* is a power its catchment area A ($L=A^{0.64}$). If length L is given the inverse the catchment area is a power of the length ($A=L^{1.563}$, Fig. 410 and Fig. 411). All the figures are experimental, obtained by observing many catchment areas and rivers.

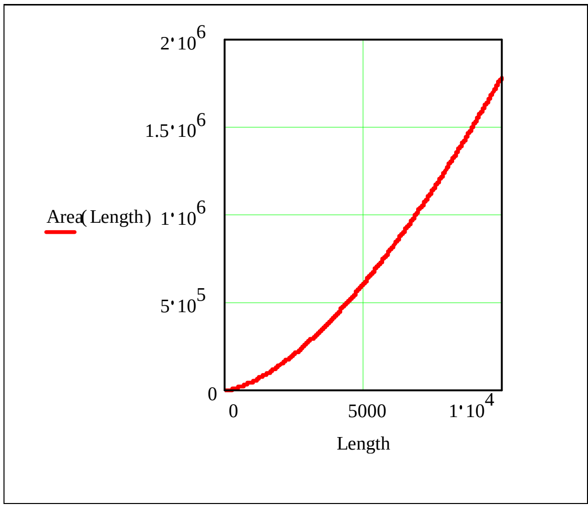


Fig. 410 Catchment area related to the length of a river section

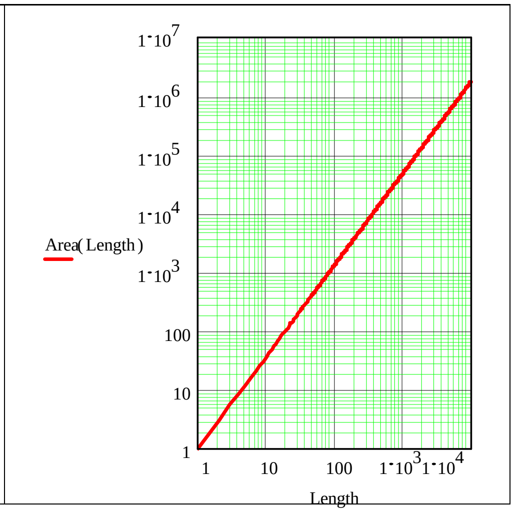


Fig. 411 Logaritmic representation of Fig. 410

Check Fig. 403 by counting the corresponding squares in Fig. 402 of a specified order and its length. Compare your measurements with Fig. 411 and *Fig. 405*.

3.1.13 Local morphologies

A river can be described by its morphology. It is the credit of William Morris Davis (1912, die erklärende Beschreibung der Landformen (Leipzig und Berlin) that for the first time a system is formulated based on development according to evolution. He describes the evolution of the valleys of the first order rivers as a V-shape without a valleybottom that develops in a wide valley with a valleybottom. This river will develop at the end in a real lowland river as we all know in The Netherlands from the river Rhine. Later scientists built further on his theory and adapted it where it was necessary. Fig. 414 - Fig. 420 show such a development with adaptations.

A classification according deposits is also developed. The faster the water streams the coarser material can be transported as load. This means that at decreasing velocity of streaming a river will deposit first the coarse material. The slower the stream becomes the finer the sediment will be that will be deposited. Near glaciers coarse material is sedimented and a lowland river will deposit fine material as sediment. Moreover a river in a flat will tend to meander. By doing so the meander curves will move downstream due to the undermining of the outside curve by the streaming water.

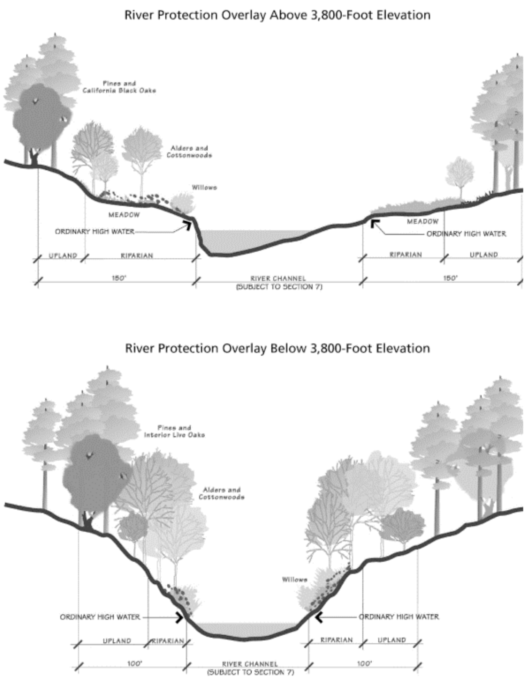


Fig. 412 River curves causing different vegetation[a]

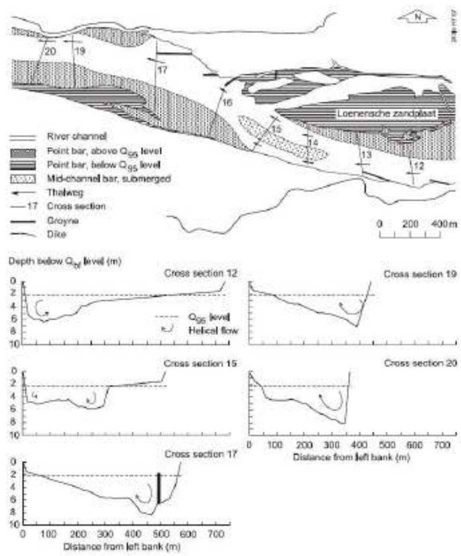


Fig. 413 Water flows causing different river bottoms[b]

Every unevenness can cause an alteration the course of the river; many different channels of a river can be recognized in lowland river. So the water takes diverse and changing courses. Lower sections still bear rough material wearing out the outside parts of a bend into meanders, because rough material laid down there in the same time becomes a water barrier until heavy showers force a break through Fig. 415 and Fig. 417.

[a] http://geographyfieldwork.com/RiverEfficiencyCompetency.htm;
http://www.nps.gov/archive/yose/planning/mrp/html/07_rmrp_ch1.htm
[b] http://igitur-archive.library.uu.nl/dissertations/1983151/c7.pdf

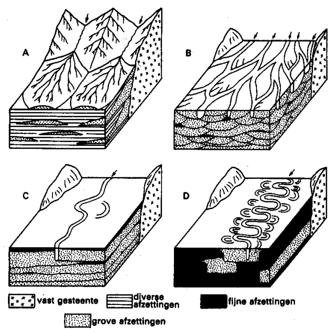


Fig. 414 Forms of deposit[a]

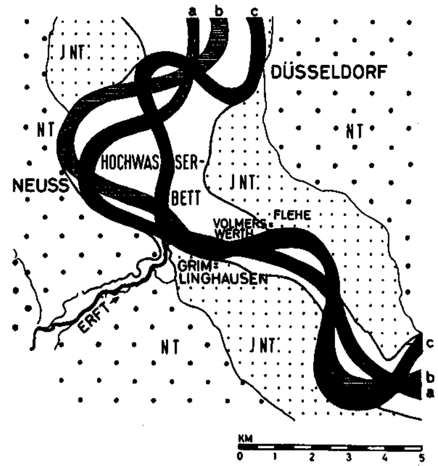


Fig. 415 Move of Rhine near Neuss from Roman times (a) via Middle Ages (b) until recently[b]

In low lands finer deposits raise the bed in calm periods forcing water to find easier courses. A high discharge of a river causes even an river system with many branches in a lowland area. Such a system is called a braided river.

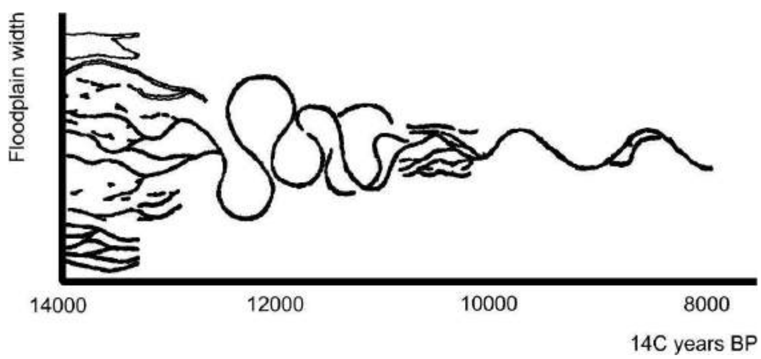


Fig. 416 Change of river behaviour in time[c]

The morphology of the braided river is not very stable; it changes often depending the amount of water.

[a] Allan cited by Zonneveld (1981) page 148
[b] Hoppe cited by Zonneveld (1981) page 149
[c] Tebbens et al. (1999), cited by Kroonenberg (2006)

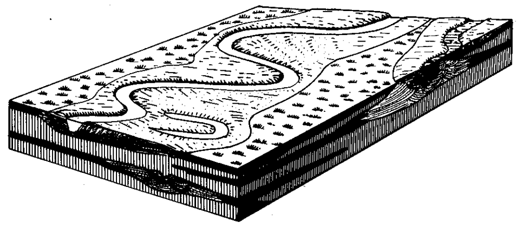


Fig. 417 Meandering river with historical deposits[a]

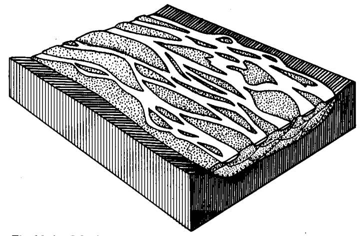


Fig. 418 Twining river[b]

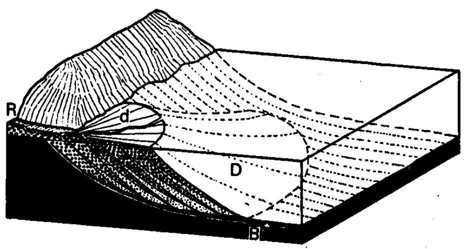


Fig. 419 Delta development with river (R), top-sets (d) and fore-sets (D)[c]

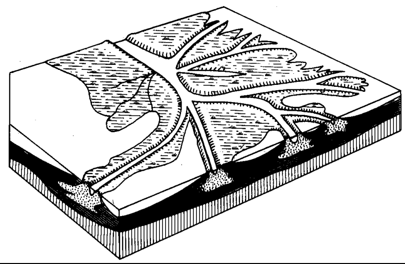


Fig. 420 Mississippi delta[d]

The Rhine area downstream of Lobith is formed by both the process of meandering during quiet periods and braiding during periods with large differences of water discharges (Fig. 421).

[a] Zonneveld (1981) page 143
[b] Zonneveld (1981) page 144
[c] Escher 1948 cited by Zonneveld (1981) page 160
[d] Zonneveld (1981)page 161

From Lobith Rhine distributes water via Waal, Lower Rhine and IJssel in historically changing proportions.

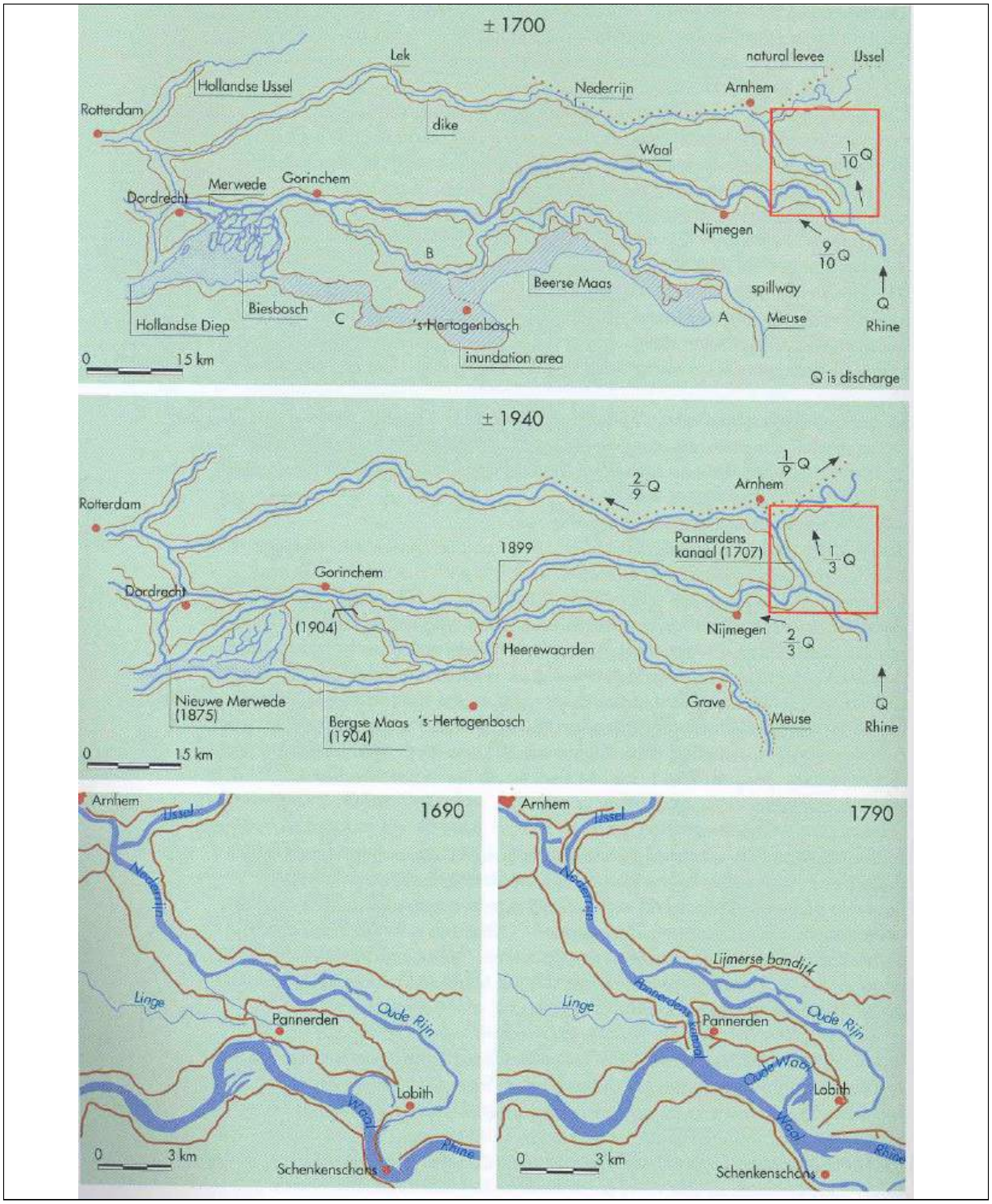


Fig. 421 *Historical distribution of Rhine water from Lobith*[a]

3.1.14 Measuring velocities to get Q

[a] Huisman, Cramer et al. (1998) page 38

The velocity v of water in a river can be measured on different depth vertical lines h with mutual distance stretches b of the cross-section B (Fig. 422). You can determine any partial discharge by multiplying v x b x h.The summon of the outcomes in cross section A for the different stretches b to get Q = Σ(v·b·h) is an approach for the discharge
In the equation v is the mean stream velocity of the river and the velocity can easily be measured on site.

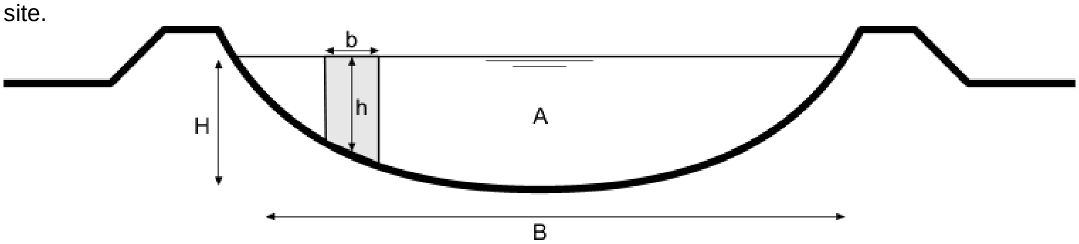
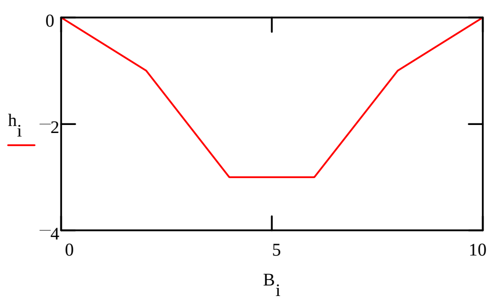


Fig. 422 *Profile of a river*[a]

For example: asked the river drainage Q (Fig. 424), given h_i, b_i and v_i from profile subdivisions (Fig. 423).



$h := \begin{bmatrix} 0 \\ -1 \\ -3 \\ -3 \\ -1 \\ -0 \end{bmatrix} \cdot m$	$b := \begin{bmatrix} 0 \\ 2 \\ 2 \\ 2 \\ 2 \\ 2 \end{bmatrix} \cdot m$ $B_i := \sum_{x=0}^{i} b_x$	$v := \begin{bmatrix} 0 \\ 1 \\ 2 \\ 3 \\ 2 \\ 1 \end{bmatrix} \cdot \frac{m}{sec}$
height h	*width b coordinate B*	*velocity v*

Fig. 423 *Data from profile*

[a] Akker and Boomgaard (2001)

$i := 0..5$ $a_i := b_i \cdot -h_i - \frac{1}{2} \cdot b_i \cdot \left(-h_i - -h_{i-1}\right)$ $A := \sum_i a_i$ $A = 16 \cdot m^2$	$Q_i := v_i \cdot a_i$ $Q := \sum_i v_i \cdot a_i$ $Q = 36 \cdot m^3 \cdot sec^{-1}$	v_i $0 \cdot m \cdot sec^{-1}$ $1 \cdot m \cdot sec^{-1}$ $2 \cdot m \cdot sec^{-1}$ $3 \cdot m \cdot sec^{-1}$ $2 \cdot m \cdot sec^{-1}$ $1 \cdot m \cdot sec^{-1}$	a_i $0 \cdot m^2$ $1 \cdot m^2$ $4 \cdot m^2$ $6 \cdot m^2$ $4 \cdot m^2$ $1 \cdot m^2$	Q_i $0 \cdot m^3 \cdot sec^{-1}$ $1 \cdot m^3 \cdot sec^{-1}$ $8 \cdot m^3 \cdot sec^{-1}$ $18 \cdot m^3 \cdot sec^{-1}$ $8 \cdot m^3 \cdot sec^{-1}$ $1 \cdot m^3 \cdot sec^{-1}$
profile subdivisions	*drainage per subdivision*	*velocity*	*surface*	*drainage*

Fig. 424 *Drainage (profile subdivisions and velocities)*

3.1.15 Discharge Q on different water heights

The depth H of the river in a cross-section varies, but it can be measured on site. Then, the drainage Q(H) can be calculated by a practical formula apparently characteristic for the profile concerned. However, periods of high drainage Q or regular floodings in winter change profile and … the formula. Comparing measurements like in Fig. 423 on different water heights you often find a curve like a parabola, approached by $Q = a \cdot H^b$ or $H=(Q/a)^{1/b}$ (Fig. 425). Parameters 'a' and 'b' should be found non-theoretically by experiment, seem to characterise the profile.

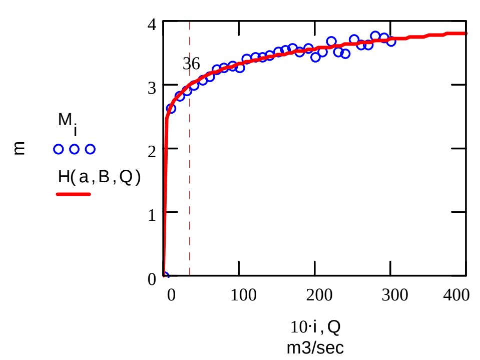


Fig. 425 '*Measurements' M_i and* Q(a,B,H) = $a \cdot H^B$ or the inverse *H(a,B,Q)*= $(Q/a)^{1/B}$ to get H on the y-axis

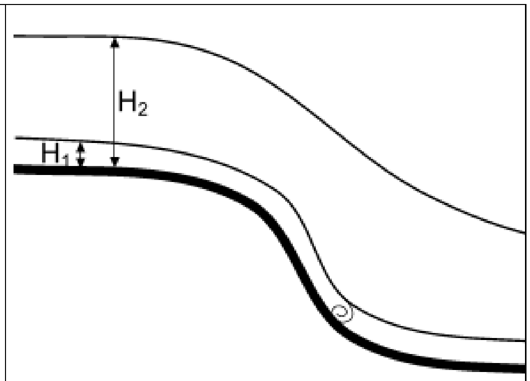


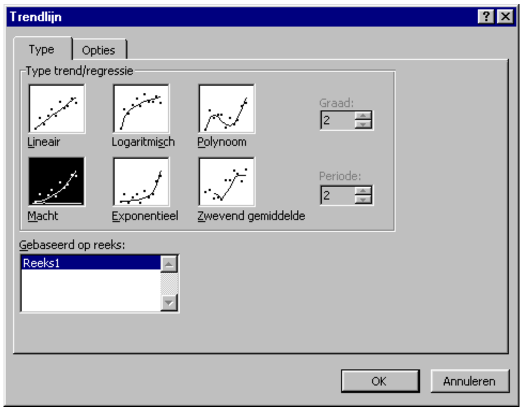
Fig. 426 *Change of boundary condition downstream; a 'drowning' waterfall*[a]

Measurements deviate from the formula because velocity varies. When measurements can not be simulated by a smooth curve, it is probable that conditions downstream are changed by high water levels. Two graphs should then be drawn; one until the point of change, one for the higher values. When for example a waterfall downstream suddenly 'drowns' at increasing water levels (Fig. 426) the slope of the curve will change by the increase of velocity.

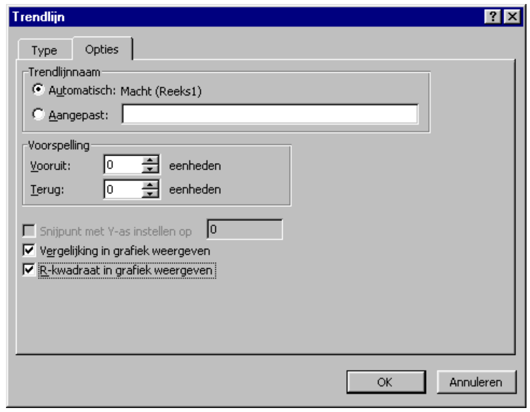
3.1.16 Interpolation of experimental data by using Excel

Constants a and b can be found by the least squares method provided by Excel using graphs (see *Fig. 427*). Enter the data of the measurements of height and drainage calculated according to Fig. 425 in two columns. Make a point graph and select it.

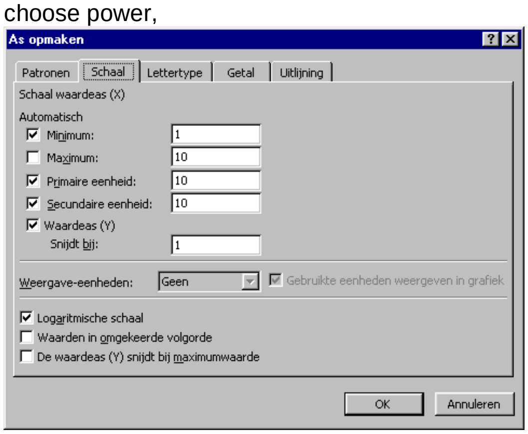
[a] Akker and Boomgaard (2001)



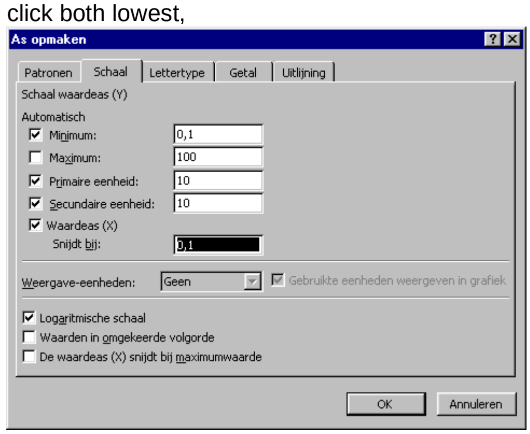
choose power,



click both lowest,



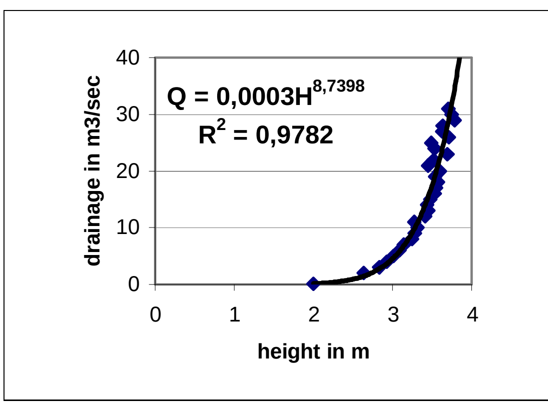
click axis,



choose logarithmic,

Fig. 427 Adding regression lines in Excel point graphs

Choose 'add trend' in 'graph' from the main Excel window above, and graphs like Fig. 428 and Fig. 429 with power regression line and formula are calculated by the program.
With R^2 near to 1 you have a reliable formula. In Fig. 428 we used 'measurements' of Fig. 425 putting the independently variable measurements on the x-axis this time to find a=0.0003 and b=8.7398.



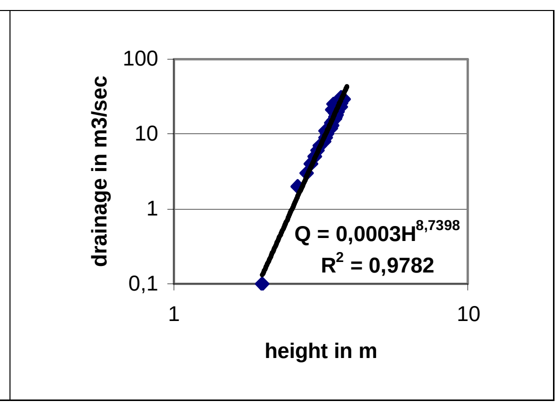


Fig. 428 '*Measurements' M_i and* Q(a,b,H) = $a \cdot H^b$ Fig. 429 *Logarithmic representation of* Fig. 428

The logarithmic representation log Q = log a + b log ($H-H_0$) produces a straight line easy to extrapolate to other heights and drainages. But be careful, there could be jumps in velocity by downstream events.

If you have made graphs before and after the jump because measuremens could not be simulated by a smooth curve, each interval in Fig. 429 has different slopes representing different behaviour.

3.1.17 Calculating drainage Q with a rough profile

Just like wind, water slows down by roughness of the bed. The cross length of roughness in a wet profile P (Natte Omtrek) is calculated by summing hypothenuses of triangles according to Pythagoras characterised by the square root of $(b_i)^2+(h_i-h_{i-1})^2$ (see Fig. 422 and Fig. 431).
Considering the profile as a function H=f(x) we can read the waterlevel H from accompanying left border x_1=l and right border x_2=r as values from f(x) (Fig. 430). The length of roughness P within the cross section (Natte Omtrek = wetted contour) and the surface of the wet cross section A are both calculated as a function of H (Fig. 431).

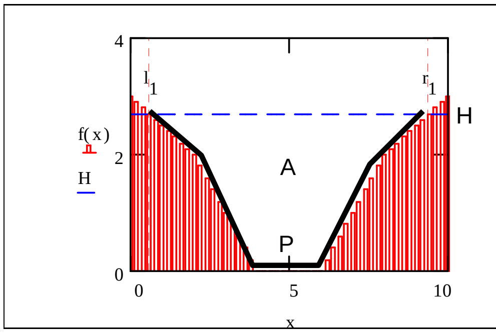


Fig. 430 *Profile as a function*

Cross length by Pythagoras:

$$P = \sum_{j=l_1}^{r_1} \sqrt{\left(X_{j+1}-X_j\right)^2+\left(Y_{j+1}-Y_j\right)^2}$$

Surface wet cross section:

$$A(H) := H\cdot\left(r_1-l_1\right) - \int_{l_1}^{r_1} f(x)\,dx \qquad R(H) := \frac{A(H)}{P}$$

Fig. 431 *Calculating wet cross section A and cross length of roughness P (NatteOmtrek)*

When we divide the surface of the wet cross section A of a stream by this cross length of roughness P we get a measure indicating what part of the flowing water is hindered by roughness called 'hydrolic radius' R = A/P in metres.

Method Chézy

The average velocity of water v = Q/A in m/sec is dependent on this radius R, the roughness C it meets, and the slope of the river as drop of waterline s, in short v(C,R,s).
According to Chézy v(C,R,s)=C√Rs m/sec, and Q = Av = AC√Rs m^3/sec. Calculating C is the problem.

Method Strickler-Manning

Instead of v=C√Rs, Strickler-Manning used

$$v := \frac{R^{\frac{2}{3}}\cdot s^{\frac{1}{2}}}{n}\cdot\frac{m}{sec}$$

with roughness n taken from Fig. 432.

acteristics of bottom and slopes	n	
	from	until
Concrete	0.010	0.013
Gravel bed	0.020	0.030
Natural streams:		
Well maintained, straight	0.025	0.030
Well maintained, winding	0.035	0.040
Winding with vegetation	0.040	0.050
Stones and vegetation	0.050	0.060
River forelands:		
Meadow	0.035	
Agriculture	0.040	
Shrubs	0.050	
Tight shrubs	0.070	
Tight forest	0.100	

Fig. 432 *Indication of roughness values n according to Strickler-Manning*[a]

Method Stevens

Instead of $v=C\sqrt{Rs}$ Stevens used $v=c\sqrt{R}$ considering Chézy's $C\sqrt{s}$ as a constant c to be calculated from local measurements. So, $Q = Av = cA\sqrt{R}$ m^3/sec and c is calcuated by $c=(A\sqrt{R})/Q$. When we measure H and Q several times (H_1, H_2 …H_k and Q_1, Q_2 … Q_k), we can show different values of $A(H)\sqrt{R(H)}$ resulting from Fig. 431 as a straight line in a graph (Fig. 433). We can add the corresponding values of Q we found earlier in the same graph reated to $A(H)\sqrt{R(H)}$. When we read today on our inspection walk a new water level H1 on the sounding rod of the profile concerned we can interpolate H1 between earlier measurements of H and read horizontally an estimated Q1 between the earlier corresponding values of Q to read Q from graph.

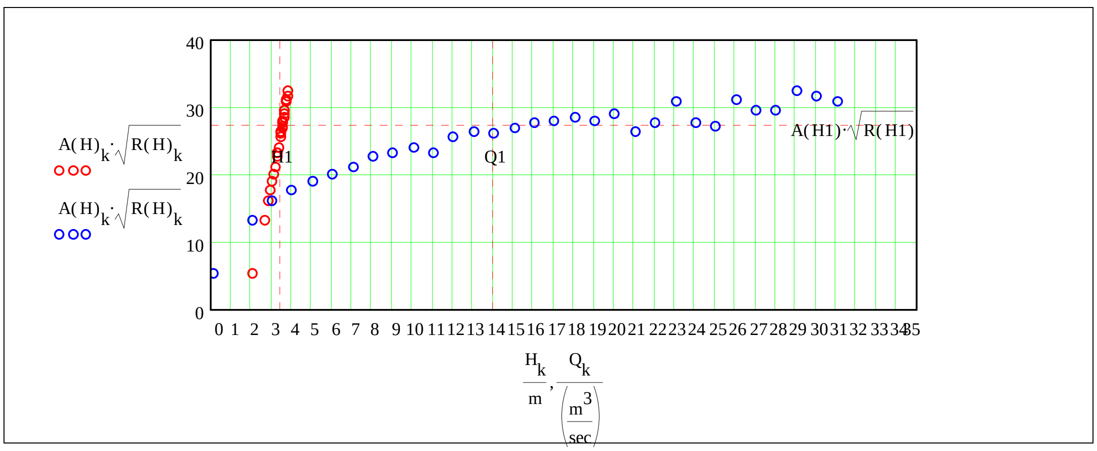


Fig. 433 *Graph used according to Stevens with 'measurements' of* Fig. 428

However, from these 'measurements' c appears to be not very constant, but the graph remains a practical way to estimate Q from H.

[a] Akker and Boomgaard (2001)

3.1.18 Level and discharge regulators

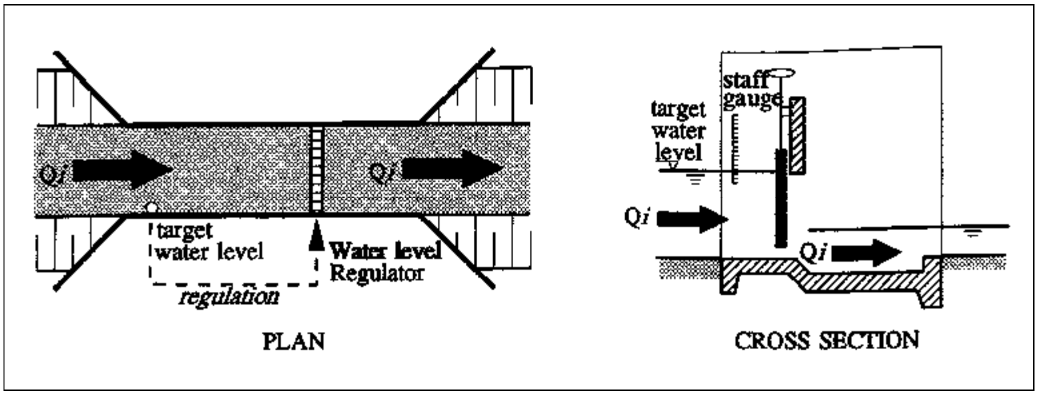


Fig. 434 *Level regulator with level as target*[a]

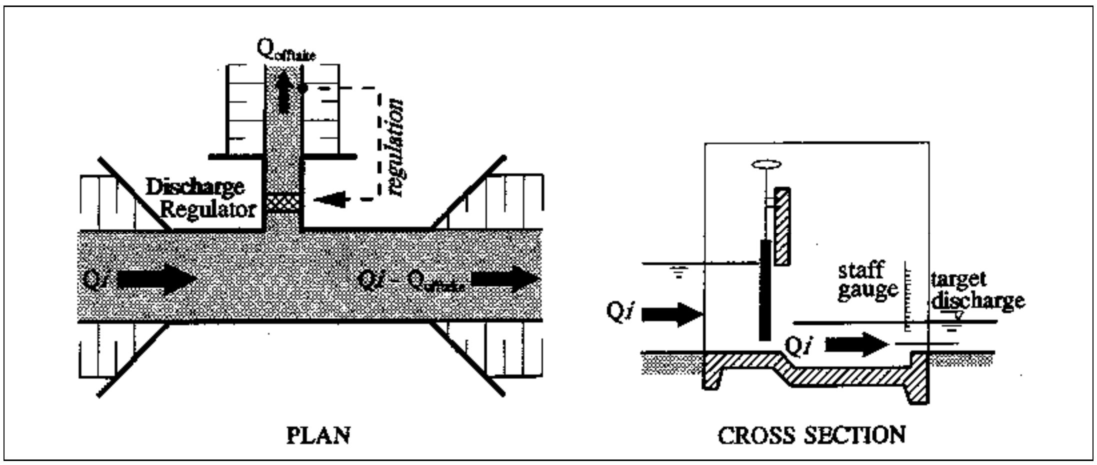


Fig. 435 *Discharge regulator with discharge as target*[b]

[a] Ankum (2003) page 156
[b] Ankum (2003) page 156

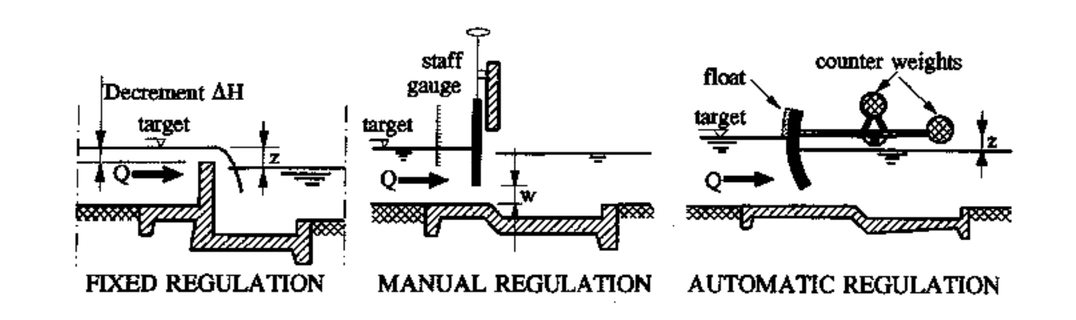


Fig. 436 *'Manners' of regulation*[a]

The fixed regulators are called weirs (stuwen), manual or automatic regulators are called gates (schuiven).

[a] Ankum (2003) page 167

3.2 Civil engineering in The Netherlands

3.2.1 History

The colors of *Fig. 437* indicate the area in the Netherlands that would become submerged if there were no flood protection dikes. The flooding area as indicated is supposed to occur during modest river floods (up to 4000 m^3/sec at the German/Dutch border) and a normal high tide at sea. However, it was not always like that. In 2000 years that area has increased into the current surface by rising external water levels and falling ground levels (see *Fig. 464*).

Fig. 437 Potential threads[a]

duration	period			issues
1000	100 -	1100		settlement ancestors
500	1100 -	1600	x	Erection dikes, confined contours
250	1600 -	1850	x	Waterlogging control, developing drainage
125	1850 -	1975	x	Riverworks (regulation, normalisation canalisation)
62	1920 -	1982	x	Zuiderzee works
32	1955 -	1987	x	Delta works
16	1975 -	1991	x	Major purification plants
8	1985 -	1993	x	Policy documents tuned (RO, WHH, Trprt, Milieu)
4	1993 -	1997		Pilot schemes, integrated approaches
2	1997 -	1999		Evaluation RWS-200 year
1	1999 -	2000		New water Policy 21st century
	new approaches		x	determined by disasters

Fig. 438 Reverse half time of the Dutch water management[b]

To cope with regular floods Dutch water management started by erecting terps in the first milennium A.D. and dikes in the next 500 years. At that time the dynamic water surface was confined and the next 250 years the emphasis of water management became waterlogging control and drainage of reclaimed land. Then, in a period of 125 years the Dutch regulated, normalised and canalised their rivers. In a continuing half time of water management policy new priorities developed like Zuiderzee, Delta and purification works (see *Fig. 438*). In the last few decades all these continuing efforts were integrated by national policy documents, pilot schemes and evaluation for future safety.

Apart from its threats, water as a medium for trade and transport and as a military barrier for external attacks was also a crucial ally in the development of Dutch independence and perhaps a factor in keeping the nation out of World War I.

Water as military barrier

In the past, the Dutch have created again and again water corridors and water defence systems for the military defence of (parts of) the country. In addition, all major cities developed their own defence system, quite often this is still visible on today's maps of the old cities. In the east and south, huge wild peat areas offered some kind of natural protection against invaders from the east and south east. Where the sub soil contained solid sandy deposits, in other words where realistic chances existed that enemies could penetrate, military fortresses were developed (Nieuwe Schans, Boertange, Coevorden, Grol, Doesburg, Mook, Roermond, etc., see *Fig. 439*) Also along the southern flank of the river area cities developed as military fortresses against invaders from the south (Grave, Den Bosch, Hedel, Willemstad).

Water as primary connection

In parts of the country, through the ages there always have been various options to create water corridors during (threatening) wartime, in particular in north – south direction. These wet corridors were

[a] *RWS*
[b] *author De Bruin*

situated in between major military fortresses. To get these systems activated, a well designed (and maintained!) system of sluices, dikes and locks was developed, in combination with natural water systems that could provide sufficient inundation water during critical periods. Today, the remnants of these provisions are cultural elements in the landscape. Quite often money is spent on renovation and restoration, no longer for military reasons but to safeguard a cultural heritage.

Transport

Paved (or railed) roads in the water saturated soft soil areas in the Netherlands gradually started developing from the middle of the 19^{th} century. Around 1800, the best, safest and quickest way to move from the government buildings in The Hague to the navy harbours in Den Helder and Hellevoetsluis was still taking a horse via the beach! That is a major reason why through the ages all the major waterways in the Netherlands were also used for shipping. Until late in the 20^{th} century, most domestic transport of cargo and passengers was done by ship ('trekvaart', beurtvaart). In fact for all important routes and waterways specific (sailing) vessels were developed. The remains of this fleet are now the backbone of the leisure industry. Today, about 35% of all the cargo transport in the Netherlands is still going via waterways; compared to this figure in other countries this is extremely high.

The daily water management of major waterways as shipping routes is still crucial. Shipping developments on the international Rhine also determine the major nautical developments on Dutch domestic waterways. The historic and today's development of cargo transport on the international Rhine (in other words the economic importance of that river), has not been and is not determined by (fluctuations in) the Dutch economy, but first of all by the German economy. The Rhine is the major hinterland connection of the ARA ports (Amsterdam, Rotterdam, Antwerp), and shipping developments have been coordinated and controlled by the International Central Commission for Navigation on the Rhine (CCNR) since the defeat of Napoleon (1813 Waterloo, Vienna Congress 1815). It is the oldest still functioning international body in the world.

International trade

International trade always has been important for the development of the Netherlands. More in particular sea trade on a global scale. It has also determined the intensive navy orientation of society. It is remarkable that for the protection of the capital (Amsterdam, the old trade centre) the so called 'Stelling van Amsterdam' has developed, while for the military protection of the national government centre (The Hague) only a poorly functioning water corridor was available.

Fig. 439 Water as ally[a]

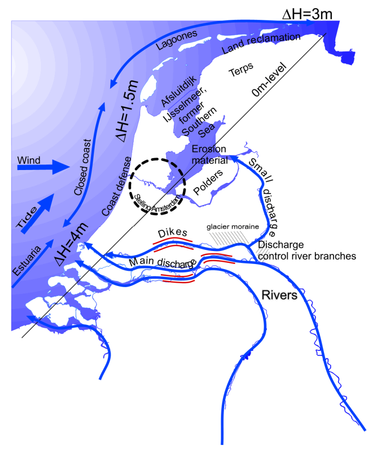


Fig. 440 Water as enemy [b] [88]

3.2.2 The distribution of water

The purpose of the Rhine canalisation (3 weirs in the Lower Rhine/Lek branch, plus some bend cuts in the upper reach of the IJssel river) was to gain more control, during low river discharges (of the Rhine at the German Dutch border), of the fresh water distribution via the two bifurcations (Pannerdensche Kop-PK-, IJsselkop -IJK-) to the rest of the country (see *Fig. 441*). Extra fresh water to the north is needed during the dry season, because the IJsselmeer (IJssellake) evaporates about one cm a day during a warm summer day, causing too many shallows in the navigation channels in the IJsselmeer after some weeks of a dry period. In addition, such a dry period often occurs in the growing season of crops in the adjacent polders around the IJsselmeer , so at that time an extra need exists for fresh water. More fresh water coming down via the IJssel (being the main feeder of the IJsselmeer) can be achieved by closing the weir at Driel.

[a] *author Bruin*
[b] *author Bruin*

Fig. 441 Weirs directing water northwards and southwards[a]

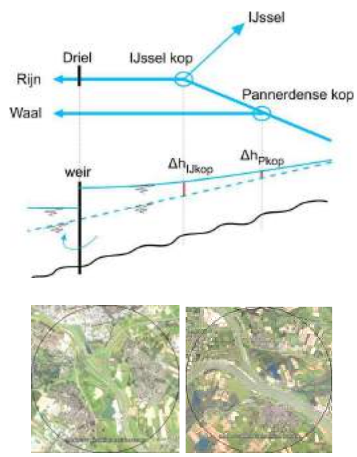


Fig. 442 IJK, PK, Weir of Driel regulating Dutch water distribution[b]

The Driel weir is the most important fresh water tap of the country. By lowering (= partly or entirey closing the Lower Rhine) the so called visor gates, a backwater effect is noticeable till upstream Lobith, so also at both bifurcations IJK (more) and PK (less). Because the width of the major channel in the Waal branch is 260 m, and the width of the IJssel major channel only 80 m, the amount of discharge taken from the Lower Rhine will distribute over IJssel and Waal in the order of magnitude 40–60 % / 60-40 %, so as an average 50/50%. However, the lowering of the Driel weir is only possible if first the two other weirs at Hagestein (Lek) and Amerongen (Lower Rhine) are lowered, with the purpose to create sufficient navigable depth in the entire length of the river between IJK and the tidal zone near Rotterdam.[89]

Salt water intrusion

Because the weirs are only closed during dry periods (low discharge of the Rhine at the German-Dutch border), the fresh water discharge coming down the Lek to Rotterdam will be minimised; as a consequence the salt water intrusion from the sea may harm the drinking water inlet east of Rotterdam along that river. This is not acceptable, so there must be compensation to minimise that salt water effect. It can be done by first closing the Haringvliet sluices, in a way that a backwater effect is created up till at least the Moerdijk zone. Then, all the fresh water coming down both the Meuse and Waal rivers will be sent north to Rotterdam and Hook of Holland. This surplus fresh water is sufficient to stop the salt water intrusion as mentioned.[90]
So one can conclude that a strategic water management of the IJsselmeer is determined by the flush regime of the Haringvliet sluices, via the canalisation of the Lower Rhine.

3.2.3 The threat of floods

The major rivers and the sea always have threatened the Dutch society during severe floods. The tidal characteristics and the regime of the river discharges have determined the development of the flood protection systems in the country. Due to large scale drainage and reclamation over a period of many centuries, major parts of the land where peat deposits at the surface and in the subsoil exist(ed), have subsided. This process is still going on as long as the polders are kept dry with artificial means (pumps, see *Fig. 470*). Due to climate change, expectations are that the sea level will rise and the regime of the major rivers will change (higher peak flows, longer dry periods[91]). As a result, the dense populated areas in the western and centre part of the country will further subside and the river levels and sea level will rise (see *Fig. 446*).

[a] *author Bruin*
[b] *De Bruin, Google Earth*

In the past, dike breaches along the rivers have occurred frequently during floods, more in particular during severe winters when ice jams blocked the major streams. There are also well known examples of severe floods by storm surges from the sea, the last major attack was in 1953. During the last 50 years, strong political policy decisions on safety against flooding have determined how flood control measures (coastal defence systems, dike strengthening along estuaries, lakes and rivers) have been designed and implemented. Due to expected climate change, new standards and approaches for adapted policies are considered or already carried out (Room for the Rivers programme). Safety along the major rivers can only be achieved in concert with measures taken by riparian countries in all river basins situated upstream of the Netherlands.

The present map of the Netherlands is fully determined by human intervention with the purpose of flood control and safety. One has to distinguish the rivers and the coastline.

The rivers

Along the rivers, the regulation, normalisation and sometimes canalisation (Meuse, Lower Rhine), in combination with (confined) flood plain management and dike structures (often but not always with a public road on top) have determined safety; as have the controlled discharge distribution over the various Rhine branches Waal, Lower Rhine and IJssel) during all stages at two bifurcations (Pannerdensche Kop, PK; Ijsselkop, IJK) and the artificial drains at the downstream end of the rivers (Nieuwe Merwede, Bergse Maas, Keteldiep/Kattendiep. Note: the normalised major channels of the river branches are state owned; however the land in the flood plains is mostly owned by private people, including foreign landownership).

The coast

Along the coastline, one has to distinguish at least four major systems of coast development (see *Fig. 440*):[92]

1. estuaries and (clay) island fixation in the south west;
2. a closed sandy coastline in the west (dunes);
3. a fully controlled lagoon in the centre with a primary (Afsluitdijk) and secondary (bunds around reclaimed polders) defence system, and
4. land reclamation in between sandy islands and a clay protection dike in the north (Waddenzee).

There is a litoral drift of the tide along the coast in northerly direction, tidal differences fluctuate between the southwest , the centre and the north east between 5m - 1,5m - 4m (see *Fig. 443*).

Levels and kinds of water

The line on *Fig. 441* between Sluis (Zeeuws Vlaanderen) and Eemshaven (Groningen) is exactly 45 degrees to the north arrow. It is a symbol, representing the 0-line (NAP, normal Amsterdam level, the one and only uniform chart datum in the whole country).

Fig. 443 shows the effort of increasing the elevation of dikes above the sea level along this line after the rare desastrous floods of 1953. They are mainly elevated to 4 metres above regular high tide (different along the coast). It shows also the ground level in Holland, as far as Amsterdam being even lower than the bottom of the IJsselmeer. The blue and red bars left in the drawing show the level of rivers and roads, canals and lakes in the polders. This representation indicates the logic of crossings by tunnels rather than by bridges even if the soil is weak, if dikes have to be crossed and if the densely populated area offers many spatial barriers.

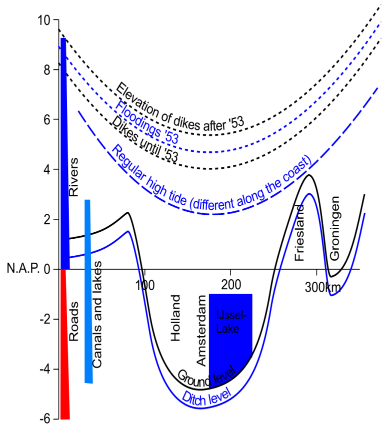


Fig. 443 Levels on the line of Fig. 441[a]

	SURFACE WATER					
	SALT		BRACKISH		FRESH	
	cur.	stag.	cur.	stag.	cur.	stag.
deep	Oosterschelde, Waddenzee	Grevelingen, Veerse Meer	Haringvliet	Biesbosch	Uiterwaarden Maas, Uiterwaarden Rijn	IJsselmeer, Oostvaarders plassen
shallow						
bank						
swamp						
bottom						
	GROUNDWATER					

Fig. 444 Kinds of water in the Netherlands[b]

The many resulting kinds of surface water (deep, shallow, bank, swamp, bottom, salt, brackish, fresh, current, stagnant) in the Netherlands are an important basis for its ecological diversity (see *Fig. 444*).

Rainfall and seepage

Heavy rainfall and seepage determine also the design criteria of water management measures in the country. In populated and industrialised areas, a severe rainfall with critical intensity must be pumped out completely within a period of 24 to 48 hours.[93] This urges the need for adequate pumping and drainage systems in the flat and low situated areas where due to wind effects, proper drainage by gravity is impossible; in addition proper maintenance of these systems is necessary. This can only be achieved by proper supervision and effective enforcement, so also the institutional aspect of water management (legislation, rules and regulations, set up of management authorities, finances, skill and staff, etc.) is a matter of crucial importance.

3.2.4 Risks of flooding

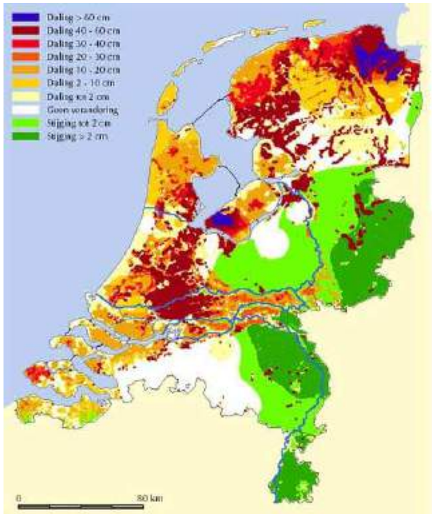
February 1995

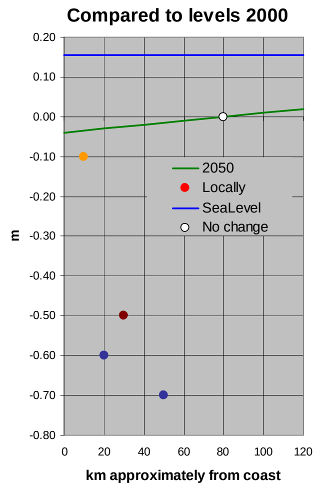
At Lobith in February normally a water level of approximately 10m NAP and 3000m^3/sec is measured. But in 1995 it was approximately 17m NAP and 12 000m^3/sec, the second highest discharge of the century (1925: 13 000m^3/sec). Evacuation of 200 000 inhabitants was ordered by the Royal Commissioner of Gelderland Terlouw when floods threatened Betuwe area downstream of Lobith. One million cattle had to be moved. It caused extreme traffic jams on roads the like of which had never been envisaged. The dikes barely held out, becoming wetter and wetter.[94]

Active debate on safety

Afterwards, the real threat of inland floods raised public awareness and the need to make plans to increase safety.[c] If the present state of inland dikes and other hydraulic circumstances is not changed, we apparently have to expect threats of a disaster like 1995 twice a century (a recurrence time of 50 years).

[a] *author Bruin*
[b] *author Bruin*
[c] *http://www.ruimtevoorderivier.nl/upload/WAAL-MAATREGELENBOEK.pdf*





Source:

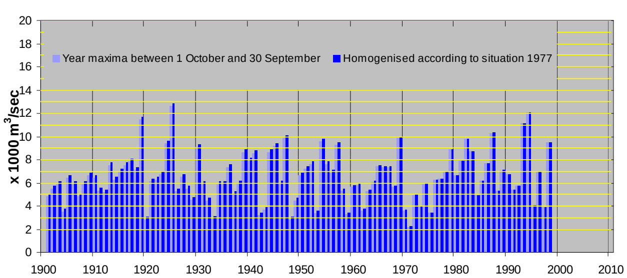
Fig. 445 Subsidence expected by 2050[a]

Fig. 446 Sealevel rise and subsidence expected by 2050

But the hydrological circumstances change. Perhaps we should expect more rain in winter (less in summer) as a result of climate change. Germany and Switzerland have drained their meadows so much, that any rainfall upstream reaches the river Rhine faster than ever. Moreover, the west of the Netherlands faces a general subsidence of at least -3cm until 2050 (locally –70cm, see *Fig. 445*).[95] Increasing the height of dikes along the rivers is necessary, but it does not solve the question how to drain the discharge into the sea while its level rises through climate change (15 cm by 2050?, see *Fig. 446*).

Normal distribution of maximal discharges

Looking at the average yearly maximal discharges[b] of past years (see the 98 years in *Fig. 447*) you can calculate their average maximum discharge (6.6454m^3/sec) and their standard deviation (2.1408m^3/sec) to draw a 'normal distribution' based solely on these two numbers (see *Fig. 448*). From that normal probability distribution you can extrapolate the probability per class of 1000m^3/sec wide (see *Fig. 449*).



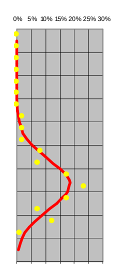


Fig. 447 Extreme discharges of the river Rhine per year

Fig. 448 Probability

[a] *RWS*
[b] *http://www.rijkswaterstaat.nl/rws/riza/home/publicaties/rapporten/2002/rr_2002_012.pdf*

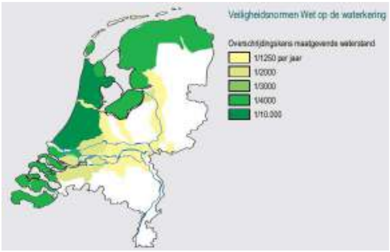
m^3/sec year maximum measured in 98 years		**m^3/sec class**	**probability/year**		**Year/probability (recurrence time)**	
average	**6 645**		➪			
standard deviation	**2 141**		➪			
		>1 000<2 000	0.58%	once in	174	year
smallest observed	2 280	>2 000<3 000	1.77%	once in	57	year
		>3 000<4 000	4.37%	once in	23	year
		>4 000<5 000	8.68%	once in	12	year
		>5 000<6 000	13.87%	once in	7	year
average	**6 645**	>6 000<7 000	17.81%	once in	6	year
		>7 000<8 000	18.38%	once in	5	year
		>8 000<9 000	15.25%	once in	7	year
		>9 000<10 000	10.18%	once in	10	year
		>10 000<11 000	5.46%	once in	18	year
		>11 000<12 000	2.35%	once in	42	year
largest observed	12 849	>12 000<13 000	0.82%	once in	122	year
		>13 000<14 000	0.23%	once in	439	year
		>14 000<15 000	0.05%	once in	1,961	year
		>15 000<16 000	0.01%	once in	10,881	year
		>16 000<17 000	0.00%	once in	75,115	year
		>17 000<18 000	0.00%	once in	644,950	year
		>18 000<19 000	0.00%	once in	6,887,859	year
		>19 000<20 000	0.00%	once in	91,495,720	year

Fig. 449 Normal probabilities per discharge class of the river Rhine

However, that is only a very first approach, because the formula for an asymmetrical distribution (see *Fig. 367*) or a distribution otherwise different from the normal distribution may fit the data better.
The percentages are represented less precisely and eloquently than their reciprocal value: the number of years you can expect between two occurrences of that class (recurrence time). That measure has political value.

Risk acceptance

The Parliament of the Netherlands once decided to accept 1 casualty per million inhabitants per year caused by environmental disasters (accepted risk). So, the number of casualties per class of discharge causing floods has to be calculated to plan the measures to meet the accepted risk of that rare discharge. Which area is flooded by which discharge, and how many people live there? Many studies have been executed to get answers on that question. They make clear that 1 casualty per million inhabitants per year would lead to unacceptable measures producing other kinds of risks. So, the Parliament decided in 1960 to accept the higher risk of a disastrous flooding of rivers once in 1250 years.[96] In other areas surrounded by dikes (dijkringen) that risk acceptance is lower or higher according to their economic value (see *Fig. 450*).



Source:
Fig. 450 Current safety standards for floods (MNP, 2004)

Source:
Fig. 451[a] *Proposed changes of safety standards* (MNP, 2004)

However the 'human and economic value' has increased substantially compared to the costs of water safety management. So, these safety standards are in discussion (see *Fig. 451*).

Calculating and extrapolating recurrence time directly from data

If you number the discharges Q from high to low (rank number r), in 98+1 years of experience the first largest maximal discharge has a recurrence time of 99/1 year, the second (including the first!) 99/2 and so on (see *Fig. 452*).

year	m^3/sec	rank	recurrence time
	Q	r	99/r
1901	5 058	77	1.3
1902	5 715	68	1.5
1903	6 081	60	1.7
1904	3 731	89	1.1
1905	6 697	44	2.3
1906	6 121	57	1.7
1907	5 058	77	1.3
1908	6 101	58	1.7
…	…	…	…
1925	12 849	1	99.0
…	…	…	…
1992	5 758	65	1.5
1993	11 100	4	24.8
1994	12 060	2	49.5
1995	4 112	84	1.2
1996	7 004	38	2.6
1997	3 912	87	1.1
1998	9 487	11	9.0

Fig. 452 Ranking maximum discharge per year, calculating recurrence time

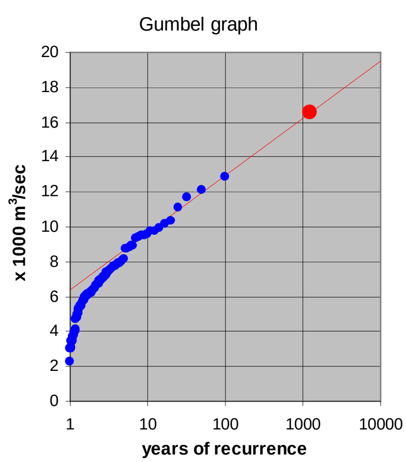


Fig. 453 A Gumbel graph of Fig. 452

If you plot them in a graph with a logarithmic x-axis (Gumbel graph[97], see *Fig. 453*) you can extrapolate the higher discharges to be expected roughly by a straight line.[b] *Fig. 453* shows a discharge of approximately 16 500 m^3/sec recurring every 1250 years with a big spot. So, for any river you can indicate every observation y on that graph if you know the last time that level was reached (x years ago)[c]. Nearly any kind of theoretical probability distribution (like the normal one on page 212) will also produce a nearly straight line for the higher levels in the Gumble graph. That method is used for many kinds of natural disasters like earth quakes and eruptions of vulcanoes.

[a] *http://www.rivm.nl/bibliotheek/rapporten/500799002.html*
[b] *http://www.humboldt.edu/~geodept/geology531/531_handouts/equations_of_graphs.pdf*
[c] Download Gumble paper from *http://geolab.seweb.uci.edu/graphing.phtml*

However, the slope 's' and elevation 'e' of the straight line chosen have great effect. In *Fig. 453* a line with formula Q(r) = s·ln(r)+b m^3/sec was chosen, where s = 1.43 and e = 6.36.[a]

3.2.5 Measures to avoid floods

Inundation?

One of the proposed measures is, to inundate indicated polders preventively in case of emergency. But a 1m deep polder of 1km^2 (1 000 000m^3) would store 12 000m^3/sec water only for 83 seconds at least if it is not sloping. In case of sloping you should half that capacity. If you would like to store 16 000m^3/sec during a week to be safe for many centuries because you cannot discharge that amount into the sea because of sea level rising after these centuries, you need 10 000km^2 (a quarter of the Netherlands). However, you can reduce the needed storage because you still can discharge into the sea, be it at low tide or by huge pumps. But this simple and much too rough calculation shows at least the dimensions of the problem.

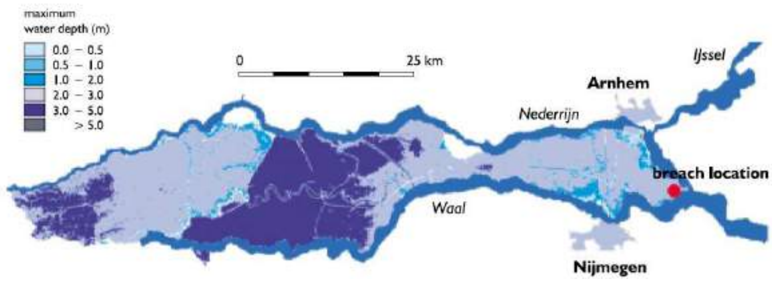


Fig. 454 Maximum water depth during a flooding in Betuwe along the Rhine after a dike breach and a peak discharge of 18.000 m^3/s[b]

Other measures

So, construction of retention basins or more general widening of the riverbed in the Netherlands solely cannot be a substantial solution to avoid rare flooding in a river system. Dikes along the rivers have to be heightened, but which height is enough? Deepening the river (filled up quickly with sediment) or making the dikes higher increases the capacity to discharge, but moves the problem to the west where more people live. So, retention in the Rhine basin upstream has to increase to avoid extreme situations downstream. This is discussed by the international Rijncommissie Koblenz.

[a] *http://team.bk.tudelft.nl/* > publications 2006 Hydrology.xls
[b] *http://www.ncr-web.org/downloads/NCR18nl-2002.pdf*

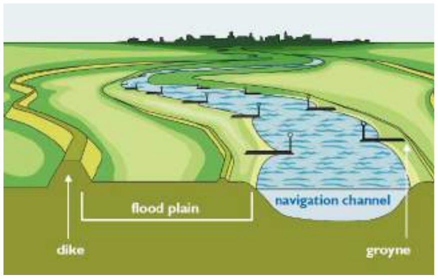


Fig. 455 Schematic representation of a low land river[a]

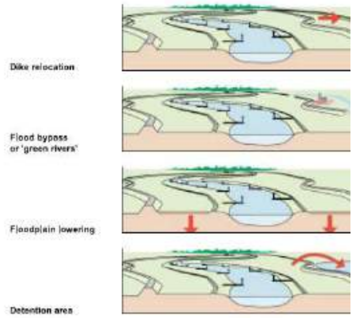


Fig. 456 Measures improving Rhine discharge[b]

How to design for floods?

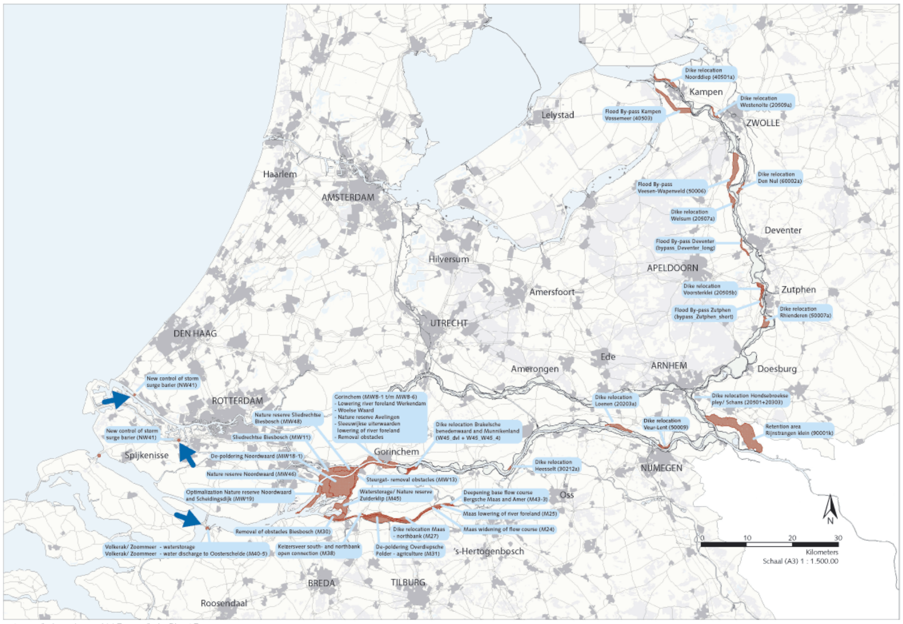
To be prepared for floods a landscape will have to be designed mainly as a natural area (see *Fig. 457*).

Fig. 457 Anticipated vegetation structure and land use along the Dutch Rhine as a 'green river'[c]

Room for the river

On 19 December 2006 the Dutch Parliament accepted a Spatial Planning Key Decision (SPKD, in Dutch: Planologische Kernbeslissing PKB) concerning a series of measures along the rivers known as 'Room for the river' (see *Fig. 458*). However, the final set of measures should be determined by commitment of local stakeholders and administrators. To get that commitment Delft Hydraulics has developed a game to determine the effects of any single measure in solving the problem[d].

[a] *http://www.ncr-web.org/downloads/NCR18nl-2002.pdf*
[b] *http://www.ncr-web.org/downloads/NCR18nl-2002.pdf*
[c] *http://www.ncr-web.org/downloads/NCR18nl-2002.pdf*
[d] *RWS* download from *http://www.wldelft.nl/soft/blokkendoos/*



topografische ondergrond (c) Topografische Dienst Emmen

Fig. 458 A series of measures known as 'Room for the river'[a]

3.2.6 Coastal protection

Disasters stimulating major civil engineering works

As shown in the sketch map of the Netherlands (see *Fig. 440*), there are various major coast forms, differing fundamentally. For the design, strengthening and maintenance of the coastal defence, all these major forms need continuously specific tailor made attention. A universal fact is that disasters are needed to make progress. Also in coastal water management, tragic disasters have determined human intervention in developing the Dutch coast line. One can refer to the big flood in the southern part of the former Zuiderzee in 1916, when severe flooding occurred causing nearly 20 deaths and huge damage; this disaster accelerated the political approval of starting the Zuiderzeewerken (Zuiderzee works) designed by Lely. And of course the storm surge on February 1st, 1953, which initiated the Deltawerken (Deltaworks).

History

In the past, coastal and river works were done by trial and error and on a relatively small scale. If the works that needed to be done were simply too big and complicated, land was given up (again). In those days, coastal engineering was more or less a matter of ''If we cannot do what we want, we will do what we can.''. Apart from not having proper large tools, current knowledge and practical experience were not enough to justify efforts in coastal development on any sort of large scale. Fundamental coastal research and model investigations were only developed in the Netherlands from the early 1930s. At that time, three major civil engineering works were developed, i.e. the Afsluitdijk (Enclosure dike, whereby the 'Zuiderzee' was renamed the 'IJsselmeer'), the big lock for seafaring vessels at IJmuiden at the end of the Noordzeekanaal (North Sea Canal) and the completion of the Maaswerken (Meuse works; Julianakanaal locks, with the biggest head in the country). Till then, water related research for Dutch clients was often done abroad, for example in Karlsruhe (Rehbock laboratory).

[a] *http://www.ruimtevoorderivier.nl/*

Zuiderzeewerken and Afsluitdijk

The preparations and design for the Zuiderzeewerken in the 1920s urged the need for developing a good mathematical basis for proper tidal computations, to be able to predict with sufficient accuracy changes in water levels along the coast of the Wadden Sea after the closure of the Afsluitdijk. In this respect in particular one name must be mentioned: Lorentz. He developed modern tidal calculations, needed to estimate the impact of the Zuiderzee works (Afsluitdijk) on the tidal regime along the northern Dutch coastline. In fact, one can conclude even after 75 years that the sandy bottom of the Wadden Sea has still not reached a new equilibrium since the closure in 1932, due to the severe changes in the tidal movements as introduced by human intervention at that time.

3.2.7 The Delta project

For all major infrastructure, political approval is necessary by means of a special law being adopted by Parliament. Such a law not only describes the need for the work itself, but also the financing and how institutions are required for design and implementation. The Delta Act was adopted in 1956, three years after the February ’53 surge. At the time, repair to the damage and building of new structures was already going full speed ahead. So in fact the financing of those efforts had not yet been approved by Parliament till 1956. The country was in a sense at war, so military means were accepted. For nearly 25 years (in the period 1953 – 1977), the execution of the solid dams in the south west was never a real political question: the need for implementation was simply a political fact because ‘safety first’ was the guiding motive after the disaster in ’53 when about 1850 people were killed. Only in the mid-seventies, when the last episode of the Deltaworks scheme started with the closure of the Oosterschelde (Eastern Scheldt), socio economic and environmental changes on a national scale prompted the need for a complete revision of the engineering approach to this major work (*Fig. 459*) showing many innovative coastal constructions.

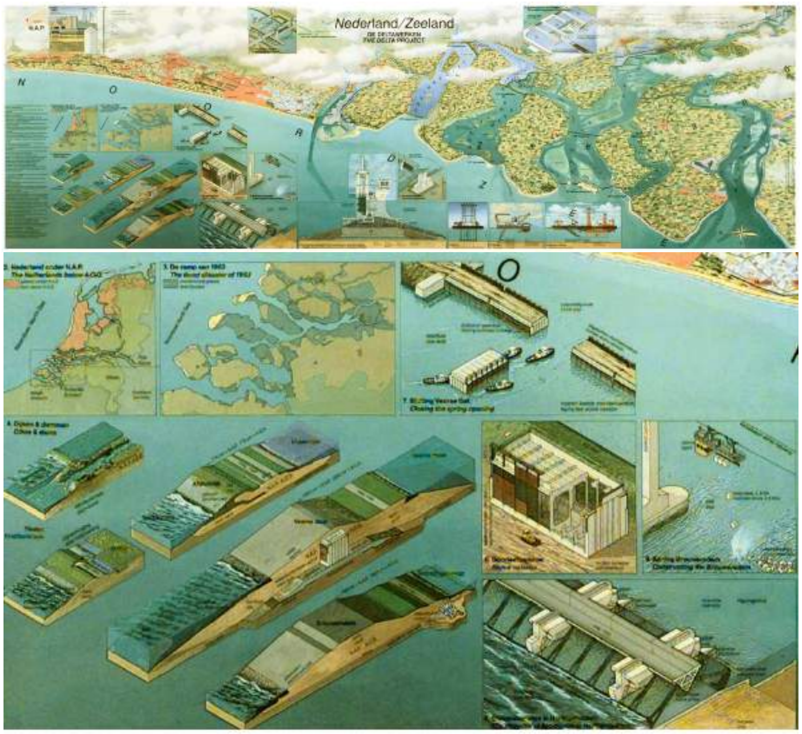


Fig. 459 Delta project[a]

A variety of interventions

It is remarkable to notice the huge level of human intervention since 1953, needed to close the estuaries in the south west. As the crow flies over a distance of about 100 km between Hook of Holland and Cadzand/Belgian border, 9 different ways have been used for closing off tidal creeks and estuaries, involving (systems of) primary dams (years as mentioned indicate year of commissioning). From north to south they are: the Nieuwe Waterweg (floating movable barrier, 1998), Brielse Maas (sand supply, 1952), Haringvliet (sluices, dam and by passing lock, 1970), Brouwersdam (caissons and cable, 1968), Oosterschelde (open barrier, 1986), Veerse Gat (caissons, 1961), Westerschelde (open estuary, dike strengthening, 1985), Braakman (sand supply, 1951), and Zwin (gradually closed by natural phenomena).

In addition there are 6 other solutions for the closure of so called secondary dams (some of them located on a former tidal slack) in the Deltaworks scheme, for example the Hollandse IJssel barrier (a main steel gate and a second one just for safety reasons in case the first one has a failure, 1956), the Volkerakdam (caissons plus major locks, and sluices (1969), Grevelingen (cable, minimising the tidal volume in the Brouwershavense Gat before closure (1961), Krammerdam (major locks with a sophisticated salt/fresh water control system, 1982), Markiezaatdam (compartment dam of clay and sand with a lock, to minimise the tidal volume at the Oosterschelde barrier and to control water quality in the Scheldt-Rhine canal, around 1980), Zandkreekdam (sand supply, minimising the tidal volume in the Veerse Gat before closure, 1960). To complete the variety of closure works in this part of the Netherlands, one must also mention the Sloedam and the Kreekrakdam, both needed for the railway connection to Vlissingen (clay and sand dams, 1870).

Funding

Considering all this, in the 20^{th} century the Dutch have reached apparently a point that can now be characterised as 'we can do what we want". Such a huge and costly scheme could only be

[a] *Hettema and Hormeijer, 1986*

implemented because the Dutch society was prepared to allocate the necessary funds from its own resources, so political support remained consistently positive. On the other hand: if a country in the Third World were to ask a donor organisation (for example the World Bank) to finance a closure scheme in a complicated tidal area with at least ten solutions, this would never been accepted. Such an investment for the safety of only 200,000 inhabitants behind the structures is according to present standards of international donor organisations simply NOT considered as feasible (!).
Note that in 1990, Rijkswaterstaat was awarded the Maaskant Prize for the Deltaworks, in particular for the way the whole project is flexible in its spatial planning and technical set up, and for the way it has proven to be useful also for new sectors developed after the period of design and execution, for example leisure and environment. For more general information on these works, see the jury report.

3.2.8 The central coast line

The centre coast line of the Netherlands between Hook of Holland and Den Helder can be characterised by a system of sandy dunes. Because of the lateral drift in northerly direction along the coast, there is some continuous ongoing erosion of the sandy coastline(see *Fig. 460*). The effect over time is visible at the Hondsbosse Zeewering, where the original tow of the revetments at the seaside was constructed (stone construction, 1875) in line with the low water line on the beach in those days. Today, the low water coastline has moved over about 70 m in easterly direction.

Sand transport

In 1991, Parliament adopted a coastal defence law, giving the green light for regular sand supply (beach nourishment) to maintain the position of the low water line as it was in 1991. Since then, year after year, at some places along the entire coast, nourishment works are carried out outside the tourist season. Like the closure of the IJsselmeer by the 30km Afsluitdijk in 1932 this major project of the fifties caused changes of yearly natural sand transport in the North Sea and Wadden Sea The sand moved mainly from the inland waters as growing islands in front of these works. To stabilise protruding beaches and islands, large amounts of sand from the sea had to be added artificially to these beaches(see *Fig. 461*).

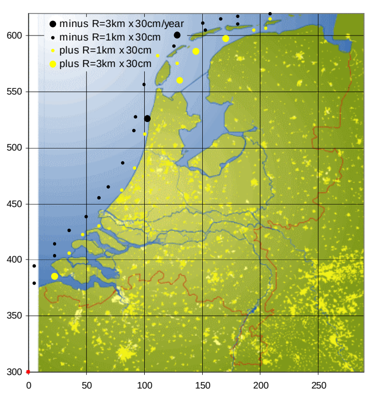


Fig. 460 Natural yearly sand transport[a]

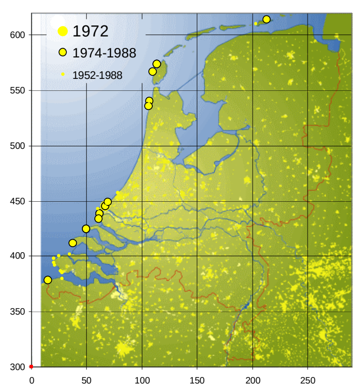


Fig. 461 Artificial incidental sand supply[b]

Fresh water in dunes

Over their entire length, the sandy dunes are important for building up and maintaining a 'fresh water bubble' in the sub soil, floating on the salt groundwater underneath. This fresh water system is an extra (groundwater) protection against salt intrusion in critical areas behind the dunes, for example the Westland. In many cases, the fresh water volume in the dunes is artificially kept above certain levels for drinking water supplies in the west. The inlet water originates from the major rivers in the country, Rhine and Meuse, and is pumped through pipelines.

---
[a] *After: Waterman, 1992*
[b] *After: Waterman, 1992*

A special development is de Kerf, west of Schoorl (Noord-Holland). There, in the late nineties, the primary dune ridge was artificially cut to allow the penetration of salt water during rather high tides (about twice a year). The environmental development and habitat have been carefully studied and followed by many institutions since then.

The Afsluitdijk

The Afsluitdijk is presently being renovated, to meet the recent standards for flood protection and safety/reliability. Also the capacity of the sluices may be increased shortly. Sluices, bridges across the locks bypassing the sluices, and dike (alignment) had special design criteria for military reasons. They really have worked: in 1940, Kornwerderzand was the only place in Holland where the invaders could not get through. In the original design of the dam, space was reserved for the construction of a rail track as well. A deep cut for the planned track is still visible on the former island of Wieringen, alongside the motorway to Den Helder. The excavated clay from that deep cut has been used for the creation of the last refuge hill (terp) built in the Netherlands to date; at Wieringerwerf in the Wieringermeer. Indeed it was used by some locals after the German army blew up the surrounding polder dike at the end of WWII. Today, on top of that 'terp' there is a public swimming pool (again the world upside down).

3.2.9 The northern defence system

The sea defence system in the north is rather complicated, because of the sandy islands, the Wadden Sea with all its environmental and morphological extremes, the so called old 'Landaanwinningswerken' and the strengthened long clay sea defence dike between the Afsluitdijk and the Dollard. For the purpose of this chapter, the most interesting aspects are the auxiliaries in the sea coastal defence system, for example the ferry terminals, harbour law outs and terminal structures, the various breakwaters (Harlingen, Delfzijl), navigational aid systems, and the leisure facilities. They all can be used as informative and illustrative examples when designing a specific issue in relation to coastal engineering aspects. Whatever further intervention will be needed in the near future, the fact is that for the 21st century the situation of designing and constructing large scale works can now be described as 'are we still allowed to create what we can?'.

The historical value of the northern islands

Finally, a last aspect when it comes to coastal engineering, the logistics of the execution and implementation of impressive works. It deals with the supply of material in isolated and so far undeveloped areas. This can be illustrated with two examples from the past. For more modern and contemporary equivalents, everyone can use their common sense.
First, when visiting the Wadden islands in the north, many brick houses can be seen that have been built through the ages. This is remarkable, because there have never been brickyards on the islands. Even some lighthouses, like the famous Brandaris (Terschelling), were constructed exclusively with bricks. One may wonder where originally all those bricks came from.

This has everything to do with the flourishing Hanseatic League in the past. Wooden sailing vessels came from the Rhine basin, heading for the Hansa cities in the north and beyond (Baltic Sea). Bricks were transported by ship from brick yards in the river area (flood plain), and handled manually. In those days, where no machinery existed, this was done stone by stone by so called head loading. More astonishingly, each stone of the Brandaris light house must have been handled this way at least six times (or most probably even more), when being moved between the brick yard somewhere in the flood plain to its final place in the structure. En route they were brought on rather small vessels over dangerous and difficult waters.

Second, a similar development can be seen on a larger scale, for distant overseas destinations. The VOC vessels in the 17th-18th century took bricks as ballast on their journey from Holland to the Far East, for example to present-day Jakarta. When visiting the city today, one can still see the typical bricks and tiles of Dutch origin, used in the construction of buildings there.

Design with nature

To stimulate local inland movement of sand and clay from the sea (stopped after these 'hard' defence works) the policy of coastal defence has changed gradually into a 'design with nature' approach.

Fig. 462 Slufter on the isle of Texel[a]

This involves opening up some 'hard' defences where it is safe (slufters) allowing the sea to come in, bringing sand and clay into these calm inland waters causing the development of beautiful dynamic natural areas calling the original state of the Netherlands to mind.

3.2.10 Polders

3.2.11 Need of drainage and flood control

History

Wetland areas may need drainage to be used for living and agriculture. The draining was started to obtain more space for these activities. The first method of draining was with the help of open ditches and trenches. The water was drained by sluices on lower lying waterways like rivers or at low tide at the sea (see *Fig. 463*). Later when the difference in height of water between the drainage area and the river or sea became too small or even negative, the land was drained by pumps (see *Fig. 464* and *Fig. 470*).

A polder is a piece of land that forms a hydrographical entity. In low lying areas a polder is surrounded by embankments or dikes. Even a lake can be transformed into land (see *Fig. 463*).
This reclamation is also called a polder because the groundwater level is managed in an artificial manner. Such land reclamations are always situated below the surrounding water level.

[a] *Google Earth*

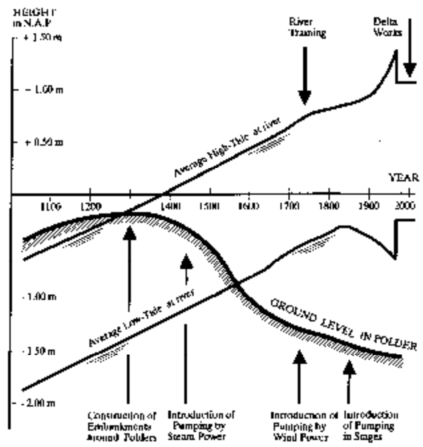


Fig. 463 A short history of polders[a]

Fig. 464 Rising outside water levels and dropping ground levels[b]

Draining an area starts a process of changes in the soil. The ground level will settle and drop depending on the type of soil. Peat soil will actually totally disappear by chemical processes and the ground level will be lowered by the equivalent of the thickness of the peat layer. Also the introduction of better methods and pumps will lower the groundlevel (see *Fig. 464*).

Desired groundwater levels

It is obvious that since the groundwater level is managed artificially , there are several desirable groundwater levels. The depth of the groundwater level depends on the activity that will take place in that area and the type of soil. For grassland a high groundwater level is no problem for growing, but having cattle on that land will be more problematical as the cattle will destroy the grass by walking on it and no food will be left. For crops the depth of the groundwater level is dependent on the type of crop. Grasslands may be wetter, dryland crops should be dryer than 1m below terrain (*Fig. 465*

[a] *Source unknown*
[b] *Ankum, 2003; page 71*

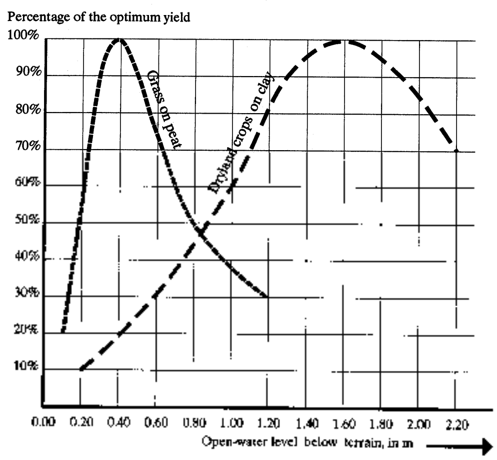


Fig. 465 Crop yields for different open water levels[a]

Urban areas

For urban areas the groundwater level is kept at approximately 1m below ground level for different reasons such as foundations and wet crawl spaces. Also the construction of cables and pipes in the streets is easier under dry circumstances.(see *Fig. 466*).

Fig. 466 Flooding of a canal in Delft[b]

Fig. 467 Deep canal in Utrecht

Urban areas need dry crawl spaces to keep unhealthy moist out of the buildings but they need wet foundations as long as they are made of wood. Groundwaterlevel is often recognisable from open water in the area. In higher parts of the Netherlands like in Utrecht canals show a level of several metres below ground level (see *Fig. 467*).

The distribution of polders worldwide

Lowlands with drainage and flood control problems cover nearly 1million km^2 all over the world (Fig. 468) and nearly half the world population lives there because of water shortages elsewhere (RWS (1998).

x1000 km2	1 crop	2 crops	3 crops	Total
North America	170	210	30	400
Centra America		20	190	210
South America	60	290	1210	1560
Europe	830	50		880

[a] *Ankum, 2003; page 53*
[b] *Paul van Eijk*

Africa		300	1620	1920
South Asia	10	460	580	1050
North and Central Asia	1650	520	20	2190
South-East Africa			530	530
Australia		310	120	430
				9170

Fig. 468 *Area of lowlands with drainage and flood control problems*[a]

3.2.12 Artificial drainage

Inhabited or agricultural areas below high tide river or sea level (polders) have to be drained by one way sluices using sea tides or pumping stations (see *Fig. 470*, *Fig. 473*).
Fig. 469 is the oldest known example of draining by one way sluices at low tide dating from the 11th century.

Fig. 469 *The oldest one way sluice found in the Netherlands and its modern principle*[b]

[a] *Ankum, 2003, page 2*
[b] *Ankum, 2003, page 68 and 38*

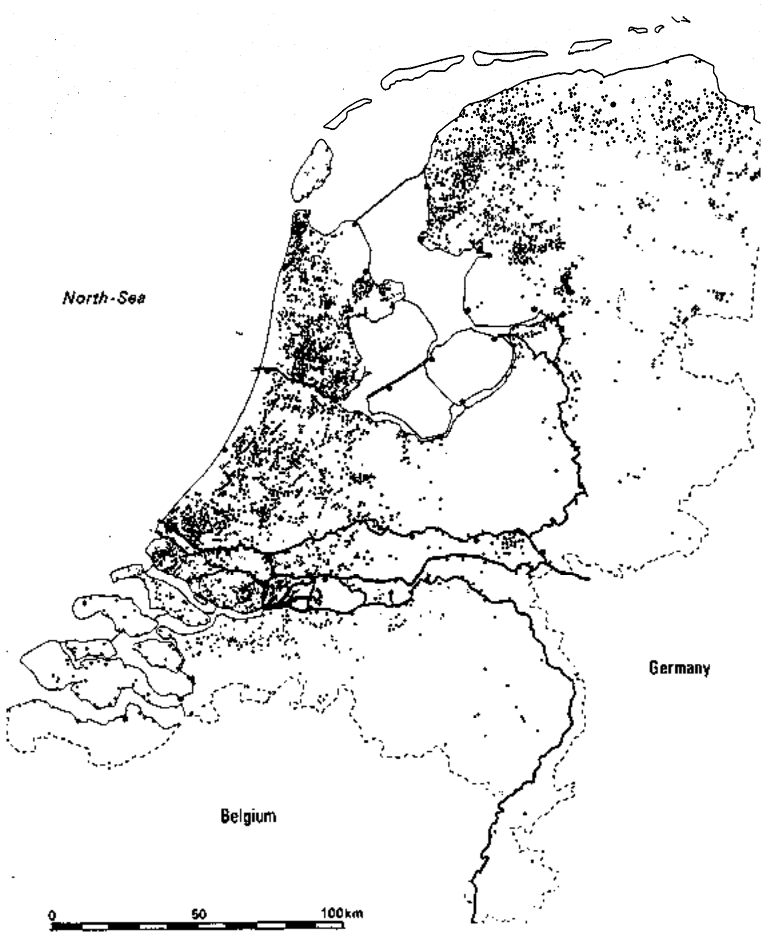


Fig. 470 Pumping stations in the Netherlands[a]

One way sluices lose their purpose when average sea and river levels rise and ground level drops mainly because of the subsidence of peat polders (*Fig. 464*). Drying peat oxidates and disappears and so the ground level of the polder will drop below river or sea level.

The area is divided in smaller entities or compartments that are surrounded by belt canals (boezemkanalen), protected by dikes and internally drained by races (tochten), main ditches (weteringen), ditches (sloten), trenches (greppels), and pipe drains. As the system of outlet canals(boezemkanalen) transports the water from the land to the river or the sea and they are all connected with each other it is also possible to use these waterways for shipping. The area is made accessible for shipping traffic by locks.

[a] *Ankum, 2003, page 78*

Compartments

Fig. 471 shows the belt system of Delfland and the compartments. Each compartment has its own sluice or pump and outlet canal or 'boezem'.

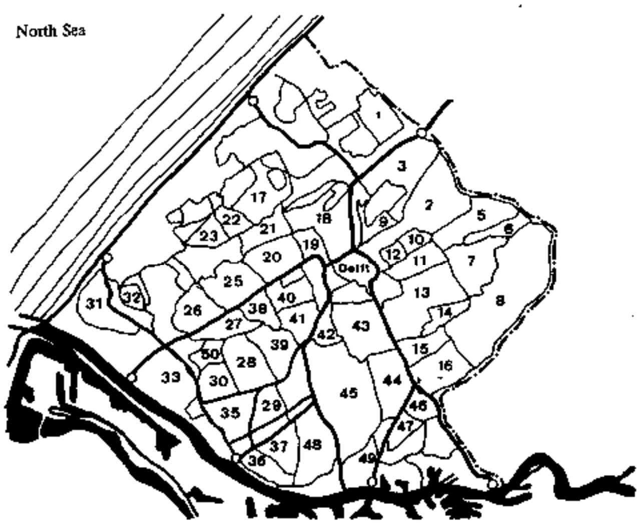


Fig. 471 The belt ('boezem') system of Delfland[a]

Methods of impoldering or pumping step by step

The reclamation and drainage of the polders is done by pumps. The pumps are driven by wind, steam or electricity depending the technical knowledge of the time. The methods used depend on the depth of the polder. Draining marshland is often done by one step of pumping or even by a one way sluice when the land is adjacent to a tidal river or the sea. But after settling of the soil in the course of time it can be necessary to use more steps for pumping. Especially when the only force to drive the pumps was by wind, rows of windmills were used for draining the polder. The most famous row of windmills in the Netherlands are those of Kinderdijk in Zuid Holland.

The methods used for draining polders with different altitudes are pumping at once from the deepest part using gravity by collecting first the water from the deepest level or draining step by step compartments separated by dikes and weirs saving potential energy (*Fig. 473*).

[a] *Ankum, 2003; page 62*

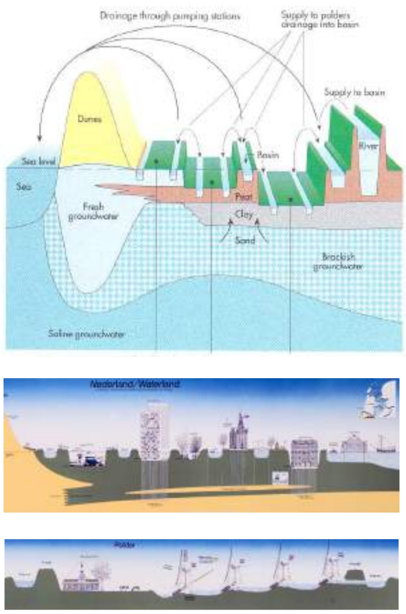


Fig. 472 Lowland system[a]

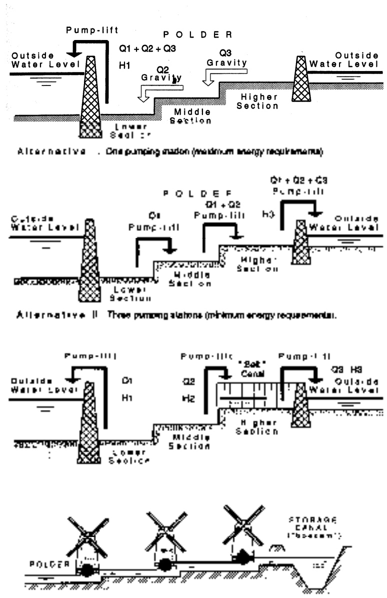


Fig. 473 Drainage by one to three pumping stations, in earlier times by a 'row of windmills' ('molengang')[b]

[a] Huisman, Cramer et al., 1998 page 36 ; Veer
[b] Ankum, 2003; page 76 and 55

3.2.13 Configuration and drainage patterns of polders

Polders are optimally drained by a regular pattern of ditches (see *Fig. 474*, *Fig. 475*).

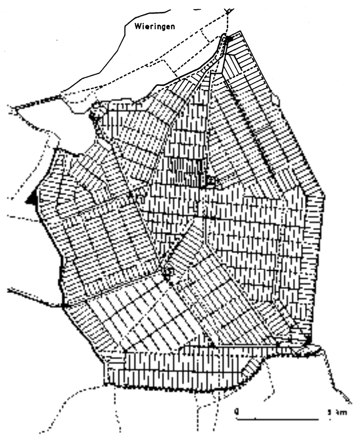


Fig. 474 Wieringermeer polder[a]

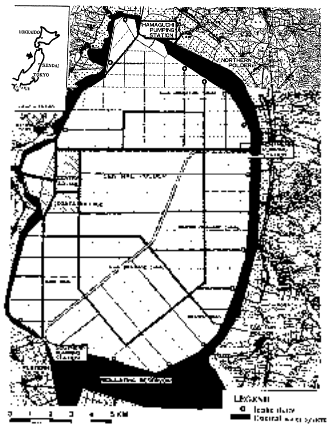


Fig. 475 Hachiro Gata Polder in Japan[b]

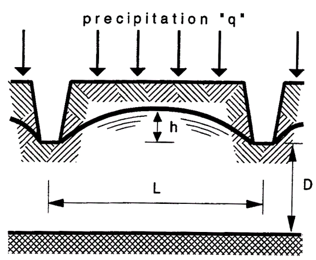


Fig. 476 Variables determining distance L between trenches[c]

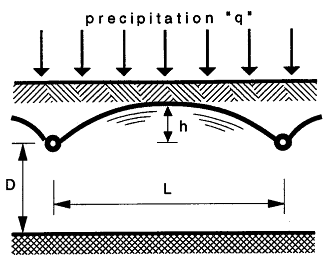


Fig. 477 Variables determining distance L between drain pipes[d]

Calculation of distance for drains in a polder

The necessary distance L between smallest ditches (see *Fig. 476*) or drain pipes (see *Fig. 477*) is determined by precipitation q [m/24h], the maximum acceptable height h [m] of ground water above drainage basis between drains and by soil characteristics. Soil is characterised by its permeability k [m/24h] (see *Fig. 478*).

$L=2\sqrt{(2kh/q)}$ is a simple formula to calculate L. If we accept h=0.4m and several times per year precipitation is 0.008m/24h, supposing k=25m/24h the distance L between ditches is 100m.

[a] *Kley 1969*
[b] *Ankum, 2003 page 42 and 82*
[c] *Ankum, 2003; page 36*
[d] *Ankum, 2003; page 36*

Type of soil	***Permeability k in m/24h***	
gravel	>1000	
coarse sand with gravel	100	1000
coarse sand, fractured clay in new polders	10	100
middle fine sand	1	10
very fine sand	0.2	1
sandy clay	0.1	
peat, heavy clay	0.01	
un-ripened clay	0.00001	

Fig. 478 Typical permeability k of soil types

However, the permeability k [m/24h] differs per soil layer.
To calculate such differences more precisly we need the Hooghoudt formula described by Ankum (2003) page 35.

3.2.14 Drainage and use

Parcel ditches are used as property boundaries. In this way agricultural and urban activities are easily to separate from each other. Any use has its own requirements for parcel division. Systems of parcel division have to take dry infrastructure into account. Different network systems have to be combined in the polder for a good completion of drainage as well traffic.

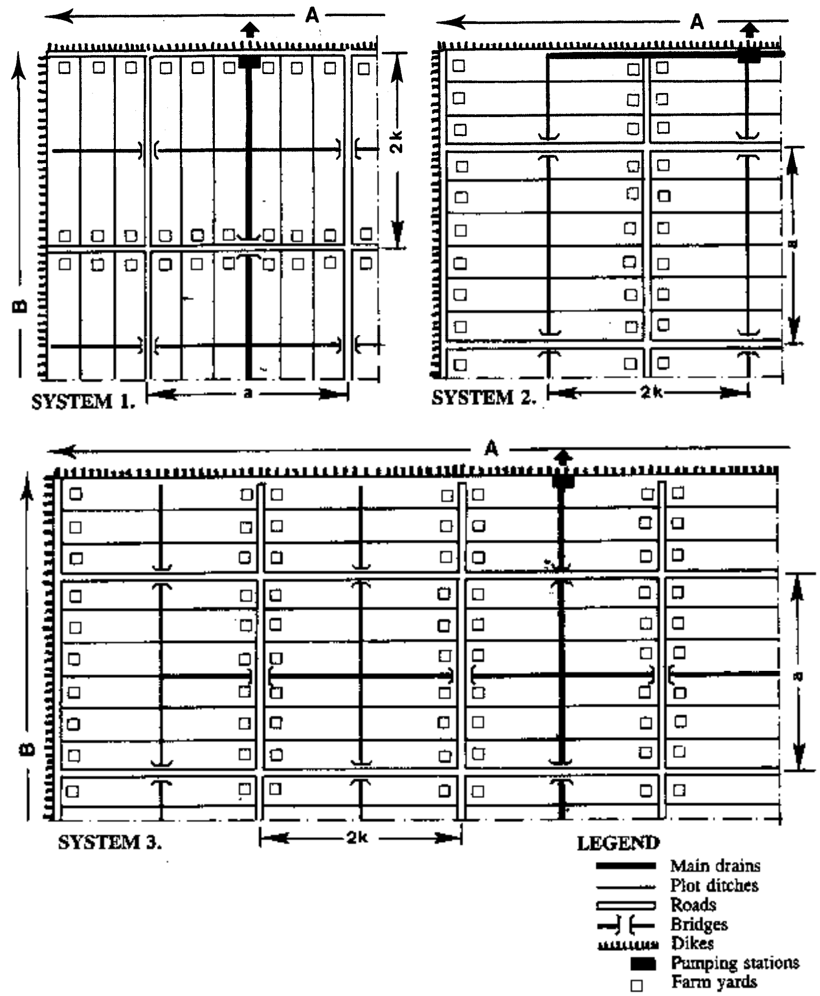


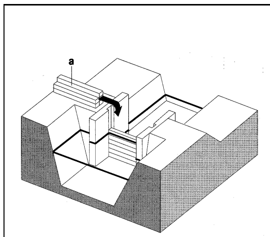
Fig. 479 *Alternative systems of plot division in polders*[a]

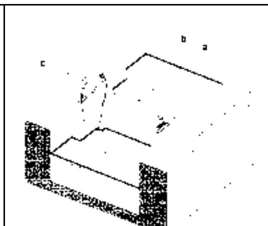
We will elaborate that in 3.4.16.

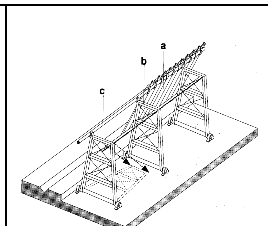
3.2.15 Weirs, sluices and locks

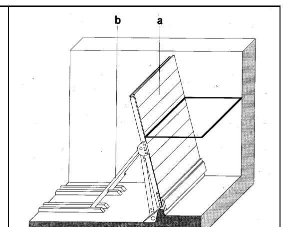
There are many types of water level regulators elaborated by Arends (1994) (Fig. 480, Fig. 481, Fig. 482).

Weirs









[a] Ankum (2003) page 59

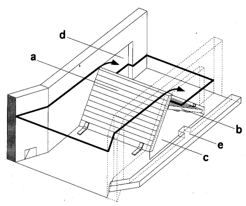
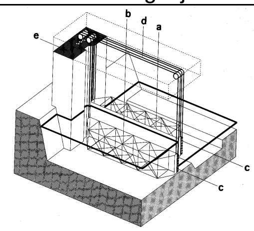
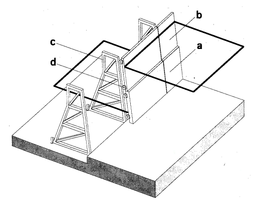
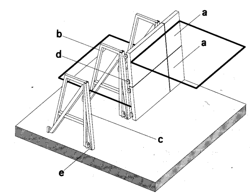
Schotbalkstuw	Schotbalkstuw met wegklapbare aanslagstijl	Naaldstuw	Automatische klepstuw
			
Dakstuw	Dubbele Stoneyschuif	Wielschuif rechtstreeks ondersteund door jukken	Wielschuif via losse stijlen ondersteund door jukken

Fig. 480 *Types of weirs*[a]

Sluices

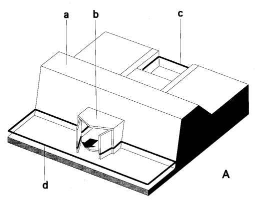
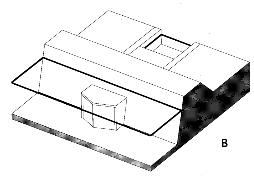
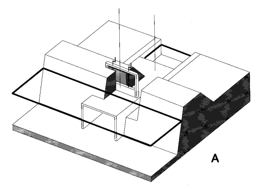
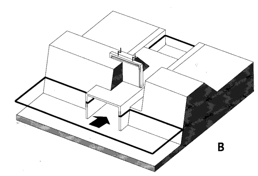
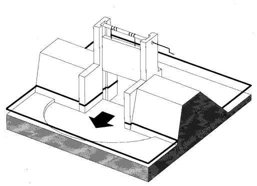
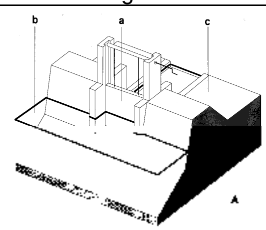
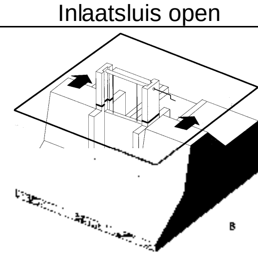
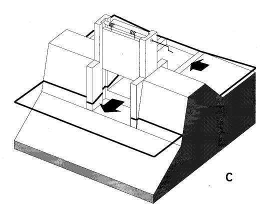
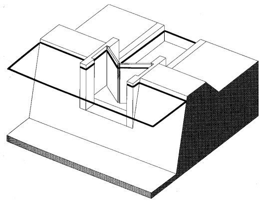
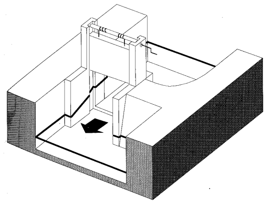
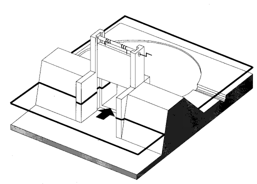
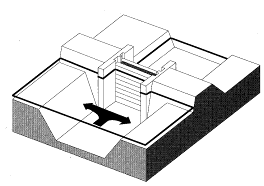
			
Uitwateringssluis open	Uitwateringssluis closed	Inlaatsluis open	Inlaatsluis closed
			
Irrigatiesluis	Ontlastsluis closed	Ontlastsluis flooded	Ontlastsluis open
			
Keersluis	Spuisluis	Inundatiesluis (military)	Damsluis (military)

Fig. 481 *Types of sluices*[b]

[a] Arends (1994)
[b] Arends (1994)

Locks

To allow accessibility of shipping traffic you need locks at every transition of water level.

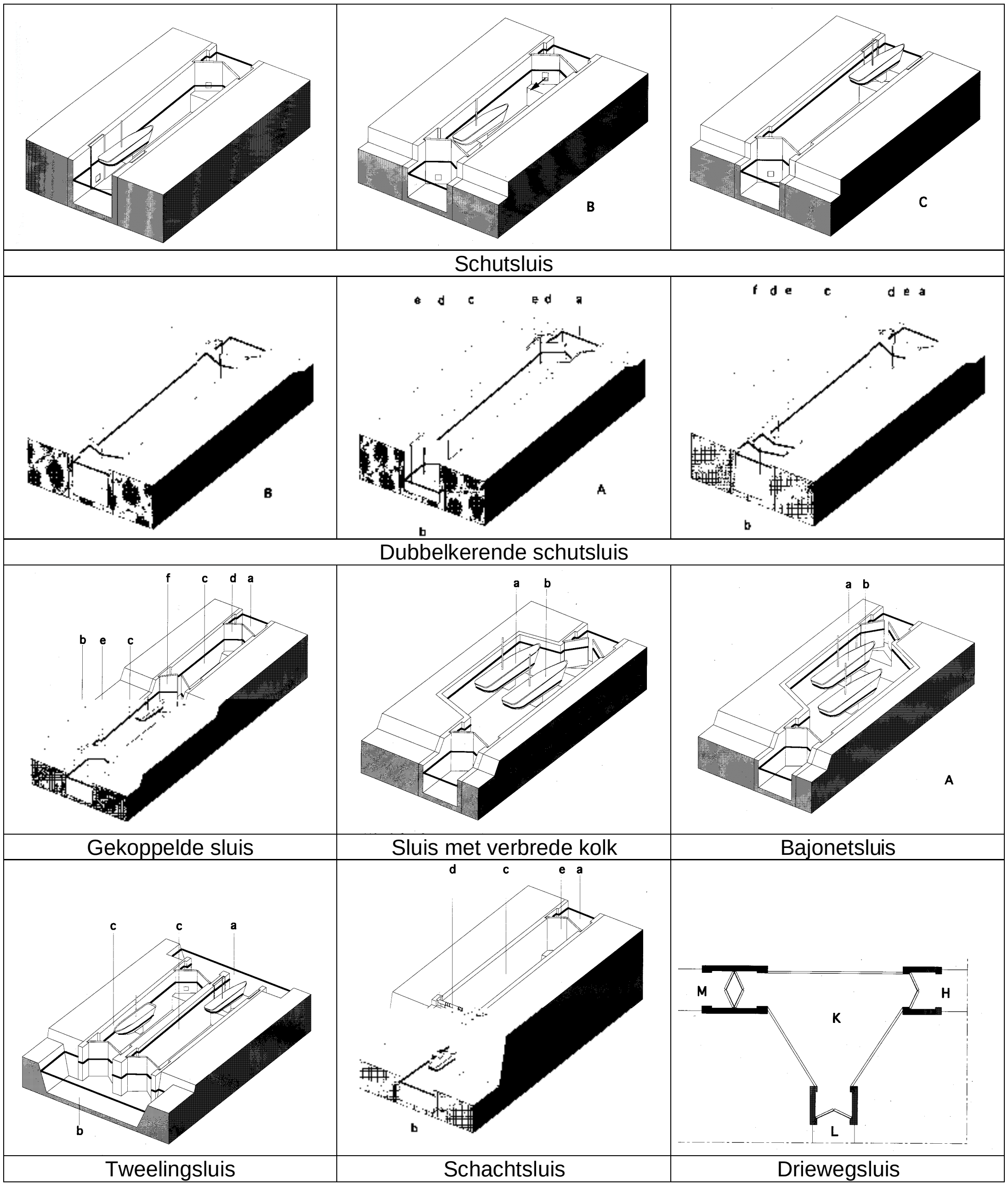


Fig. 482 *Types of locks*[a]

Entrance and exit

Any regulator, culvert, sluice, lock or bridge requires a structure with entrance and exit of water needing space themselves (Fig. 483).

[a] Arends, G.J.(1994) Sluizen en stuwen (Delft) DUP Rijksdienst voor de Monumentenzorg

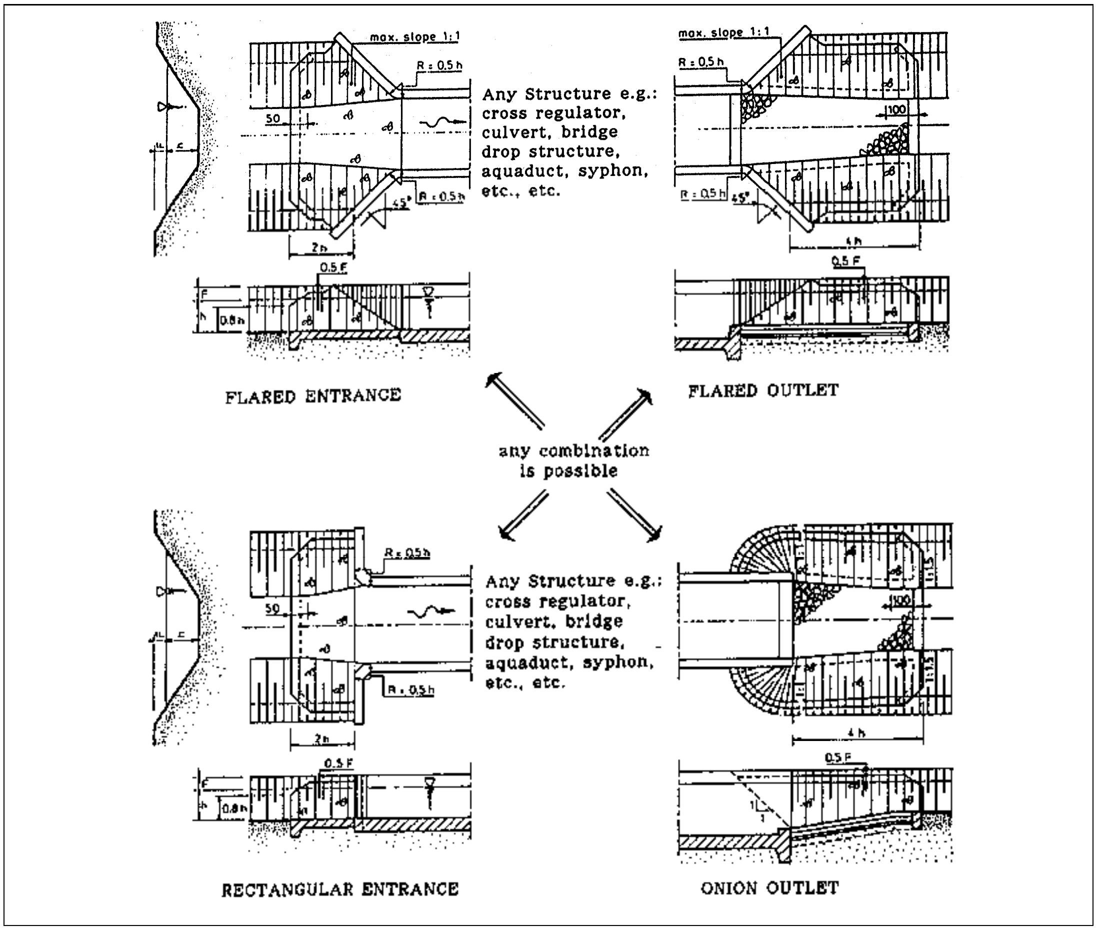


Fig. 483 *Samples of the 'entrance' and 'exit' of a structure*[a]

3.2.16 Water management tasks in the landscape

Civil engineering offices are involved with many water management tasks (see *Fig. 484*).

[a] Ankum (2003) page 164

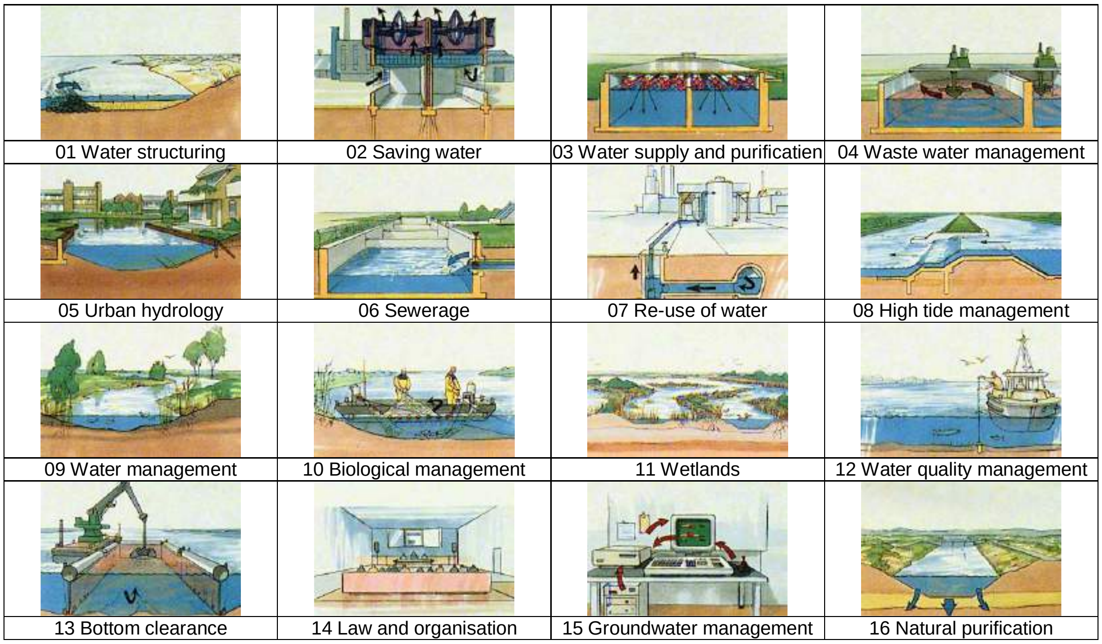


Fig. 484 Water managemant tasks in lowlands[a]

3.2.17 Local water management maps

For a long time now, maps have existed of The Netherlands showing the areas governing their own water management (Waterschappen)[b], and their drainage areas (*Fig. 485* above). Overlays show hydrological measure points (*Fig. 485* below left) and the supply of surface water (*Fig. 485* below right).

RWS (1985)

[a] *Das (1993)*
[b] *http://www.uvw.nl/pagina_6390.html*

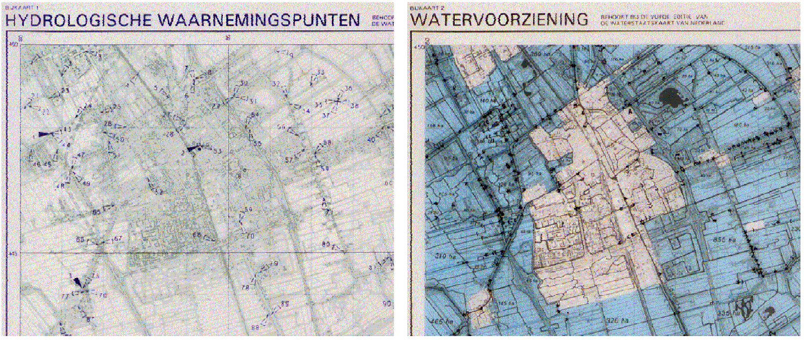


Fig. 485 Hydrological maps of Delft and environment[a]

On the first map you can find the names of compartments, pumping-stations, windmills, sluices, locks, dams, culverts, water pipes. However, these maps are no longer available in hardcopy anymore by fast development of GIS in the nineties.

[a] *RWS, 1985, 1984*

3.3 Water policy

3.3.1 Coordination of different administrative sectors

The storage of water in the lower parts of The Netherlands will put heavy demands on the surface. The 4th National Plan of water management policy V&W (1998, stressing environment), and its successor 'Anders omgaan met water' V&W (2000) (stressing security) marked a change from the accent on a clean to a secure environment, as did the 4th National Plan of environmental policy VROM (2001) compared with its predecessors. Several floods in The Netherlands and elsewhere in Europe have focused the attention on global warming and water management. The future problems and proposed solutions are summarised in the figures below. Storage is a central item in reducing the risks for lowlands.

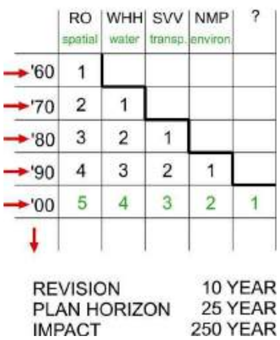


Fig. 486 Dutch Policy documents

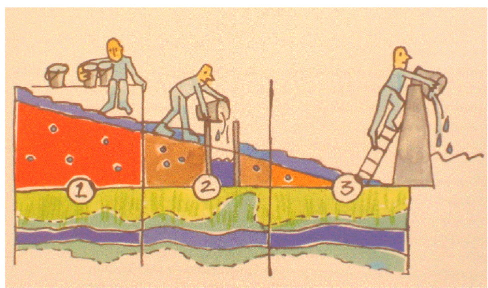


Fig. 487 Strategies: 1 care, 2 store, 3 drain[a]

Budget

Public sector institutions dealing with infrastructure must spend a lot of money over a time span, always longer than a budget year. Planned expenses must be properly argued (transparency) in annual work plans and need the approval of Parliament (democratic decision making). The approval must be based on a long term policy (political consistency).

Stakeholders

Water related infrastructure facilities are always multi functional; there are always more users and uses, so priorities must be set after political debates (public disclosure) and approval, and the management must integrate the interests that exists in society (integrated water management). The public must be informed on developments and criteria (regular communication with media and NGOs), data must be accessible (preferably for free) reliable and retrievable(web site). All this has to do with good governance.

An acceptable vision first

Integrated water management means that attention must be given to many sectors. Often, first an acceptable vision is needed to start a firm discussion. But usually a vision alone has no legislative status, it is just a recommendation (reference is made to 'Omgaan met Water' –V&W, 1984- and 'Plan Ooievaar' -1986-). More is needed for generating fundamental commitments for the infrastructure sector. In practice, means are always limited so choices must be made based on priorities and criteria. Avoiding random and un-controlled diffuse discussions, a strong target must be set and made visible to all involved parties in both the public and private sector. Such a well documented target needs political approval in Parliament, its implementation must be feasible in economic terms of course, and also both in technical and socio-economic terms.

[a] *V&W, 2000*

Parliamentary approval of long term organisation and finance

Yhis meant that Parliament must not only give its approval to a policy target as such, but also to the finances and the institutional set up needed for implementation over a longer period of years. Such a period is always longer than the ruling period of an elected politician in power. So, there is a need for political consistency to avoid a (sudden) change of major political targets during the implementation period of infrastructure schemes. One may guess how many cabinets with different political colour have ruled the Dutch nation in the period 1953 – 1986, the implementation period of the Deltaworks. During such a long period there always must one ministry as implementing agent and an institution as executing agent that is accountable for the project.

Gradual development of policy documents

The above pleads for a gradual development of one or more Policy document(s) with sufficient legislative status. This cannot be done over night. The way this has been developed in the Netherlands is elaborated hereafter, see also *Fig. 486*.

Rebuilding the nation after World War II

After World War II, in the late forties and fifties the rebuilding of the Dutch nation took shape. In the late fifties it led to a public awareness that at least some coordination was needed on spatial planning; it finally led to a first policy document on spatial planning around 1960. By law it was approved that a revision should take place every 10 to 12 years, and that the planning horizon of a policy document was 25 years. For the implementation, annual workplans of the involved ministries and related public sector organisations needed approval of Parliament (and –of course- still do). Also the way consistent spatial planning had to develop at various levels (national, regional, local) was described. And with additional proper legislation, matters such as disclosure, supervision, enforcement and management (in the public sector) became organised as well.

New public awareness of problems in the sixties

The country developed further, but due to industrialisation and urbanisation, pollution of surface waters became manifest. There was a growing public awareness that a new policy paper was needed on the water management of surface waters. A first version was adopted in Parliament in 1970, a period in which the second version of a revised policy paper on spatial planning was also developed. But because spatial planning and water management were two main responsibilities of different ministries under politicians of different political parties and the public sector organisations responsible for execution were still working in a top-down approach, there was hardly any coordination between the working floors of the two involved ministries during the preparations of these two policy papers.

Traffic and transport in the seventies

In the late seventies, traffic and transport in the Netherlands became a real problem. In a period where the working culture in the public sector changed from a top-down approach to a bottom-up attitude, and the working floors of separate ministries were allowed to exchange information and views directly with colleagues from other ministries, a first policy document on transport developed. First there were some separate draft versions for different sub-sectors and modes (rail-road-water-pipeline-transmission-telecom).

Integrating policies in the eighties

But Parliament forced the three main ministries involved (Economic Affairs, Public Works, Housing) to prepare a second version in the late eighties on inter modal and integrated transport issues, to be relevant also to water management and spatial planning. In the meantime, a third and fourth version of the policy paper on spatial planning developed, as well as a second and third version of the policy paper on water management (revision compulsory by law, every 10 to 12 years). Also in the late eighties, a first policy paper on nature development and environment got Parliamentary approval, finally leading to a situation at the beginning of the 21st century where four major policy papers on infrastructure sub-sectors were aligned and adopted by parliament: on Spatial Planning, on Water Management, on Transport and on Environment and Nature (respectively the 5th, 4th, 3rd, and 2nd version, see again *Fig. 486*).

Bottom-up and horizontal external contacts on the working floor

An important lesson learned from the development as described is the fact that altogether the time for a more effective alignment of the policy papers could have been shorter from the very beginning if the

ministries had accepted an internal working culture, to be characterised as 'bottom-up and horizontal external contacts on the working floor'.
Furthermore it is obvious that when every square inch of land surface has at least a triple function, and every cubic meter of water multi purpose function, adequate planning is only possible when integrated policy plans are adopted by Parliament, and when consistent political support is more or less guaranteed over many years (at least decades).

Public transparency

And it has been experienced during the numerous public disclosure meetings throughout the years, in particular during discussions with well informed NGOs, that the transparency of infrastructure plans and projects is really crucial. Much time (and money!) would have been saved if, as part of the process of public disclosure, relevant files and data had been made public and accessible (web site in recent years) in advance, and if important NGOs had been consulted at much earlier stages of planning preparations. We all have noticed the negative image of more recent large scale projects, such as HSL (High-Speed Line), Betuwelijn (railway), 2nd Maasvlakte (extension of Port of Rotterdam), dike strengthening, 5th runway at Schiphol, etc. One may guess why …….

One integrated policy document?

Today, one may ask how the situation will be after a new revision (following the law) of all these policy documents shortly. It is expected that in the near future only one integrated policy document will be issued, dealing with the complete national infrastructure (wet and dry), nature and environment, and transport, including budget allocations (see last horizontal bar and vertical column in *Fig. 486*). For an efficient implementation and execution, it includes that further fundamental reform of public sector institutions is unavoidable. No doubt more independent Agencies will be separated from the public sector (as has been done recently with Rijkswaterstaat), and that as a whole the present number of civil servants in the public sector will further decrease due to privatisation schemes and the streamlining of public sector organisations. Legislation, rules and regulations will further become adapted and aligned to international standards and developments (EU, global warming, international waters, CO_2 emissions, etc.). Technical and operational tasks will further shift from the public to the private sector. EU-directives will further develop and determine the daily management of infrastructure (water directives, bird habitat directives, etc.).

3.3.2 Water boards

Water boards are among the oldest government authorities in the Netherlands. They literally form the foundation of the whole Dutch system of local government; from time immemorial they have shouldered the responsibility for water management for the residents of their area. In polders this mainly involves regulating the water level. It has always been in the common interest to keep water out and polder residents have always had to work together. That is what led to the creation of water boards. Due to mergers, there are 27 water boards in The Netherlands (2006)[a]. Their borders don't coincide with municipal borders.

What is a 'waterboard'?

A water board is a public body with a special function; it is in charge of the water management of a certain area. In Holland there are in total some 27 water boards, in the last hundred years many smaller water boards have joined, so the number has decreased substantially.

Goals and tasks of waterboards

The general goal of water boards is water management in the broadest sense of the word. In Holland where half of the country is located below sea level, this requires special measures. The western part of the country is for the larger part located below sea level; polders determine the landscape and water management.

1. Maintenance, construction and keeping up the water defense in the form of dikes, dunes, quays and dams.
2. Management of water level, water quantity, water quality
3. Taking care of waterways, roads as traffic systems

[a] *http://www.uvw.nl/pagina_6390.html*

Territories of water boards are defined on the basis of watersheds, either naturally defined like in the east or man-made like in the case of polders. Borders quite often cross provincial and municipal borders

The structure of the water boards varies, but they all have a general administrative body, an executive board and a chairperson. The general administrative body consists of people representing the various categories of stakeholders: landholders, leaseholders, owners of buildings, companies and, since recently, all the residents as well. Importance and financial contribution decide how many representatives each category may delegate. Certain stakeholders (e.g. environmental organisations) may be given the power to appoint members. The general administrative body elects the executive board from among its members. The government appoints the chairperson (Dijkgraaf) for a period of six years. The general administrative body is elected for a period of four years (as individuals, not party representatives). Unlike municipal council elections, voters do not usually have to go to a polling station but can vote by mail or even by telephone.

3.3.3 Delfland Waterboard

The city of Delft and also the campus of Delft University of Technology is located in a landscape that is composed of polders. The watersystem of these polders is managed and maintained by a water board that is called 'Delfland Water Board'.

Fig. 488 Delfland Waterboard

The campus area is located in two polders (see).

Fig. 489 The 'Wippolder'

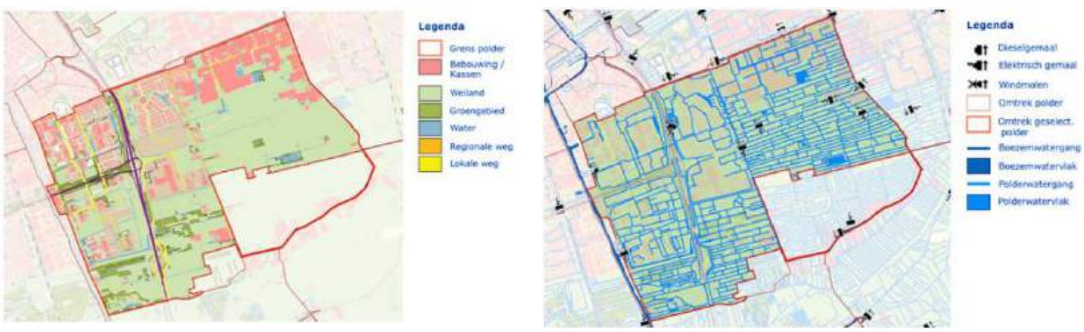


Fig. 490 The 'Zuidpolder'

Delfland is one of our country's twenty-seven water authorities. The area in which Delfland operates is bordered by the North Sea, the Nieuwe Waterweg and the Berkel en Rodenrijs line, Zoetermeer and Wassenaar. On an area of 41,000 hectares, about 1.4 million people live and work, and approximately 40,000 businesses are established. This makes the Delfland region one of the most densily populated and most highly industrialized areas of the Netherlands. The region is furthermore renowned for its intensive glasshouse horticulture both in the Westland area and around Pijnacker.

The three key tasks of Delfland - maintenance of dikes and dams, water level control, and water quality control. These are intricately related. The manner in which you construct and maintain quays, for example, has consequences for the quality of the water. Delfland always performs its tasks from "a broad view"; taking into account all possible relevant factors, a form of integrated water management. To achieve tha, Delfland strives for cooperation with other authorities and institutions both public and private. A good execution of the key tasks, cooperation and consideration for natural qualities; these are the three directives of Delfland's policy. The Water Board thereby does not limit itself to the struggle against water, but also for water. Because no water means no life. Water is life!

Maintenance of dikes and dams

The Delfland region is located far below sea level. And if a dune or dike should collapse, the land behind it would flood immediately. The consequences of a collapse in the Delfland region would be felt as far as the Utrechtse Heuvelrug. To limit the danger, Delfland maintains the sea and river flood defence structures and quays. Safety is, of course, crucial in the management and maintenance of the dikes and dams. In addition to safety, the past few years have also seen increasing attention being devoted to the landscape, nature and recreation.

The main or so-called primary maintenance of dikes and dams consists of two components: the seawall and the river flood defence structure. This primary maintenance of dikes and dams of Delfland must be able to withstand a wind-force and water level which, on average and statistically speaking, do not occur more than once every 10,000 years.

Water management
Water management involves the regulation of the water level in streams, lakes, ditches, moats and canals. This is vital for developments, agricultural businesses, the shipping industry, nature and recreation. The height at which the water level of an area is set depends on the use and function of that area. The level in nature reserves and protected areas, for instance, often fluctuates, while farmers prefer a relatively low water level to prevent their land from becoming too wet. The management of water levels is also of great importance for the shipping industry. If the water level is too low, large ships will run aground; if it is too high, the vertical clearance under bridges will become insufficient.

Water quality
Delfland ensures an optimum quality of the surface water in its management region. This key task entails the purification of wastewater and the limiting of discharges into surface water wherever possible. After all, clean and pure water is important to humans, but also to animals and plants. Delfland therefore creates conditions that lead to a better-optimized habitat for plants, aquatic plants and animals. This can be done by constructing nature-friendly banks for example, or through ecological maintenance of waters and quays

3.3.4 Spatial plans checked on their impact on water: 'Watertoets'

The text below is derived from official papers[a] concerning the way spatial plans have to be checked on their impact on water management in The Netherlands. From 1 November 2003 onwards the 'watertoets'[b] is legally obligatory in making regional plans, master plans and zoning plans in The Netherlands.

Scope
The 'watertoets' concerns all waters and all water management aspects like:

1. guaranteeing the level of safety;
2. reducing floods, increasing resilience of water systems: care, store, drain (see *Fig. 487*);
3. sewage: care, store, drain; reducing hydraulic load of sewage purification installations;
4. water supply: right quality and quantity at the right moment; counteract adverse effects of changes in land use on the need for water;
5. public health: minimising risks of water related diseases and plagues, reducing risks of drowning;
6. counteracting increasing subsidence and reduction of land use possibilities;
7. counteracting ground water inconvenience;
8. surface water quality: achieving and maintaining good water quality for people and nature
9. preservation / realisation of proper ground water quality for man and nature;
10. counteracting drying out (verdroging): protecting characteristic ground water depending on ecological values, cultural history and archaeology;
11. development and protection of a rich, varied and natural wet nature.

Waterparagraph
In any of the plans concerned, a description of the way the consequences of the plan have been taken into account (water paragraph) has to be included.
Beyond safety and water inconvenience the consequences for water quality and drying out have to be mentioned and how the obligatory water advice of the water manager has been taken into account.

Contents of a watertoets
Generally:
1. elaboration of roles of different participants;
2. products: appointments, water advice and waterparagraph;

[a] *http://www.watertoets.net/pdf/aandeslag.pdf*
[b] *http://www.watertoets.net/pdf/bestuurlijkenotitie.pdf*
http://www.watertoets.net/paginas/helpdesk/handleidingen.html?reload_coolmenus
http://www.watertoets.net/paginas/contact.html?reload_coolmenus

3. spatially relevant criteria;
4. the relationship with the obligartory environmental impact assessment;
5. the environmental impact assessment;
6. compensation: legislative aspects and examples.

Embedding in procedures:
1. municipal procedures: master plans, zoning plans, elaborations, changes and exceptions;
2. regional plans, their elaborations and non-legal provincial plans;
3. environmental impact assessment procedures for traced out roads;
4. plans for broadening roads and provincial roads;
5. reconstruction, land use - and ground clearing plans.

Regional elaborations
In 2007 the Province of South-Holland published indications of surface claims for water surface in zoning plans[a]: 8,5% times the paved surface and + 1,5% x the unpaved surface.
The Waterboard Rijnland (around Leiden) suggested in 2007 keeping 6% of the overall urban area to be water surface[b]. The Waterboard Delfland claims volumes of water per specific surface according to *Fig. 491* [c]. However, these global norms nowadays should be determined according to the local context.[98]

	m^3/ha
paved surface (housing, employment, greenhouse areas)	325
unpaved surface (grassland, nature, leisure)	170
arable land	275

Fig. 491 Standards for water reservoirs inside and outside the urban area[d]

3.3.5 Water management in spatial design

Water is the source of all life on earth. The distribution of water, however, is quite varied; many locations have plenty of it while others have very little. Oceans, rivers, clouds, and rain, all of which contain water, are in a frequent state of change (surface water evaporates, cloud water precipitates, rainfall infiltrates the ground, etc.). The circulation and conservation of earth's water is called the 'hydrologic cycle' (see *Fig. 353* and Verhallen, 1999). There are five processes in the hydrologic cycle: condensation, precipitation, infiltration, runoff, and evapotranspiration. These processes occur simultaneously and, except for precipitation, continuously. The hydrologic cycle takes place in the hydrosphere, this is the region containing all the water in the atmosphere and on the surface of the earth.

What is the problem with water?
Shortage of fresh water world-wide is already apparent right now but will be even larger in the future. The world population is still growing, at this moment not all people have access to good quality fresh water and finally the consumption of fresh water per person is still increasing.
Water is the most valuable of our natural resources. It is, however, predicted that an alarming percentage of major cities are going to be running short of it in the next decade. How will this rising demand for water be met? In the 2nd International Architecture Biennale in Rotterdam (Flood, 2005), the world wide problem of water shortage was the key issue of the Biennale and its exhibitions.

The systems approach; water and water system
The hydrologic cycle is based on a systems approach; the cycle is seen as a system. It is important to realise that this approach is also needed in all planning and design. This means that for every site the hydrologic cycle has to be defined and quantified in headlines. For instance in Holland we have a surplus of rainwater in winter, while we have a shortage in summer due to higher evaporation and less

[a] *http://www.helpdeskwater.nl/watertoets/*
[b] *http://www.rijnland.net/*
[c] *http://www.hhdelfland.nl/*
[d] *Waterboard Rijnland 2007*

rainfall. Hydrologists can calculate the quantities related to the hydrologic cycle at a given site. Of course soil conditions, topography and ground water table are also important to consider the impact of the water cycle as a whole.

3.3.6 Hydrologic cycle and water system

A dynamic aspect of water management

The hydrologic cycle is a conceptual model that describes the storage and movement of water between the different spheres; biosphere, atmosphere, lithosphere, and hydrosphere at a given site or area. Water on earth can be stored in any one of the following reservoirs: atmosphere, oceans, lakes, rivers, soils, glaciers, snow fields, and groundwater. Water moves from one reservoir to another by processes like evaporation, condensation, precipitation, deposition, runoff, infiltration, sublimation, transpiration, melting, and groundwater flow.

The planetary water supply is dominated by the oceans. Approximately 97 % of all the water on earth is in the oceans. The other 3 % is held as freshwater in glaciers and ice caps, groundwater, lakes, soil, the atmosphere, and within life. Water is continually cycled between its various reservoirs. The typical residence times of water in the major reservoirs is different. On average water is renewed in rivers once every 16 days. Water in the atmosphere is completely replaced once every 8 days. Slower rates of replacement occur in large lakes, glaciers, ocean bodies and groundwater. Replacement in these reservoirs can take from hundreds to thousands of years. Some of these resources (especially groundwater) are being used by humans at rates that far exceed their renewal times.

The need for water management

It is clear that we need a certain strategy for water management that is based on the hydrologic cycle in a certain area. Here we want to work out an example of water management policy in Holland: Water Assessment.

The Netherlands is a highly urbanised delta of which a large part is situated below sea level. The problem of water management is already an old one, like in other delta landscapes. In the past decade the country has been faced with extremely high river discharges which forced thousands of people to evacuate, with flooded areas caused by extreme rainfall, with groundwater problems in urban areas and drying out of certain nature reserves. It is widely acknowledged that, to prevent a further increase of these problems, changes are necessary in water management as well as in spatial planning. In contrast with what the name may suggest, Water Assessment (WA) is a process of interaction during spatial design, rather than a test on water aspects of a completed spatial plan afterwards.

The objectives of Water Assessment (WA)

The objectives of WA are to guarantee that water interests are taken into account in spatial and land use planning, so that negative effects on the water system are prevented or compensated for elsewhere. This integration of water in spatial planning works in two ways: a plan is assessed on its implications for the water system and the restraints that the water system puts on land use are made explicit.

WA is not meant to be a new procedure, but a process of interaction that is fully integrated into existing spatial planning procedures. When Environmental Impact Assessment or Strategic Environmental Assessment (as prescribed by the EU) has to take place as well, both assessments partly take place parallel and provide each other with information.

Water Assessment as part of spatial and landuse planning

To ensure the integration of water aspects into the spatial planning process, ‘Water Assessment’ has been introduced in 2001. Water Assessment is a process in which water managers are involved actively in the development of any spatial plan from the earliest stages on. This instrument has only recently been introduced, but the results up till now are promising.

The different steps in WA

1. The initial phase; agreements on water criteria and co-operation during the planning process. In the initial phase, which starts as soon as the ideas about the plan start developing, the spatial planning authority takes the initiative to inform the water authority. The result of this initial phase is an agreement on the assessment criteria and the further process to be followed.

2. The developing phase; water recommendation In this phase the water authority and the spatial planning authority work interactively and creatively together on the design of the plan. In the Water Recommendation - which is a formal advice - the water authority informs the spatial planning authority on its findings and makes, if necessary, recommendations for adjustments of the plan.
3. The decision-making phase; water paragraph Based on the Water Recommendation the spatial planning authority makes the necessary final adjustments to the plan.
4. The reviewing phase; a ‘go!’ for realisation

3.3.7 Water quality and management

A qualitative aspect of water

The hydrologic cycle is not only needed to get insight into the quantitative aspects of water and the water system, it also forms the basis for the management of water quality. The earth's water supply remains constant, but man is capable of altering the cycle of that fixed supply. Population increases, rising living standards, and industrial and economic growth have place greater demands on our natural environment. Our activities can create an imbalance in the hydrologic equation and can affect the quantity and quality of natural water resources available to current and future generations. Water use by households, industries, and farms have increased. People demand clean water at reasonable costs, yet the amount of fresh water is limited and the easily accessible sources have been developed. As the population increases, so will our need to withdraw more water from rivers, lakes and aquifers, threatening local resources and future water supplies. A larger population will not only use more water but will discharge more wastewater. Domestic, agricultural, and industrial wastes, including the use of pesticides, herbicides and fertilisers, often overload water supplies with hazardous chemicals and bacteria. Also, poor irrigation practices raise soil salinity and evaporation rates. These factors contribute to a reduction in the availability of potable water, putting even greater pressure on existing water resources.

Urbanisation

Large cities and urban sprawl particularly affect local climate and hydrology. Urbanisation is accompanied by accelerated drainage of water through road drains and city sewer systems, which even increases the magnitude of urban flood events. This alters the rates of infiltration, evaporation, and transpiration that would otherwise occur in a natural setting. The eplenishing of ground water aquifers does not occur or occurs at a slower rate. Together, these various effects determine the amount of water in the system and can result in negative consequences for river watersheds, lake levels, aquifers, and the environment as a whole. How to deal with our water resources is one of the major problems in the future since the world population is still growing, the consumption per person is still increasing and the demand for industrial use of water also increases.

Water resources

On the basis of the hydrologic cycle you can determine how much water from natural resources you have available on the basis of natural renewal of the water quality. Renewable water resources include waters replenished yearly in the process of the water turnover of the earth. These are mainly runoff from rivers, estimated as the volume per unit of time (m^3/s, km^3/year, etc.) and formed either within a specific region or from external sources, including groundwater inflow to a river network. This kind of water resource also includes the yearly renewable upper aquifer groundwater not drained by the river systems. However it should be noted that, on the global scale, these volumes are not large compared with the volume of river runoff and are of importance only for individual specific regions. Another important aspect is to take into account how much time these processes take.

What we see now on a large scale is that we renew water resources on the basis of technological means; by waste water purification and even the production of fresh water from sea water at an industrial scale. Even though this might technologically be possible, the cost is extremely high. In ecological sense it takes also lots of energy and material. So in the long run it is much more efficient to make use of water resources in a conscious way; to not overuse, to store the rainwater in stead of pumping it into the sea and to keep the different water qualities apart.

3.3.8 Sustainability and water management

The planning and design on the basis of watersheds

The aspect of sustainability in landscape planning is addressed in planning and design on the basis of watersheds. A watershed is the geographic area where all water running off the land drains to a given stream, river, lake, wetland, coastal water or other waterbody. Watershed planning and management comprise an approach to protecting water quality and quantity that focuses on a watershed as a whole. This is different from the traditional approach of managing individual wastewater discharges, and is necessary due to the nature of polluted runoff, which in most watersheds is the biggest contributor to water pollution. Polluted runoff is caused by a variety of land use activities, including development, transportation, agriculture and forestry, and may originate anywhere in the watershed. Watershed planning is sometimes a difficult subject to define because of all the different ways in which it has been practised throughout the world is depending on each watershed's unique characteristics, people, and other factors (Verhallen, 1999).

Landscape planning

In landscape planning not only the landuse types and their possible pollution is taken into account, also the storage or infiltration of water for dry periods is part of the problem. The location of both depending on stream direction of the waterways is crucial; no polluting landuse upstream! The amount and location of waterstorage depends on the quantities that are described in the hydrologic cycle. Most planning efforts share a few common points like:

1. Inclusiveness and co-ordination between people involved
2. Watershed framework and the hydrologic cycle for the region in question as a basis for the landscape plan
3. Plan to preserve and/or improve the quality of life and the environment
4. Long term planning and management
5. Development of a watershed plan

A watershed plan

A watershed plan is a document that includes a

1. Characterisation of the watershed as a physical network (total area, land ownerships, natural resources, environmental concerns, etc.)
2. Prioritisation of environmental concerns (water quality, urban growth, recreation, etc.)
3. Implementation plan (strategy for the long run, best management practices, funding opportunities, etc.)

In landscape planning the approach should always be based the principles of watershed planning. Landscape planning does take into account more aspects than watershed planning; the topographical and historical aspects of the site and most important it develops a strategy for the landscape development in the long run (Simonds, 1961, 1997). It is not only a static description of aspects of the watershed alone, it looks ahead on the basis of the principles defined in the watershed plan. In landscape architecture the work of McHarg (1971) is a good example of a more comprehensive and integrated approach to landscape planning than watershed planning alone. Also Clay (1979) gives a series of examples from landscape architecture in which water plays an important role and the principles of watershed planning are applied. Note how old these plans are! For Holland, Boekhorst et al. (1996) give examples of the work of Nico de Jonge in which water plays an important role at the scale of the Dutch region. We can conclude with the statement that no sustainability in landscape planning is possible without taking into account the watershed and the hydrologic cycle.

An integrated approach of water management and spatial planning

The problem of water management needs a comprehensive scope and approach (Verhallen, 1999). Planning and design can contribute to that approach in a general approach for design and water management; the water systems approach as an integrated approach for landscape design at different levels.

I. Water forms the basis for the understanding and insight into the landscape as a natural system.

- The start of any project should be the distinction of different levels of the water system and their spatial form. In all cases you first define the watershed and drainage pattern. In mountainous areas this is fairly simple if you have a topographic map with the contour lines. In delta landscapes like in Holland you mostly use the polders as the spatial and hydrological units in the landscape.
- A next step is the global description of the hydrological cycle in the study area. Rainfall spread over the year, evaporation and topography help you define the understanding of the water system in headlines.

II. If you have done the landscape analysis, you can start to apply the spatial representation of the program to the existing site. In this phase of spatial organisation of the landuse there are the following guiding principles as a basis:

- Water runs from high to low; use this in the location of the different types of landuse
- Organise forms of landuse according to their rate of pollution; the least polluting in the higher areas, the most polluting downstream.
- In Delta landscapes organise water flows from fresh to salt water environments
- In the organisation of time, start with a long term strategy and then work out the short term interventions.
- Another principle is to work from ‘natural’ to ‘artificial’

III. General principles for the approach of the water management for the 21st century

- Conserve water at the place as much as you can locally
- Store what you can not conserve, locally
- Organise letting in and transport elsewhere of water. Make a distinction and also a spatial separation of clean and polluted water; do not mix them!

3.4 The second network: roads

There are other networks than wet connections, for example the roads (dry connections) we add in this chapter. And they interfere. More kinds of networks like those of pedestrians, cyclists, public transport, rail and their characteristics we will elaborate later.

3.4.1 Names and scale

Everybody knows many names of wet and dry connections, regardless of their function (*Fig. 492*). They seem to fit nearly logarithmically on a constant difference of scale multiplying the mesh width each time approximately by 3. That rather precise scale articulation has practical backgrounds.[a]

NETWORK		BLUE LEGEND		BLACK LEGEND	
density	mesh/ exit interval		NAME	nominal width	NAME
km/km^2	km nominally	width 1%		m	
0.002	1000	≥10000	**sea**		
0.007	300	3000	**lake**	120	**continental highway**
0.02	100	1000	**stream/pond**	100	**national highway**
0.07	30	300	**river/waterway**	80	**regional highway**
0,2	10	100	**brook/canal**	70	**local highway**
0.7	3	30	**race**	60	**urban highway**
2	1	10	**watercourse**	40	**district road**
7	0.3	3	**ditch**	30	**main street**
20	0.1	1	**small ditch**	20	**street**
70	0.03	0.3	**trench**	10	**path**

Fig. 492 Names of networks on the higher levels of scale[99]

However, in reality it is sometimes more, seldom less than 3 and often the highest and lowest orders are missing. For example clay grounds do not need trenches and sandy grounds start their drainage by brooks. In the same way rural areas do not need streets every 300m. In The Netherlands they start with roads every 1km as you can check on topographic maps.

[a] Nes, R.v. and Zijpp, N.J.v.d. (2000) *Scale-factor 3 for hierarchical road networks: a natural phenomenon?* (Delft) Trail Research School Delft University of Technology.

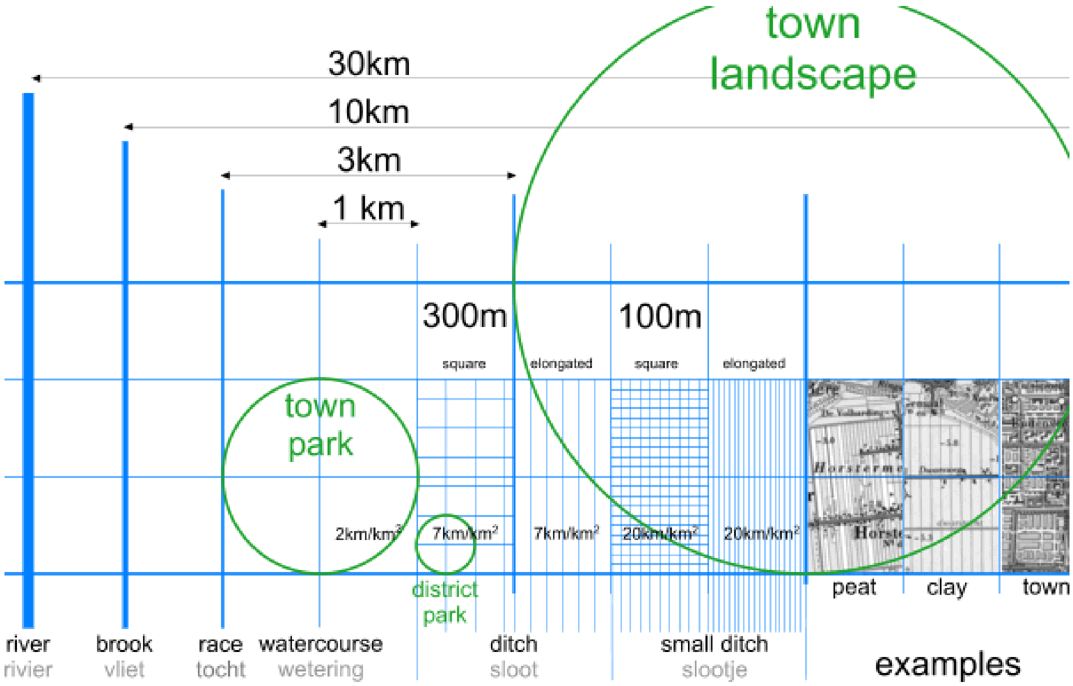


Fig. 493 The styling of wet connections

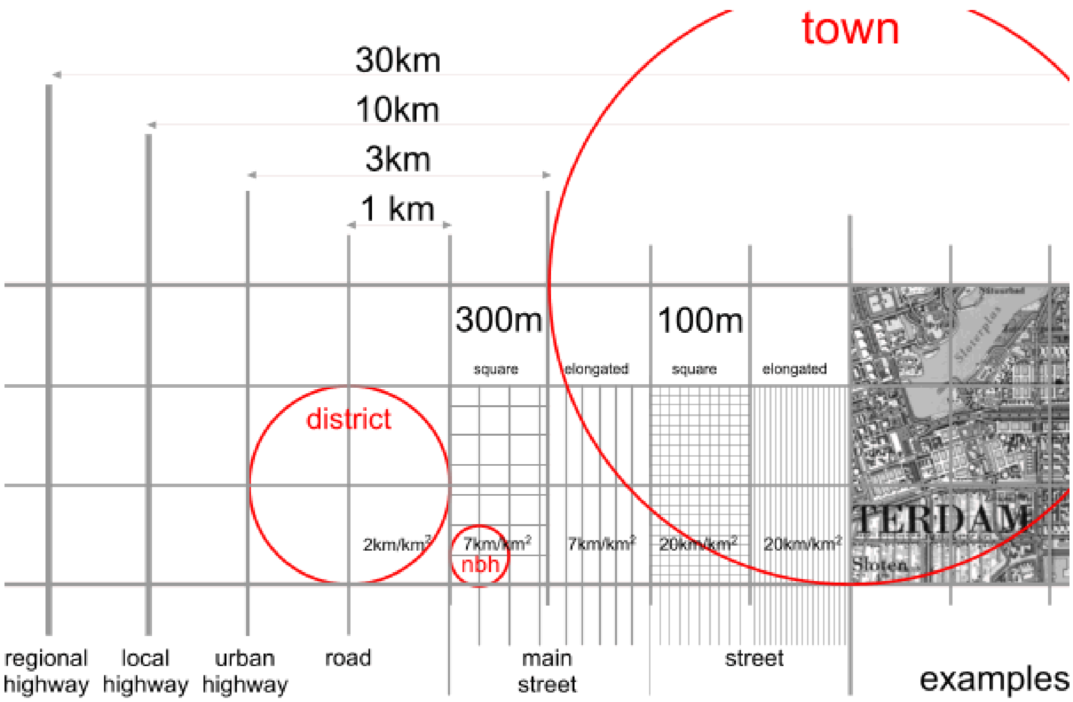


Fig. 494 The styling of dry connections[100]

3.4.2 Functional charge of networks

These neutral names get their time-bound character by changing function. Dry and wet networks get their contemporary meaning by 'functional charge' in Fig. 495. Their density implicates the level of investment.[101]

Nominal mesh width	***30m***	***100m***	***300m***	***1km***	***3km***	***10km***	***30km***	***100km***
Density (km/km²)	*70*	*20*	*7*	*2*	*0.7*	*0.2*	*0.07*	*0.02*
wet connections								
name	**trench**	**small flooded ditch**	**a flooded ditch**	**watercourse**	**race**	**brook**	**river**	**lake**
indicative width 1%		*1m*	*3m*	*10m*	*30m*	*100m*	*300m*	*1000m*
other names			stream	stream	stream	stream		
		urban canal	urban canal	urban canal	urban canal	industrial canal/waterway	canal	canal
functions			draining			drainage pool (from polders)		
Nominal mesh width	***30m***	***100m***	***300m***	***1km***	***3km***	***10km***	***30km***	***100km***
dry connections								
name	**path**	**street**	**main street**	**road**	**urban highway**	**local highway**	**regional highway**	**national highway**
an exit every ...km	*10m*	*30m*	*100m*	*300m*	*1km*	*3km*	*10km*	*30km*
indicative width	*10m*	*20m*	*30m*	*40m*	*60m*	70m	80m	100m
functions	pavement	opening to a hamlet	neighbourhood street	district road, village road, country road	urban highway, main road	urban highway	provincial highway	national highway
	footpath	residential walk	walking route	cycle route	cycle ride			
Duurzaam Veilig (long-term safety)	Woonpad, free of cars	Woonstraat, restricted entry for cars	Erftoegangs-weg, sojourn function	Gebieds-Onsluitings-Weg, opening to an area	Stroomweg, throughway			
public					bus	express	fast bus	Interliner
Nominal mesh width	***30m***	***100m***	***300m***	***1km***	***3km***	***10km***	***30km***	***100km***
railway line					tram	lightrail	regional	national
a supportive base					*300m*	*1km*	*3km*	*10km*
functions						*the underground/metro*	*local train*	*intercity train, Argus*
					hybrid systems	*hybrid systems*	*hybrid systems*	

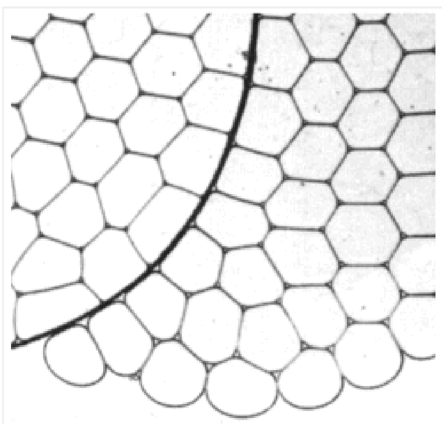
Fig. 495 *The time-related functional charge of networks*

3.4.3 Rectangularity forced by connections of a higher level

The most efficient enclosure is made by surrounding the enclosed area with a minimum length of road. As well known, the result is a circle. But in a continuous network, it is approximated by a hexagonal system.[102] This minimal ratio between periphery and area is demonstrated 3D by many natural phenomena[a] (cells in a tissue) where preference is given to a minimal ratio between outer area and inner content.

Soap bubbles

A good example is a cluster of soap bubbles. A cluster of soap bubbles forced into a thin layer produces a two-dimensional variant. The bubbles arrange themselves in polygons with an average of six angles.
However, if one pulls a thread through them, the nearest bubbles will re-arrange themselves again into an orthogonal pattern (*Fig. 496*). Urban developments from radial to tangential can also be interpreted against this background. The interlocal connections pull the radial system straight, as it were. The additional demand for straight connections over a distance longer than that between two side roads (here called a 'stretch') introduces rectangularity.
Every deflection from the orthogonal system then is less efficient.[103]



Hildebrandt and Tromba (1989) [b]

Fig. 496 The formation of right angles

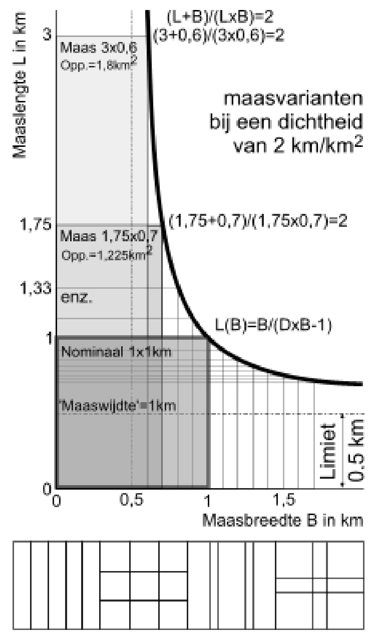


Fig. 497 Length (L) and width (W) of the mesh for a given net density of (D=2)[104]

Marbles in a framework

This can be clarified by engaging in a thought experiment: Imagine a rectangular framework with hinged corners that is completely filled with marbles. If one re-shapes this framework into an ever narrower parallelogram, then there will be space for fewer and fewer marbles, so, in every case, the rectangular shape proves to be optimal, in this respect. The only network that could compete with this, which has lines running from a rectangular grid, is a triangular grid, but it is immediately clear that it is inferior because of its unfavourable perifery/area ratio. For instance, the parallelogram in the thought experiment that became ever more skew, matches an angle of 60° in an equilateral triangular grid. Apart from the disadvantage caused by deviating from the right angle, an extra connecting line is needed to cut the parallelogram into two equilateral triangles.

[a] d'Arcy Thomson, W. (1961). *On growth and form*. (Cambridge UK) Cambridge University Press.
[b] This figure is taken from: Stefan Hildebrandt and Anthony Tromba, *Architectuur in de natuur, de weg naar de optimale vorm* (Mathematics and optimal form), Wetenschappelijke Bibliotheek Natuur en Techniek, Maastricht/Brussel, 1989, ISBN 90 70157 81 0.

Mesh width and mesh length

Fig. 497 shows a sequence of relationships between mesh width and length in rectangular meshes with a net density of 2 km per km^2 (the same density means the same investment!).
Length and width of *squares* are 2/density. The same density also occurs in a pattern of roads that go infinitely in one direction every 0.5 km. Thus, when the length and width of the mesh 1/d = 0.5 km, the ratio between length and width is at its limit.[105] In that case, where the net density is 2 km per km^2 there can be no 'crossroads' any more.[106] This consideration only applies to an orthogonal system.

3.4.4 Superposition of levels

In connection with the red and blue legend one can imagine their superposition as follows:

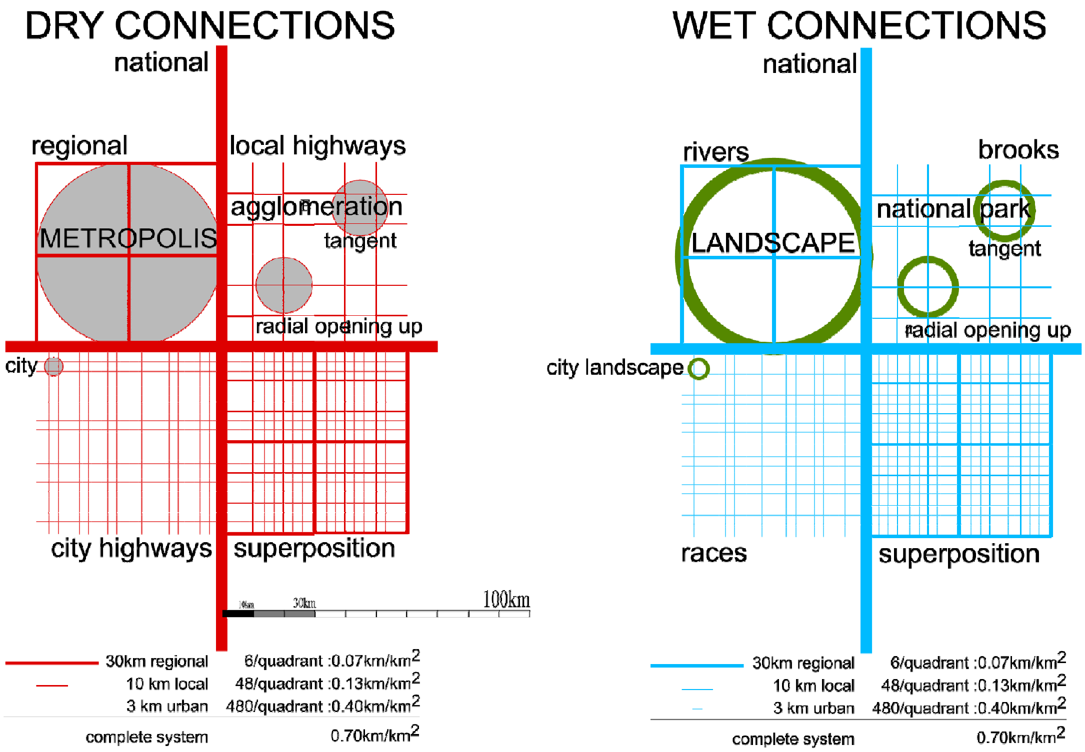


Fig. 498 *Superposition of networks*

Urban area is radially crossed or tangentially surrounded by infrastructure.
By superposition of the higher order over the lower order, the density of the lower order decreases.[107]
By superposing the wet connections over or under the dry connections, both networks interfere (interference, see page 3.4.5).

3.4.5 Interference of different networks

When one lays different (wet and dry) networks over each other, an interference occurs that defines the number of crossings, and, because of this, the level of investment in civil engineering constructions (Fig. 499).This can be done in different ways. Separating instead of bundling them fragments space more. The diversity of interference has important impacts on ecology and cultural identity.

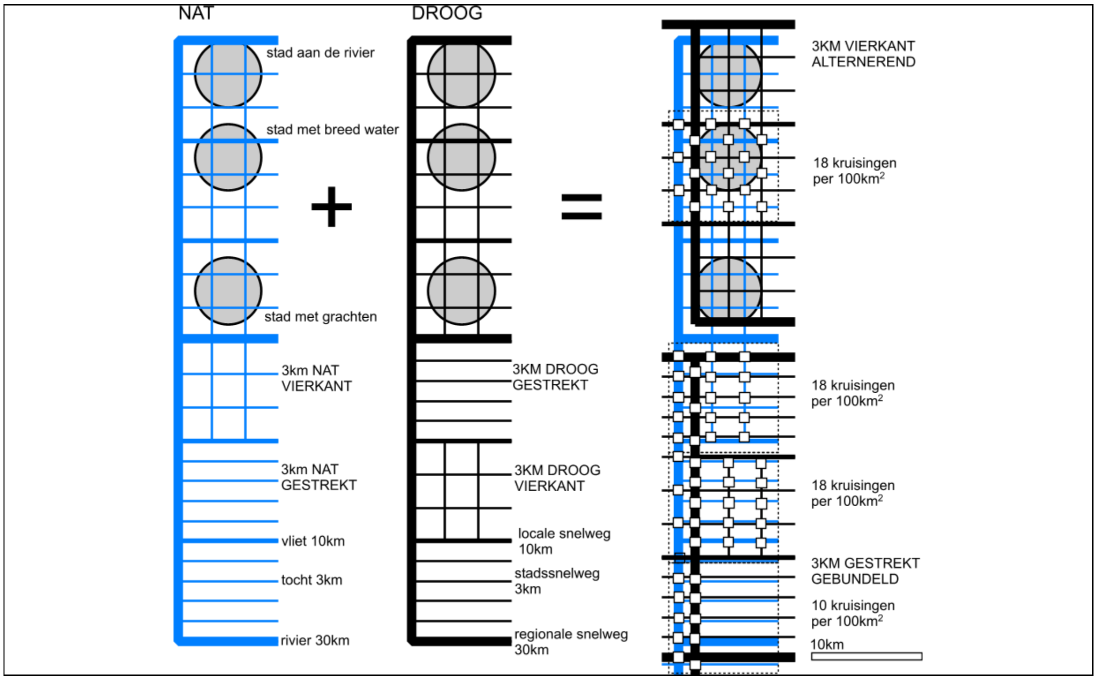


Fig. 499 Interference between wet and dry networks.

The position of urban areas with respect to orders of magnitude of water and roads dictates their character to a large extent. The elongation (stretching) of networks reduces the need for engineering constructions when their meshes lie in the same direction.[108] If one bundles them together, this also helps to prevent fragmentation. The aim of the 'Two network strategy', on the other hand, is to position water, as a 'green network', as far away as possible from the roads (in an alternating manner). However, this has the effect of increasing fragmentation by roads and watercourses.

3.4.6 Crossings

Mutually crossings of waterways seldom separate their courses vertically (*Fig. 500*) as motorways do (*Fig. 501*).

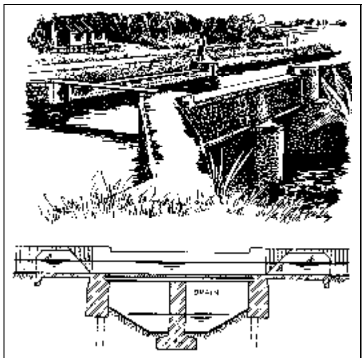


Fig. 500 Crossing of separated waterways[a]

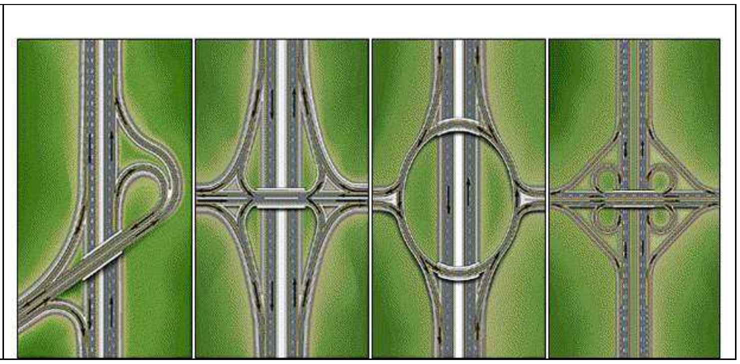


Fig. 501 Crossings of highways[b]

More often their water levels are separated by locks or become inaccessible for ships by weirs or siphons.

However, crossings between ways and waterways have to be separated vertically in full function anyhow. And they often occur.

Fig. 502 Rivers, canals and brooks

Fig. 503 Superposition races

[a] Ankum (2003) page 160
[b] Standaard and Elmar (?)

Fig. 504 Interference with highways

Fig. 505 Interference with highways and railways

The same kind and level

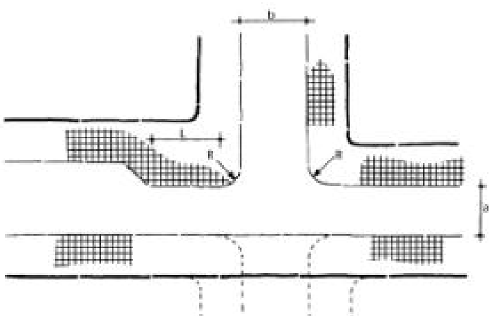


Fig. 506 R=300m Sojourn area road crossing for mixed traffic[a]

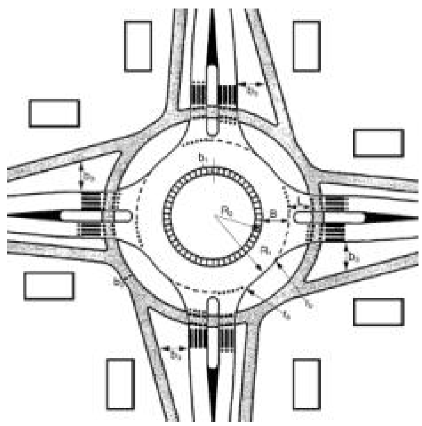


Fig. 507 R=1km Opening up road (GOW) single lane roundabout – with freely located cycle path and cyclists having right of way[b]

[a] A.S.V.V.(2004): 12.3.1
[b] A.S.V.V.(2004): 11.2.3

Limitating crossing movements

Camillo Sitte[a] already showed T crossings have less conflict points (*Fig. 508*). Modern roundabouts translate a normal crossing in 4 T-crossings.[109]

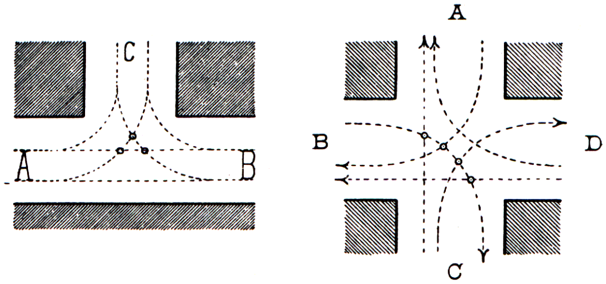


Fig. 508 Less conflict points in T-crossings[b]

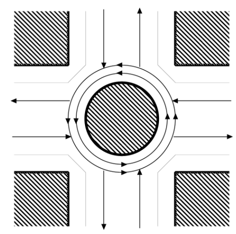


Fig. 509 An actual roundabout[c]

Before roundabouts came into use, attempts were made to design safer T-crossings on town (R=3km) and district (R-1km) level.

Town level

Fig. 510 Sketch Zoetermeer 1969[d]

Fig. 511 Actual situation[e]

[a] Sitte, C. (1991). *De stedebouw volgens zijn artistieke grondbeginselen.* (Rotterdam) Uitgeverij 010.
[b] Camillo Sitte (1889) Der Städtebau nach seinen künstlerische Grundsätzen
[c] Bach en De Jong (2004)
[d] B. van Gent (1999), p. 2/6
[e] CDRom de nationale Stratengids van Nederland met kaarten van de Topografische Dienst te Emmen (Den Haag) Citydisc

District level

Fig. 512 Sketch for district Driemanspolder-West (Meerzicht)[a]

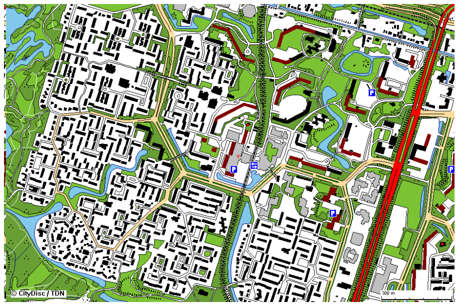


Fig. 513 Actual situation[b]

However, gaining safety this way produced faster driving. So T-crossings did not produce more safety after all. Moreover, non-perpendicular T-crossings make orientation more difficult. Roundabouts are safer.

The same kind and different level

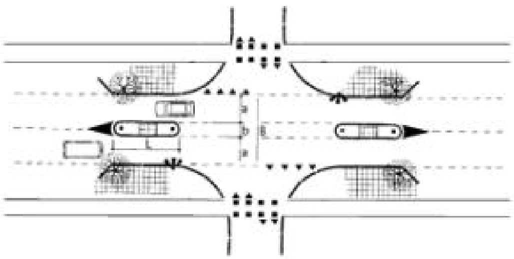


Fig. 514 Central guiding – at a crossing R=1km Opening up road (GOW) – R=300m Sojourn area road[c]

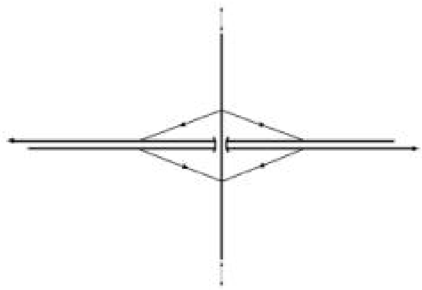


Fig. 515 Haarlemmermeer solution – at a crossing R=3km Throughway – R=1km Opening up road (GOW)[d]

[a] B. van Gent (1999), p. 2/30
[b] CDRom de nationale Stratengids van Nederland met kaarten van de Topografische Dienst te Emmen (Den Haag) Citydisc

[c] A.S.V.V.(2004): 11.2.5
[d] A.S.V.V.(2004): 10.1

Different kind and level

Especially when the canal is a belt canal with a higher level than the other waterways many complications arise. Extra space is needed for weirs, dikes and sluices, perhaps even locks and many slopes not useful for building. The slope the city highway gets from crossing the high belt canal could force to make a tunnel instead of a bridge. Anyhow, several expensive bridges will be necessary and some of them will be dropped from the budget, causing traffic dilemmas elsewhere.

Fig. 516 Neighbourhood street crossing canal and railroad in Utrecht

The slope behind the bridge in *Fig. 516* is not steep enough to get a tunnel under the railway high enough for busses (2.60m here is too low).

Count your crossings (costs)

Fig. 517 shows how different dry and wet networks in different orders cause crossings of different kinds.

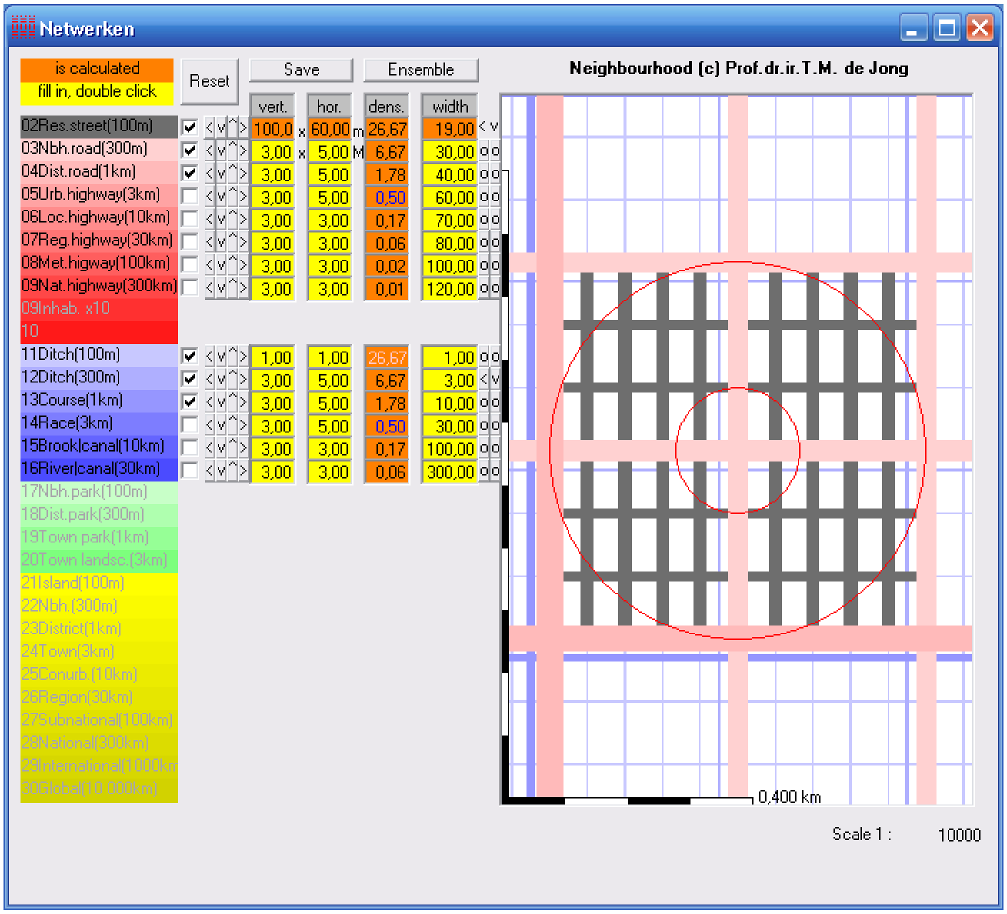


Fig. 517 Interference of dry and wet networks in different orders causing crossings of different kinds[a]

Trenches and ditches become drains or (underneath roads) culverts in the urban area, but main ditches (3m wide) and water courses (10m) or even larger waterways have to be crossed by bridges. From 6 different kinds of interfering crossing in *Fig. 517*, *Fig. 518* counts 35 crossings in 5 types.

	residential streets (20m wide)	neighbourhood streets (30m wide)	district roads (40m wide)
main ditches (3m wide)	16	8	4
water courses (10m wide)		5	2

Fig. 518 Five types of interfering crossings supposed in Fig. 517

And there are superposed crossings as well.

[a] Jong (2001)

Bridges

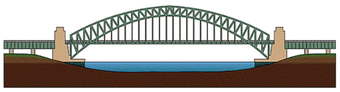
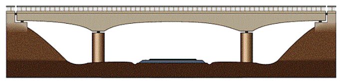
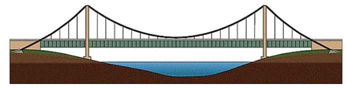
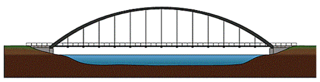
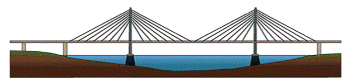
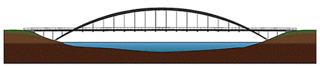
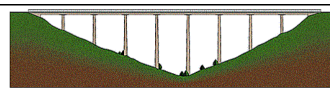
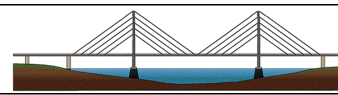
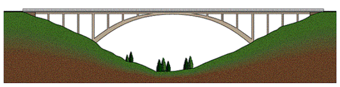
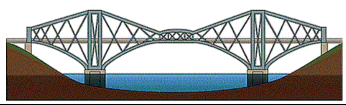
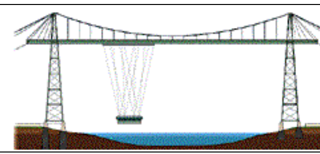
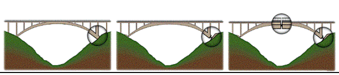
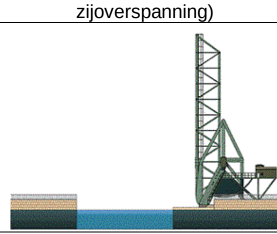
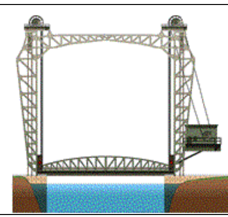
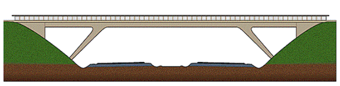
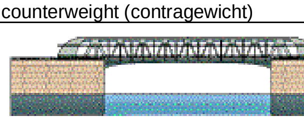
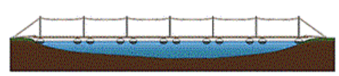
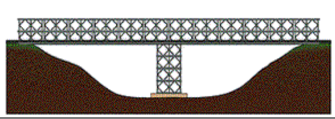
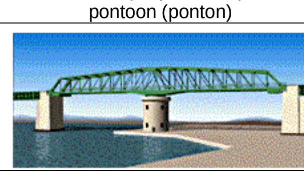
based on pressure	*or*	*tension*
		
arch bridge (boogbrug) approach ramp(aanbrug) thrust (horizontale druk) deck (rijvloer) trussed arch with upper and lower chord (vakwerkboog boog met boven- en onderrrand) abutment (landhoofd)	beam bridge (balk- of liggerbrug) abutment (landhoofd) overpass, underpass (bovenkruising, onderdoorgang) deck (brugdek) continuous beam (doorgaande ligger) pier (pijler) parapet (leuning)	suspension bridge (hangbrug) anchorage block (ankerblok) suspension cable (hangkabel) suspender (hanger) deck (rijvloer) center span (middenoverspanning) tower (toren) side span (zijoverspanning) abutment (landhoofd)
		
trough arch bridge (boogbrug met laaggelegen rijvloer)	multiple span beam bridge (balk- of liggerbrug met meer overspanningen)	fan cable stayed bridge (waaiertuibrug) cable stay anchorage (tuiverankering)
		
half-through arch bridge (boogbrug met tussengelegen rijvloer)	viaduct	harp cable stayed bridge (harptuibrug)
		
deck arch bridge (boogbrug met hooggelegen rijvloer)	cantilever bridge (kraagliggerbrug, cantileverbrug) suspended span (zwevend brugdeel) cantilever span (uitkragende zijoverspanning)	transporter bridge (zweefbrug) trolley (wagen) platform (platform)
		
fixed two-hinged three-hinged arch (ingeklemde, tweescharnier~, driescharnierboog)	single-leaf bascule bridge (enkele basculebrug) counterweight (contragewicht)	lift bridge (hefbrug) guiding tower (heftoren) lift span (val)
		
portal bridge (schoorbrug) portal frame (portaal) pier (pijler)	double-leaf bascule bridge (dubbele basculebrug)	floating bridge (pontonbrug) manrope (mantouw) pontoon (ponton)
		
	Bailey bridge (baileybrug)	swing bridge (draaibrug)

Fig. 519 *Names of Bridges and their components*[a]

[a] Standaard and Elmar (?)

based on pressure	*or*	*tension*

These types of bridges could be made of steel, concrete or wood. Depending on the material they have a different maximum span (Fig. 352).[110] [111] [112] [113]

english name	dutch name	span in m.	notes	
multiple span beam bridge	balk- liggerbrug met meer overspanningen	unlimited		
viaduct	viaduct	unlimited	old-fashioned	
ferry bridge	pontbrug	unlimited		
suspension bridge	hangbrug	2000	wind-sensitive	
fan cable stayed bridge	waaiertuibrug	1000	wind-sensitive	
harp cable stayed bridge	harptuibrug	1000	wind-sensitive	
cantilever bridge	kraagliggerbrug, Gerberligger	550		
arch bridge	boogbrug	500	steel	
trough arch bridge	boogbrug met laaggelegen rijvloer	500	? with draw connection	
fixed two-hinged three-hinged arch	ingeklemde, tweeschanier-, driescharnierboog	500	? with draw connection	
half-through arch bridge	boogbrug met tussengelegen rijvloer	500	?	
deck arch bridge	boogbrug met hooggelegen rijvloer	500	?	
beam bridge	balk- of liggerbrug	250	steel truss, framework	
arch bridge	boogbrug	200	stiffened bars	
floating bridge	pontonbrug	200	military	movable
lift bridge	hefbrug	150	old-fashioned	movable
portal bridge	schoorbrug	150	between supports with tube beam	
beam bridge	balk- of liggerbrug	100	steel concrete	
beam bridge	balk- of liggerbrug	100	concrete tube beam	
transporter bridge	zweefbrug, transbordeur.	100	? old fashioned 1895-1920; 2 in europe left	movable
double-leaf bascule bridge	dubbele basculebrug	100		movable
swing bridge	draaibrug	60	even as aquaduct	movable
arch bridge	boogbrug	50	hout	
single-leaf bascule bridge	enkele basculebrug	50		movable
portal bridge	schoorbrug	40	? concrete	
beam bridge	plaatliggerbrug	30	or wider with large construction height	
beam bridge	balk- of liggerbrug	30		
strauszbridge	ophaalbrug	25		movable
beam bridge	balk- of liggerbrug	20	2m wood truss, framework	
beam bridge	spoorverkeer staal	15	small construction height	
ship bridge	schipbrug	10	? te doesburg	movable
beam bridge	balk- of liggerbrug	10	wood	

english name	dutch name	span in m.	notes	
raft bridge	vlotbrug	10	? floating from under approach ramp	movable
crane bridge	kraanbrug	10	old-fashioned	movable
roll bridge	rolbrug	8	one example 67m	movable
clap bridge	klapbrug	8	without counterweight	movable
	valbrug	5	old-fashioned (castles)	movable
	oorgatbrug	1	for mast only, old-fashioned (hindeloopen)	movable
Bailey bridge	Baileybrug		military	

fig. 520 *Maximum span of different bridges*[a]

The construction height below deck is often limiting factor.

Costs of bridged P.M.

Tunnels

3D crossings need slopes. *Fig. 521* shows a highway on 0.1m height without slopes. You have to dig out the tunnel until –2.9m. By doing so, you need cycle slopes of more than 80m at both sides.[114] The tunnel construction extends to 197.13m width. Imagine the problems to keep it dry, imagine the costs, imagine the problems you raise designing the adjacent neighbourhoods.

First calculation		talud	zijberm	rijbaan	middenberm	daglichtschacht	middenberm	rijbaan	zijberm	talud
m hoogte wegdek	0,10									
m breedte met taluds	**24,00**	0,50	2,00	7,00	1,00	3,00	1,00	7,00	2,00	0,50
m tunnelhoogte	2,40									
brugdek	0,60									
m totale breedte met 2 normale fietshellingen	**197,13**									

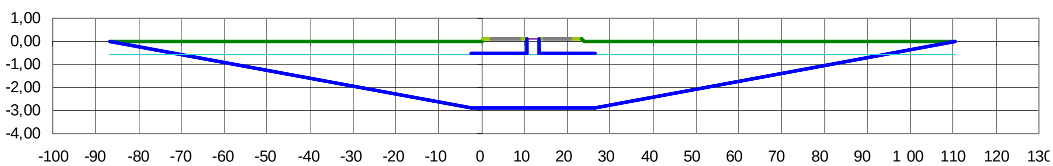


Fig. 521 First calculation of slopes in a tunnel for cyclists below a highway

---
[a] Jong (1996)

Fig. 522 shows a highway on 2m with slopes on both sides, totally 43m wide. The tunnel can be made on –1m, so the slopes meet nearly on 0m making the total width 44.4m.

		talud	zijberm	rijbaan	middenberm	daglichtschacht	middenberm	rijbaan	zijberm	talud
Second calculation										
m hoogte wegdek	2,00									
m breedte met taluds	**43,00**	10,00	2,00	7,00	1,00	3,00	1,00	7,00	2,00	10,00
m tunnelhoogte	2,40									
brugdek	0,50									
m totale breedte met 2 normale fietshellingen	**44,40**									

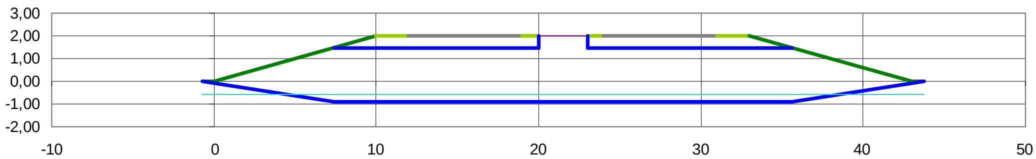


Fig. 522 Second calculation of slopes in a tunnel for cyclists below a highway

3.4.7 A traffic network

A street is more than traffic space. However, this chapter restricts itself to traffic space, like traffic specialist would do if (s)he had no attention for context. A street is not a summing up of measures needed for traffic, but is is good to know which measures are used by specialists. Many measures mentioned here, are no more than rules of thumb to start with.

3.4.8 Measures

Any kind of traffic has characteristic measures.
Design measures are deduced from the distribution of actual measures (see *Fig. 523*).
Normally the 5% largest measures are left aside for design.

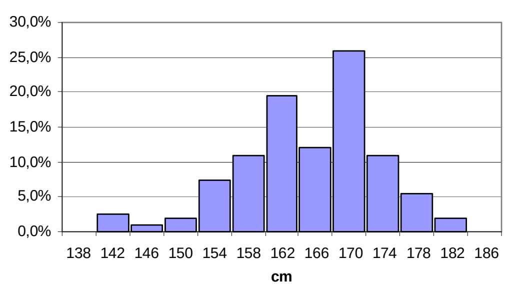


Fig. 523 Dispersion of real car widths in 2004; 95% < 1.80m [a] [115]

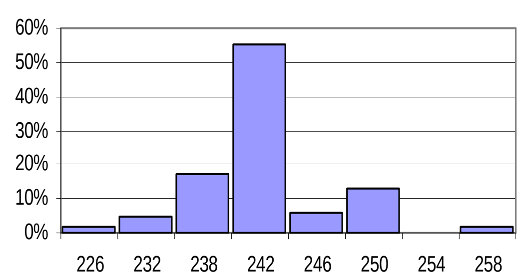


Fig. 524 Width of parking places in 1980 [b] [116]

However, these measures can change in time and occasionally not apply. So, you need margins. For example, in *Fig. 524* the parking space for a car is much wider than the width of an average car,

[a] *A.S.V.V(2004) p. 77-78*
[b] *ANWB-Verkeerskunde (1980) nummers 6 en 10*

because at parking places people have to step in and out at both sides. Moreover, taking the largest turning circle of cars you need space to turn in, not only in width, but also in length. So, a street with cross parking should be wider than the 95 percentile of car lengths (5m).
That is why car parking requires a quarter of pavement in the urban surface.

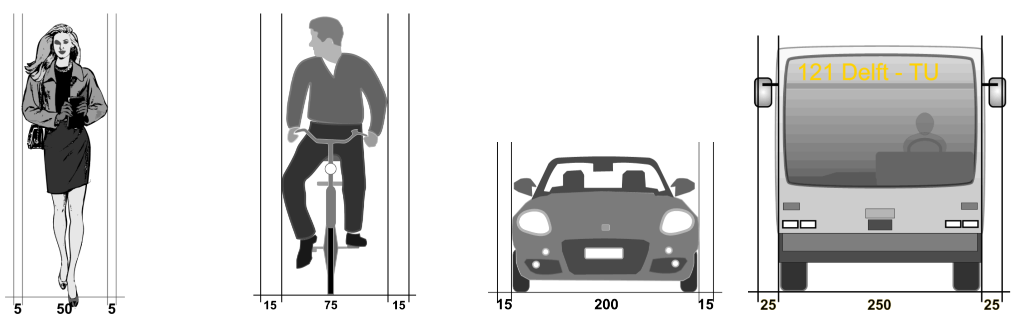
Fig. 525 1.20m for a pedestrian

Fig. 526 2.40m for a parked car

In The Netherlands normal paving-stones used on side walks are an unit of measure easy for reference if you are walking on the street or taking photographs (0.30x0.30m). From *Fig. 525* you can learn a kerb is half a tile wide and for walking you need at least two tiles if you don't have luggage. From *Fig. 526* you can learn that the parking spaces of our Faculty are 2.40m wide.

3.4.9 A residential street

In a residential street occasionally you need space for larger vehicles like moving vans, ambulances, vans of police, fire brigade or service vehicles, often necessary in residential areas.
Pedestrians carrying luggage or pushing baby buggies need 1.5x more space than without such loads as shown in *Fig. 527*.



Pedestrian
50 + 2 x 5 ≅ 60 cm[117]

Cyclist
75 + 2 x 15 ≅ 100 cm[118]

Car 30 km/h
200 + 2 x 15 ≅ 230 cm[119]

Bus 50 km/h
255 +2 x 25≅ 300 cm[120]

Fig. 527 Primary profile spaces needed

A usual residential street gives way to two loaded pedestrians walking both ways (for instance one with luggage and one with a baby buggy passing each other, say 2m paved surface with 6 tiles of 0.30m + a 0.15m kerb + 0.05m margin) as sidewalks. On the roadway two vans should be able to drive both ways with a margin because they swing a little when they move (say 6m). If you draw sidewalks at both sides the pavement will count 2+6+2=10m. That is easy to remember for residential streets without parking places (as in *Fig. 524*). With parking places and gardens it could be =20m (*Fig. 528*), but we do not yet take them into account. We will do that at page 266 and further.[121]

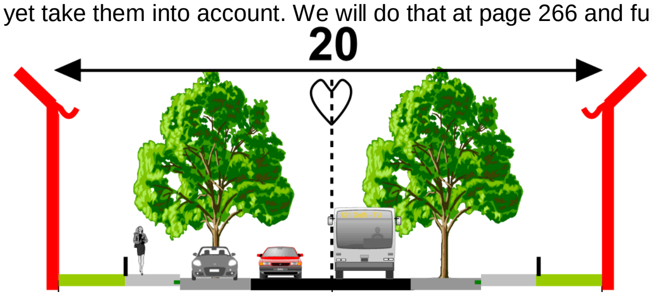


Fig. 528 A residential street (2.5 + 2 + 2.5 + 6 + 2.5 + 2 + 2.5 = 20m)[a]

However, you do not need that width of pavement all along the road. Cars can wait when they see someone approaching from the other side. Pavement can locally be narrower (for example 1+3+1=5m), slowing down the cars or just wider (for example 3+6+3=12m) to make more speed or to give children and pedestrians more space on the sidewalks. A roadway of 6m width, has two 'lanes' for both directions. You can remove one locally. You can halve the sidewalks locally as well, but do not remove at one side one of them unnecessarily, otherwise pedestrians have to cross the road. If you do not have to give way to large cars or speeds higher than 30km/h the lane can get the minimum width of 2.30m. For even lower velocities without large vehicles the pavement is suitable for mixed use with pedestrians, say 1.90+0.60≅2.50m.

3.4.10 Space for speed

For higher design velocities you should take more margin for swinging. For normal cars at 30km/h you need 2.25m per lane, and 0.30m extra is no luxury. But at 50km/h you need 2.75m per lane, and at 70km/h 3.25m.[b] Along walls or obstacles, drivers keep even more distance (obstacle fright) to prevent damage.

Drivers also keep distance to cars ahead. The higher the velocity, the more distance they will keep. Above 30km/h that growing distance even decreases the capacity of the road (*Fig. 529*)![122]
That means, to keep the same capacity you need more lanes.

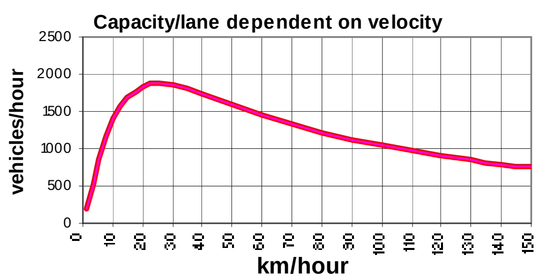


Fig. 529 A higher speed decreases the capacity of the road[c]

As you can see, roads designed for more than 2 000 cars per hour in one direction (that is approximately 20 000 per day[123]) need at least more than one lane per direction.[124]

[a] Simple quick profile drawings can be generated by Excel with a worksheet *http://team.bk.tudelft.nl/Databases/Databases.htm* > *Wegprofielen maken met excel .xls*
[b] ASVV …
[c] *http://team.bk.tudelft.nl/Databases* > Hoe de capaciteit van wegen afneemt bij hogere rijsnelheid

Moreover, at 50km/h you have to give separate way to cyclists along the road and at 70km/h at crossings as well if you accept the Dutch appointments ‘Duurzaam Veilig” (see *Fig. 575*).

3.4.11 Roads of a higher level

If you leave your home to go for a ride, you start on a ‘residential street’ (some 20m wide) via a larger ‘neighbourhood road’ (say 30m) reaching an even larger ‘district road’ (say 40m) and so on.
On the average every third road of each level you can make a turn to a road of a higher level (see *Fig. 530*, do not take it too serious, it is a rule of thumb)[a]. The question arises at which mutual absolute distance you have to draw them in urban design. To keep it simple, we take 30m for the smallest residential paths, 100m for residential streets, 300m for neighbourhood roads, and 1000m for district roads (*Fig. 530*).

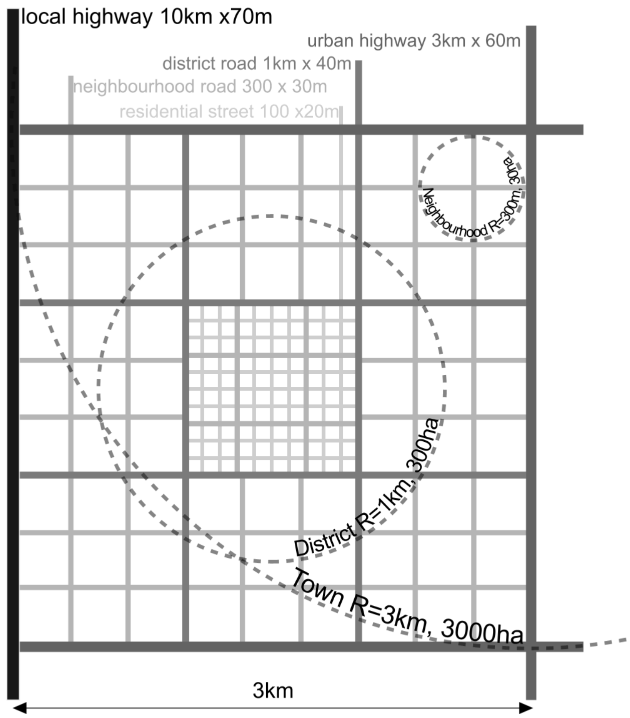


Fig. 530 Four orders in a network hierarchy

3.4.12 Urban islands in a network

Public pavement for traffic and parking is expensive. It has to be paid by lots a municipality can sell, surrounded by that public space (municipal land development). The housing allotments below, include a substantial area of expensive parking spaces as well. They are made by the computer programme Standaardverkaveling.exe.[b] Starting points are:

1. centre lines of surrounding roads on a multiple of 30m (preliminary main grid);
2. roadways everywhere 6m wide, not needed everywhere, but including a reservation for wider roads of higher level in the network elsewhere;

[a] Nes, R. v. and N. J. v. d. Zijpp (2000). Scale-factor 3 for hierarchical road networks: a natural phenomenon? (Delft) Trail Research School Delft University of Technology.
[b] Try it yourself, the programme is downloadable from *http://team.bk.tudelft.nl* > Publications 2003

3. parking standard everywhere more than 1 parking place per dwelling along the road, starting at least 5m from road corners, only drawn along roads North and South (indicated as 'N' and 'S'[a]) in the drawing of the urban island (an urban ensemble completely surrounded by roads);
4. sidewalks seldom smaller than 2m wide;
5. no front gardens yet;
6. dwellings 5x10m, 2 floors high with roof timbers of 3m on lots of 100m2 housing 2.25 inhabitants in rows not exceeding 40m to avoid extra dilatation;
7. path around the back 1m wide;
8. green areas are drawn East and South filling up the main 30m grid. They show the space saved by design operations, but can be used to enlarge the lots for sale as well, diminishing public space (pavement + green).

These starting points can be changed easily in Standaardverkaveling.exe. However, for the time being they are kept constant below to study the change in allotment performance by design transformations.

Mirroring the smallest urban island

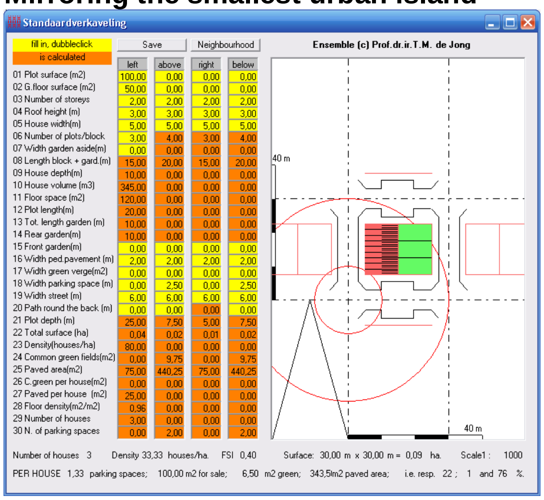


Fig. 531 30x30m

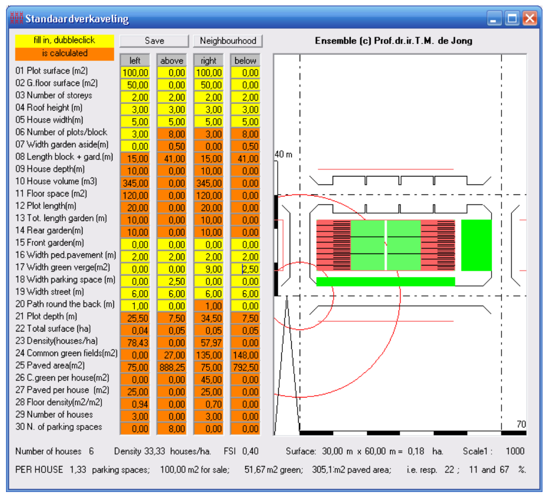


Fig. 532 30x60m W-E mirroring

The picture shows an urban island with three houses with gardens surrounded by sidewalks and streets. North and South of the island there are parking lots for 2 cars each. The allotment is mirrored at the other side of the street.

The smallest urban island taken in consideration here has a grid measure of 30x30m. The consequence of small urban islands is an excessive surface of public pavement (here 76%!), leaving relatively little for sale (here maximally 22%) paying for that public space.[125]

The effect of a first design transformation, W-E mirroring, elongates the urban island reducing public pavement (here into 67%). The gained surface produces a green margin of 9m drawn East and 2.50m drawn South. Now, at that length, one side with parking places is enough to reach more than 1 parking place per dwelling.
The shadow of the N side is best suitable for parking. Now, W and E roads are used for entrance to houses at both sides and back gardens get more privacy. The lots for sale differentiate in morning~ and evening sun lovers.

In *Fig. 532* greenery is drawn East to get an idea of road profiles and crossings without greenery in the corner left below in the drawing, where circles are drawn with a radius of 10 and 30m. For children in the afternoon and in the summer evening green area can better be designed in the West as well to have sunny playgrounds. That does not change the counted figures left and below of the drawing.

[a] The North an South sides of an urban island are best suitable for parking for two reasons. Their surface enlarges the North-South distance between outer walls of dwellings, giving more acces to sunlight, and the shadow of North walls is welcome to parked cars.

Taking sun into account

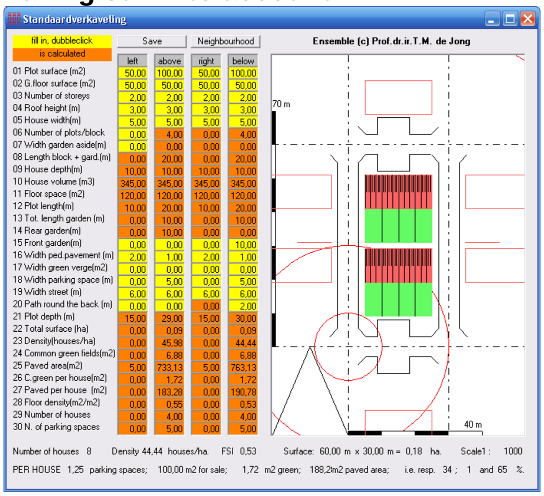


Fig. 533 60x30m N-S Turning and multiplying

N-S turning and repeating gives both blocks South gardens. Now, the short sides of the urban island are used for parking, forcing cross-parking to reach >1 parking places per dwelling. The path round the back is enlarged at the expense of sidewalks to give proper front access to the Southern block.

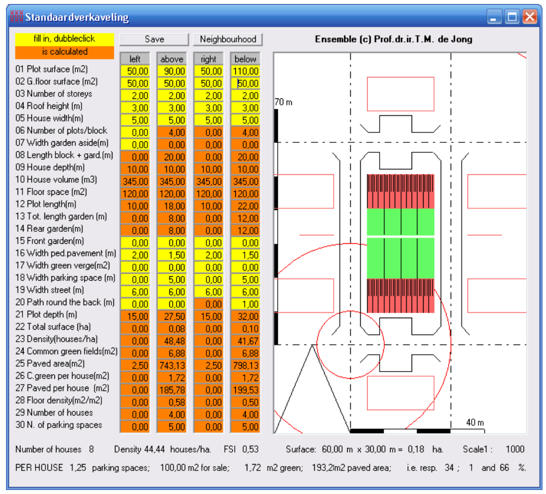


Fig. 534 60x30m N-S mirroring

N-S mirroring introduces North gardens, drawn longer here to get a partly sunny view on the N garden still. It differentiates the lots for sale in size and suggests a different dwelling type for sun lovers with south gardens and artistic life style with Northern light rooms like studios.

Elongating

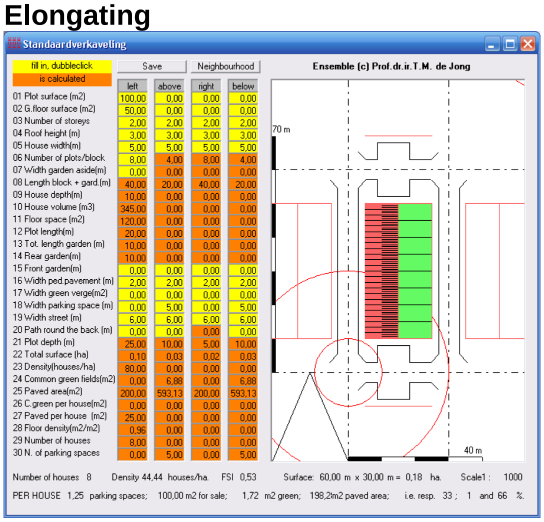


Fig. 535 60x30m elongating

To reach the same capacity of *Fig. 534* by one sided elongating avoids the path round the back utilizing the side walk, giving back a proper size to the sidewalks N and S. East gardens are suitable for people who like morning sun in the garden and in the sleeping room. Pavement is still 66%.

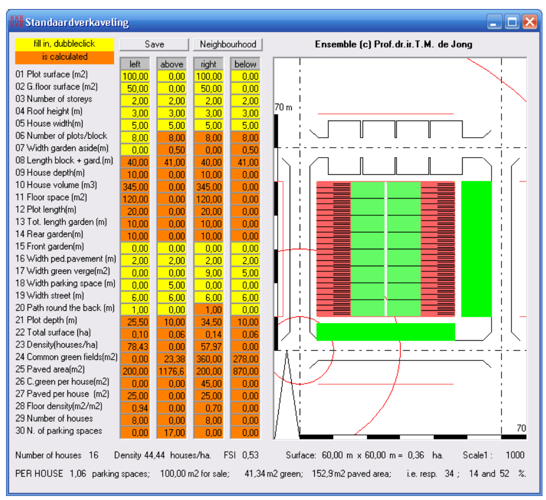


Fig. 536 60x60m mirroring

Mirroring gives evening people a chance as well and both gardens more privacy. It differentiates use and plantation. The enlargement of the urban island again reduces the amount of pavement, now into 52% in favour of the margins possibly used as green area: 9m East and 5m South.

L-shape and U-shape

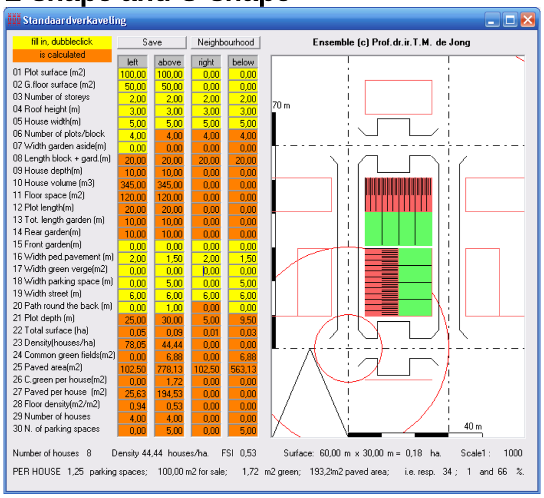


Fig. 537 60x30m L-shape

Introducing perpendicular blocks provides streetcorners with front entrances in 2 directions. That gives the beginning of an urban look and safety by private control of public space on both roads involved. To improve that effect design solutions for corners, not implemented here, would be nice. Such solutions will struggle with smaller or no gardens in the corner.

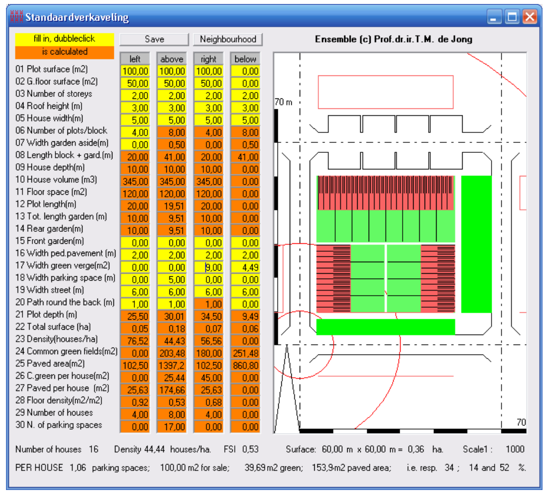


Fig. 538 60x60m U-shape

Mirroring the L-shape produces U-shaped allotments with one open side, here avoiding North gardens. It has the same advantages as previous mirroring transformations, in this case reducing pavement from 66% in *Fig. 537* into 52% and introducing green margins of 9m East and 5m South. S gardens go 0.5m around the back now, giving space for ivy-covered side façades avoiding grafitti.

Closed urban islands

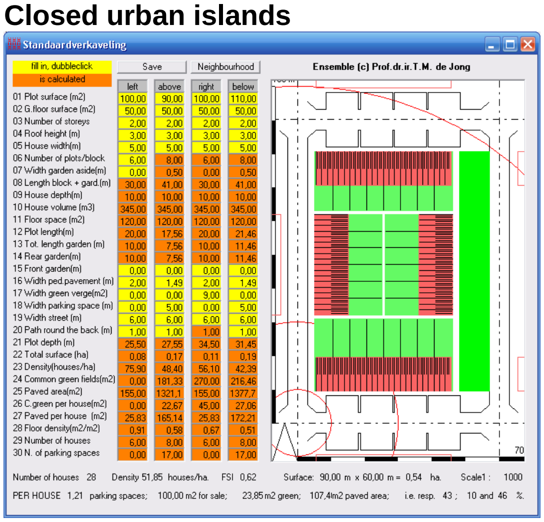


Fig. 539 90x60m Closing

Closing the urban island with front entrances on every surrounding street produces a usual allotment type of 90m length, leaving a 9m green margin East to fill the urban grid of multiples by 30m. Limiting parking places to N and S urges cross parking at both sides to have more than 1 parking place per dwelling leaving little space for sidewalks.[126]

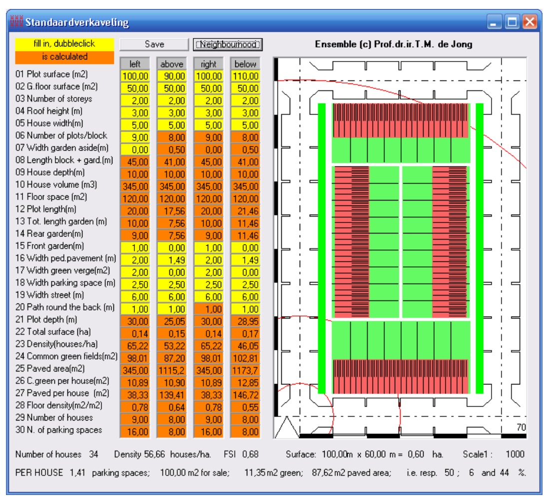


Fig. 540 Elongating and adapting 100x60m

N-S elongating to 100m is easy by adding 2 houses West and East. However, the shortage of parking places then forces parking at all sides. By giving up cross parking N and S, there is space for 6 extra houses in total. The reduction of pavement is 2% only, but the number of parking places is 1.4 per dwelling. This time the green margin is distributed W and E to make trees possible.

In *Fig. 540* we leave the starting points of page 266 behind and start to look at a higher level. On that level new spaces for mobility are needed. By the way, the elongated blocks of *Fig. 540* exceed 40m and need an extra dilatation, which is expensive.

3.4.13 A neighbourhood

If we multiply the module (**M**) of *Fig. 540* (100x60m) 5 times E-W and 3 times N-S (*Fig. 541*) we reach the mesh width (300mx300m) for neighbourhood roads (30m width of pavement[127]) mentioned at page 266. We now have 15 modules together surrounded by larger neighbourhood roads needing extra space.

Traffic production

These 'neighbourhood islands' we call 'neighbourhood quarters', because 4 of them make a neighbourhood.

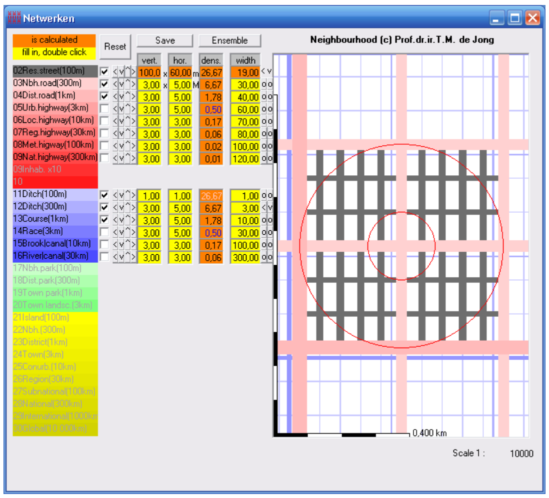


Fig. 541 A neighbourhood, multiplying Fig. 540

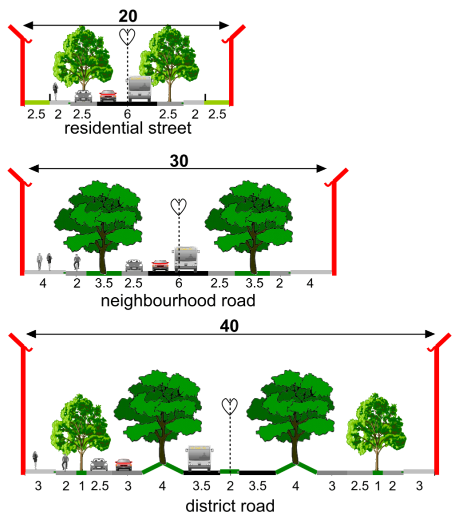


Fig. 542 Profiles normalised to 20, 30 and 40m

Suppose every urban island contains some 75 people going out 4 times a day of which 3 by car. Suppose 1/3 of the car trips the driver is accompanied by a passenger, 1 trip is done by walking or cycling.[a] So, a block produces 75x2x2≅300 car movements per day, because they are not only going out, they are coming back as well. That normally means 30 car movements per hour per island. Let them use two of four streets around the block. So, a residential street has some 15 car movements per hour and much more in peak hours. And there are visitors as well.[128]

Space for facilities

The neighbourhood of *Fig. 541* does not only need extra space for pavement of neighbourhood roads, but also for neighbourhood facilities like green, water, a school, shops and offices. Moreover, it has to accommodate facilities of higher level like district roads (40m wide). They produce car movements as well, but in the same time they make part of the modules involved unsuitable as residential area. Moreover, not all modules will reach 56 dwellings per ha or a floor space ratio (FSI) of 68% reached in *Fig. 540*, because many lots are larger than 100m^2. Suppose there are 1000 inhabitants per neighbourhood, it produces 1000x2x2≅4000 car movements per day using half of the neighbourhood roads available. So, a neighbourhood road has some 2000 car movements per day or 200 per hour and much more in peak hours.[129] And there are visitors as well.

[a] CBS …

3.4.14 A road hierarchy

Going on like that we can make a table with approximate measures (in reality they will vary around that measure) for any type of road in a hierarchy (*Fig. 543*, do not take it too serious: it is a rule of thumb).

Class	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
	residential path	**residential street**	**neighbourhood road**	**district road**	**urban highway**	**highway**	**regional highway**	**metropolitan highway**
directly served area	estate	ensemble	neigh-bourhood	district	town	conur-bation	region	metropoli-tan region
m radius | mesh | crossing distance	**30**	**100**	**300**	**1000**	**3000**	**10000**	**30000**	**30000**
directly served inhabitants	10	100	1000	10000	100000	1000000	3000000	10000000
number of dwelling layers	1	2	3	4	6	7	8	10
Profile								
Left half until median strip								
profile key								
m facade height	2,75	5,50	8,25	11,00	16,50	19,25	22,00	27,50
m private use	1,00	2,50						
m sidewalk	0,50	2,00	4,00	3,00	3,00	3,00	3,00	3,00
m cycle track1			2,00	2,00	3,00	3,00	3,00	3,00
			3,50	1,00	1,50		1,75	
m park1	2,50	2,50	2,50	2,50	2,50	2,50	2,50	2,50
m parallel road				3,00	3,00	3,00	3,00	3,00
m park2								
				2,00	3,00	3,00	3,00	4,50
m cycle track 2								
				2,00	3,00	3,00	3,00	4,00
m hard shoulder					2,50	2,50	2,50	2,00
m lanes	1,00	3,00	3,00	3,50	6,50	13,00	16,25	26,00
m park 3								
m median strip				2,00	4,00	4,00	4,00	4,00
Right half from median strip mirrored	5,00	10,00	15,00	19,00	28,00	33,00	38,00	48,00
m total	**10,00**	**20,00**	**30,00**	**40,00**	**60,00**	**70,00**	**80,00**	**100,00**
m pavement	8,0	15,0	23,0	28,0	41,0	54,0	60,5	79,0
Physical infrastructure								
m width between facades	10	20	30	40	60	70	80	100
km/hour design velocity	10	30	50	70	90	110	130	150
m minimum lane width	1,75	2,25	2,75	3,25	3,25	3,25	3,25	3,25
number of lanes	1	2	2	2	4	8	10	16
Capacity (possible use)								
vehicles/h capacity per lane	500	1000	1500	2000	2000	2000	2000	2000

Class	1	2	3	4	5	6	7	8
	residential path	residential street	neighbourhood road	district road	urban highway	highway	regional highway	metropolitan highway
directly served area	estate	ensemble	neigh-bourhood	district	town	conur-bation	region	metropoli-tan region
m radius | mesh | crossing distance	**30**	**100**	**300**	**1000**	**3000**	**10000**	**30000**	**30000**
vehicles/hour capacity	**500**	**2000**	**3000**	**4000**	**8000**	**16000**	**20000**	**32000**
vehicles/24 hour capacity	5000	20000	30000	40000	80000	160000	200000	320000
Use | Intensity								
residential								
directly served inhabitants	10	100	1000	10000	100000	1000000	3000000	10000000
car rides/inhabitant/day	2,00	2,00	2,00	1,00	0,20	0,10	0,05	0,02
%surrounding infrastructure used	50%	50%	50%	50%	50%	50%	50%	50%
light vehicles/24 hour intensity	20	200	2000	10000	20000	100000	150000	200000
cargo								
kg cargo/inhabitant per day	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
kg cargo/vehicle	10	100	1000	1000	1000	1000	1000	1000
cargo vehicles/24 hour intensity	2	2	2	20	200	2000	6000	20000
service								
service visit/inhabitant/day	0,01	0,01	0,01	0,02	0,01	0,00	0,00	0,00
service vehicles/24 hour intensity	0,20	2,00	20	400	2000	2000	6000	20000
total								
vehicles/24 hour intensity	22	204	2022	10420	22200	104000	162000	240000
vehicles/hour intensity	**2**	**20**	**202**	**1042**	**2220**	**10400**	**16200**	**24000**
vehicles/hour peak intensity								
% use by car = intensity/capacity	0,4%	1,0%	7%	26%	28%	65%	81%	75%
dB(A) noise on façade[a]	66	59	62	74	80	84	90	96
% devaluation houseprice by noise[a]	10%	5%	7%	22%	34%	40%	48%	54%

Fig. 543 Approximate characteristics of a road hierarchy as a model

All assumptions of *Fig. 543* are arbitrary and can be changed in the similar spreadsheet 'hierarchy.xls'.[b] This spreadsheet draws the adapted profiles as well. The text below explains the concepts.

Spatial measures

In *Fig. 543* '**m radius**' is a nominal measure (read 300m and think 'something between 100m and 1000m' or 'neighbourhood', with a diameter of approximately 600m) for the area involved. It applies the mesh width of the theoretical network as well, the distance between crossings of roads of the same level (turn distance). '**Directly served inhabitants**' is as elastic as the nominal radius (read 1000 inhabitants and think 'something between 100 and 10 000 inhabitants').

The '**Profile key**' gives a possible division of half the profile including the median strip, summarised without the median strip, supposing the other half is mirrored. So, the total distance between façades is two times half the profile.

[a] *calculated according to SRM1*

[b] Downloadable from *http://team.bk.tudelft.nl/Databases/Databases.htm* > *Wegprofielen maken met excel .xls*

Traffic measures

The '**km/hour design velocity**' shows which speed of cars is supposed determining the '**minimum lane width**' of the lanes out of which the roadway is composed. The '**number of lanes**' is determined by the expected number of cars per hour calculated in line '**vehicles/hour intensity**'.
The actual intensity is something else than the capacity, the maximum possible intensity without congestion, for example in peak hours. They are compared in the **% use by car** = intensity/capacity. Above a certain percentage (60%?) you can expect congestion in peak hours.

Non-residential traffic

The **light vehicles/24 hour intensity** is calculated here by multiplying the number of directly served inhabitants, the number of car rides/inhabitant per day and the **%surrounding infrastructure** used as we did already on page 270 for residential and neighbourhood roads. There we mentioned already 'there are visitors as well'. In the neighbourhood it does not count so much, but on roads of higher level cargo transport and service traffic is more important.

How to count that? Here we found a very simple, but perhaps not very reliable way. We estimate the **kg cargo/inhabitant/day** and divide it by an estimated **kg cargo/vehicle** to get the number of **cargo vehicles/24 hour**. In a comparable way the number of **service visits/inhabitant** per day produces the **service vehicles/24 hour intensity**. Summing these lines produces the **number of vehicles/24 hour intensity**, which divided by 10 produces, **vehicles/hour intensity**.

Noise

The **dB(A) noise on façade** depends on many things like intensity and distance to the façade. It is a rough estimate, but it determines **% devaluation of house prices** by noise.[a]

3.4.15 From a model back into a real city

This chapter started by real measures of cars (*Fig. 523*), derived models about a hierarchy of roads with different capacity and intensity (induction from particular into general). We neglected many aspects of urban context. Now, we have to check how reliable these models are, knowing that reality always differs (deduction form general into particular).

Deduction into a special case

A complete survey should take more cases to check the theory. Here we take one case only and we do not check all assumptions (hypotheses). In *Fig. 544 The urban area around Dordrecht*, we find 6 levels of roads. The resolution does not permit to see residential paths (1). But we see residential streets (2, white) , neighbourhood roads (3, yellow), district roads (4, same colour, but somewhat thicker), urban highways (5, purple), highways (6, red), regional highways (7, red and orange). We have drawn circles of nominally 3, 1 and 0.3km around parts we nowadays call city, district and neighbourhood.

Deviation of predicted measures

Let us start with Papendrecht. It has some clear squares of approximately 500x500m neighbourhood roads while our model states 300x300m. Should we adapt our model?

[a] It is calculated with a formula given in the thesis of Ruiter, E. P. J. (2004). The Great Canyon. Reclaiming land from urban traffic noise impact zones. (Zoetermeer) Peutz b.v.

Fig. 544 The urban area around Dordrecht[a]

Elsewhere (for example in the central part), there are smaller mesh widths (sometimes 100m). The model fits better the average. Moreover, we appointed: "read 300m and say 'something between 100m and 1000m' ". So, reality deviates within the appointed tolerance of the model. If our model fits the average, we can say: "Papendrecht has a relatively large mesh width for its neighbourhood roads".

Do we count the right hierarchy class?

But perhaps there is more going on. Do some of the drawn residential streets have neighbourhood road characteristics? To decide that, we need to enlarge the detail (*Fig. 545*). No, the map is correct, all streets with the square of neighbourhood and district roads are approximately 20m wide from façade to façade, perfectly according to what we stated in *Fig. 543*. The neighbourhood roads fit the prediction to be some 30m wide as well. However, the district road is not 40m, but 50m wide. There are two possible reasons.

Spatial context driven deviations

There is something more to learn from *Fig. 544* after all. We supposed there would be a district road every 1km, but in Papendrecht we see only one within a radius of 1km (diameter 2km). However, there is interference with the network of rivers clarifying why the second one is not realized. A second one here would not have enough use to legitimate the cost. The river limits its bearing surface. The model supposes a homogeneous topography while reality is heterogeneous. Nevertheless the density of district roads is low comparing to the model, so the remaining one needs more capacity.

Superposition

From Papendrecht we learn also that a district road appearing in a grid of neighbourhood roads can take over a neighbourhood function (superposition, we will discuss that in paragraph 3.4.4). That is another reason to increase its capacity and thereby its width.

[a] CDRom de nationale Stratengids van Nederland met kaarten van de Topografische Dienst te Emmen (Den Haag) Citydisc

Fig. 545 A Papendrecht detail

Fig. 546 A central Dordrecht detail

Fig. 547 Dordrecht some 350 years ago[a]

So, we keep the model for the time being, because it keeps us attentive on regularities in the existing urban tissue to be applied in urban design.

The time-dependency of a model

By the way, *Fig. 545* and *Fig. 546* illustrate how much surface can be occupied by non residential functions, as we stated in paragraph 3.4.13. *Fig. 547* shows what we call a city changes in time. Holland's oldest city in the 17th century (Dordrecht) and Amsterdam were very large that time but now we call their surface (R=1km) a district. All other cities in the Atlas of Blaeu[a] from 1652 are even smaller. They had a radius R=300m (walking distance). That is what we now call a neighbourhood. On Bleaus maps you see closed urban islands everywhere with closed corners as well. The urban density was much higher than we are used to nowadays. One of the factors of decreased density is the mobility space we need for cars and their parking lots. The way the urban islands became open allotments in the 20th century is described by Castex and Panerai.[b] What would be the cause?

[a] Blaeu, J. (1652). *Toonneel der Steden van Holland - Westvriesland - Utrecht*. (Amsterdam)
[b] Castex, J., J.-C. Panerai, et al., Eds. (1990). *De rationele stad. Van bouwblok tot wooneenheid. Met een nawoord van Henk Engel.* Teksten architectuur (Nijmegen) SUN.

3.4.16 Traffic surface

Ensembles (R=100m)

Fig. 548 and *Fig. 549* show two allotments of 100 dwellings (225 inhabitants) in rows of 10 on 1.8 ha. So, there are 56 dwellings/ha and FSI= 56% while the floor space per two storey dwelling is 100m^2. From total area 62% surface is for sale and 38% is public space including 1 parking place per dwelling and roadway pavement of 3.2m wide.

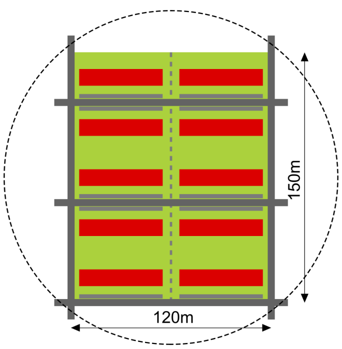


Fig. 548 100 dwellings along residential streets with parking in front of the house: 15% pavement, 23% green area

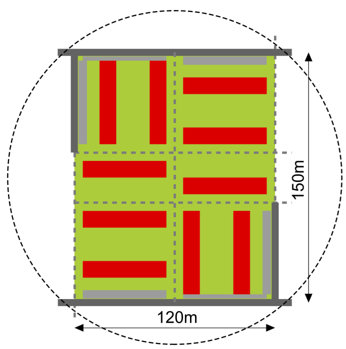


Fig. 549 Reduced pavement by residential paths, parking at 1 minute walk: 10% pavement, 28% green area

Fig. 550 Reduction of street pavement, increase of green area comparing Fig. 548 and Fig. 549[a]

However, in *Fig. 549* parking is concentrated at the boundaries. People have to walk 1 minute more than in *Fig. 548* to reach their cars, partly living at residential paths, saving 1/3 of pavement![130] That reduces municipal costs (or ground prices and taxes for private persons) substantially. By doing so, there is 1/5 more green area (5% green of total area), resulting in a much greener look without cars. That area could become public green, but it can be sold as well reducing municipal costs again. The disadvantage is, you can not easily come close to your home with luggage, moving vans and other vehicles. And you can not see your car from your home.

[a] PPD-ZH(1970)

Neighbourhoods (R=300m)

Multiplying a module like *Fig. 549* by 8 around a centre, produces a neighbourhood of 1800 inhabitants, enough for some facilities like a school (1ha black square in *Fig. 551* to *Fig. 553*), playgrounds, some shops and enterprises or public facilities. By locating parking spaces at the boundaries of the ensembles, at daytime some residential parking space can be used by users of the facilities, avoiding extra facility parking space.

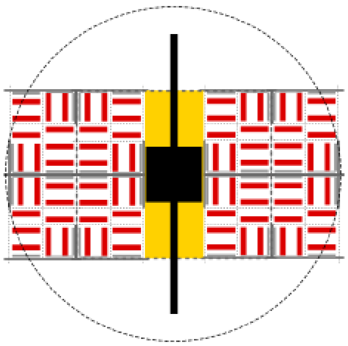


Fig. 551 300m central road

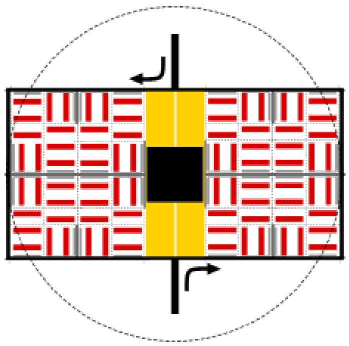


Fig. 552 1800m peripheral one way road substituting 600m residential street

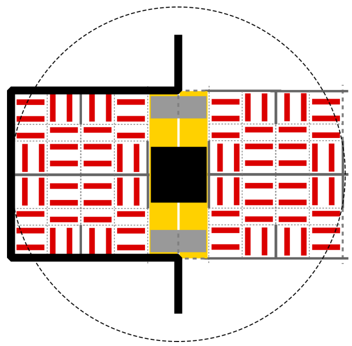


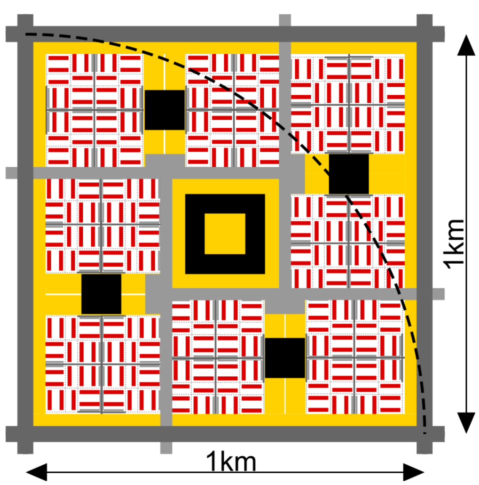
Fig. 553 900m peripheral road substituting 300m residential street, central parking

A central neighbourhood road costs least pavement, but it divides the neighbourhood and the school in two parts (*Fig. 551*). A peripheral road costs much more road length, unless it is part of a grid used for adjacent neighbourhoods as well. A one way solution (*Fig. 552*) may half pavement and barrier effect but causes detours. A one sided peripheral road leaves the other side open to the field and causes long walking distances. Concentrated parking on neighbourhood level could mean a 10 minute walk to your car (*Fig. 553*).[131]

However, these choices are often subordinate to the environment, mostly a district grid (*Fig. 554*).

Districts (R=1km)

Multiplying the module from *Fig. 551* by 4 (7200 inhabitants) the surface fits in a 1x1km grid of district roads (40 wide), leaving open a 30m surrounding margin and a centre (*Fig. 554*) in each district quarter. That centre can be used for additional district green, facilities or housing (4ha black square), utilizing concentrated residential parking in day time. The grid permits to leave out 1200 m neighbourhood streets according to the model of *Fig. 543*, but asks 8x90=720m extra residential roads to give access to all ensembles.[132]



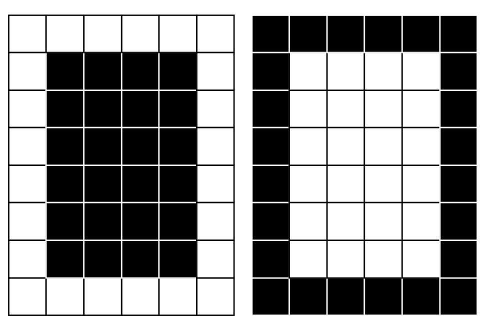
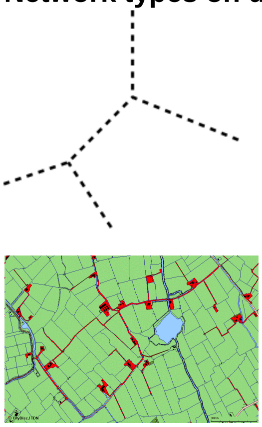


Fig. 554 A small district or district quarter *Fig. 555 Same built-up area optically full or empty*[a]

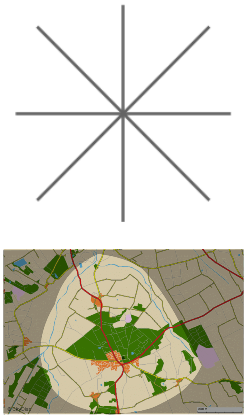
Fig. 555 shows the optical principle of leaving the centre open, applied in *Fig. 554* on the level of the quarter and on the level of its centre: the same surface left (4x6=24) gives a more spacious effect located in the periphery (6x8-4x6=24 as well: the 'Tummers-De Bruin effect'). A positive side-effect is better accessibility of the built-up area. On an even smaller scale *Fig. 554* shows another principle of central squares: do not make an X-crossing, give access roads along the square a view on larger buildings (here schools). Berlage designing the Mercator square in Amsterdam called it the 'turbine principle'.[133] The resulting T-crossings refer to Camillo Sitte as cited before (*Fig. 508*).

[a] Tummers, L. J. M. and J. M. Tummers-Zuurmond (1997). *Het land in de stad; de stedebouw van de grote agglomeratie*. (Bussum) THOTH.

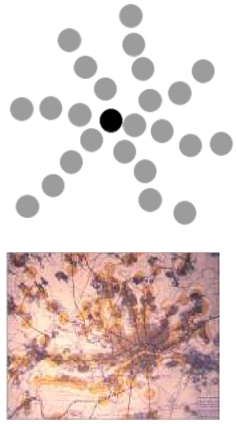
Network types on differrent levels of scale



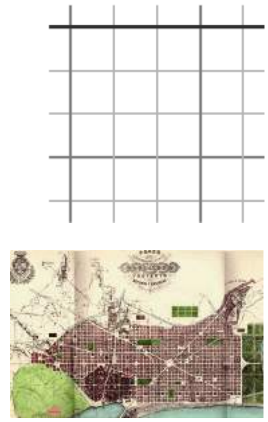
R=1km
Fig. 556 Shortest path for pedestrians



R=3km
Fig. 557 Radial for the market



R=10km
Fig. 558 Stops for public transport



R=0.1-10km
Fig. 559 Grid for car(riages)

Neighbourhoods in a distict

The hexagonal grid proposed by the American traffic expert Buchanan (1963)[a] [134], *Fig. 560* produces neighbourhoods of R=300m suitable in a grid of R=1000m.

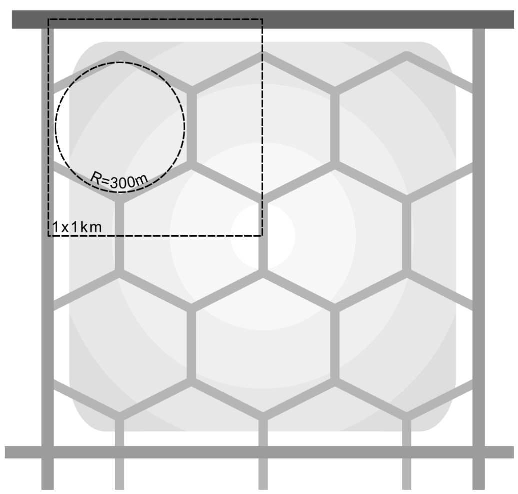


Fig. 560 The Buchanan grid put in a square 2x2km

[a] Buchanan, C. (1963). *Traffic in Towns. The specially shortened edition of the Buchanan report.* (Harmondsworth, Middlesex, England) Penguin Books.

Ensembles in a conurbarion

Fig. 554 showed how a regular grid of district roads and neighbour streets solves some problems arising if you look at an isolated neighbourhood only.[135] The most famous urban grid is built in Barcelona, designed by Cerdà (1867).[a] He designed urban islands in squares of normally 133x133m (*Fig. 561*).[136]

A neighbourhood contained 25 islands (R=300m!) with bevelled 16m high building blocks making small squares on all crossings (*Fig. 562*).[137] The islands are enclosed by residential streets of 20m wide (*Fig. 563*), neighbourhoods by neighbourhood roads of 30m wide (*Fig. 564*), district (4 neighbourhoods) by district roads of 50m wide with a large median strip (*Fig. 565*).[138] A district had a market.

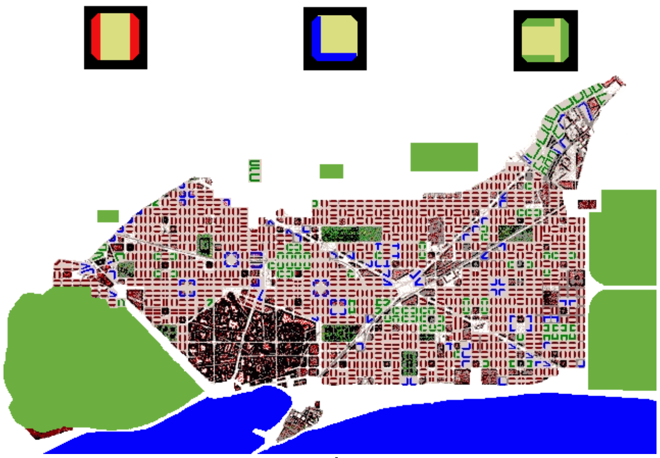


Fig. 561 Plan Cerdà (1867) in Barcelona

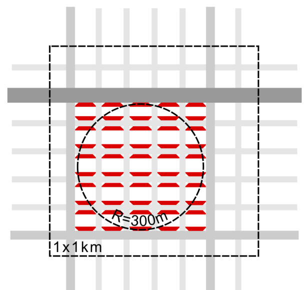


Fig. 562 A Cerdà neighbourhood

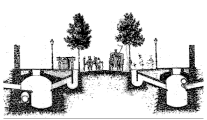


Fig. 563 Streets 20m

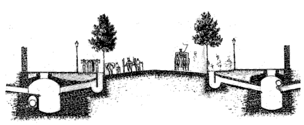


Fig. 564 Roads 30m

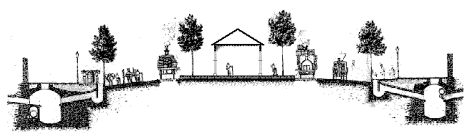


Fig. 565 District roads 50m wide

District quarters

Bach (2006) sums up the advantages of a rectangular grid concerning its flexibility giving next examples here all drawn at the same scale in a square of 1x1km.[139]

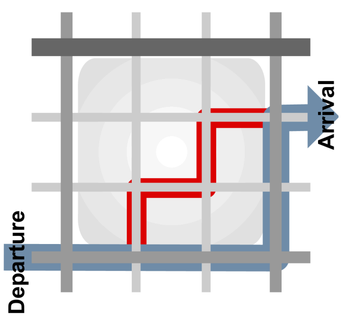


Fig. 566 Making a short cut as long as the detour

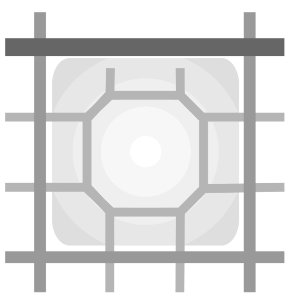


Fig. 567 Easily providing a centre

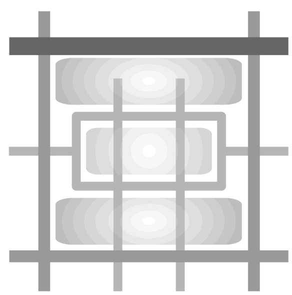


Fig. 568 Easily diminishing access crossings

[a] Cerdà (1867) *Teoria General de la urbanizacion y aplicacion de sus principios y doctrinas e la reforma y ensanche de Barcelona*, see also for Dutch readers *http://odin.let.rug.nl/~kastud/barca/c/inl.html*

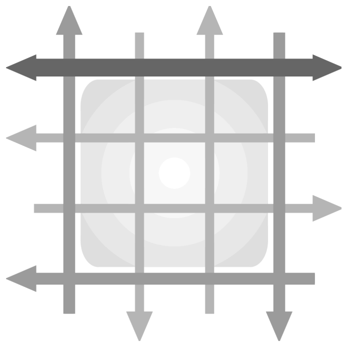


Fig. 569 Easily introducing one way traffic

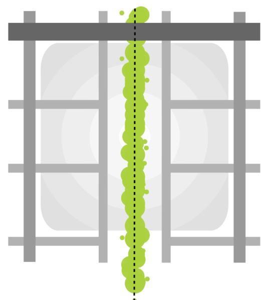


Fig. 570 Easily giving way to other networks like cycle paths

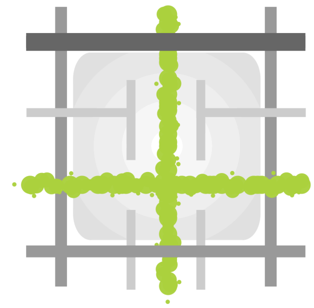


Fig. 571 Easily accepting ongoing green lines

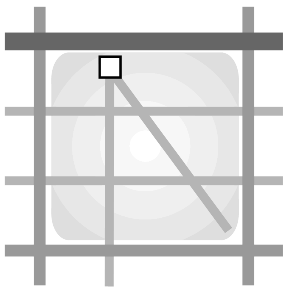


Fig. 572 Exceptions draw special attention

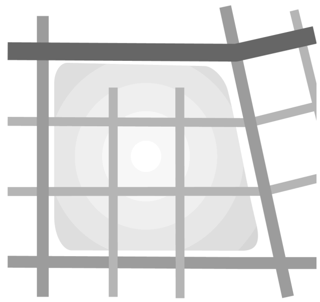


Fig. 573 Easy hinging to other grids

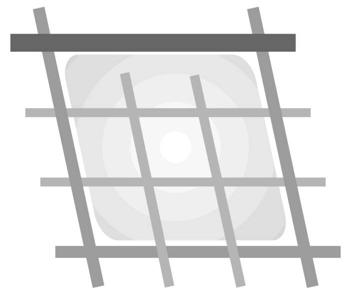


Fig. 574 Crooked grids keep easy orientation

Fig. 575 A grid makes appointments like Dutch Duurzaam Veilig easy to explain[a]

As discussed on page 251 by thought experiment, the content of a crooked grid (*Fig. 574*) is less than a rectangular one, while its outline is the same as the square. So, it will cost more pavement per inhabitant..

[a] Bach …

From radial into orthogonal in time

According to *Fig. 496* by increasing through traffic towns changed from a spider into a fly in the regional web.[140]

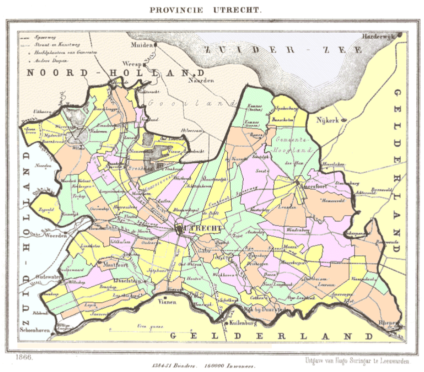


Fig. 576 Utrecht from radials in 1866 …[a]

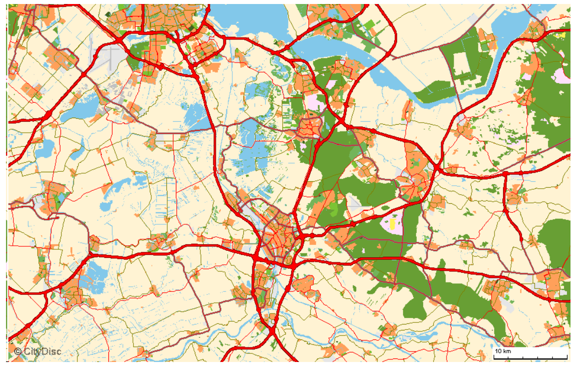
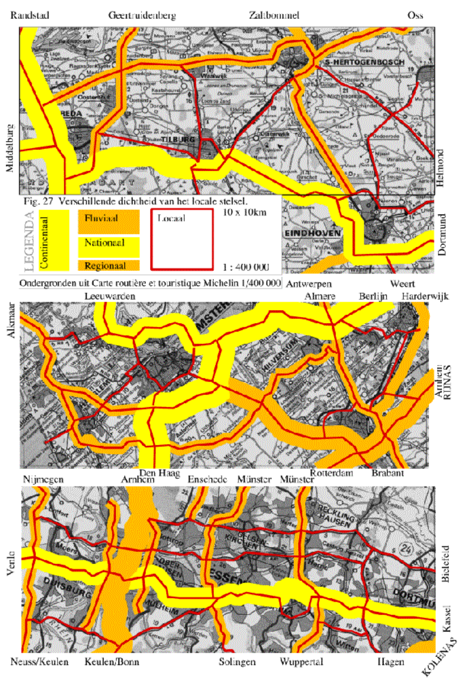
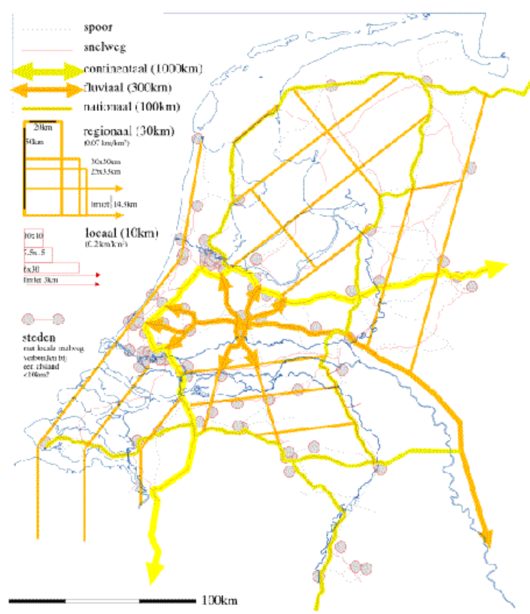


Fig. 577 via tangents into a large-scale grid[b]

Regional networks within a national network



R=30km
Fig. 578 Regional networks

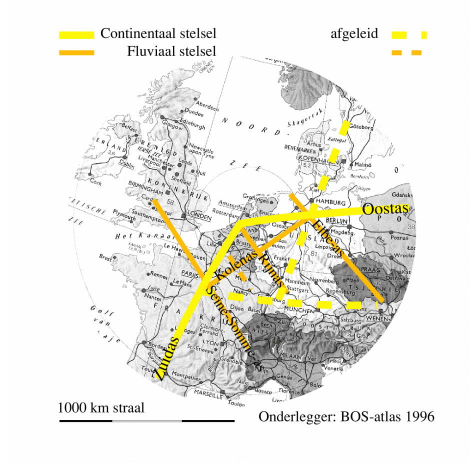


R=100km
Fig. 579 National networks

[a] Provincie Utrecht (1866)
[b] CityDisc (2001) Stratengids (Den Haag) CDrom

National networks within an international context

R=300km
Fig. 580 Fluvial networks

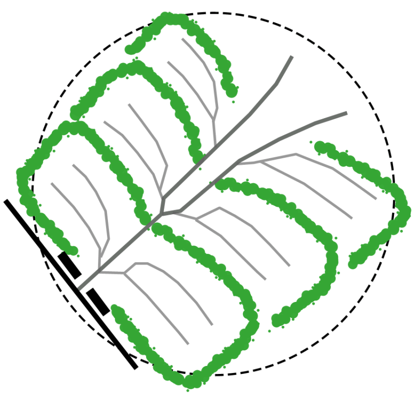


R=1000km
Fig. 581 Continental networks

Slow traffic and public transport

The pedestrian is the basal connector of urban life and all other kinds of its traffic. Not taking care for the pedestrian fragments the residential area, the neighbourhood, the district and the town. It increases casualties promoting the car and these processes strengthen each other. So, care for the pedestrian is the core of urban design. That (p)art of urban design is discussed thoroughly by Bach (2006).[141] So, in this chapter we only summarize some highlights from his work. The cycle increases the velocity reached by human power in flat countries, extending what we call slow traffic, elongating its tracks.

Pedestrians



R=300m
Fig. 582 Reichow: car first

R=300m
Fig. 583 Runcorn: pedestrian first

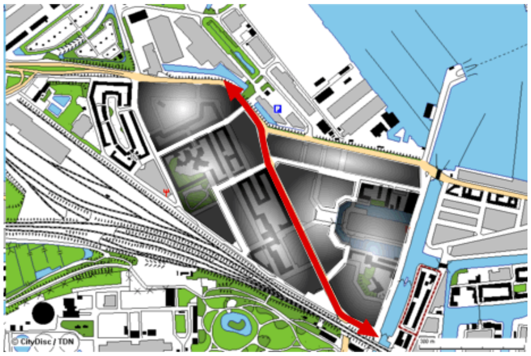


Fig. 584 Cars dividing a neighbourhood

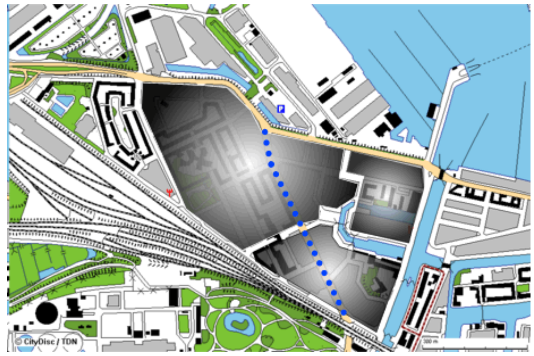


Fig. 585 Traffic calming

Cyclists

Cyclists and pedestrians take the shortest way.
So, they introduce radial lines and new crossings in car oriented grids that force detours.[142]

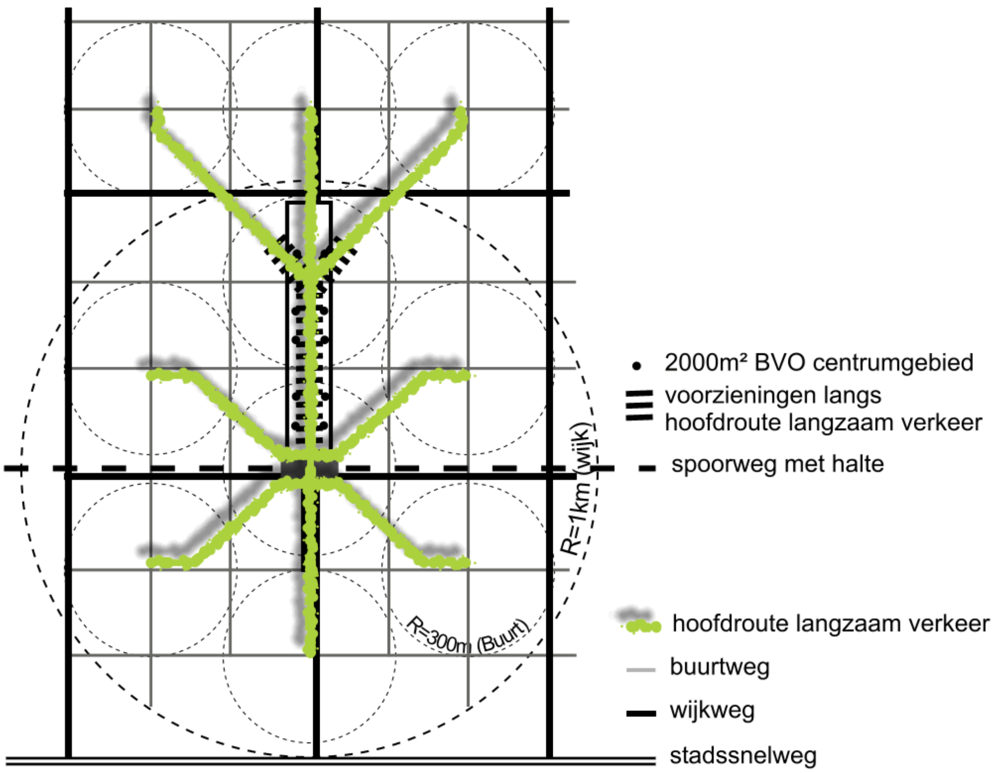
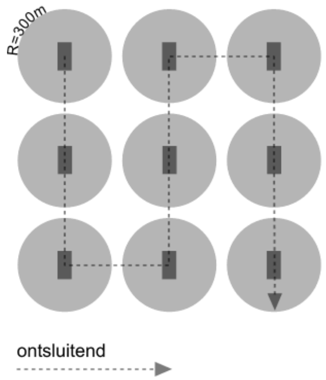


Fig. 586 Radial with a minimum of crossings

Busses

At the beginning of the twentieth century the lay-out strategy of public transport lines by busses changed from collecting travellers (*Fig. 587*) into connecting travellers (*Fig. 588*).[143]



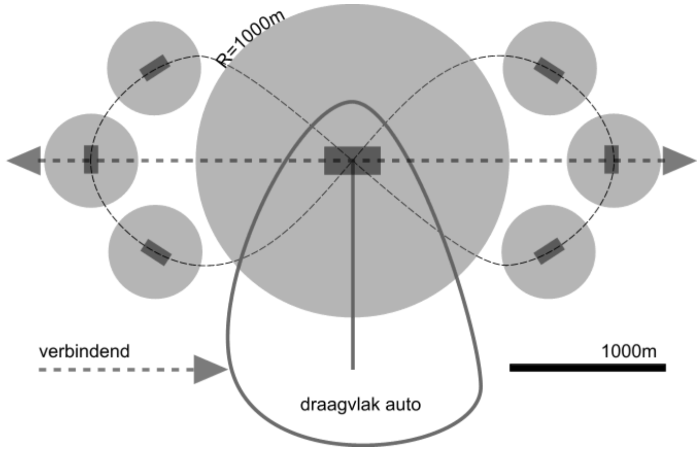


Fig. 587 Collecting travellers

Fig. 588 Connecting travellers

Bus stations

There are two principally different types of bus stations: island type (*Fig. 589*) and herringbone type (*Fig. 590*).

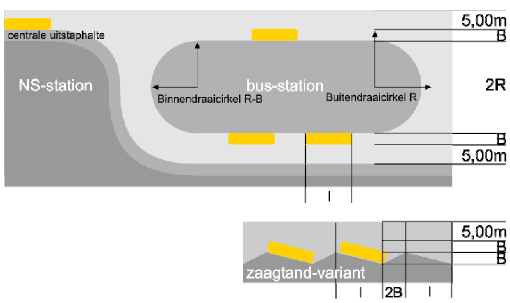


Fig. 589 An island type of central bus station

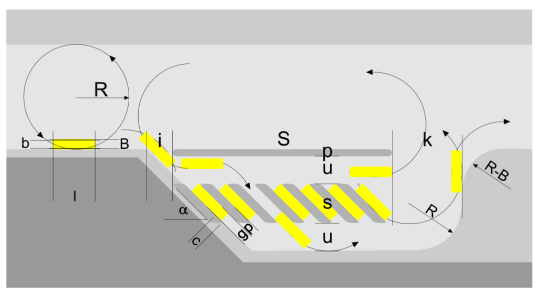


Fig. 590 A herringbone type of central bus station

Bus stops

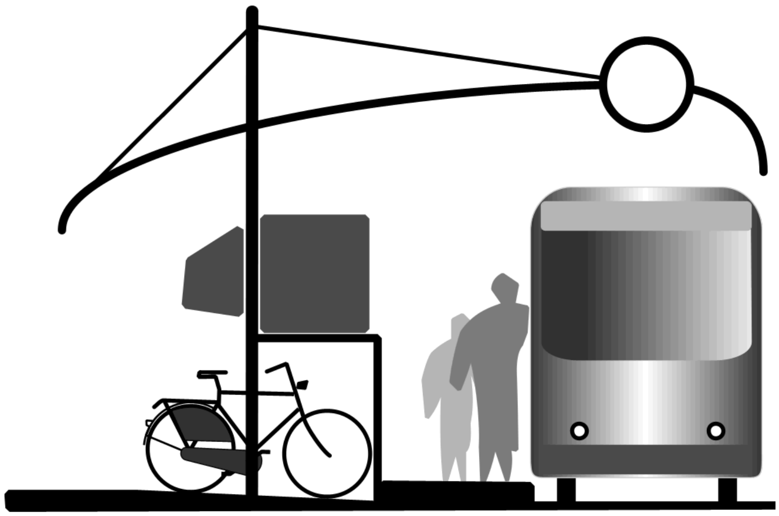


Fig. 591 Bachs (2006) bus stop concerning passengers' demands

Fig. 592 An artists' bus stop

Fig. 593 A Curitiba bus stop

Tramways and metro

		bus	tram	fast tram	(semi)metro	NS-sprinter
	min.	0.0	0.0	0.0	0.0	0.0
km radius served area		**0.3**	**0.3**	**0.5**	**0.6**	**0.8**
	max.	0.4	0.4	0.6	0.8	1.0
	min.	0.3	0.3	0.4	0.7	1.5
km stop distance		**0.4**	**0.4**	**0.6**	**1.1**	**1.8**
	max.	0.5	0.5	0.7	1.4	2.0
	min.	12	12	18	30	40
km/h velocity		**16**	**16**	**22**	**35**	**45**
	max.	20	20	25	40	50
	min.	2	2	4	5	7
km average ride		**4**	**4**	**7**	**10**	**14**
	max.	6	6	10	14	20
minutes ride		**15**	**15**	**20**	**16**	**18**
stops per ride		**10**	**10**	**13**	**9**	**8**
	min.	1000	1667	3333	8000	13333
passengers per hour		**2000**	**3333**	**6667**	**16000**	**26667**
	max.	3000	5000	10000	24000	40000
passengers per stop		**200**	**333**	**524**	**1768**	**3457**

Fig. 594 Some characteristics of urban public transport[144]

Light rail combines all velocities.[145]

From *Fig. 594* you can draw pictures like *Fig. 595*.

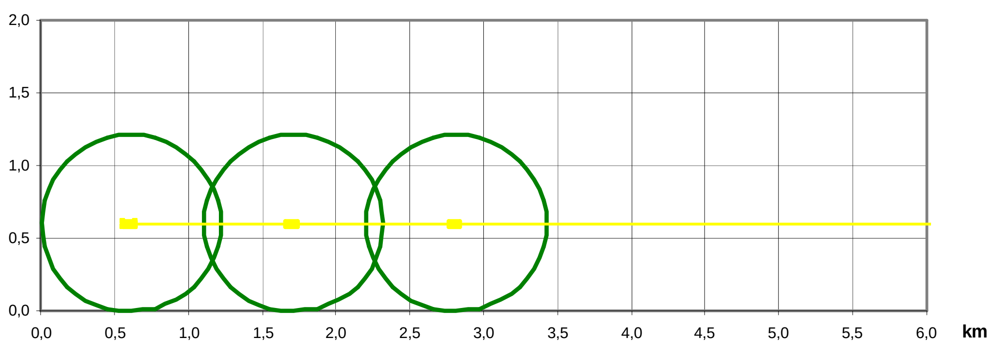


Fig. 595 A metro from Fig. 594with 0.6km radius of served area around a stop and 1.1km stop distance

Supposed you know the line length of *Fig. 595* (for example 10km), you can calculate the number of stops (9+1) and the km^2 served area (10πR^2 minus overlaps) of all stops together. Supposed you know the number of served inhabitants per hectare (100) and the %inhabitants expected to use metro (14%, see *Fig. 594*) you can calculate the number of passengers per day (15144, *Fig. 596*). That will determine whether the line is exploitable or not.[146]

km line length	10
distance between stops	1.1
number of stops (9+1)	10
km² served area	11
inh./ha	100
number of served inhabitants	110195
14% passengers per day	15144

	inh. / dwelling	dwellings/ ha	m² Floor Space /dwelling	%FS (100%·FSI)
for example:	2,3	43	100	43%

Fig. 596 Calculating the profit of the metro line from Fig. 595

Railway-stations

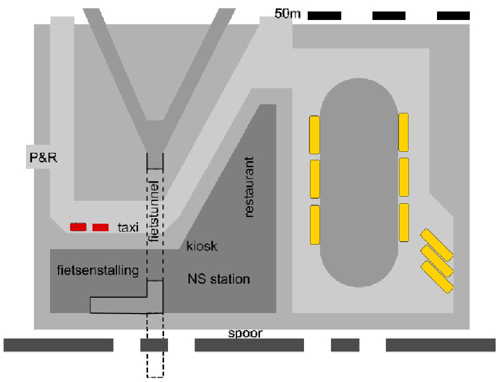


Fig. 597 A railway station accessible for cyclists, pedestrians and busses

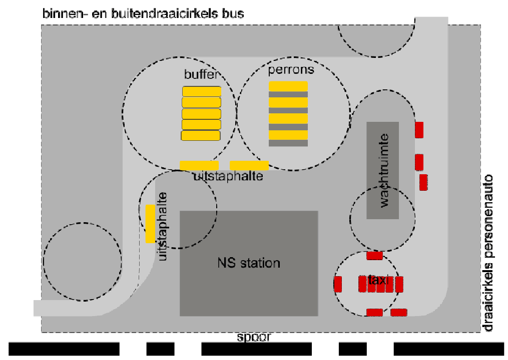


Fig. 598 A railway station for cars based on inner and outer turning circles of busses and cars

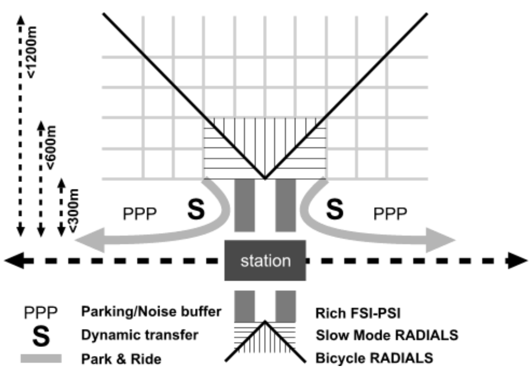


Fig. 599 Approaching the railway station according to Bach (2006)

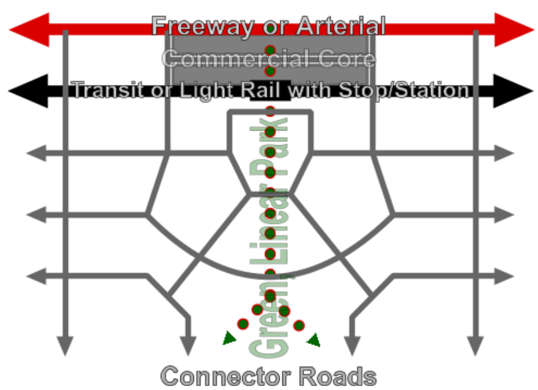


Fig. 600 Approaching the railway station according to Calthorpe

3.4.17 Harbours P.M.

Airports
Seaports
Inland ports

3.5 Other networks: cables and ducts

Increasing use of urban subsoil

Urban development plans are increasingly determined by the urban subsoil.
Problems and requirements associated with groundwater and load bearing capacity can be solved technically (see chapter **Error! Reference source not found. Error! Reference source not found.**, page **Error! Bookmark not defined.**).
In addition, the installation of cables, ducts and drains requires more and more space under the built-up area. As a result, ever stricter requirements have to be met with respect to the relative position of drains, cables and ducts. And don't forget underground storage space, for example for the disposal of glass, paper and other recyclable materials from containers placed in groups in the city. This often makes it difficult to find or make underground space, no matter how much we would like to get rid of these ugly containers by placing them underground.

Additional aboveground facilities

This chapter does not only take a closer look at on the use of underground space in urban areas, but also at space for beam transmitters and other forms of overhead and underground infrastructure.
The branch points and transitions from regional networks to urban networks also play an important part in urban development. Take for example the transition from overhead high-voltage transmission lines via transformers to an underground electricity distribution network. On the other hand a region may have ducts that do not occur in the urban landscape, yet are important for the city.

Regional ducts

On a regional level, ducts generally have a different effect on the use of topsoil than in towns, such as large underground water and gas distribution pipes and underground conveyor pipelines from dock areas to users, for example oil pipelines to the Ruhr region and Antwerp. On a regional scale, however, electricity cables that are underground in cities are aboveground in rural areas, such as the many high-voltage transmission lines across the Netherlands.
Although the spatial use of ducts on a regional scale means fewer restrictions on land use in urban areas, careful consideration must be given to the installation of pipes in the countryside. The ducts and cables in the transition zones from rural to urban areas restrict urban land use and urban developments. Consideration must also be given go maintenance of infrastructure in the country side.

Tunnels

In addition to pipes and ducts, more and more tunnels are being constructed, such as road tunnels and rail tunnels under waterways and rail tunnels to preserve the landscape. Examples that illlustrate the state of art in 2001 are the Rotterdam rail tunnel under the Nieuwe Waterweg, the Betuwe railway line for goods transport (under construction), and the high-speed rail link through the "Green Heart" (also under construction) of the Randstad.

Archaeological artefacts

This chapter elaborates on the different pipelines and their restrictions and limitations.
The installation of underground drains and ducts obviously involves much earth moving. As of 2002, statutory investigations must be carried out into the presence of archaeological artefacts and traces prior to commencement of building activities. Construction companies have a duty to report and to conserve archeological finds. The decision to start digging depends on the importance of the archeological find, as specified under the Malta Convention (1999). This convention has been implemented in the *Nederlandse monumentenwet* (Monuments and Historic Buildings Act)[a]
An archaeological survey was carried out as a pilot project prior to the construction of the Betuwe railway line. During the archaeological survey, important finds were made, from both prehistory and later eras. The finds included the oldest skeleton ever found of a woman (Treintje) in the Netherlands, and finds related to fishing such as a prehistoric boat, fishing nets and fishing gear, as well as Medieval houses and farms.

[a] The legal side of this Historic Buildings Act is specified in the *Stedenbouwrecht* (laws governing urban development).

Types of ducts and cables

This chapter does not aim at giving a complete list of all ducts and cables that occur on a regional scale. The emphasis is on large distribution networks for gas, electricity and water, as well as telephone networks, data networks, optical fibre networks and pipes to transport raw materials from harbours to processing plants including those in Germany and Belgium.
There are also underground discharge pipes such as sewerage pipes and sewage pressure pipelines. Not all ducts in outlying areas are run underground. High-voltage transmission lines are a good example of overhead use of cables.

In order to supplement drinking water supplies in the densely populated western part of the Netherlands, water from the rivers Rhine and Meuse are pumped to dune areas through pipes. In the dunes the water is filtered and purified into drinking water, and distributed to consumers.
All these ducts and cables have their own requirements for installation which must be met by the surrounding area and the subsoil. This not only concerns subsoil conditions and groundwater, but also topsoil conditions related to land use.
Fig. 602 shows the position of cables and ducts in a street profile outside the built-uparea in accordance with the *Nederlands Normalisatie Instituut* (Netherlands Standardisation Institute).

Space taken up by cables and pipes.

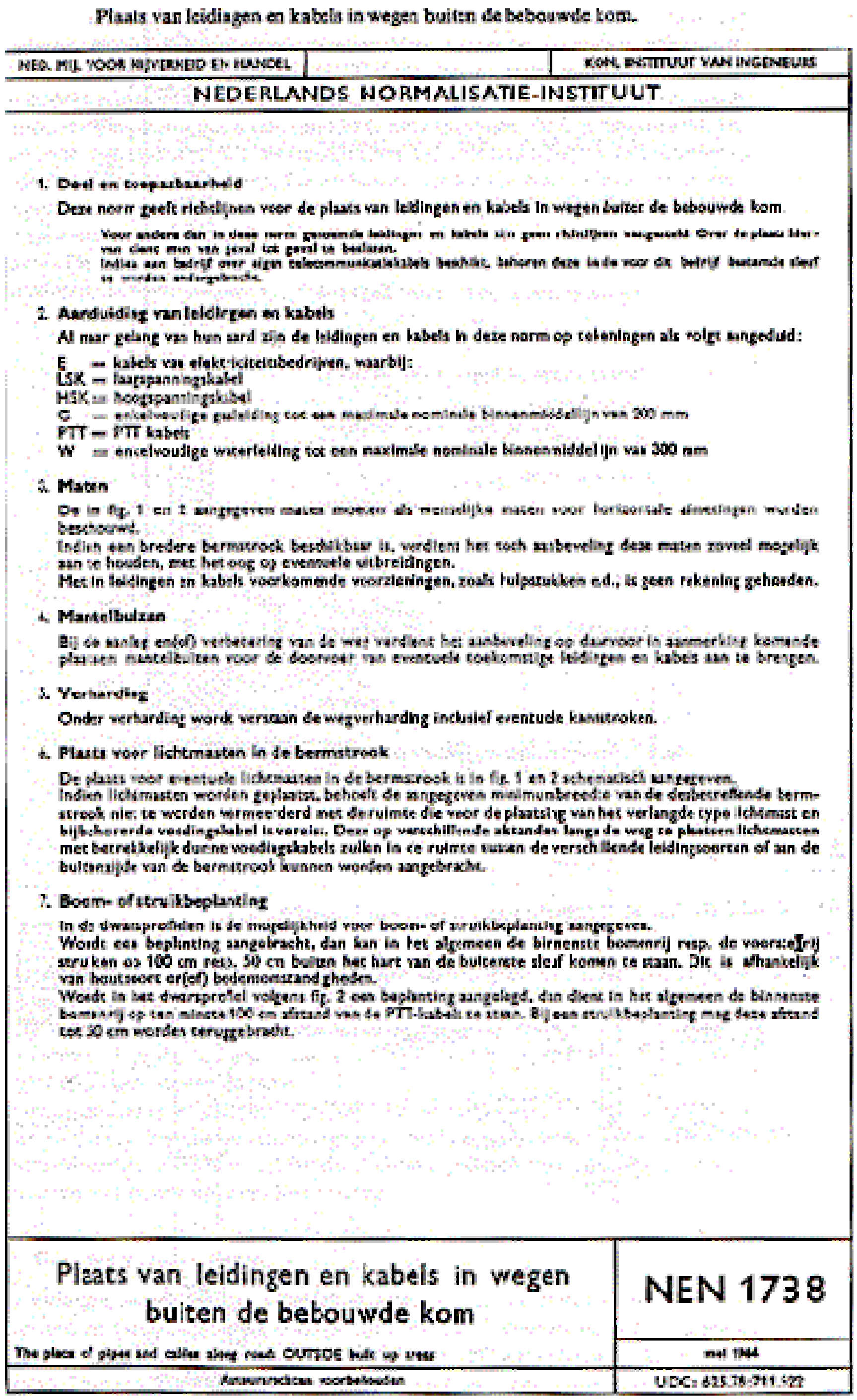
It seems harmless and easy to place obstacles such as ducts and cables underground whenever possible, and from an aesthetic point of view even desirable . Furthermore, underground cables and ducts do not have a dividing and / or barricading effect on the surrounding area as topsoil distribution networks.
Underground installation of cables and ducts, however, has implications for the land above which is kept open (not developed) for maintenance and management purposes. In addition, shrubs and trees are not allowed, as deep roots will affect the ducts and cables. Tree roots, for example, could penetrate sewage drains, causing blockages or subsidence of the soil. Moreover, ducts, cables and drains are not easily reachted and dug up in areas covered with trees, hedges and plants. Depending on the type of cable or duct, a strip of land is reserved on either side which can vary from 1m to 50m.

Risks and costs

The risk of transported material exploding and a standstill of underground transport also plays a role in the decision to keep topsoil free from obstacles.
Sometimes the price tag put on underground pipework is a determining factor in the decision-making process. Think for example of the laying of pipework in subsoil with less load-bearing capacity. Many main sewage drains are supported by piles.
With respect to electricity networks, risk consideration and possible loss of power through conduction are reasons to choose for overhead transport in the countryside across greater distances.
In summary, we can state that extensions, maintenance and management, repairs to cracks and the clearing of blockages in overhead cables and overground pipes are less costly, and that risks of transport are reduced .

In view of these considerations, pipes and cables are laid in open areas as much as possible. The Netherlands Standardization Institute has drawn up standards, the NEN standard[a] for alignment, occupied space, depth and distance between ducts and cables.

[a] NEN normen zijn te vinden in de zogenaamde normbladen uitgegeven door het Nederlands Normalisatie Instituut.



Plaats van leidingen en kabels in wegen buiten de bebouwde kom.

NED. MIJ. VOOR NIJVERHEID EN HANDEL | KON. INSTITUUT VAN INGENIEURS

NEDERLANDS NORMALISATIE-INSTITUUT

1. Doel en toepasbaarheid

Deze norm geeft richtlijnen voor de plaats van leidingen en kabels in wegen *buiten* de bebouwde kom.

Voor andere dan in deze norm genoemde leidingen en kabels zijn geen richtlijnen aangegeven. Over de plaats hiervan dient men van geval tot geval te beslissen.
Indien een bedrijf over eigen telecommunicatiekabels beschikt, behoren deze in de voor dit bedrijf bestemde sleuf te worden ondergebracht.

2. Aanduiding van leidingen en kabels

Al naar gelang van hun aard zijn de leidingen en kabels in deze norm op tekeningen als volgt aangeduid:

E — kabels van elektriciteitsbedrijven, waarbij:
LSK — laagspanningskabel
HSK — hoogspanningskabel
G — enkelvoudige gasleiding tot een maximale nominale binnenmiddellijn van 200 mm
PTT — PTT kabels
W — enkelvoudige waterleiding tot een maximale nominale binnenmiddellijn van 300 mm

3. Maten

De in fig. 1 en 2 aangegeven maten moeten als minimale maten voor horizontale afmetingen worden beschouwd.
Indien een bredere bermstrook beschikbaar is, verdient het toch aanbeveling deze maten zoveel mogelijk aan te houden, met het oog op eventuele uitbreidingen.
Met in leidingen en kabels voorkomende voorzieningen, zoals hulpstukken e.d., is geen rekening gehouden.

4. Mantelbuizen

Bij de aanleg en(of) verbetering van de weg verdient het aanbeveling op daarvoor in aanmerking komende plaatsen mantelbuizen voor de doorvoer van eventuele toekomstige leidingen en kabels aan te brengen.

5. Verharding

Onder verharding wordt verstaan de wegverharding inclusief eventuele kantstroken.

6. Plaats voor lichtmasten in de bermstrook

De plaats voor eventuele lichtmasten in de bermstrook is in fig. 1 en 2 schematisch aangegeven.
Indien lichtmasten worden geplaatst, behoeft de aangegeven minimumbreedte van de desbetreffende bermstrook niet te worden vermeerderd met de ruimte die voor de plaatsing van het verlangde type lichtmast en bijbehorende voedingskabel is vereist. Deze op verschillende afstanden langs de weg te plaatsen lichtmasten met betrekkelijk dunne voedingskabels zullen in de ruimte tussen de verschillende leidingsoorten of aan de buitenzijde van de bermstrook kunnen worden aangebracht.

7. Boom- of struikbeplanting

In de dwarsprofielen is de mogelijkheid voor boom- of struikbeplanting aangegeven.
Wordt een beplanting aangebracht, dan kan in het algemeen de binnenste bomenrij resp. de voorste rij struiken op 100 cm resp. 50 cm buiten het hart van de buitenste sleuf komen te staan. Dit is afhankelijk van houtsoort en(of) bodemomstandigheden.
Wordt in het dwarsprofiel volgens fig. 2 een beplanting aangelegd, dan dient in het algemeen de binnenste bomenrij op ten minste 100 cm afstand van de PTT-kabels te staan. Bij een struikbeplanting mag deze afstand tot 50 cm worden teruggebracht.

Plaats van leidingen en kabels in wegen buiten de bebouwde kom

NEN 1738

The place of pipes and cables along roads OUTSIDE built up areas

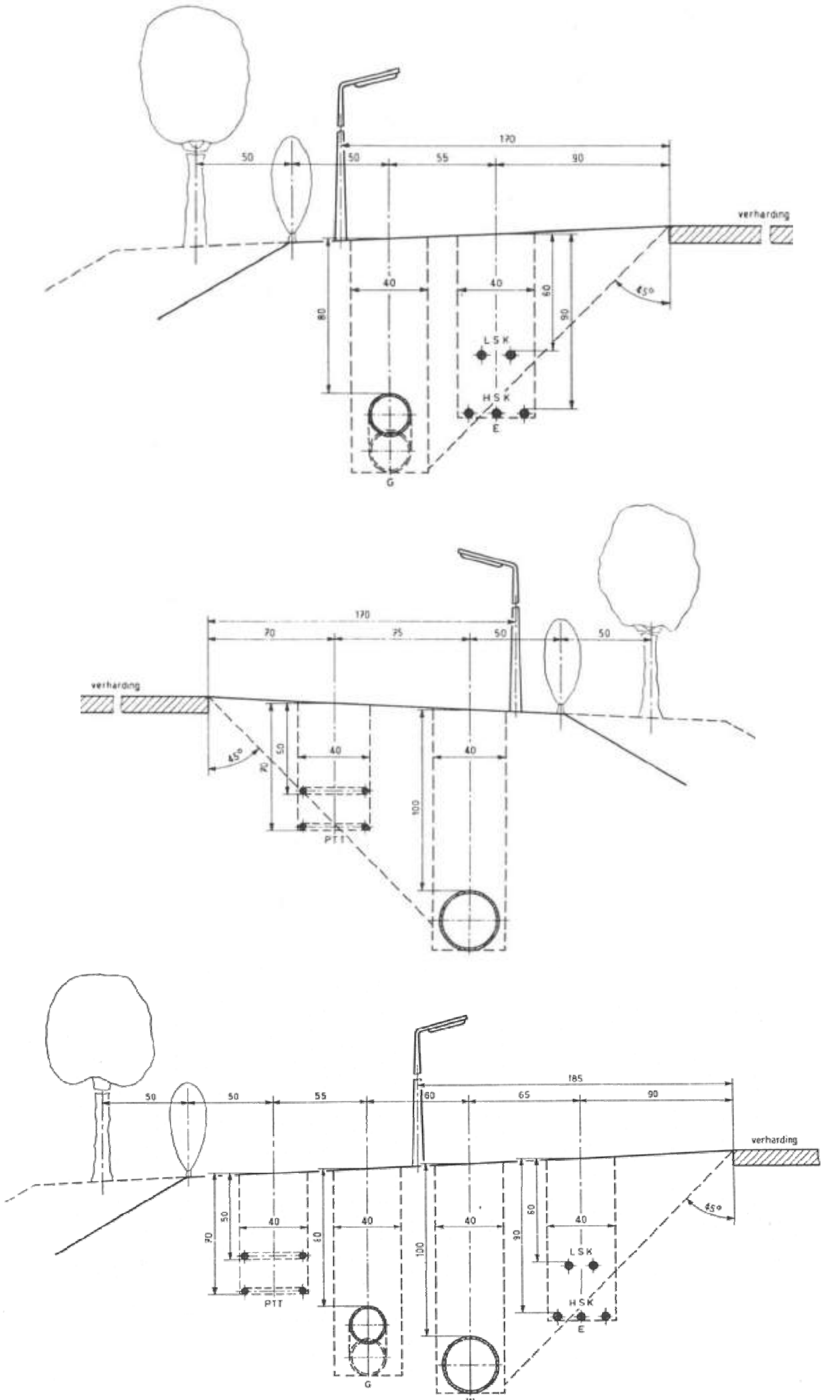
mei 1964

Aansluitend voorbehouden

UDC: 625.78:711.122

Fig. 601 NEN 1738[a]

[a] *W.A. Segeren and H. Hengeveld (1991) p. 27*



W.A. Segeren and H. Hengeveld (1991) p. 273

Fig. 602 Position of pipes and cables outside built-up areas

Bundling of pipes not only prevents fragmentation of space and needless use of space, but also reduces the barricading effect within the area.
It is recommended to check new development sites on existing underground ducts and cable and their alignment. Information is available from the provincial authorities.

3.5.1 The electricity network

We assume that there will be no changes to the power supply via electricity networks in the foreseeable future.

Avoiding losses by high voltage

A distinction is made between high-voltage grids with high kilowatt voltages and low-voltage urban distribution networks (220 V).
High-voltage transmission lines have stress levels of 380 kV, 220 kV, 150 kV and 110 kV.
The mains voltage is driven up as high as possible, as high current intensity causes heat loss.
After all: power (watt) = current intensity (ampere) X voltage (volt)
High-voltage transmission lines form an overhead distribution network in the countryside. High voltage is transformed to medium voltage, usually 10kV, in substations that work as distribution centres for urban and industrial areas. In residential areas, the medium voltage in the transformer station is coverted to low voltage (220 V).

High-voltage cables aboveground

In principle, high-voltage grids are aboveground. Areas under high-voltage cables must be kept free of obstacles in connection with swing length of possible break in a cable. This means that building is not allowed under high-voltage lines in areas exceeding 100m. In other words, a land strip of 50m on either side of the high voltage lines must be kept free of permanent obstacles. For further information on the width of a strip of land, see the relevant NEN standards. High-growing vegetation is not allowed either; temporary use of land is allowed for recreational and agricultural purposes and for nature reserves. Apart from the recreational use of land, such as parks or nature reserves, waterways and roads may cross the strip of land below the high-voltage transmission line.
Safety measures prohibit construction under high-voltage transmission lines. People's health must also be taken into consideration. Health aspects primarily concern the problems caused the magnetic fields surrounding high-voltage cables. Another health risk is a higher concentration of copper in areas with high-voltage cable lines. Further research into health risks is recommended.

Comment [T.M.de8]: P.M. zones voor uitzwaailengte bij breuk.

High-voltage cables underground

High-voltage transmission lines are only laid underground if no other solution can be found. The main reason for overhead construction is the loss of power underground because the conductor, the oil insulating layer used as a dielectric, and the earthed cable covering form a condenser, which has a disruptive effect on the phase and causes energy loss in frequently wet soil; air is a better insulator.

Interconnected regional networks

The national electricity network is divided into interconnected regions, allowing instant deployment of another network in the event of cuts and peak loads.
The Netherlands additionally uses electricity from the international European network. For example, during times of massive use of electricity mainly in winter, it comes from the Alpine regions (hydroelectric power stations). Conversely, at low-peak times, the Netherlands supply electricity to the Alpine regions by pumping up the water to help bring to level the storage reservoirs in those regions. Coal or gas-powered plants must always run at a minimum capacity to keep them on stand-by and for technical reasons. Excess capacity can be used to supply other regions in Europe.

Design considerations for the construction of an electricity network

In the Netherlands, high-voltage transmission lines usually terminate at urban boundaries. Via substations, distribution substations and transformers, electricity reaches the meter cupboard in our homes.

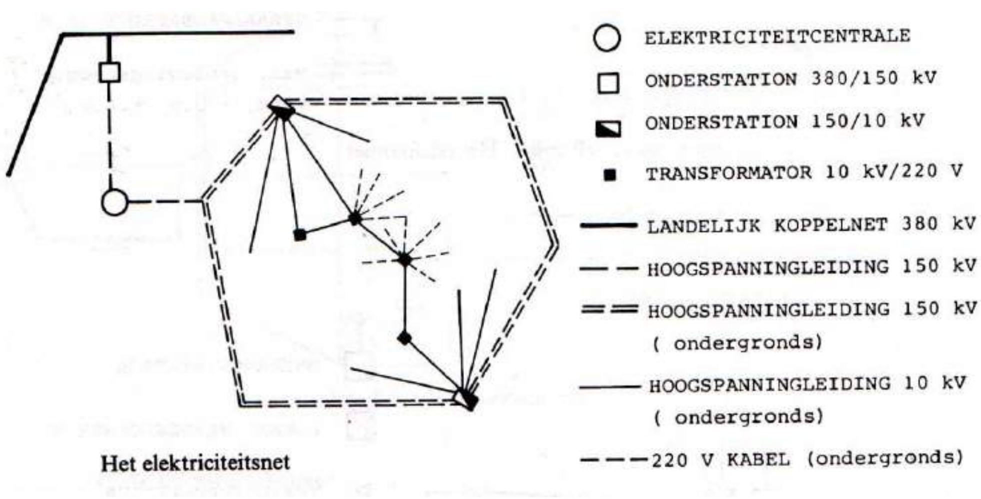


Fig. 603 The electricity network[a]

Design problems can be considered from two angles:

- alignment of new high-voltage transmission lines, and of sites for linking stations and power plants;
- changes to land use for areas around and under existing high-voltage lines

Alignment

Alignments of new pipes must satisfy the abovementioned NEN standards, and take into account future land use and/or land reservation. Adjustments over time are made only in exceptional circumstances. Cost is a key factor in this respect, as are stagnation of transport and possible risks.

Changes to land use

Changes to land use obviously involve major adjustments when an extension of an urban area is concerned. The narrow elongated strips of land beneath high-voltage lines make it difficult to fit in a new residential area.

In connection with safety and health aspects high-voltage lines often determine the boundary lines of an urban extension.

- One possibility is to leave the land under high-voltage lines unbuilt. Temporary land use may be allocated for recreational facilities, unorganised sports events etc.
- A last solution would be to lay the high-voltage cables underground. Compared with overhead installation, the costs of placing them underground is significantly higher. In addition, there will be considerable loss of power and increased maintenance costs. Although there can be no development on the strip, it can be allocated for recreational use. Road construction is allowed, provided that ducts and cables are not “covered” by obstacles. This usually means that pipework and cables are laid in a public green zone, for the alignment area needs to be kept open for safety reasons and maintenance work.
- A final option is the construction of a distribution substation with transformers, from where underground pipes form the distribution networks. Bear in mind that when you select a location for a distribution substation, the switche and compressed air in transformers make them quite noisy.

3.5.2 The gas network

The Netherlands has a national gas network ever since the discovery of natural gas in exploitable quantities. The network is connected to the natural gas extraction in Groningen and the North Sea. One network runs from Groningen and one from Noord Holland, from the pipeline landfall for extraction in the North Sea. Naturally the two networks are interconnected.

[a] *W.A. Segeren and H. Hengeveld (1991) p. 267*

Urban gas used to be produced from coal. This production was connected to local gas plants and had an urban distribution network. The networks were interconnected to avert calamities in supply and to provide additional gas at peak times. Most rural areas were not connected to a natural gas network. People used bottled gas (butane gas) to cook, while homes were heated with domestic fuel oil or coal.

Like the electricity network, the natural gas network has a distribution system. Gas pressure in rural areas is higher than in towns and cities. In distribution substations at a lower level the gas pressure of 40 bar in the national network is brought down to 25 bar for house service pipes.

Technical Design considerations of the gas distribution network.
The rural natural gas distribution network runs entirely underground. The same restrictions are placed on them as on the national electricity network with regard to obstacles to facilitate maintenance, management and safety, think of the risk of explosions underground.

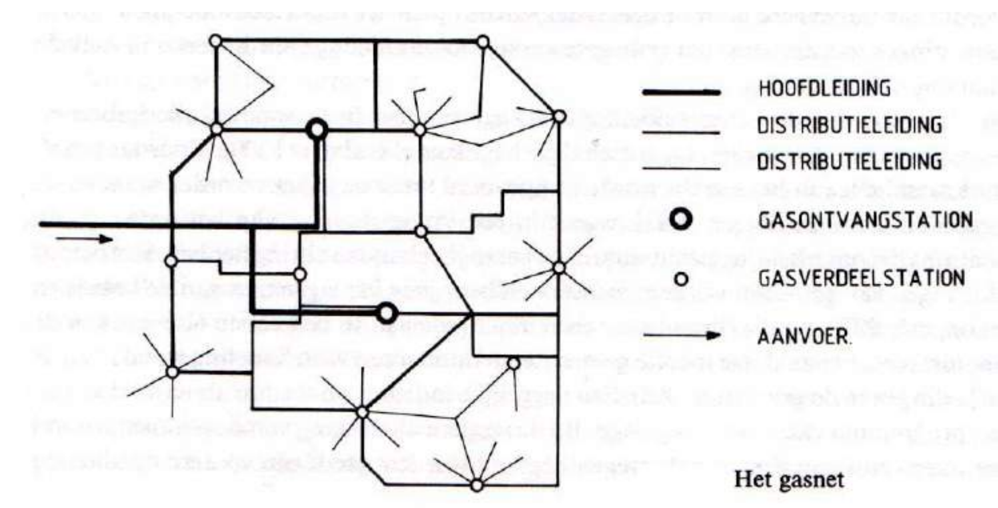


Fig. 604 The gas network[a]

In other words, strips of land with underground pipework must be free of obstacles - buildings and high-growing vegetation. Tree roots can also cause maintenance and connection problems. The width of the strips is significantly narrower than that of the electricity network, it is approximately 10-20 metres (see applicable NEN standards).

3.5.3 Water pipes

Due to the water shortage in a number of water extraction areas[b] water is brought from elsewhere to relieve the shortage in these areas. To supply the western part of the Netherlands with drinking-water, large pipes have been laid from the Rhine to the dunes where the water is infiltrated and purified. There are also water pipes leading from the Biesbos storage reservoirs to water treatment plants in urban conurbations, such as Rotterdam and surroundings. In addition, water extraction areas should also be free of pollution and polluting activities.
The network of water treatment plants to residential areas has a comparable branch system with one or more water mains to supply towns and villages, which branches off at the district and residential levels. To ensure a more reliable supply of water in districts, the pipes are installed in a ring structure.

[a] *W.A. Segeren and H. Hengeveld (1991) p. 266*
[b] Groundwater is extracted from water-catchment areas through pumping, and used as drinking water following purification. Water-catchment areas are protected against infiltration of contaminating substances such as fertilizers, petrol, etc. As a result, these areas are not suitable for all purposes.

Design considerations for installing rural water pipes.
From a design point of view, the maximum space occupied by rural distribution pipes is at most ten metres, while urban distribution pipes take up less space. Space usage depends on provincial and local acts.

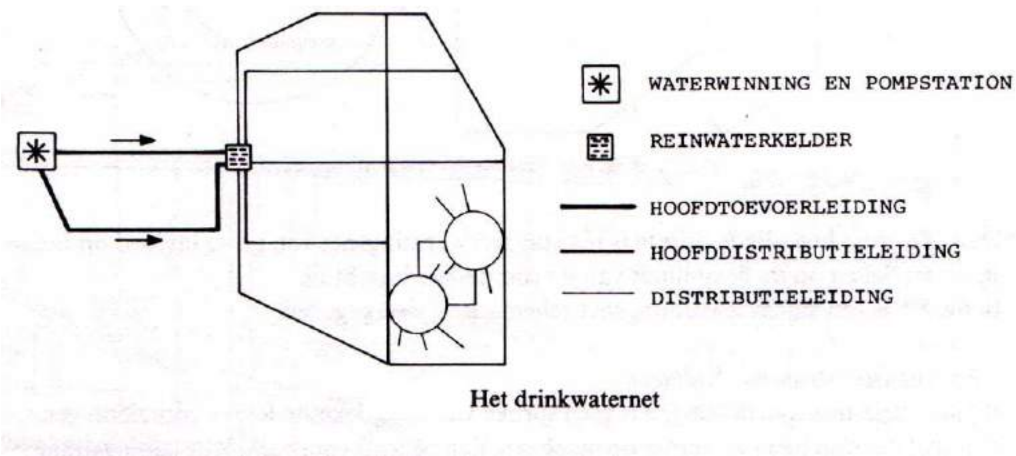


Fig. 605 Drinking-water network[a]

In general, pipes in rural areas are connected to the road network. Vegetation is not desired in view of maintenance purposes. Furthermore, the mains can be affected by roots. The distribution network must be covered by a layer of soil of at least 90 cm, which has to do with the frost limit. In the Netherlands, the fire brigade uses of drinking water to extinguish fires.

3.5.4 Pressure pipelines for sewage water

Wastewater purification plants are usually located in the country. Contaminated water and wastewater is transported through pressure pipelines from the urban areas to water treatment plants. These plants usually have a collection and purification function for a particular region. From the wastewater treatment plants pressure pipelines run to the sea and the big rivers to discharge the purified wastewater. In other cases, purified water is immediately discharged into the storage basin.[b]
Pressure pipelines for sewage water are subject to the same standards that apply to the use of the space above the pipelines. Pipe dimensions depend on the amount of sewage water that passes through them. The option of installing two adjacent narrower drains, in case of reduced discharging capacity is required due to a change in supply, is underused.

Technical considerations for installing pressure pipelines.
Here too, standards apply to pipe maintenance and the prevention of pipeline breakage. NEN standards have been drawn up, sometimes supplemented by local acts.
The space above pressure pipelines is subject to the same design requirements and restrictions concerning use and vegetation as water pipelines. A problem is also caused by the weight of the pipes. Appropriate measures must be taken with respect to soils with less bearing capacity to prevent subsidence of the pipe system. This explains why many sewage systems supported by piles.

3.5.5 The telephone network

Almost the whole telephone network runs underground. Special NEN standards apply to the installation of this network. Per region, the structure of the telephone network consists of an underground cable running from a house to the central exchange, and from there to an underground connection with the nodal point. From the nodal point, a connection is established via beam transmitters to nodal points in other areas.

[a] *Segeren and Hengeveld 1984 p. 269*
[b] A storage basin is a system of lakes, channels and ditches, where water from lower-down areas is spread out (lifted) and temporarily stored prior to being spread out to outward waters (sea and rivers in direct contact with the sea).

In addition to this underground network, there is also an aboveground network of beam transmitters. These beam transmitters are placed on tall buildings while the transmission paths must be kept free from high-rise.
Current developments in mobile telephone and other connection technologies will certainly influence the spatial use of beam transmitters. A network of lower-scale beam transmitters, masts and receivers has also been developed for the mobile telephone market. Research has shown that this development might be pose health problems.
Developments in telephone satellite connections are bound to play a prominent role in the future.

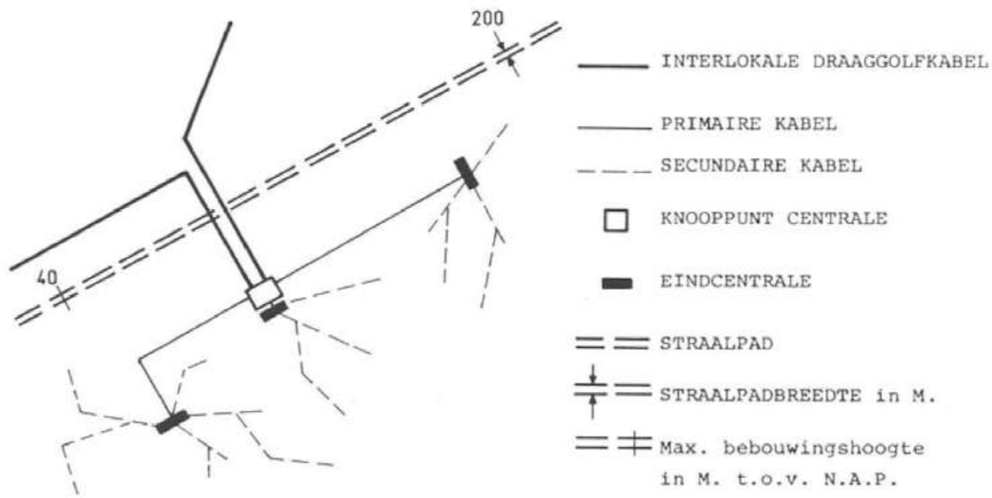


Fig. 606 Telephone network[a]

3.5.6 Radio and television transmitters

In the Netherlands, physical space is also used for transmitting radio and television signals via transmission masts which transmit signals to receivers or aerials. Obstacles can cause interference or distortion.

[a] W.A. Segeren and H. Hengeveld (1991) p. 268

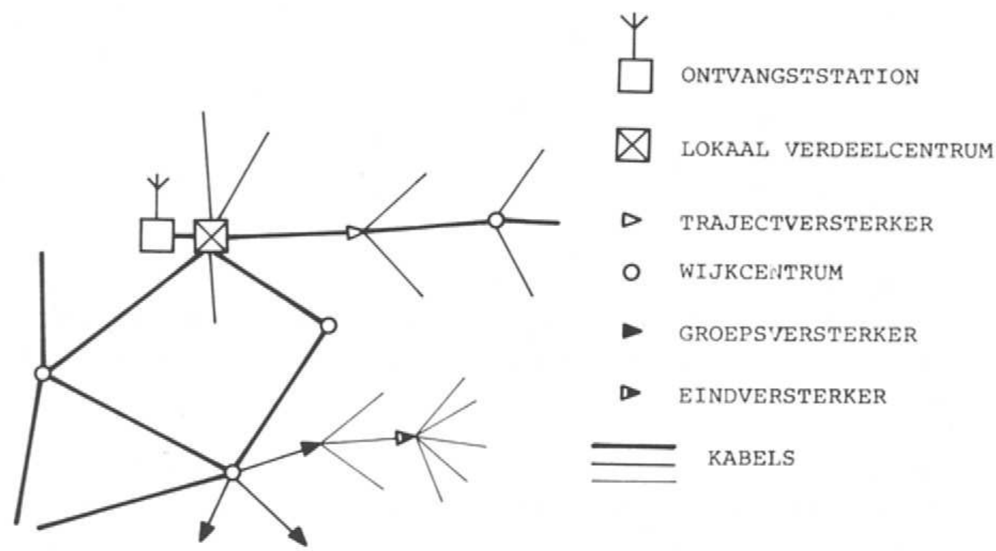


Fig. 607 Central antenna installation[a]

In urban areas, cable networks transmit these signals. The increased use of satellite connections will also result in changes to spatial use.

3.5.7 Network for the transport of raw materials

Underground and overhead pipes are increasingly used to transport raw materials from ports, sea ports or otherwise, to industrial areas. Depending on the materials to be transported, a number of restrictions must be observed. These cover safety measures for the surrounding area, such as buildings and roads, and for transport, for example pressure in gaseous substances, solution / dilution in liquids, suspension etc. Certain substances also carry a risk of explosion: berthing can give static electricity, causing devastating fires, such as oil fires in sea ports.
In general, these pipes connect the port, the unloading quay, to processing plants. Although such pipes primarily run overhead, we can also identify many, and longer, underground pipes, connecting the port of Rotterdam to the Ruhr region and the port of Antwerp for instance. Materials, transported through these underground pipes range from oil products to semi-finished products for industry; this includes secret military pipelines.
The Netherlands has also installed pipes from oil platforms in the North Sea to transport oil products such as gas and oil to processing plants and distribution companies.
In the Netherlands, approximately 20% of raw materials are transported underground through pipelines.

Design considerations of installing pipes for the transport of raw materials.

In terms of design, the use of space and corresponding restrictions governing pipelines is comparable to those of the gas network. However, depending on the material to be transported, additional measures are required.
With regard to the load bearing capacity of the soil, arrangements must be made to prevent sagging and fractures .

3.5.8 Tunnels

Tunnels constitute a special group of pipes.
The best-known tunnels in the Netherlands run under waterways, and are designed for motorised traffic. The oldest tunnel, the Maastunnel in Rotterdam, dates from before the Second World War. Amsterdam has several urban tunnels below the IJ, which connect new districts such as IJburg and Amsterdam Noord with the town centre.

[a] *Segeren and Hengeveld 1984 p. 268*

A recent development is the construction of tunnels for rail transport. The first one to run beneath a waterway was constructed in Rotterdam, and is a relatively short tunnel. The Schiphol tunnel, which was constructed beneath runways and the airport hall, is another example of a short tunnel. Both train tunnels have underground stations which require a number of additional safety measures. More recent plans include the construction of a tunnel with a railway link for goods transport between Rotterdam and the Ruhr region, and a tunnel for the high-speed railway link (*HSL*) below the Groene Hart region. These underground tunnels cover long distances. In principle, the goods transport railway tunnel requires no ventilation, provided transport is run automatically. On the other hand the HSL tunnel will need to be equipped with ventilation and escape routes.

These tunnels are constructed for a variety of reasons, such as nature conservation, reduction of noise pollution, fragmentation of the landscape, visual considerations etc.

Research has to be carried out into the construction of these tunnels with respect to location and method of construction, and safety of the load carried, both passengers and raw materials. Think of the fires in the Mont Blanc tunnel between France and Italy in 1999 and in 2005, the Tauern tunnel in Austria (2000) and the Gotthard tunnel in Switzerland (2001).

Underground metro networks are currently being constructed in Amsterdam and Rotterdam. In general, these underground systems are subject to the same standards as tunnels. Construction under existing buildings and tunnels in particular will necessitate specific demands as to construction and use. Metro systems must also have adequate escape routes.

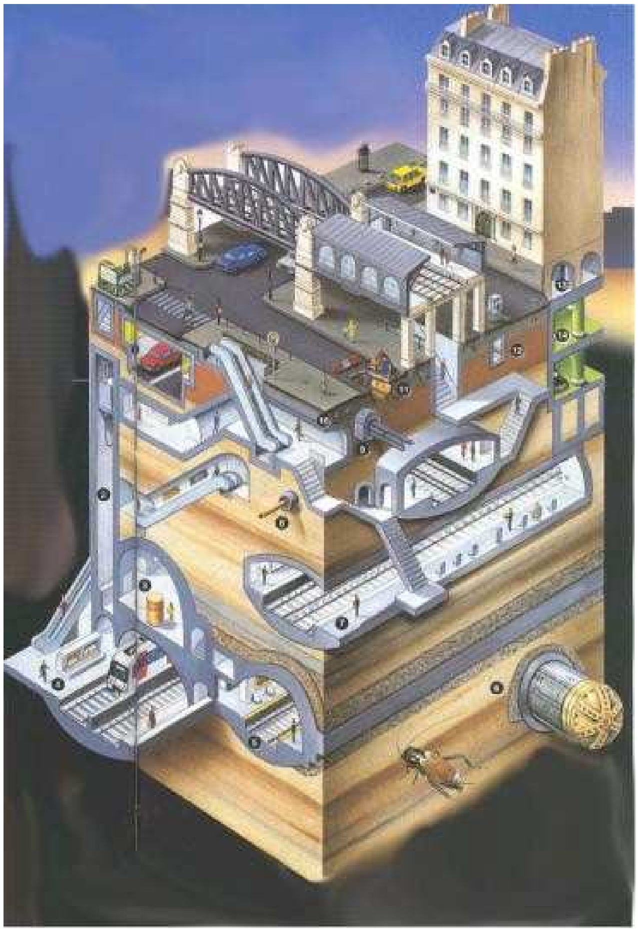


Fig. 608 Tunnels[a]

There are a number of risk factors for tunnels, such as:

- risks arising from soil conditions
- risks arising from method and construction itself and construction material, for example the choice between one or two separate tunnel tubes with one-way traffic, or one tube for freight transport and another for carrying passengers, or as in the Channel Tunnel which uses 'car trains' and 'lorry trains'
- risks arising from how the tunnel is used (calamities!); the reliability of train, lorries and cars and the type of products to be carried. Human errors in the construction and the breaking of traffic rules cannot be ruled out. Management and maintenance of these tunnelsmust be carefully monitored.

Needless to say, use of space depends on tunnel size and length. In principle, few restrictions apply to the use of space above tunnels.

3.5.9 Urban scale

Differences compared with regional scale

In rural areas, electric cables run overhead. In urban areas in the Netherlands they disappear under the ground, after high-voltage is transformed to a medium voltage of 50KV or 10KV. At district level, voltage is decreased once more via a transformer kiosk to 380V (industrial voltage) and 220V (domestic voltage). Transformer noise is caused by switching and compressed air.
In urban areas, gas pipe pressure is adjusted to domestic pressure. This takes place in distribution stations, from where the gas is distributed across a town via underground pipes.
Drinking water is distributed across urban areas via underground pipes.
The sewerage system is treated on page 304, the drainage system on page 304.
The installation of the pipe network of water, gas and sewers has some restrictions. It is obvious that the curves that the tubes make are determined by the flexibility of tubes. The sewage network also needs a fall in order to bring waste from the collecting point to the treatment plant by pumping or under pressure.

Underground conveyor pipelines

Underground conveyor pipelines for materials transported from harbour areas also play a role in urban areas. These pipelines are often bundled in pipe alleys, for which space has been allocated or reserved through decisions at national level. On an urban scale, the layout of this space must meet

[a] Standaardgidsen (1999)

requirements with regard to safety, accessibility and repair work. In general, this implies that the pipes are installed in public green strips, or incorporated in larger park areas.

Underground transport tunnels

Underground transport tunnels such as metro lines, tram tunnels and car tunnels play an important role in the use of urban areas. Decisions on transport and construction have a major impact on the urban area. Similarly, underground parking garages have a major impact on urban development. Such spaces will need to be designated or combined with the construction of intensively used buildings, such as shopping centres, large apartment buildings and offices.
New developments with respect to the construction of underground bus stations also require space, and will need to be a point of discussion in the planning process. The same applies to underground distribution centres.

Underground storage

On an urban scale, decisions are also taken with regard to small-scale underground material storage, such as the storage of glass, paper and other small-scale domestic waste that is not collected from door-to-door. This underground storage takes up considerable space, and is often difficult to fit in into existing street profiles because of the high density of underground cables, pipes, wires and drains. The containers must be safely reached by users and therefor not be installed just anywhere in a neighbourhood.

The installation of cables and pipes as part of preparing a site for habitation

With regard to planning and constrcution of a new district, the installation of cables and pipes forms part of the process of preparing a site for habitation. The advantage is that it minimises the risk of damage caused by other construction activities. Building activities, however, require their own power and water supply. In effect, this means that these pipes and cables are installed in combination with provisional supply roads prior to the commencement of building activities.
The overall installation of cables and pipes in a new district usually begins with the construction of sewage systems and district heating pipes.
Immediately after completion of the buildings, house service pipes for sewerage and district heating are installed, and the other cables and pipes including connections put in place. Approximately 6 to 13 weeks prior to completion, local municipalities give permission for the installation of underground infrastructures. Negotiations have meanwhile taken place concerning the municipal green areas, as pipes and cables are often located in green zones.

A public works time schedule of the city of Rotterdam

An example of a public works time schedule of the city of Rotterdam is given below:

- No later than 4½ months before completion, plans for making the site “liveable” have to be available. These include specifications and shop drawings of the utilities, which are made once the schemes with the road layout and the green areas are completed.
- Public tendering. This procedure can take up to 6 to 8 weeks.
- Branch pipes are installed 8 weeks before completion.
- Seven weeks before completion, drinking water pipework is installed for legal tests, which may take some time.
- Six to five weeks before completion, the utilities companies can connect up gas pipes and electric cables. Installation of house service connections can commence. Provisional supply pipes are converted to fit the distribution network, or removed.
- Four weeks before completion, house service connections are completed, and telephone and central antenna systems installed.
- The remaining 2 to 3 weeks are used to install discharges and fnish paving.

Main system in the street profile

Distribution networks are planned for urban and rural areas. They include water, gas and electricity, as well as cable networks for telephone and audio-visual appliances including computer networks. Computer cables are primarily fibre optic cables rather than the well-known copper wires.
The choice of district heating with corresponding pipes system is also made on this scale and fitted into the street profile. And don’t forget the wastewater discharge system and the sewage system either as a stand-alone or as a combined system.

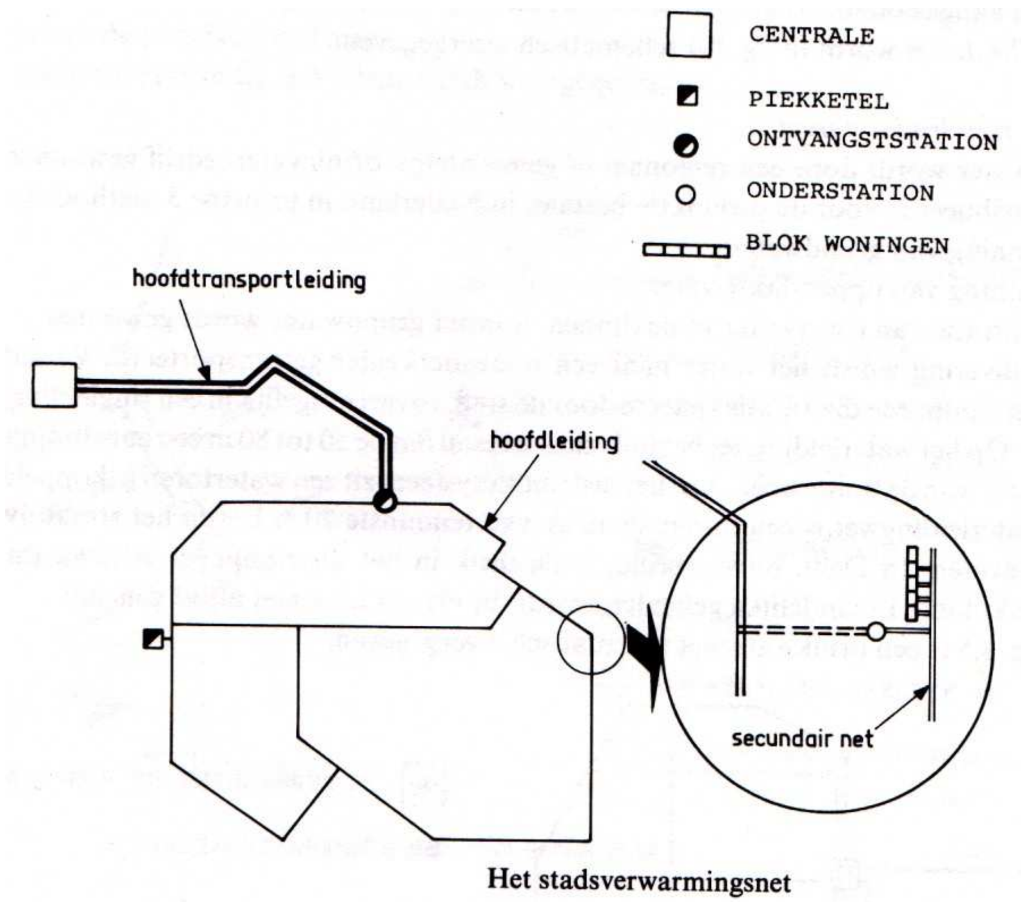


Fig. 609 District heating network[a]

Use of space and relative position

The use of space, the relative position and safety measures of the different networks are laid down in municipal regulations. Although these may differ in terms of depth and pipe combination, the regulations share similar principles. These regulations are available from the local municipality, as are maps containing information on the position of cables and pipes in the street profiles at district and urban level. Most municipalities can provide these maps in digital format. Please note however, that these maps do not specify all pipes, and that not all pipes are registered. This is particularly the case for computer network cables. These have often been installed without specific permits, and are therefore not included on plan drawings. This means most cables cannot be marked out. These networks are usually found at a shallow depth (± 30cm below ground level). *Fig. 610* shows the location of cables and pipes in a street profile of a built-up area as laid down by NEN standards.

Empty shells and combinations

A number of municipalities have begun constructing networks using empty cables ('empty shells'), which will be use at a future date. The advantage of this method is that streets need not be broken up to install new networks. Another recent development concerns the combination of networks. In Amsterdam, for example, experiments are carried out by installing fibre optic cables in sewage drains. In addition, areas with high groundwater levels need a drainage system. This system consists of canals and ponds, and a closed underground drainage system to collect surplus groundwater, storing it for shorter or longer periods before discharging it.

[a] W.A. Segeren and H. Hengeveld (1991) p. 270

Plaats van leidingen en kabels in wegen binnen de bebouwde kom.

NED. MIJ. VOOR NIJVERHEID EN HANDEL		KON. INSTITUUT VAN INGENIEURS

NEDERLANDS NORMALISATIE-INSTITUUT

1. Doel en toepasbaarheid

Deze norm geeft richtlijnen voor de plaats van leidingen en kabels in wegen *binnen* de bebouwde kom.

Voor andere dan in deze norm genoemde leidingen en kabels zijn geen richtlijnen vastgesteld. Over de plaats hiervan dient men van geval tot geval te beslissen.
Indien een bedrijf over eigen telecommunicatiekabels beschikt, behoren deze in de voor dit bedrijf bestemde sleuf te worden ondergebracht.

2. Aanduiding van leidingen en kabels

Al naar gelang van hun aard zijn de leidingen en kabels in deze norm op tekeningen als volgt aangeduid:

E = kabels van elektriciteitsbedrijven, waarbij:
LSK = laagspanningskabel
HSK = hoogspanningskabel
G = enkelvoudige gasleiding tot een maximale nominale binnenmiddellijn van 200 mm
PTT = PTT kabels
W = enkelvoudige waterleiding tot een maximale nominale binnenmiddellijn van 300 mm
R = huisaansluiting riolering

3. Uitvoering

Leidingen en kabels worden bij voorkeur onder de trottoirs gelegd. Afhankelijk van de plaatselijke omstandigheden kan een keuze worden gedaan uit de uitvoering volgens de figuren A, B of C, waarbij een uitvoering volgens fig. A of B verkieselijker is dan volgens fig. C.

4. Maten

De in fig. A, B en C aangegeven maten moeten als wenselijke maten voor horizontale afmetingen worden beschouwd.
Indien meer ruimte in de trottoirstrook (met eventuele parkeerkommen) beschikbaar is, verdient het toch aanbeveling deze maten zoveel mogelijk aan te houden, met het oog op eventuele uitbreidingen.
Indien er minder trottoirbreedte ter beschikking is, zal
– de riolering in aanmerking komen voor verplaatsing onder de rijweg;
– verder de ruimten voor de leidingen en kabels naar verhouding verminderd worden.
Indien er leidingen voor stadsverwarming worden aangelegd, dient de ruimte van 60 cm tussen de gas- en waterleiding zodanig te worden vermeerderd, dat er plaats komt voor de stadsverwarmingsleidingen. Indien de trottoirbreedte met eventuele parkeerstroken hiervoor onvoldoende is, moeten de stadsverwarmingsleidingen onder de rijweg worden gelegd.
Met in leidingen en kabels voorkomende voorzieningen, zoals hulpstukken e.d., is geen rekening gehouden.

5. Mantelbuizen

Bij aanleg en(of) verbetering van de weg verdient het aanbeveling op daarvoor in aanmerking komende plaatsen mantelbuizen voor de doorvoer van eventuele toekomstige leidingen en kabels aan te brengen.

6. Plaats voor lichtmasten in trottoirstrook

De plaats voor eventuele lichtmasten moet worden gevonden in de voor de riolering bestemde strook en is in de figuren schematisch aangegeven.

7. Boom- of struikbeplanting

In de dwarsprofielen is de plaats van de boom- of struikbeplanting niet aangegeven, maar deze moet, afhankelijk van plaatselijke omstandigheden, van geval tot geval worden overwogen.

Plaats van leidingen en kabels in wegen binnen de bebouwde kom	NEN 1739
The place of pipes and cables along roads IN built up areas	mei 1964
Auteursrechten voorbehouden	UDC: 625.78:711.522

Fig. 610 NEN 1739[a]

[a] W.A. Segeren and H. Hengeveld (1991) p. 274

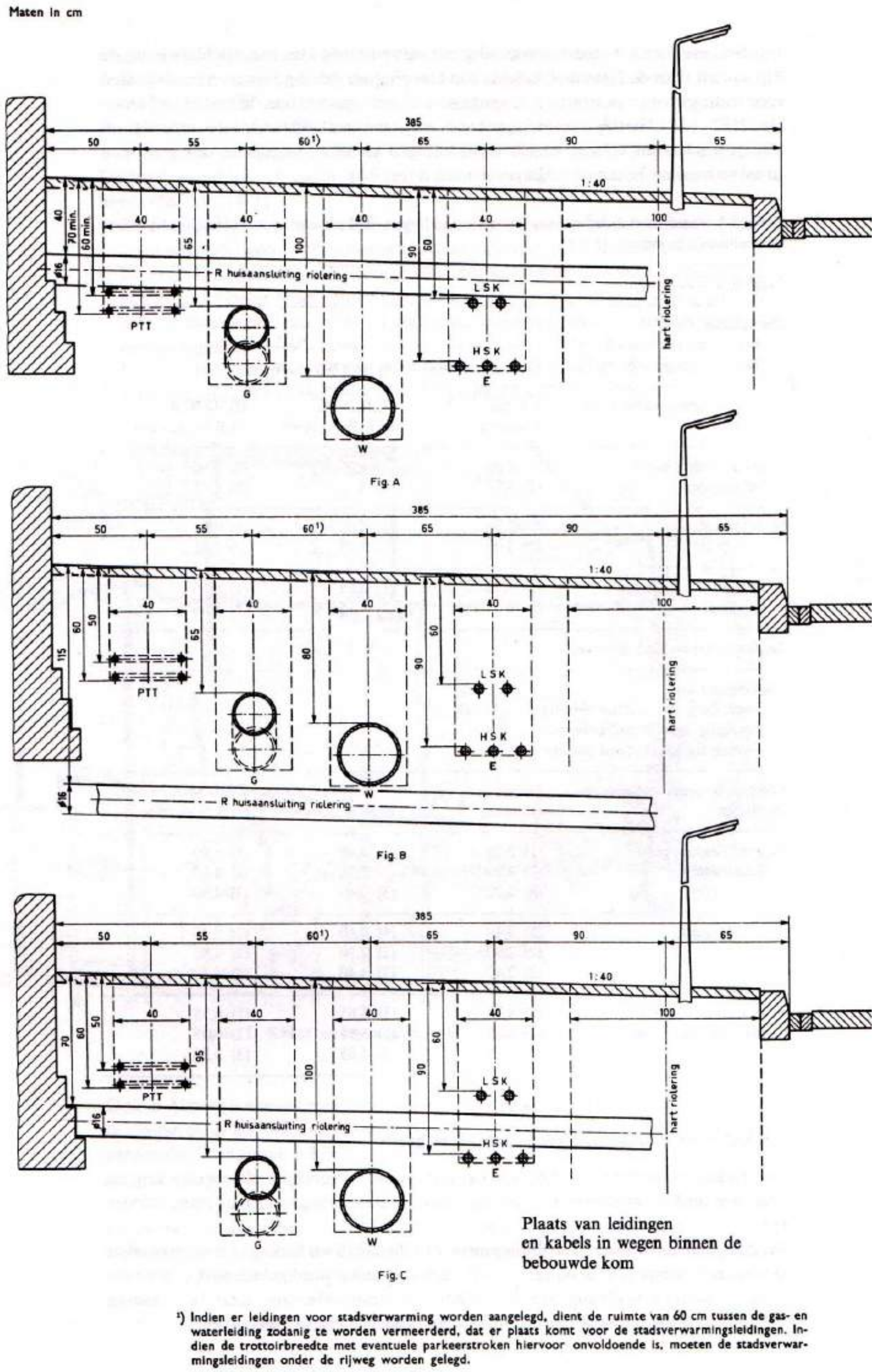


Fig. 611 Location of cables and pipes in built-up areas[a]

[a] W.A. Segeren and H. Hengeveld (1991) p. 275

Drainage

In the first place, drainage systems are meant to make development sites suitable for the construction of houses, and the maintenance of the area in question, i.e. site management. Drainage systems are designed to keep the ground-water table in built-up areas at an appropriate level to prevent water problems with foundations, cellars and pipes, on the other hand these systems are designed to discharge surplus ground water. The groundwater table is artificially kept at a predetermined level by the municipality using pumping stations.

Depth

The minimal depth ranges from several decimetres to approximately 80 cm below ground level. Depth is depends on existing foundations and pipes. Areas with wooden piles foundations, for example, have a different groudwater level: wooden piles must remain submerged to avoid rotting. In later urban areas, however, concrete and other types of foundation are used which are not affected by groundwater. The climate also determines the depth of the groundwater level in urban areas. In times of severe frost, ground saturated with water can freeze to approx. 80 cm below ground level. The frozen ground can cause pipes to burst and holes in the asphalt road surface. In the Netherlands, pipes are therefore always installed deeper than 80 cm below ground level.

Rainwater

In addition to discharging surplus groundwater, the drainage system also serves to discharge rain water and melt water which permeates the subsoil. In built-up areas, excess water from hardened surfaces, such as streets, squares and roofs, is usually discharged via a sewerage system. Underground, the drainage network consists of drainage pipes. Above ground, it made up of ditches, canals and ponds: the ‘open water system’. Water from drainage pipes is either discharged into open waters in urban areas, or transported to drainage pools, also open water, in rural areas. Surplus water in canals, waterways and ponds is discharged from the urban area to open water outside the urban area. From there, the water is carried to the rivers and/or the sea via a system of waterways and pumping stations.

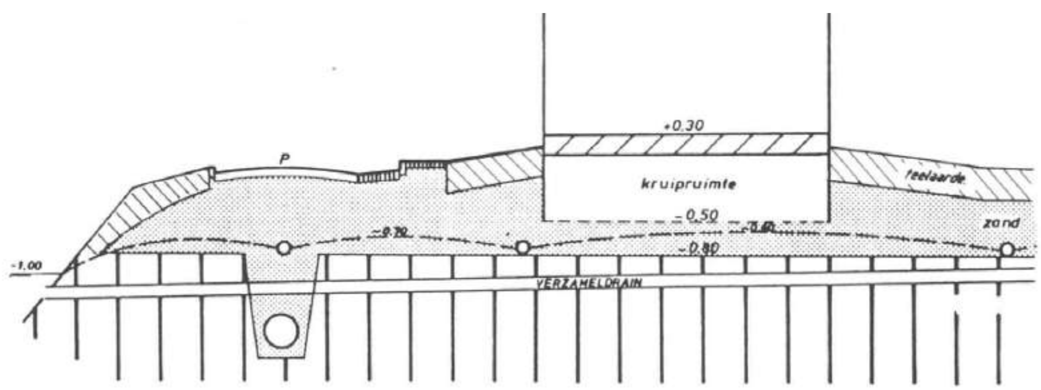


Fig. 612 Urban drainage[a]

Sewage

SewageUp until the early 20th century, domestic and industrial wastewater was usually discharged directly into surface water. In the 19th century, some towns already used various pipe systems to carry this wastewater to areas outside the built-up areas. During the course of the 20th century, sewage systems were gradually installed throughout the Netherlands. Isolated farms and houses are not always connected to the sewage system. Nevertheless, these homes must satisfy wastewater purification requirements. This can be achieved by using individual water treatment methods. Sewage systems are designed to discharge domestic water, industrial water and excess rain water safely in such a way that it does not cause health hazards. Contaminated water is purified until residual water can be safely discharged into open water.

[a] W.A. Segeren and H. Hengeveld (1991) p. 150

Autarkic systems

This chapter does not discuss buildings that use their own sewage systems to re-use grey water, i.e. rainwater to water the garden, clean buildings, wash cars, take a shower and the re-use of shower water to flush the toilet, or their own purification systems such as helophyte filters. These systems are highlighted in the context of "eco-friendly building".

The common sewage system

A sewage system consists of a collecting system, a transport system and a purification system. Particularly the collecting system is relevant to this book. This system consists of pipes, which collect wastewater and rain water and carry it to the sewage purification or discharge points.

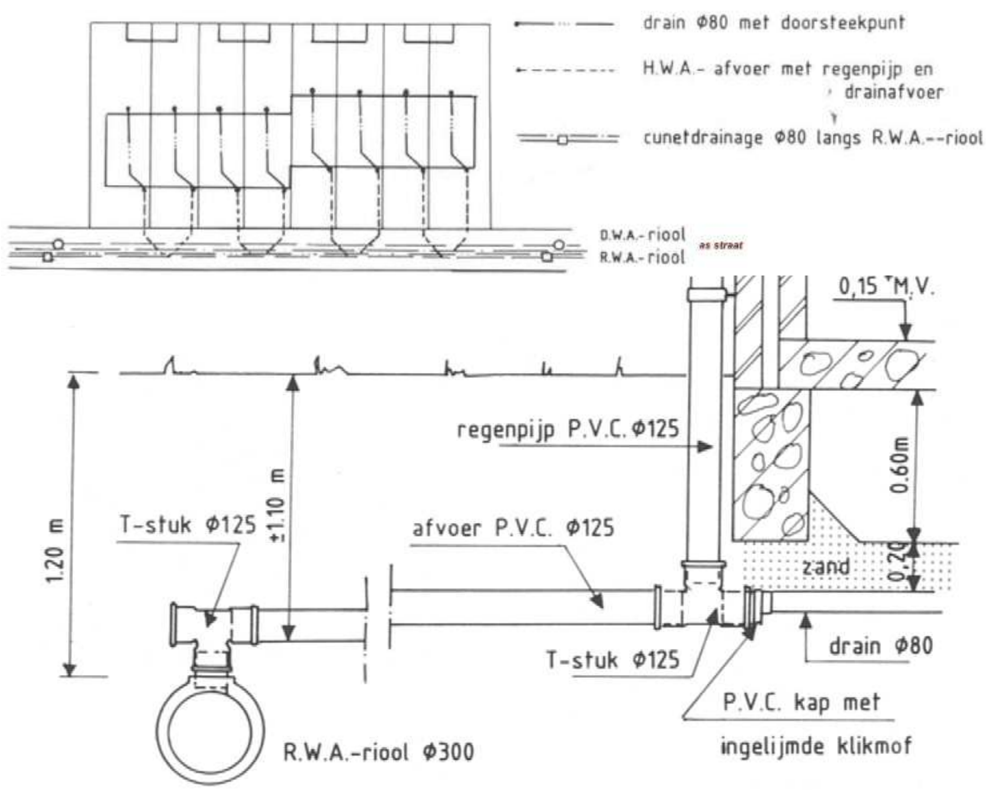


Fig. 613 Building block sewage[a]

We can distinguish the following sewage systems:

- combined systems including various improvements
- separate sewerage systems, stand-alone systems including various improved versions.

The combined system

In this system, all domestic and industrial water and precipitation, rain water and melt water of snow and hail are discharged via one combined system of pipes. Domestic connections and road connections are sloped towards the collecting sewer system. The collecting sewage pipe is drained by a pumping-station. Sewage water is transported to the sewage purification through a pressure pipeline.

[a] W.A. Segeren and H. Hengeveld (1991) p. 156

The big variable of this system is the amount of rainwater present. Large quantities of rainwater will dilute the dirty sewage water, resulting in less efficient purification. The management of the sewage purification plant is extremely complex due to strong fluctuations in sewage water concentrations and discharge peaks. The dimensions of the system is a problem. It is not economic to adjust the diameter of the pipes to the biggest quantity of sewage water that needs to be discharged. To minimize rainwater dilution and peaks in discharge additional storage capacity is made that is directly connected to the system. If this additional storage proves insufficient, overflows have been constructed to open water. Contaminated water, rainwater and sewage sludge are then discharged onto the surface water. It is obvious that this is the weakest link in the entire process. The overflow system is constructed in such a way, that the predetermined number of annual overflows is not exceeded. In the Netherlands, this has been calculated to be 3 to 10 overflows per year. Approximately 10% of rainwater is carried to surface water via overflows. This system is not the most hygienic or efficient. This is why research has been conducted into possible improvements, which resulted in a new system: a separate sewage system.

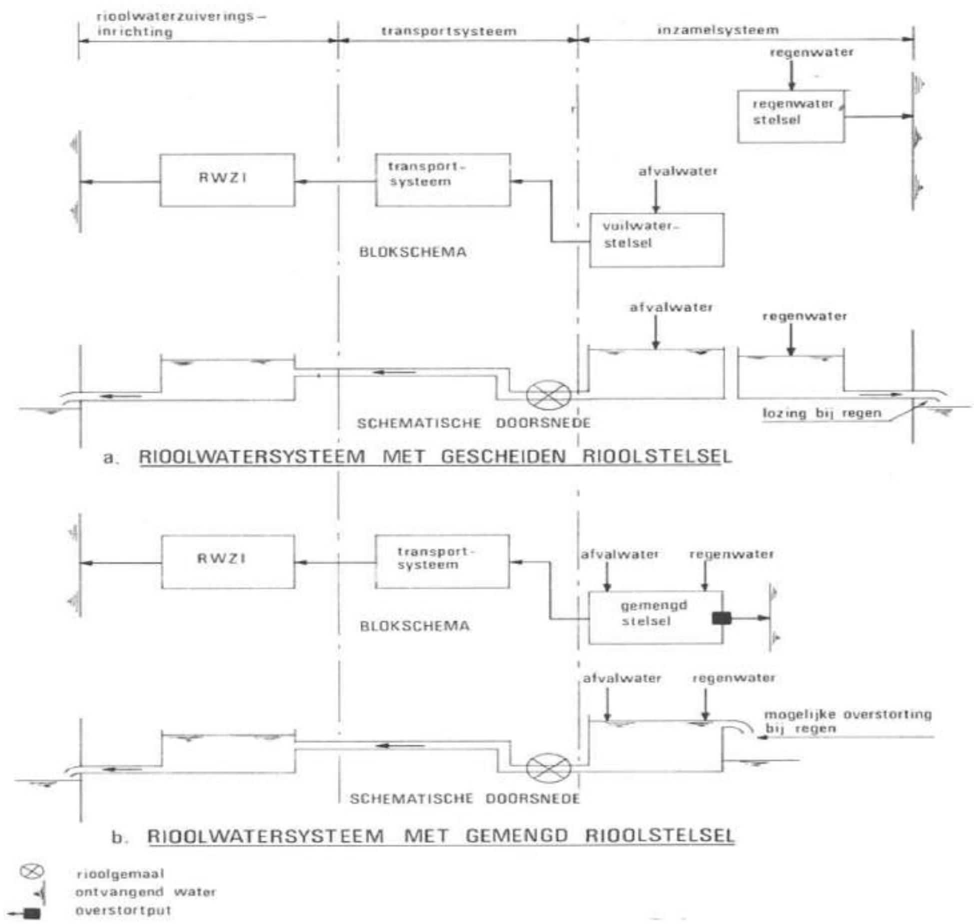


Fig. 614 Sewage systems[a]

The separate sewerage system

In this system, rainwater is separated from domestic and industrial wastewater and discharged via its own pipe system. Rainwater is always discharged directly onto surface water via street inlets. Surface water is also affected by street contamination in the form of spillages of petrol, oil, tyre abrasion and litter. In addition to preventing this kind of pollution, discharge points are equipped with filters to collect

[a] W.A. Segeren and H. Hengeveld (1991) p. 190

contaminants. The system combines drainage systems installed in the past for site development with rainwater discharge systems.
Domestic and industrial wastewater sewerage is pumped by a sewage pumping-station and discharge to a sewage purification plant. The size of the pipes depends on the average of the highest wastewater production in 24 hours.
Drainage of rainwater is a different story. The amount of annual precipitation, in the form of rain, hail and snow, shows considerable fluctuation. Furthermore, part of the precipitation enters the drainage system, part flows into the soil, part disappears through evapotranspiration and part is absorbed by plants. Water that enters the system is collected and usually discharged directly onto open water in built-up areas. Water from the streets is collected via street inlets and enters the open water via a mud trap and sometimes via helophyte filters.

The choice of a system

It will be clear that the choice of a system depends on the scale of the district or village. The unity of a system is a prerequisite; a system is only as efficient as its weakest link.
The sewage system is determined by discharge quantities. These can be divided into dry weather discharge or wastewater and rain water discharge or precipitation discharge. The required capacity per hour for dry weather discharge is approx. a tenth of the daily discharg. The average water use per person is between 100 l and 150 l. Rain water discharge, on the other hand, fluctutates as the amount of precipitation is spread unevenly over the year. Reduction in precipation water is caused by evapotranspiration, the use of water by plants and water absorption. This reduction of the original amount of precipitation water is known as the runoff coefficient (see *Fig. 615*).

Building type		**Content/ha .**	**Runoff coefficient**
Old city centre	high-density building	350	0.8
Newer districts	closed buildings	250	0.6
	open buildings	150	0.4
	with parks and gardens	100	0.25
Undeveloped, unhardened terrains			0.15
Parks			0.5

Nature of the surface	0.9
Closed road surface	0.9
Clinker paving	0.8
Metalled roads	0.45
Gravel and cinder roads	0.25

Fig. 615 Runoff coefficient[a]

Design considerations for installing cables and pipes in built-up areas.

Built-up areas are intersected with rural cables and pipes. On this level in particular, various NEN standards and municipal regulations apply, causing complications, as the limitations from rural networks stand in the way of urban developments in rural areas. This involves many hours of negotiation to find a solution.
Every municipality in the Netherlands has its own regulations, which can be inspected by municipal services. By and large, they are all identical; regulations prescribe relative position and depth in relation to the surface level. Differences are primarily manifest in load-bearing capacity of soils, and ground-water tables and groundwater levels tolerated by each individual municipality.

[a] M.R.r. Creemers, J.A.J. Atteveld and e.a. (1983) *PBNA poly-technical pocket book*

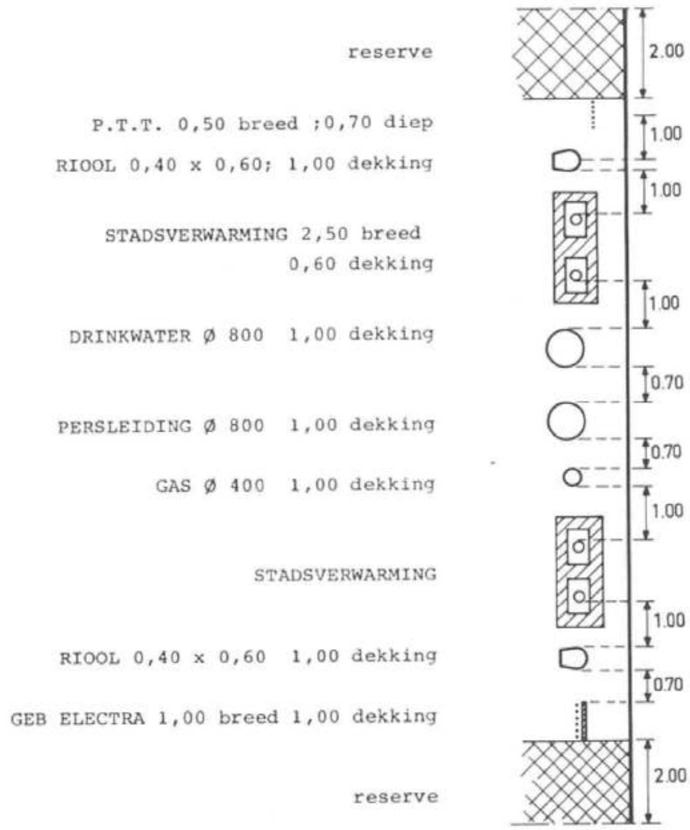


Fig. 616 Standard layout of cables and pipes in Rotterdam, Zevenkamp[a]

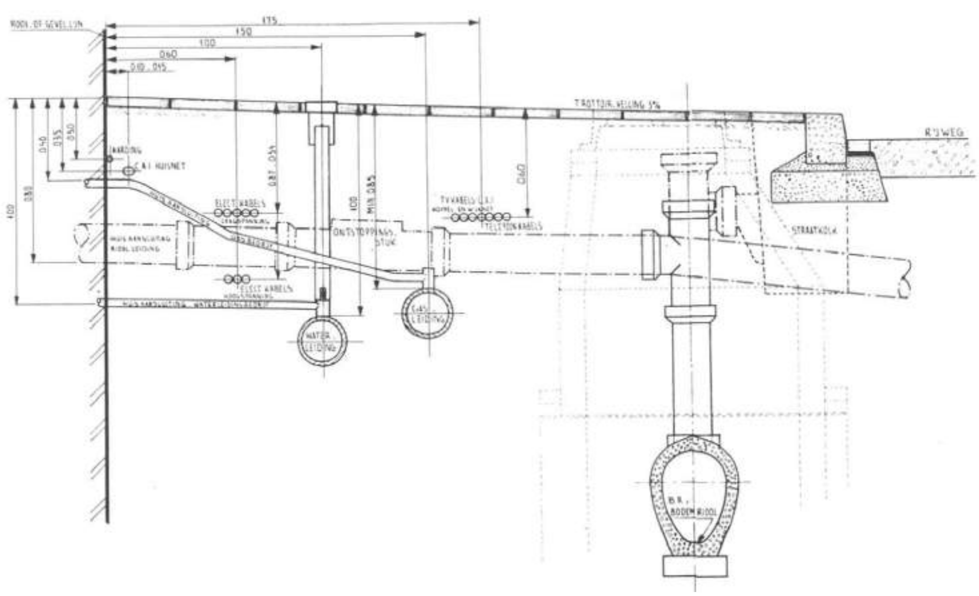


Fig. 617 Standard layout of cables and pipes Den Haag[b]

[a] W.A. Segeren and H. Hengeveld (1991) p. 271
[b] *W.A. Segeren and H. Hengeveld (1991) p. 271*

Negotiations on the position of cables, pipes and drains

Negotiations on the position of cables, pipes and drains in a new district, and corresponding municipal services, take place during the design phase of an urban development plan. During these negotiations, alternatives and potential design solutions are drawn up, taking into account technical aspects of installation such as house service connections, pipe radius, junctions of pipes, cables and drains, relative influence of the different pipes, and their position in the street profile.
The position in the street profile determines the management and maintenance of pipes and drains, as well as street furnishings such as trees, lighting and street furniture.

Aboveground facilities

The design of public grounds largely depends on the underground infrastructure. “Eco parks” and underground dustbins such as glass and paper containers are often installed near squares or, in any case, near open urban spaces. These should not be obstructed by cables and pipes.
The implementation plan regarding cables, pipes and drains for new districts is laid down at an early stage in the land registry, and is available from the local municipality.

Land registry plans

In principle, the position of all cables and pipes in existing developed areas is laid down in land registry plans, which can be consulted in the event of changes in town planning. The municipality of Rotterdam is a good example: this municipality has stored all relevant data on underground networks digitally. Other municipalities are in an advanced stage in digital processing of data, or are nearing its completion. Nevertheless, there may still be a few surprises in store, as not all installed and obsolete cables or pipes have been laid down, digitally or otherwise. In some cases information may have gone missing. Even computer network cables are not always registered because they are temporary or because contractors do not think it necessary to inform the city council.

Beam transmitters

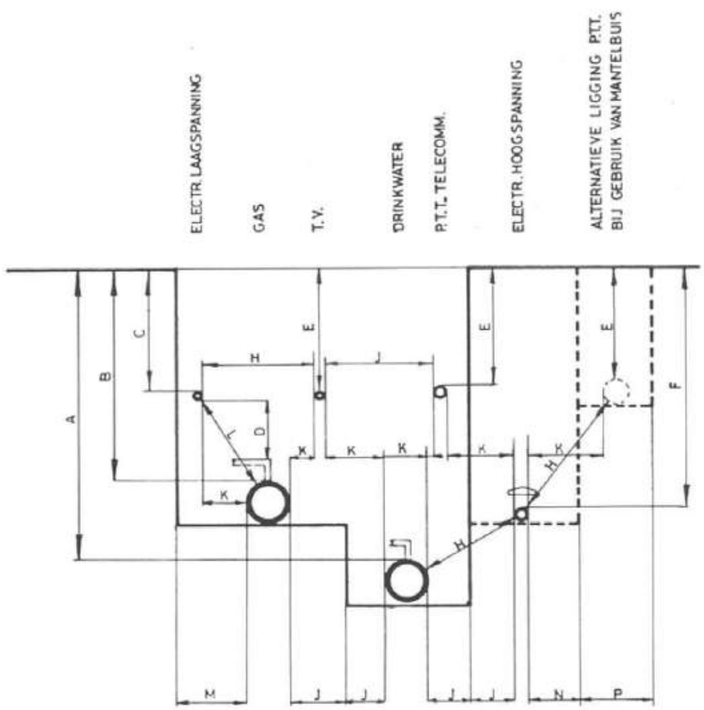
With the development of a new district urban planners should take account of beam transmitters that require physical space in towns, i.e. height and position of the buildings. A building can form an obstacle for these beam transmitters. Overall beam transmitter systems must be guaranteed in towns for adequate and profitable transmission. This can cause problems in existing built-up areas and thus requires the installation of a more compact network to guarantee adequate transmission range.

3.5.10 The future.

Combinations

New developments in the field of distribution networks, i.e. pipes, cables and wires, will take place to satisfy future demands for fast communications and connections. For example: a combined system of cable and wire ducts, or a combined system of sewer pipes and fibre optics cables, currently in an experimental stage in Amsterdam. Ducts are a particularly interesting option due to the high degree of accessibility of these pipes. However, the position of these ducts may pose problems: ducts located beneath a building may give rise to private-law cases regarding access to a building. Load-bearing capacity of the soil will need to be taken into consideration, if these ducts are not incorporated into a building. Examples to solve such problems are the communal trenches for cables and pipes used in England, and cable and pipe tunnels in the Netherlands.

The municipality of The Hague is currently installing “empty” pipes through which cables can run to provide extra capacity for new, innovative applications.
The most recent development for communication uses satelites for transmission instead of cables.



LETTER	MAAT
A	900
B	600
C	450
D	150
E	350
F	750
H	300
J	150
K	100
L	200
M	250
N	150
P	250
ALLE MATEN IN MILIMETERS.	

Fig. 618 Communal trenches for cables and pipes[a]

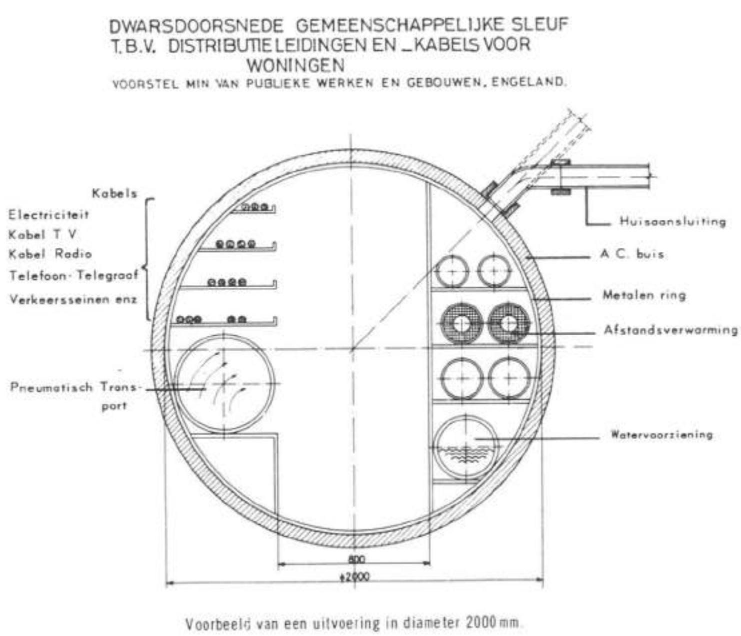


Fig. 619 Cable and pipe tunnel[b]

[a] W.A. Segeren and H. Hengeveld (1984, 1991) p. 279
[b] W.A. Segeren and H. Hengeveld (1984, 1991) p. 279