Ecologically sound urban water management.
Some quantitative and qualitative aspects.
Small scaled plant purification systems.

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International Master in Architecture. Theme 6

Course Environmental Sustainability.

Structure of this presentation.

- 1. The cooling effect of the vegetation.
- 2. Some climatological backgrounds.
- 3. Climate-proof architecture, city expansion and urban planning.
- 4. Small scaled marsh plant purification systems

The cooling effect of vegetation.

Infrared spectrum

Visible spectrum

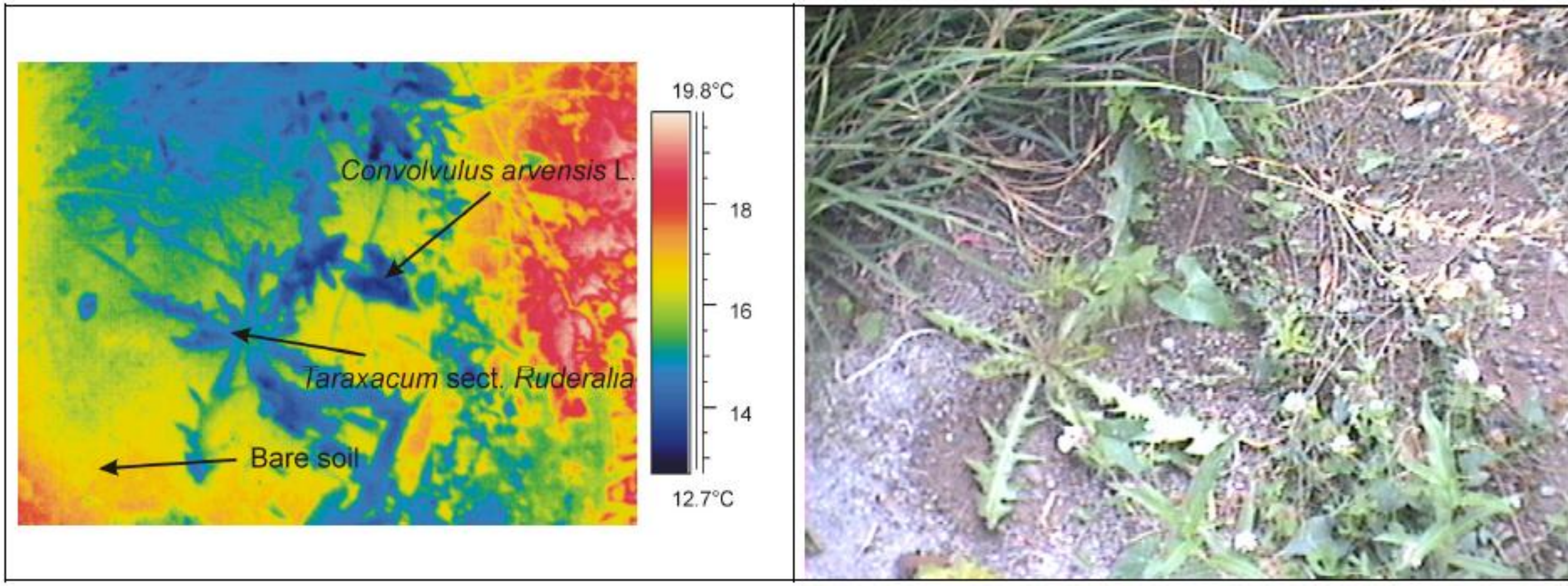


***Fig. 7* Photographs of thin vegetation in the infrared spectrum and in the visible spectrum**. The bare surface of the ground is visibly warmer than the surface of the leaves cooled by transpiration. (Třeboň, Czech Republic, 12 July 2002, 10:00 hrs).

The cooling effects of water evaporation and of transpiration through **vegetation**.

- 80-90 % of the plant biomass is water, water is also needed for photosynthesis.
- **Evaporation** includes the vaporization from the soil and from plant surfaces. **Transpiration** is the water taken by the roots, transported through the plant and leaving through the stomata of the leaves (which can be opened and closed, regulating the amount of transpiration). The total amount of involved water is **evapotranspiration**
- Because the vaporization of water needs a lot of latent heat, this system cools the local area down. The evaporation of 3 litres/m^2 of water needs 7,5 MJ /m^2. This is far more than the solar energy needed for photosynthesis: the production by photosynthesis of 10 grams plant material requires only 170 kJ.

The largest amount of heat is used by (evapo)transpiration through the vegetation in wet, green rural areas, and keeps these areas cool.

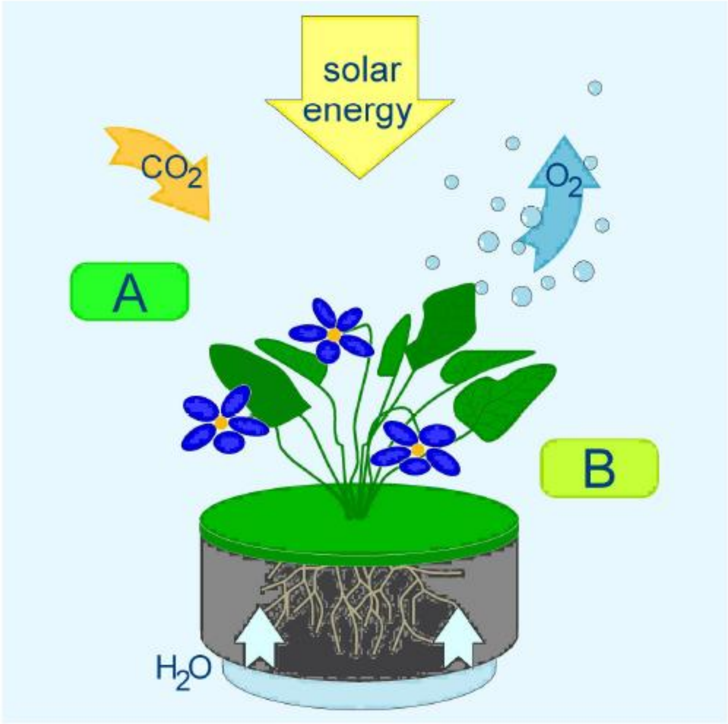


***Fig. 6* An example of the daily energy balance of CO2 and H2O fluxes per 1 *m2* of vegetation stand:** A: For the creation of 10g of dry matter, 48Wh (170kJ) are consumed for the fixing of 14g CO_2 (0.32 mol). B: Evapotranspiration (3 l) requires 2.1 kWh (7.5 MJ).

The cooling effect of vegetation.

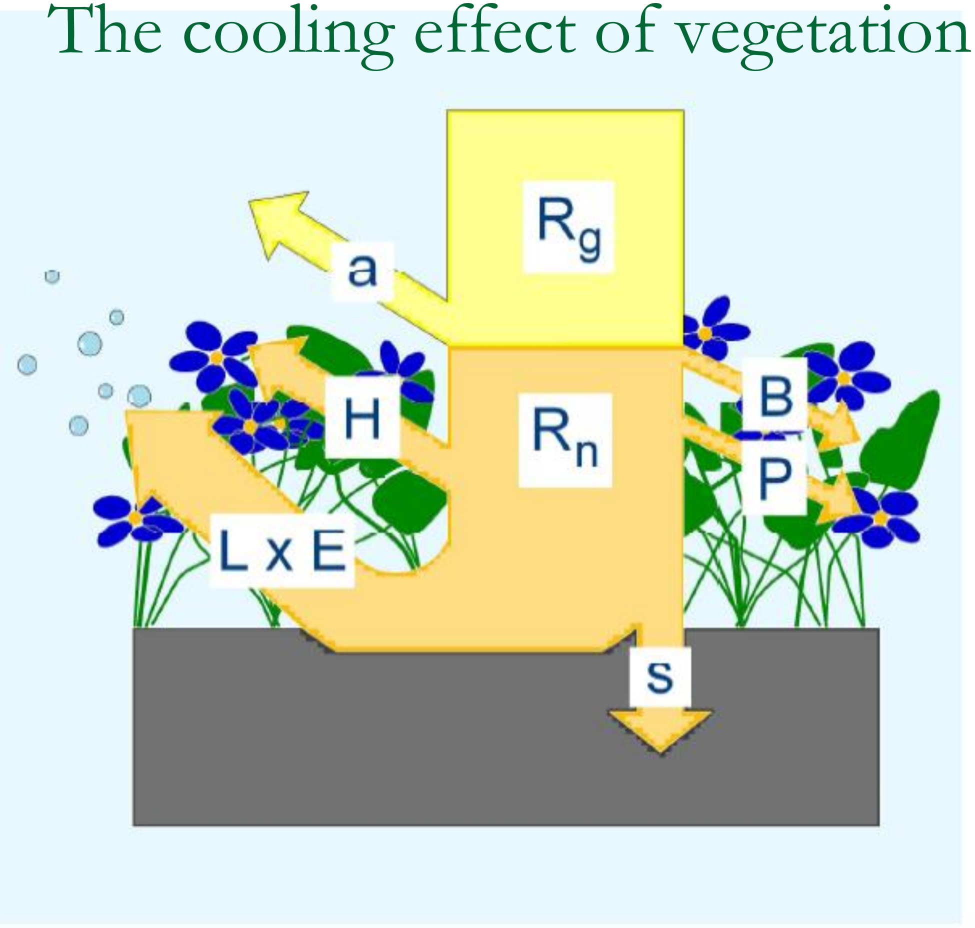


***Fig. 5* The distribution of solar energy on vegetation**

Rg – global radiation, Rn – net radiation, a – albedo (reflected radiation), H – sensible heat, L × E – latent heat x evapotranspiration (evaporation from soil and vegetation), s – flow of heat to the soil, B – accumulation of heat in the biomass, P – consumption of energy for photosynthesis

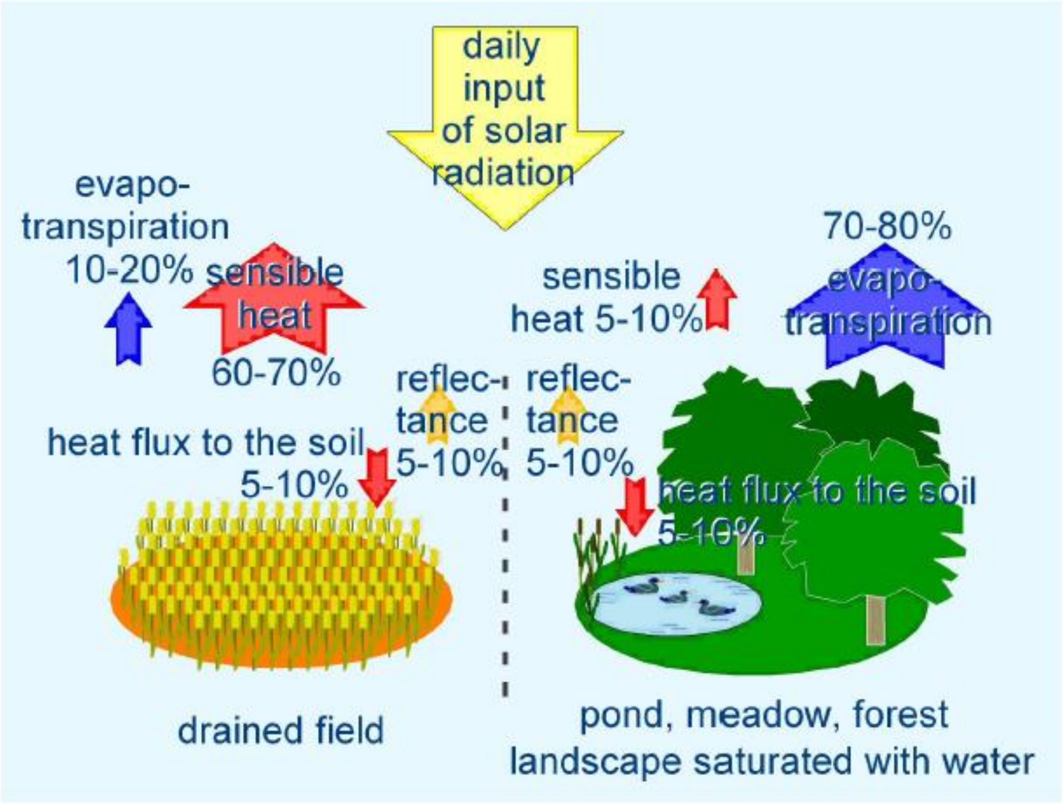


Fig. 4 **The distribution of solar energy on drained land and on a landscape saturated with water**

The input of solar energy is turned into sensible heat, in drained landscapes (left). Wetlands (right) turn solar energy into latent heat, taken away by evapotranspiration, and thus lowering local temperature.

Sensible and latent heat

The fate of incoming solar energy depends significantly on the presence of water in an ecosystem, which strongly influences the distribution of energy between the two primary flows of heat: sensible and latent heat. As the name itself suggests, sensible heat is accompanied by an increase in the temperature of substances or bodies which we can feel. Latent heat is not accompanied by any increase in temperature. Latent heat, in our case the latent heat of vaporization of water, is the amount of energy which water must receive in order to turn into vapor of the same temperature. Let us refresh our school knowledge of physics: evaporation from the free surface of a liquid takes place at every temperature, the intensity of this evaporation increasing with the temperature of the liquid, with the size of its free surface and with the removal of the vapor formed above the liquid. At boiling point, liquid evaporates not only on the surface, but also from the interior as well. The specific latent heat (that is, the latent heat per unit of mass) of water under normal pressure and at a temperature of 25 °C is 2243.7 kJ/kg. This indicates the amount of solar energy which is consumed to evaporate each liter of water without increasing the temperature (This same amount of heat is released later during condensaton of the water vapor in a colder place.).

Water on land and heat

Of course, water can change into water vapor only if it is present on land. If it is not present, a great part of the solar energy is changed into sensible heat and the temperature of the environment sharply increases. Whereas in a parched country up to 60% of solar radiation changes into sensible heat, in a country saturated with water up to 80% of pure radiation can be bound to the latent heat of the vaporization of water and only a very small portion of solar radiation is changed into sensible heat *(Fig. 4)*.

Daily temperature range on drained land (red) compared with a wetland (green).

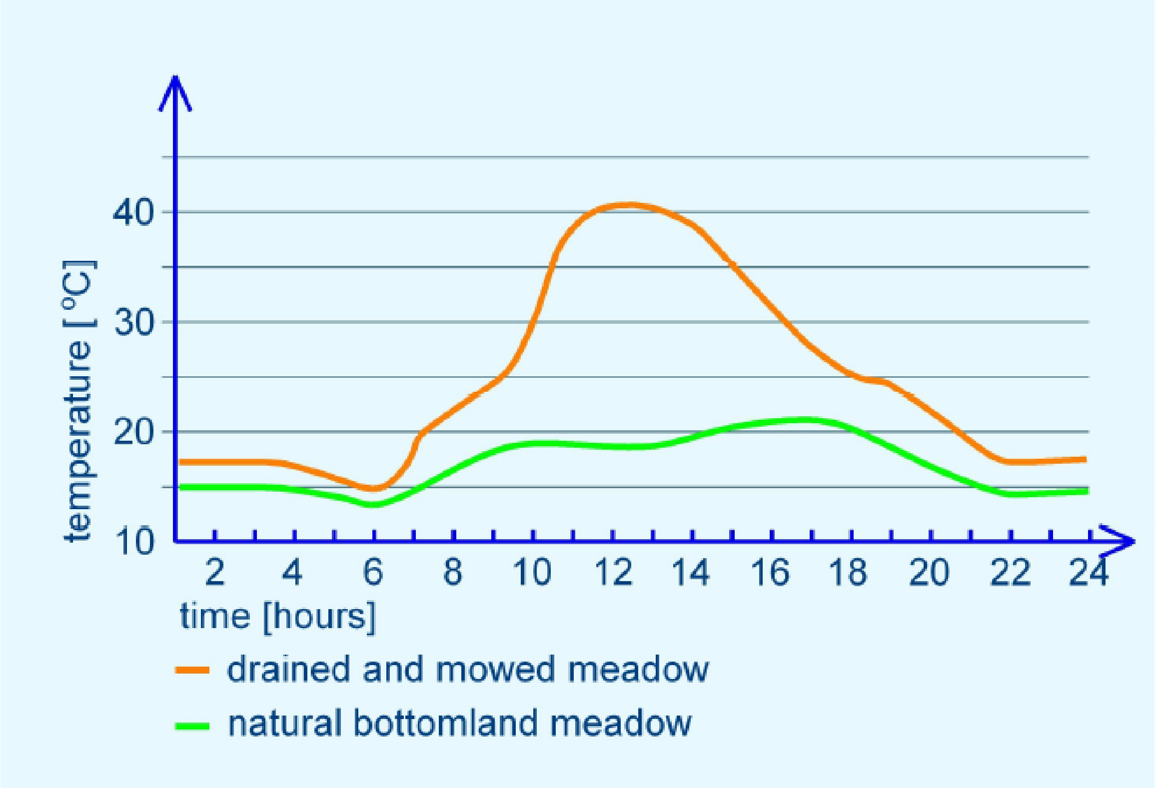
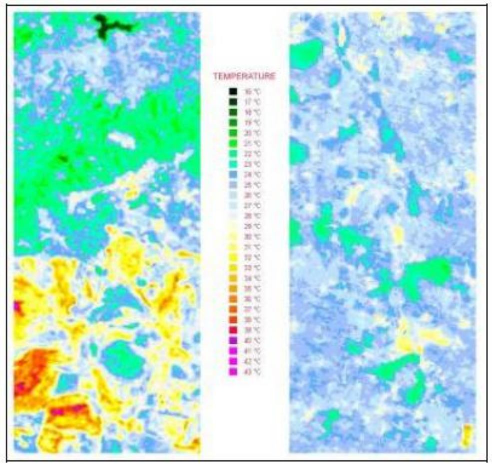


Fig. 11 **The daily course of temperatures on the surface of soil on a drained and mowed meadow and on a natural bottomland meadow**

Wetland landscapes (R) remain cooler than drier landscapes (L) The presence of water as a local temperature regulator, in both urban and rural areas (Slovakian example)

Drier landscape with few vegetation is not able to lower local temperatures



Wetland with abundant vegetation lowers local temperatures

Fig. 9 **Comparison of the distribution of sensible heat in two different types of land (Mostecko and Třeboňsko)**
The pond-covered Třeboňsko with wetlands shows a lower regional temperature difference (right) than the drier land of Mostecka (a strip coal mining area), which has insufficient vegetation (left).

As long as there is local water and moisture available (in rural but also in urban areas) the (summer) temperatures remain moderate and constant and do not exceed 30-35 °C (as in tropical and subtropical rainforests). That is because locally evapotranspirated water volumes do evacuate a lot of latent heat, which therefore is not turned into local sensible heat. From the moment on water disappeared, temperatures will increase dramatically up to 50 °C and even more. This explains desertification as a consequence of drought, but it explains also the existence of the **urban heat island effect**.

The cooling effect of vegetation in urban areas, remember the Urban Heat island effect (UHI)

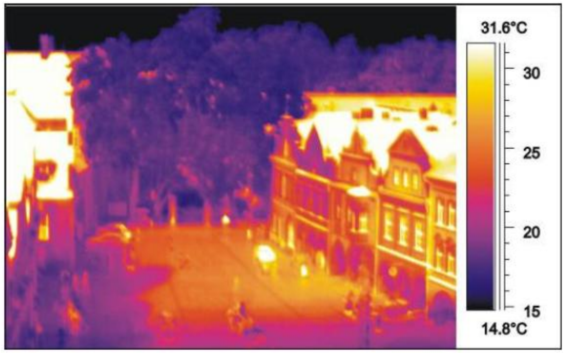


Fig. 8 **Photograph of the square and adjacent park in Třeboň, Czech Republic, taken with a thermal camera**
The differences in temperatures between the vegetation, facades and roofs of the houses is visible.

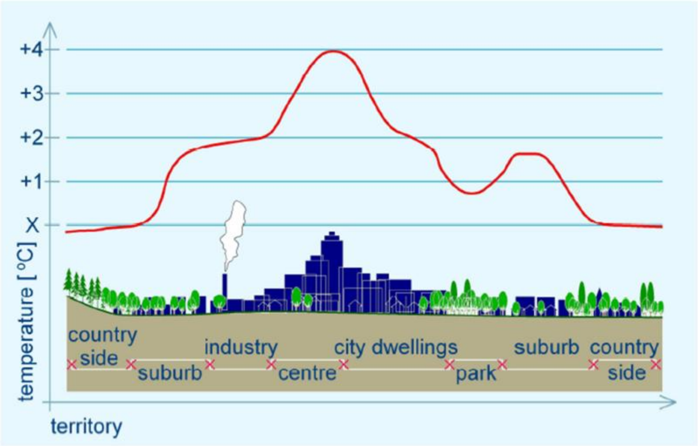
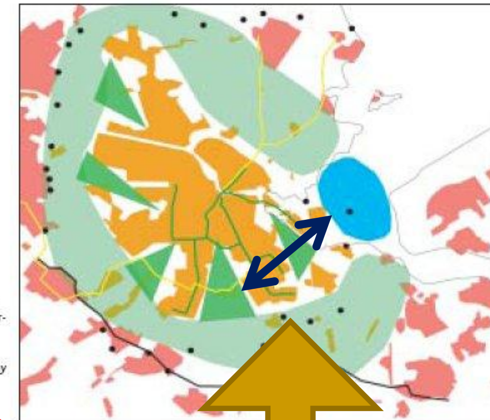


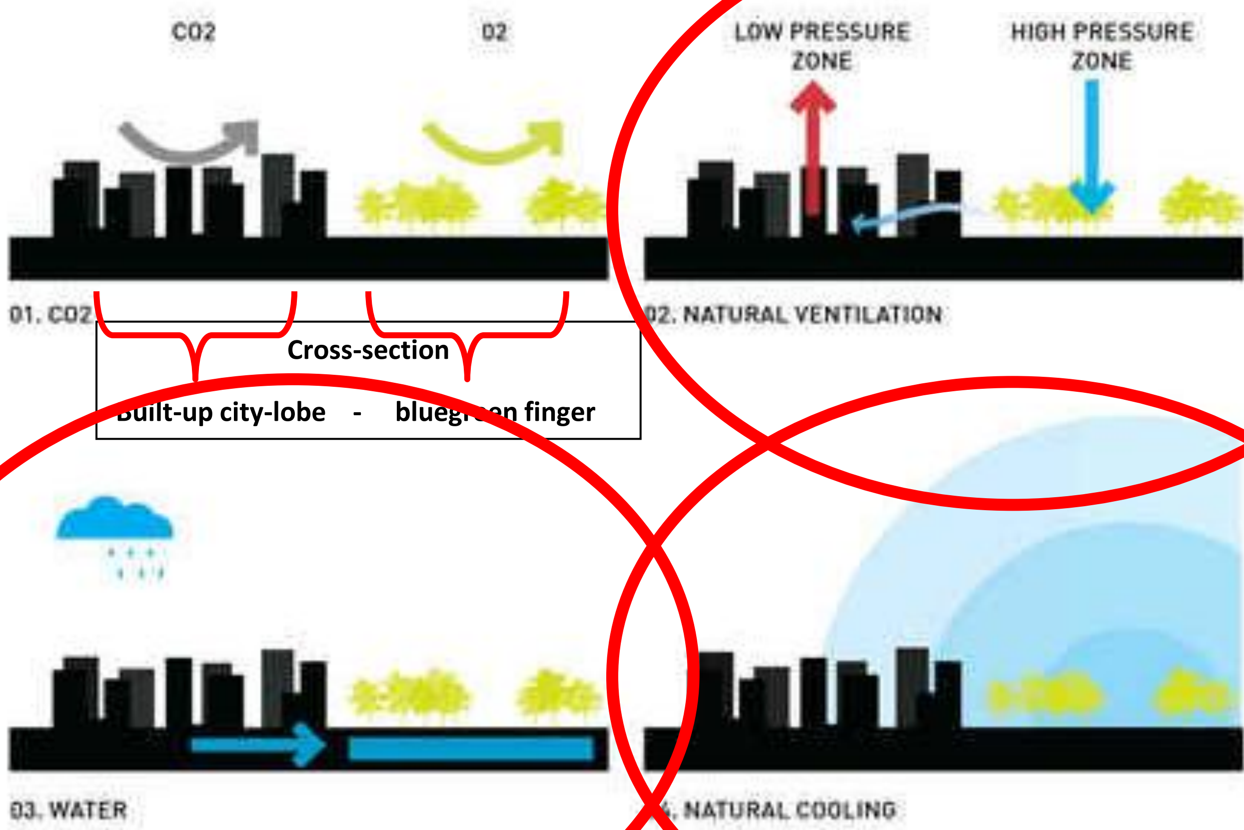
Fig. 16 **The hot climatic umbrella of an urban space**
Temperature depends on the relation between a built up area and area covered by vegetation.

This is the scientific background for understanding the occurrence of <u>the urban heat island effect (UHI)</u> in dry built-up environments, and for understanding the important role of <u>blue-green fingers in urban areas (lobe-city), as huge 'cooling infrastructure'.</u>

blue-green fingers in urban areas (lobe-city), as huge 'cooling infrastructure'.



► Rond de Amsterdamse lobbenstad ligt een groenzone. Daaromheen ontstaat langzamerhand een krans met bebouwing, een ...noemde kransstad.
The Amsterdam... city' is surrounded by a green belt. A garland of ...truction is gradually appearing around it, a s... lled garland city.



Cross-section of a lobe-city

http://www10.aeccafe.com/blogs/arch-showcase/2011/06/18/masterplan-%E2%80%9Cjuzne-centrum%E2%80%9D-in-brno-czech-republic-by-chybikkristof-associated-architects/

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The concept of the **large and small watercycles**.

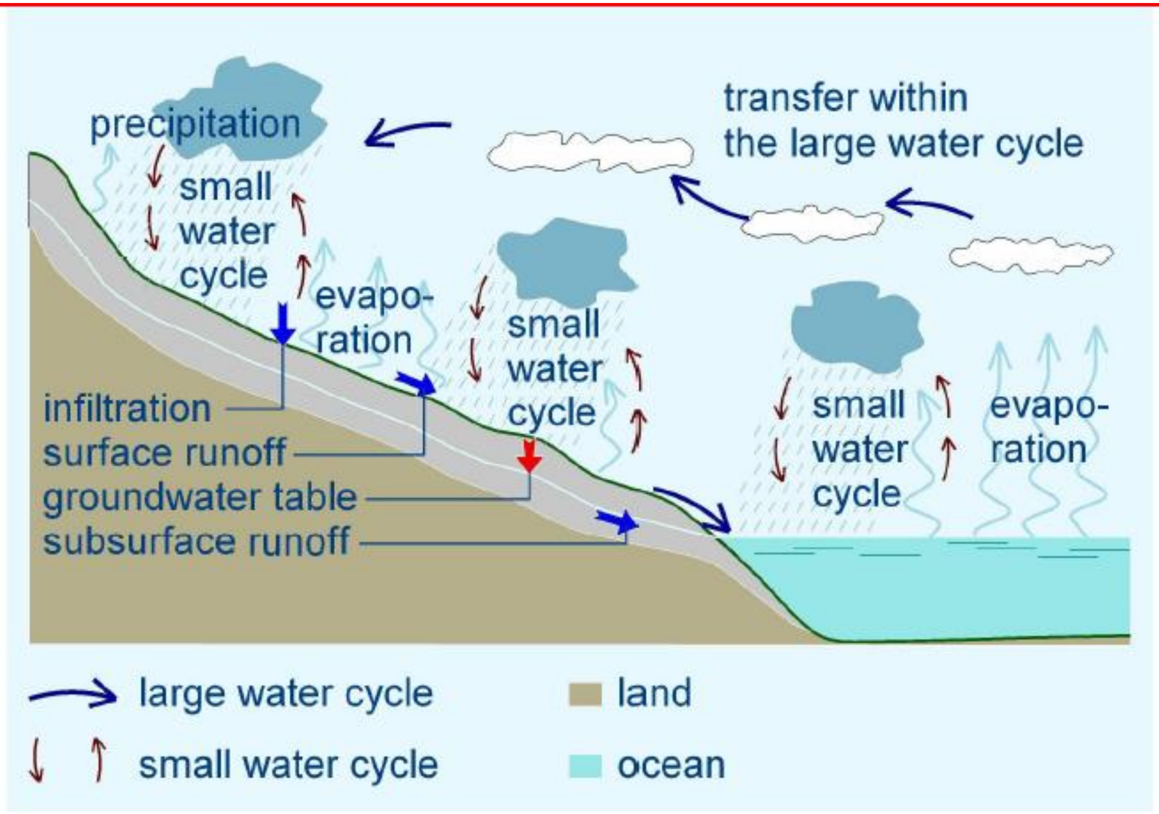


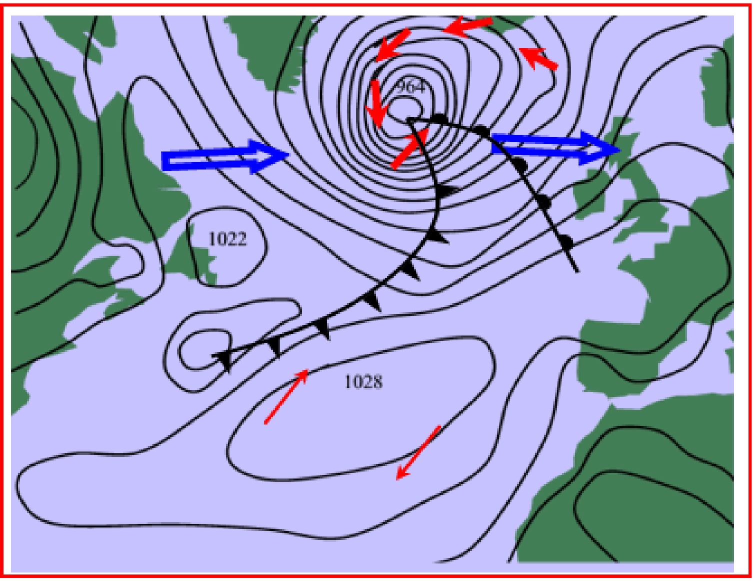
Fig. 1 **The large and small water cycles on land**

The **large water cycle**: exchange of water between oceans and land.

- 550.000 km^3 of water evaporates / year into the atmosphere, 86 % from seas and oceans, 14 % from land.
- Atmospheric precipitation falls 74 % over the seas and 26 % over land.
- So there is a contribution from oceans, endowing the land with 12 % (86 % - 74 %) more water than is locally evaporated. This surplus is transported over a great distance above the land by clouds.

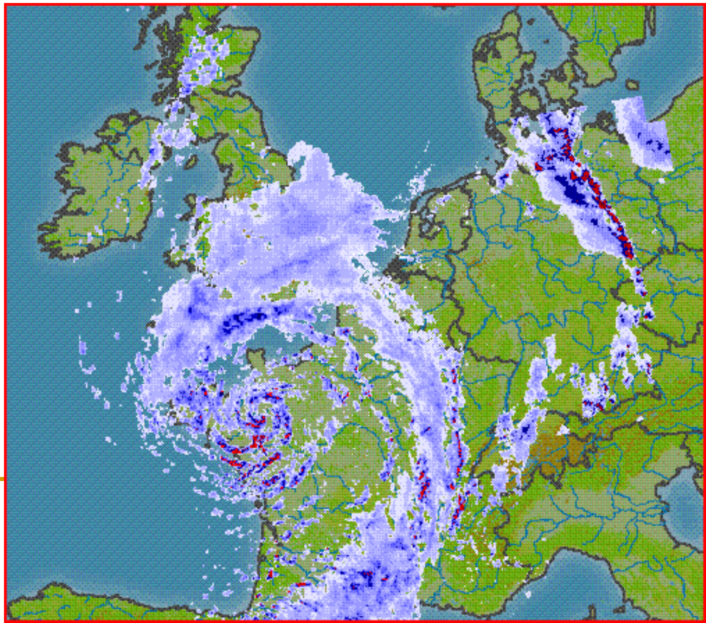
Source: Kravčík, M. et al., 2008. Water for the recovery of the climate. A new water paradigm. Košice (Slowakia), Typopress-publishing house, ISBN 978-80-89089-71-0. 122 pp. Ill

Depressions on the Atlantic ocean and North sea bring precipitation towards Europe (the large water cycle).



www.kayarchy.co.uk

Scotland: rain showers are coming on land, from the Atlantic ocean and the North Sea, carried by depressions.



The **small water cycle**: a closed circulation of *locally* evaporated and transpirated water, which falls again as precipitation in the same region.

- Average rainfall in **Slovakia** is 720 mm/year. Input from oceans is 310 mm/year. Locally produced precipitation through small water cycles is 410 mm/year (!!). So the regional precipitation comes for more than 50 % from locally evapotranspirated water.

- So mankind cannot transform and drain the land limitlessly, without having a serious impact on its local precipitation: the volume of the small water cycle will gradually decrease. So a self-reinforcing phenomenon of further drying-out of the local environment is started: *more urbanisation and run-off, less evapotranspiration, less local rainfall, more drought and sensible heat, higher temperatures because the cooling effect of the evapotranspiration is decreasing....*

Forests, wetlands, especially moorland, are contributing very much to local evapotranspiration, and to local small water cycles, cooling down local temperatures, increasing local air humidity (fog).

www.natuurrondleidingen.nl

Moorlands in Finland.

Contribution to the local water cycle, through the evaporation of a swimming pond.

Especially in dry urbanised regions it is important to restore the local contribution to the small water cycles, as is shown by this swimming pond example in which the local rain water is harvested from adjacent roofs, evaporating into the air.

A stable water cycle, over time.

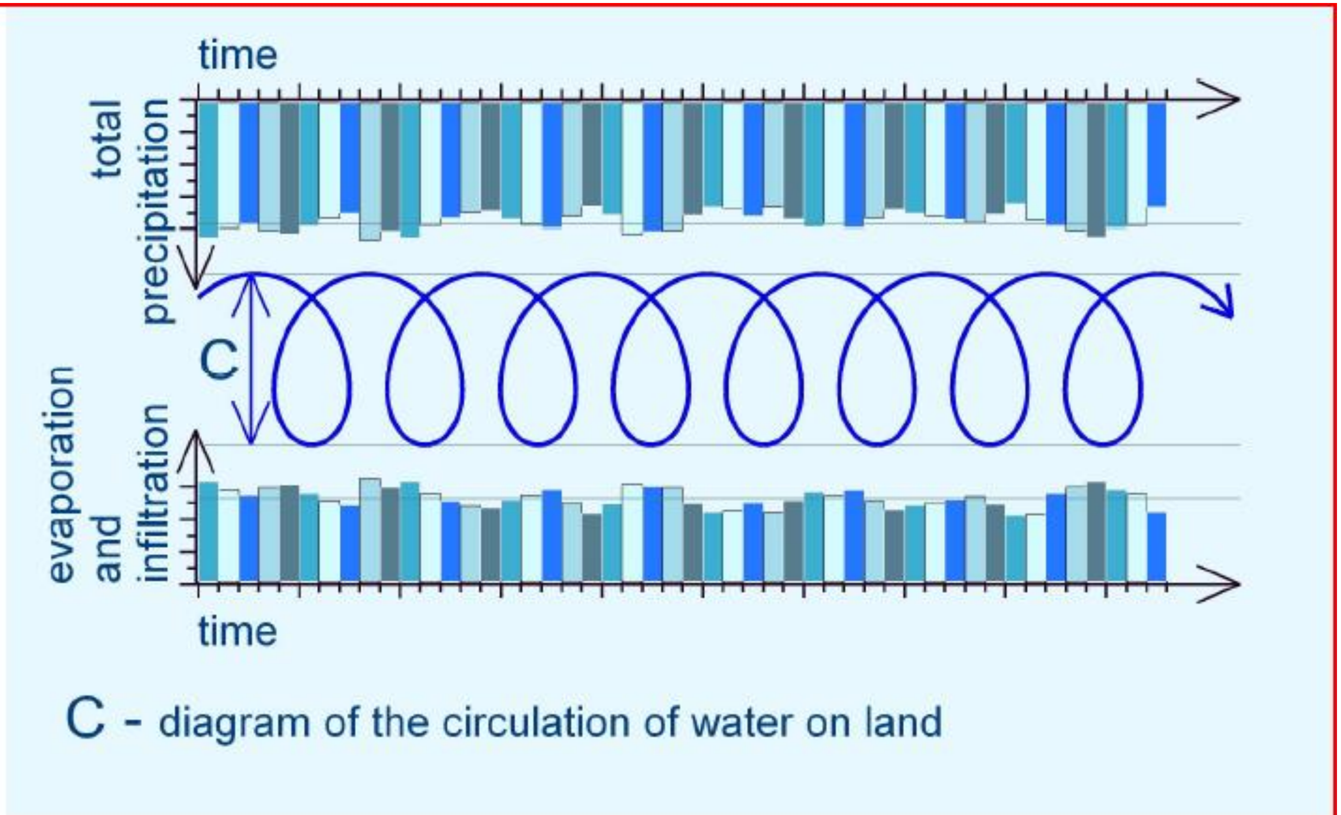


Fig. 2 **Diagram of the long-term stable water cycle on land**

Stable local evapotranspiration over time, leads to stable small water cycles providing stable local precipitation.

The small water cycle, also the short or closed water cycle, is characteristic for a hydrologically healthy country. In a country saturated with water and water vapor, water circulates in small amounts and for relatively short distances.[13] This occurs thanks to a water-vapor induced moderating of the differences in temperatures between day and night or between localities with different thermal regimes. The majority of water that evaporates condenses again in the given region or its surroundings. Frequent and regular local precipitation retrospectively maintains a higher level of groundwater and with it also vegetation and further evaporation, so that the whole cycle can be repeated again and again.

The circulation of water on healthy land

If, however, there is an extensive disruption of vegetation cover (for example, by deforestation, agricultural activities, urbanization), solar energy falls on an area with low evapotranspiration and a great part of it is changed into heat. This leads to a significant divergence of temperatures, and the differences in temperatures between day and night or between localities with other thermal regimes increase. Air currents increase, water vapor is taken further away by the warm air and the majority of evaporated water is lost from a country. Light and frequent precipitation decreases, and there is an increase in intense and less frequent precipitation from the seas. The cycle is opened and the large water cycle, which, unlike the "soft" small water cycle, is characterized by erosion and the washing away of soil nutrients into the sea, begins to predominate. The renewal of the domination of the small water cycle, which is advantageous for humanity, vegetation and the land, depends on the renewal of the functional plant cover of a territory and water surfaces in a country.

Disintegration of the water cycle

Consequences of decreasing the small water cycle.

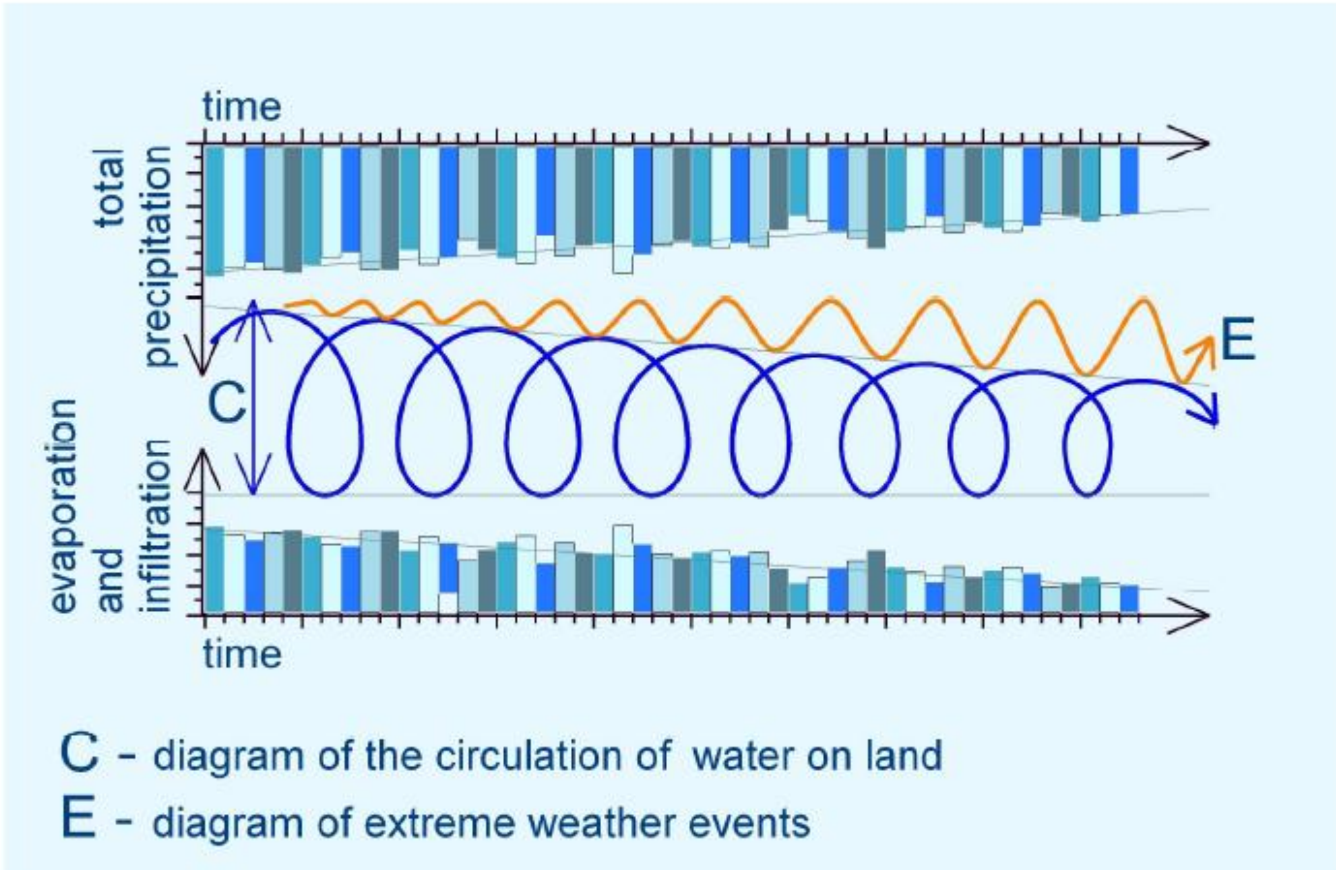


Fig. 17 **The growth of extreme weather with the decrease of water in the small water cycle**

Less evapotranspiration leads to decreasing locally generated rainfall and increasing risks **for extreme weather events,**

Slovakia, Tatra mountains. Situation 1800.

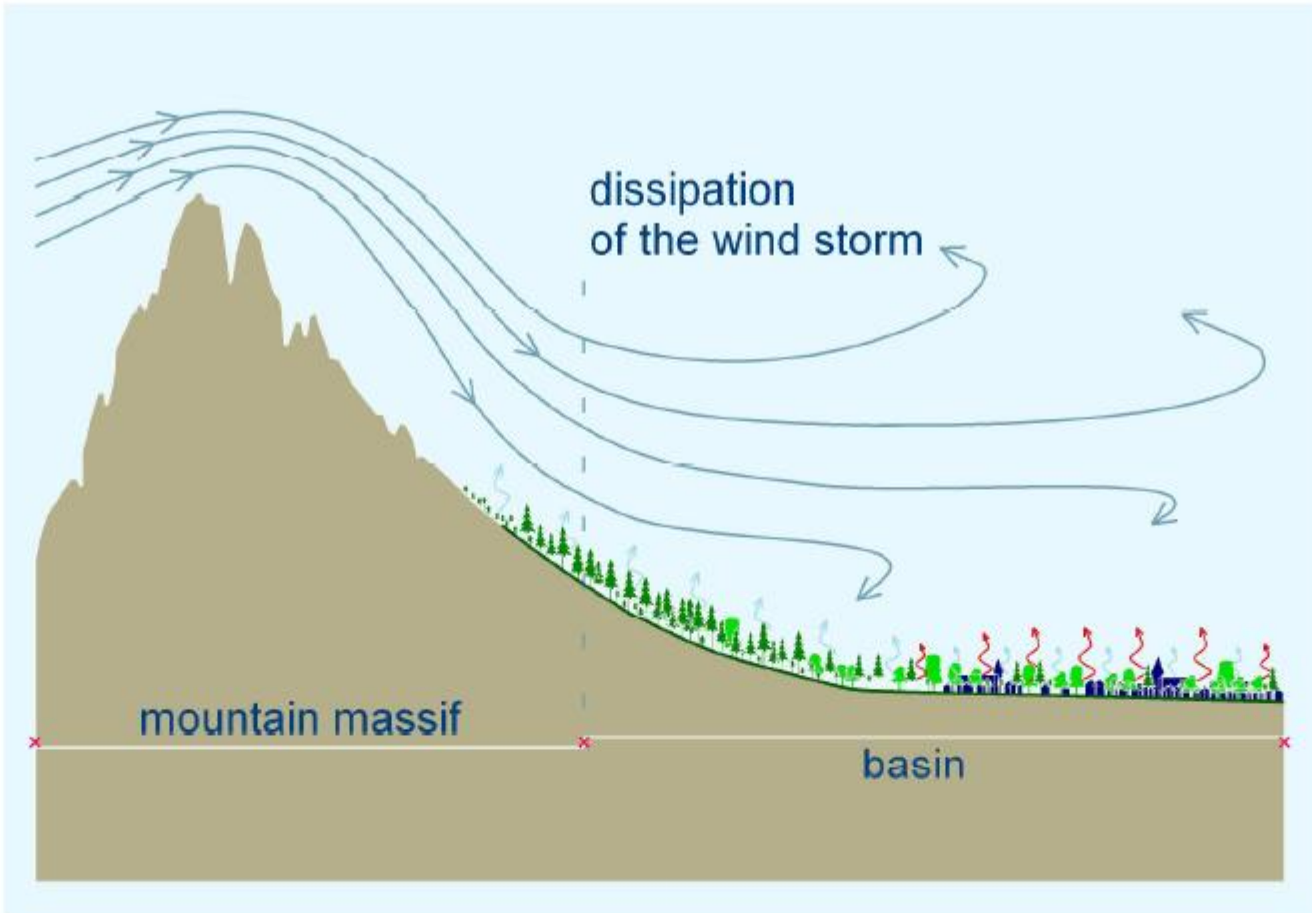


Fig. 24 **The incursion of cold air to the High Tatras regions (the Tatra bora) - the assumed state around the year 1800**
The conditions of the land under the mountains allowed for the gentle dissipation of the currents.

The destruction of the small water cycles by urbanisation and by draining for agricultural and forestry purposes.

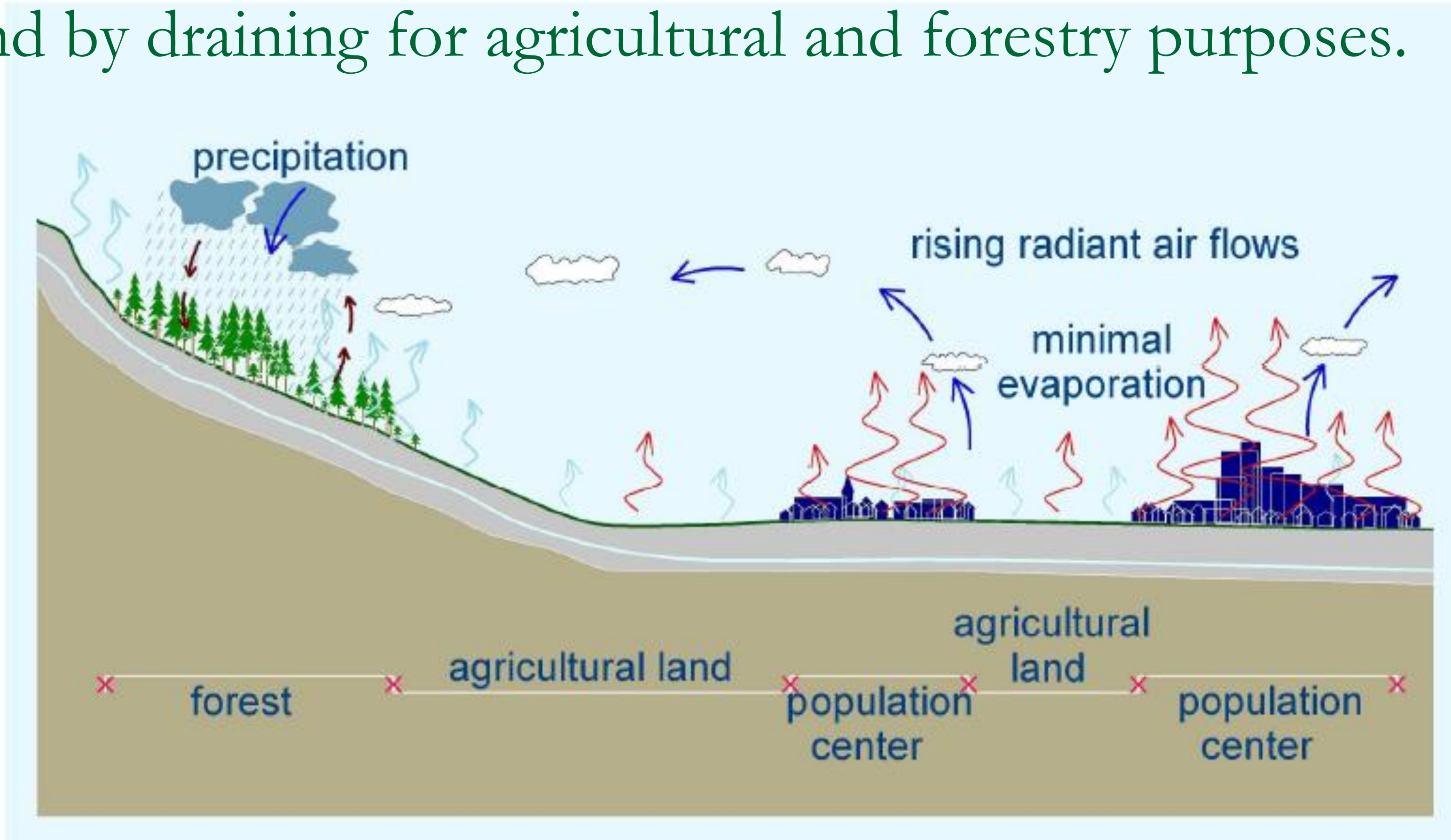


Fig. 18 **The impact of the transformation of land on the destruction of small water cycles**
Rising radiant flows push clouds to cooler environments.

Slovakia, Tatra mountains. Situation 2004.
Growing and increasing temperature contrasts thus:
Increasing risks for extreme weather events
See also flooding in **Balkan countries**
Spring 2014

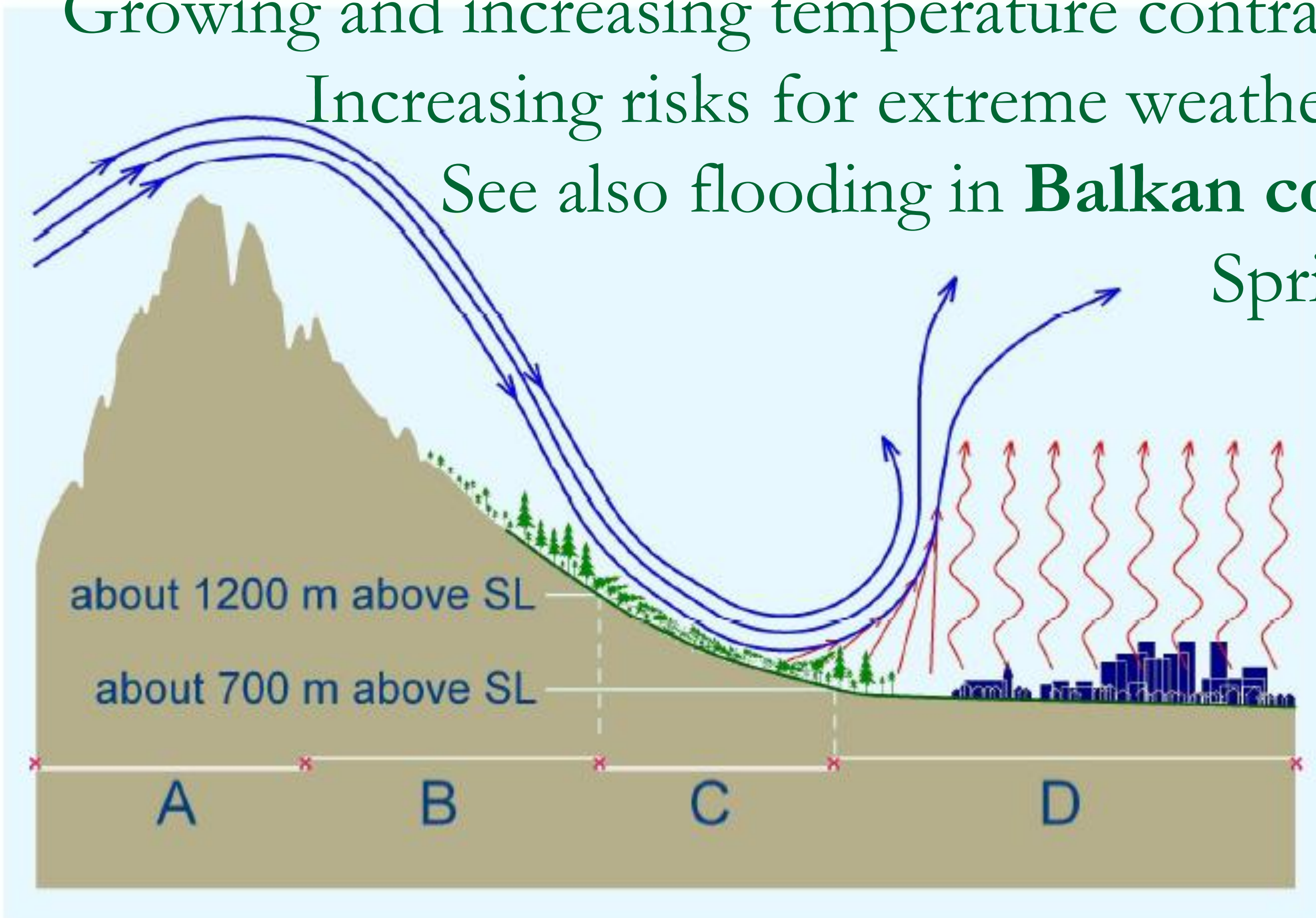


***Fig. 25* Wind storm in the High Tatra mountains, Slovakia, November 19, 2004**
Radiant flows of warmed currents from agricultural-urban areas (zone D) accelerated air currents with the rapidly falling cold front through the ridge of the High Tatra mountains: v(A) 150 – 200 km/h, v(B) < 100 km/h; v(C) 200 – 250 km/h, v(D) < 150 km/h.

So, Small water conservation measurements, such as here in the Tatra mountains (Slovakia) do matter, for *local climate* but are also *preventing flooding* downstream and *preventing erosion*

Fig. 35 **A Water Forest in the High Tatras – building water conservation measures on territory destroyed by a natural disaster**
An example of the renewal of vegetation and hydrological stabilization of a territory through the conservation of water on land.

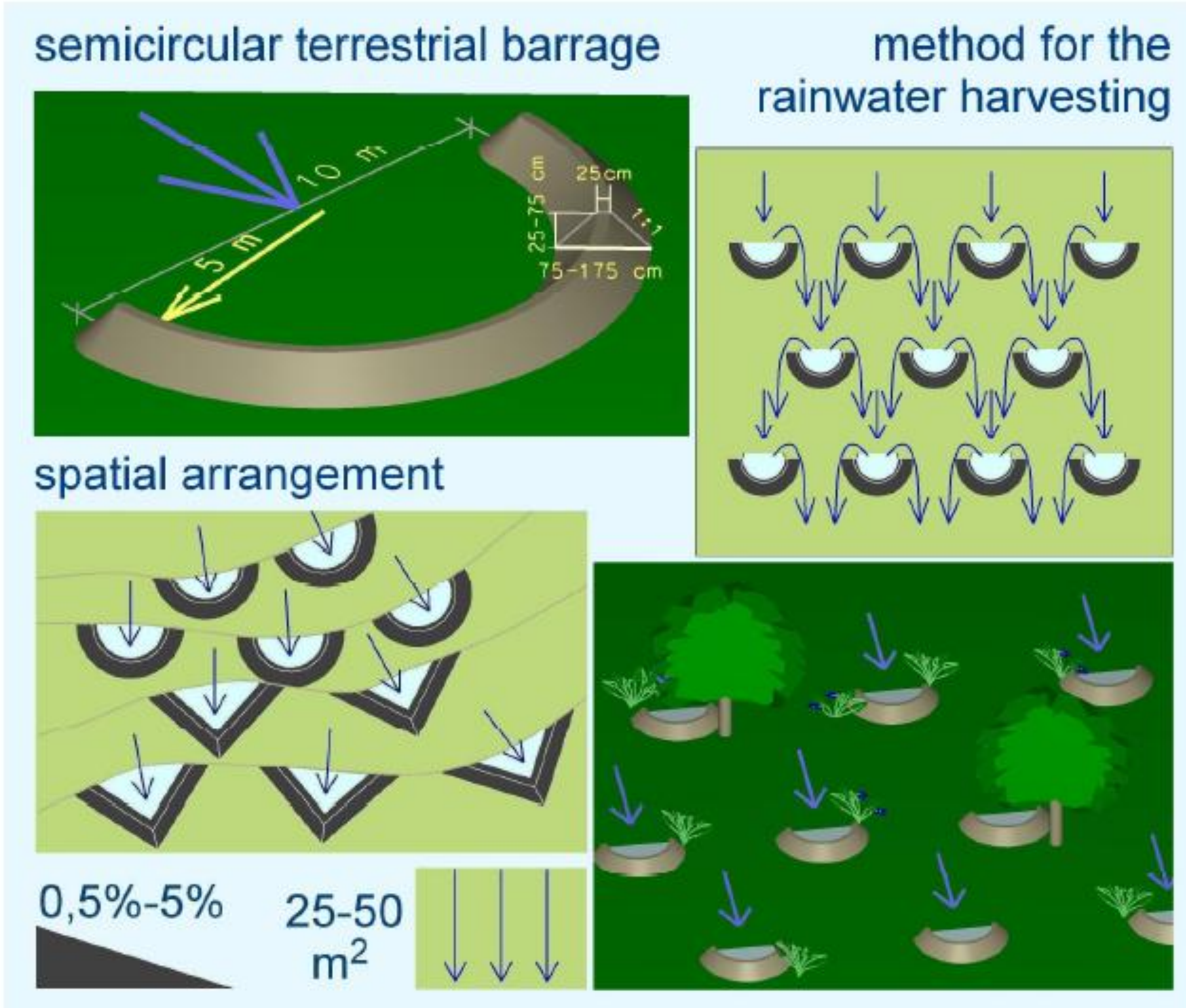


Fig. 32 **An example of cascade ground tanks for rainwater harvesting on slopes**

Different measurements aiming to tackle soil erosion and water problems. (See dvd during lecture)

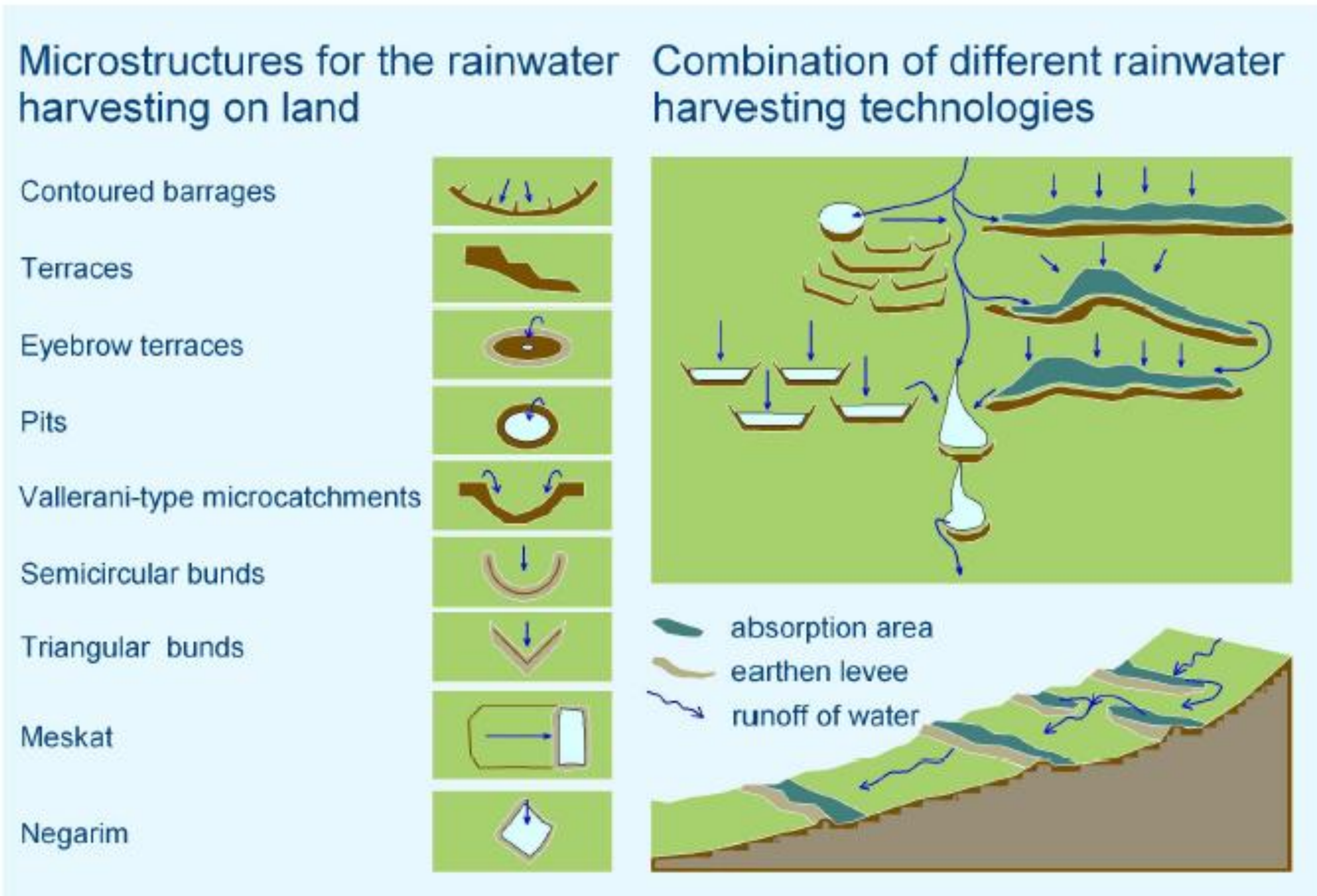


Fig. 33 **A diagram of technological measures for the protection of land against erosion and for rainwater harvesting and conservation on land**

Restoring the *small urban and rural water cycles* leads to local climate recovery and decreases risks for extreme weather events.

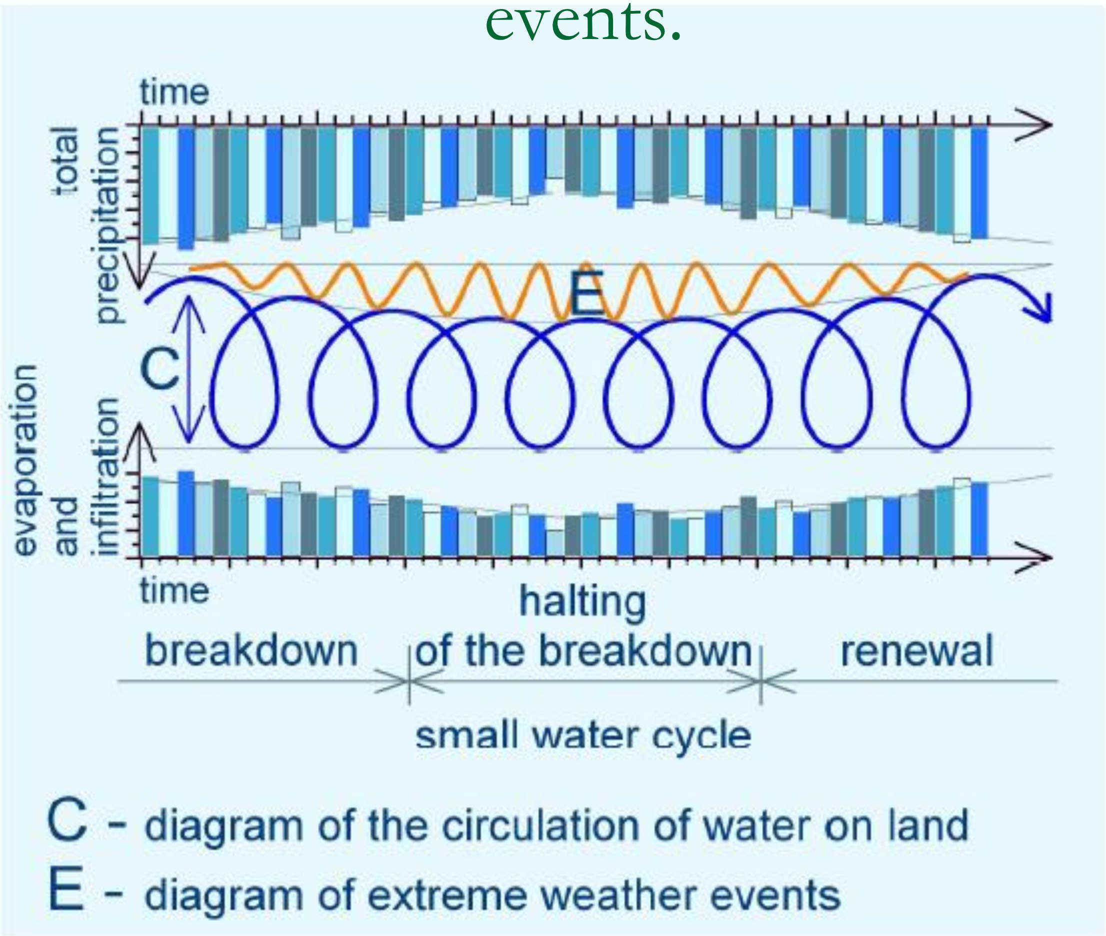


Fig. 27 **The course of destruction of the small water cycle over land until it is halted and then renewed to its original state**

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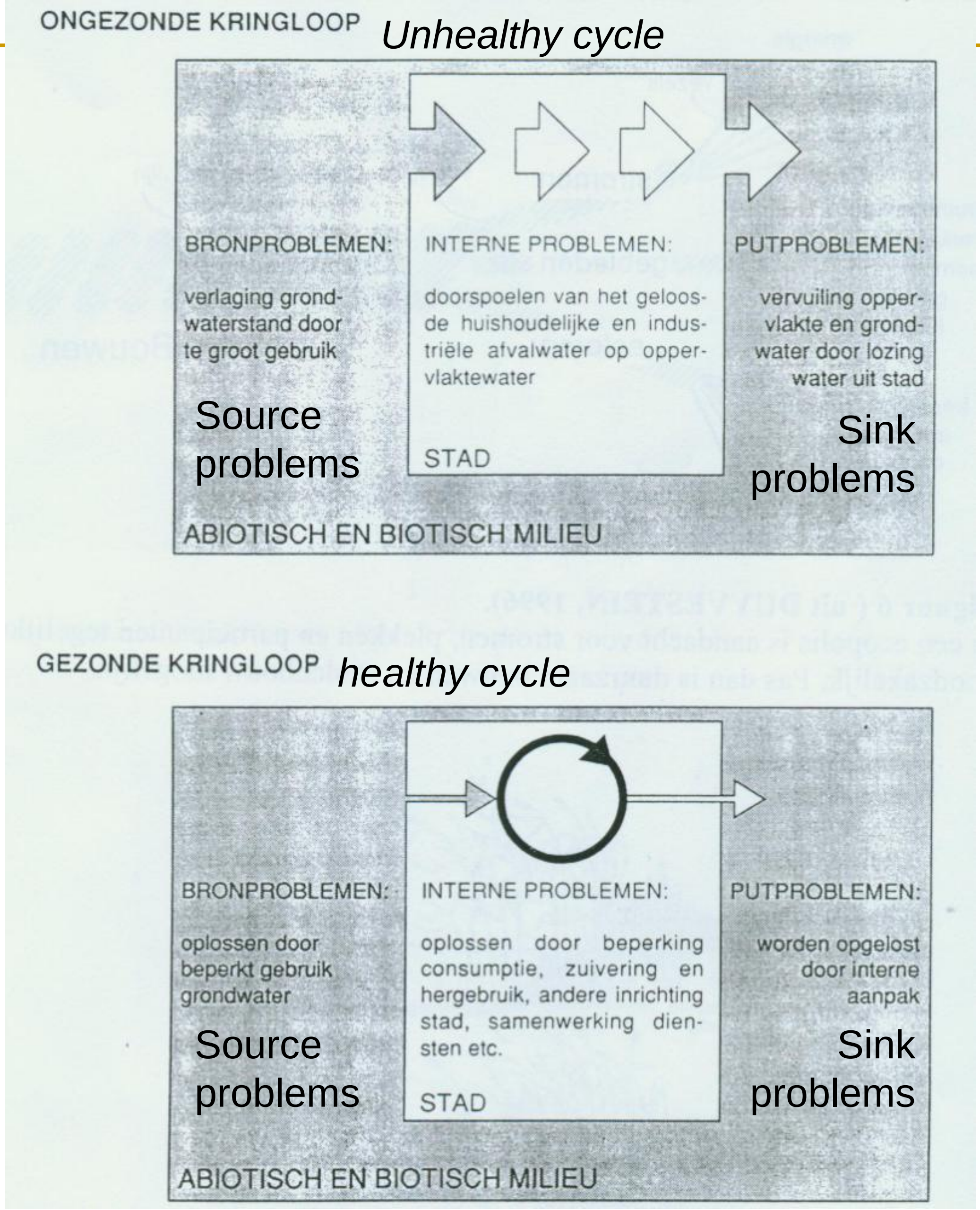
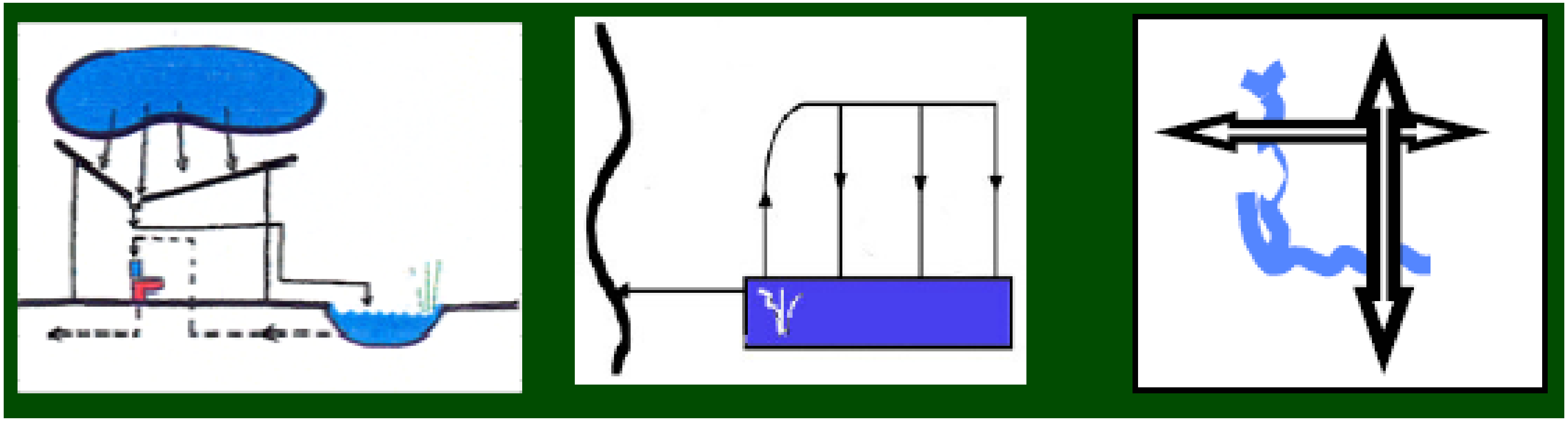


In an ecopolis the flows (IN and OUT) can be decreased by internal measures within the city, on different levels: the building, the city quarter and the whole city.

The use of **<u>water as an organizing principle</u>** at different levels *in urban and rural environment is urgently needed.*



Building level **District level** **City level and rural areas**

= INTEGRAL WATER MANAGEMENT

From Tjallingii, 2009.

Wise use of water on **the building level**

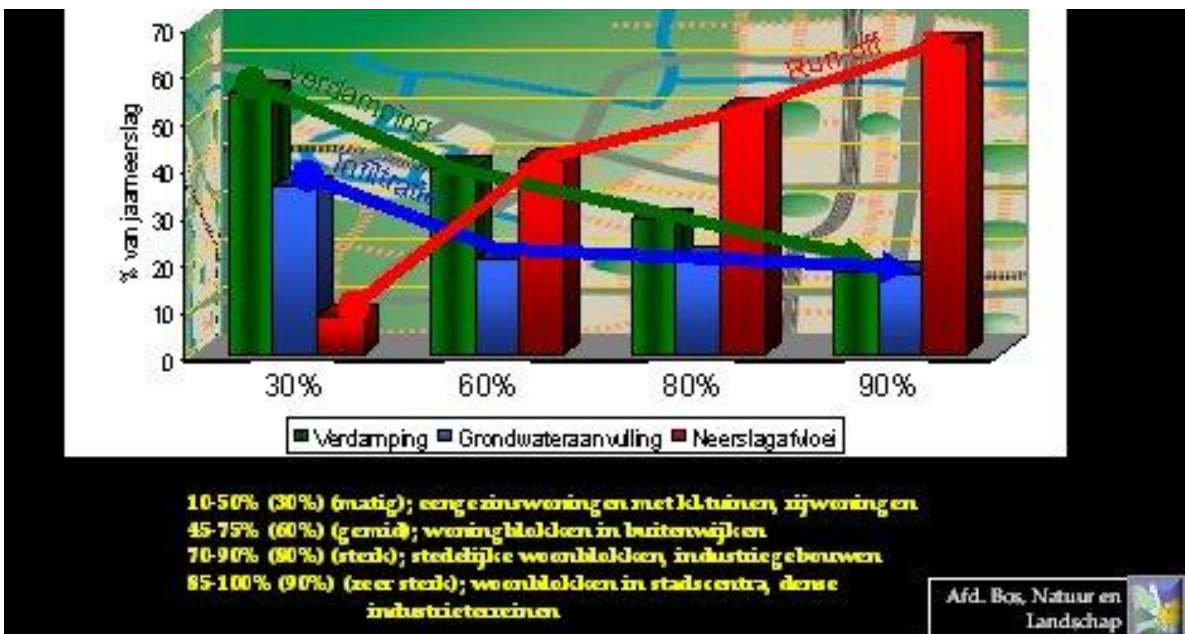
Toilets are wasting about 40 % of the drinking water in Belgium. Modern compost toilets don’t.

Ecologically sound water management on the building level: using rainwater and saving systems.

Sealing surfaces with impermeable concrete, roofs, pavements, … causes increasing amounts of rainwater which can not infiltrate and which is mostly drained into mixed sewage systems, the so-called RUN-OFF

Increasing RUN OFF

Rural Urban



Afd. Bos, Natuur en Landschap

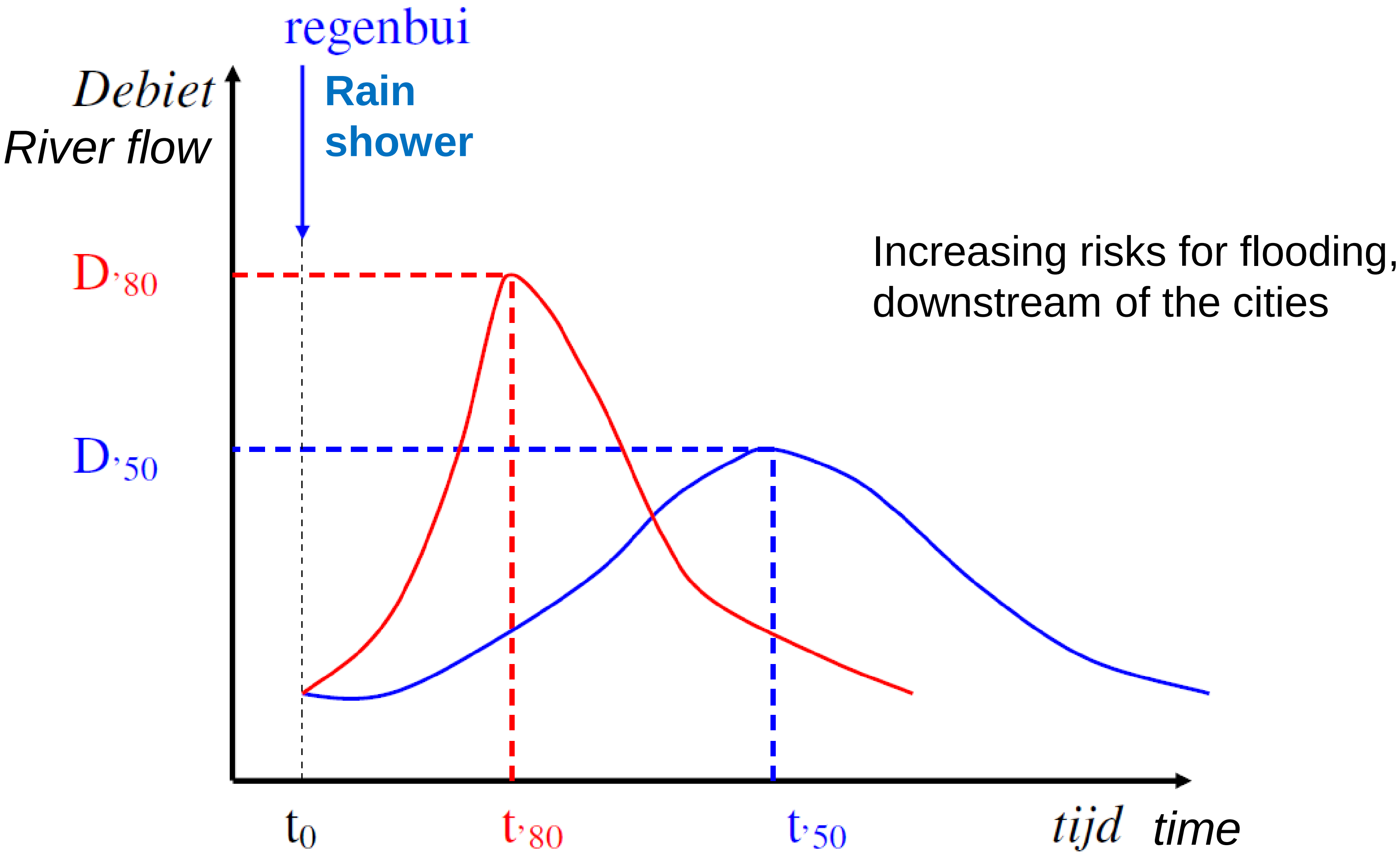
Bad examples: non-permeable seal, huge RUN-OFF. Additionally, the parking areas significantly contribute to the **urban heat island effect.**

Sint-Gillis Waas (B).
New parking areas for super markets Carrefour/GB en Aldi.

Bad examples, also by public authorities.

Sint-Gillis Waas (B): municipal parking

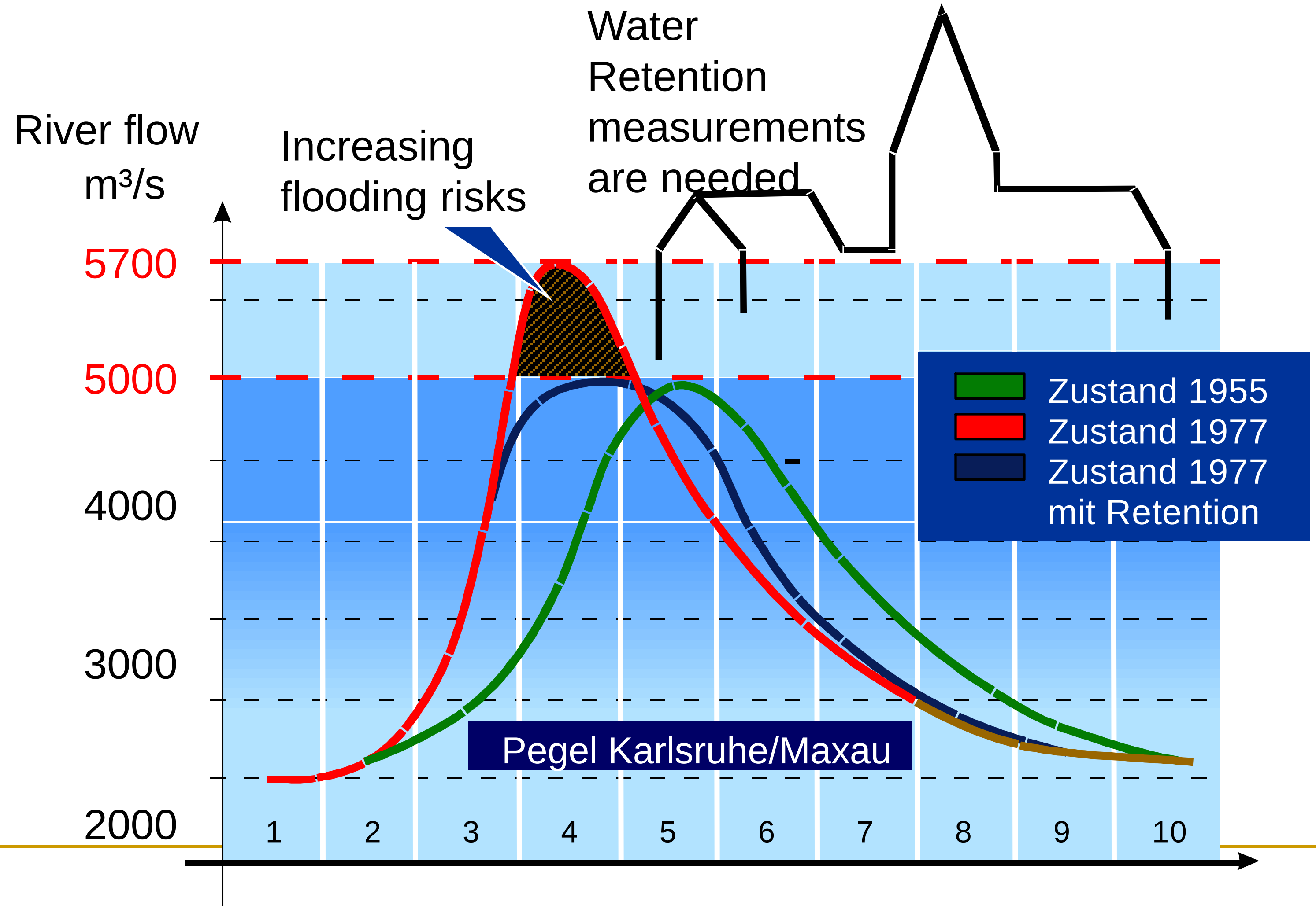
Consequences: Hydrological research of the **Bellebeek** (Belgian inland brook), (Van der Beken, 1984, University Brussels)



Current peak river flow rates from inland to the North Sea are **higher** and come **earlier** in the time after a rain shower, compared with the years 1950.

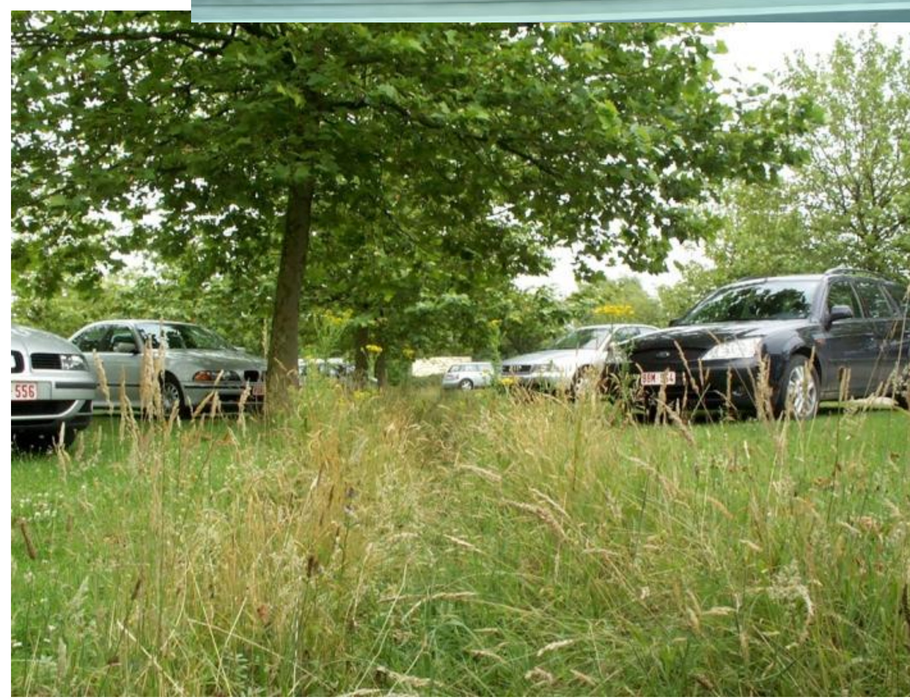
The same is the case all over Europe: example of the river **Rhine**, in the border region between France and Germany.

Source: Das Integrierte Rheinprogramm des Landes Baden-Württemberg (Hochwasserverschärfung)



Good examples: permeable parkings.

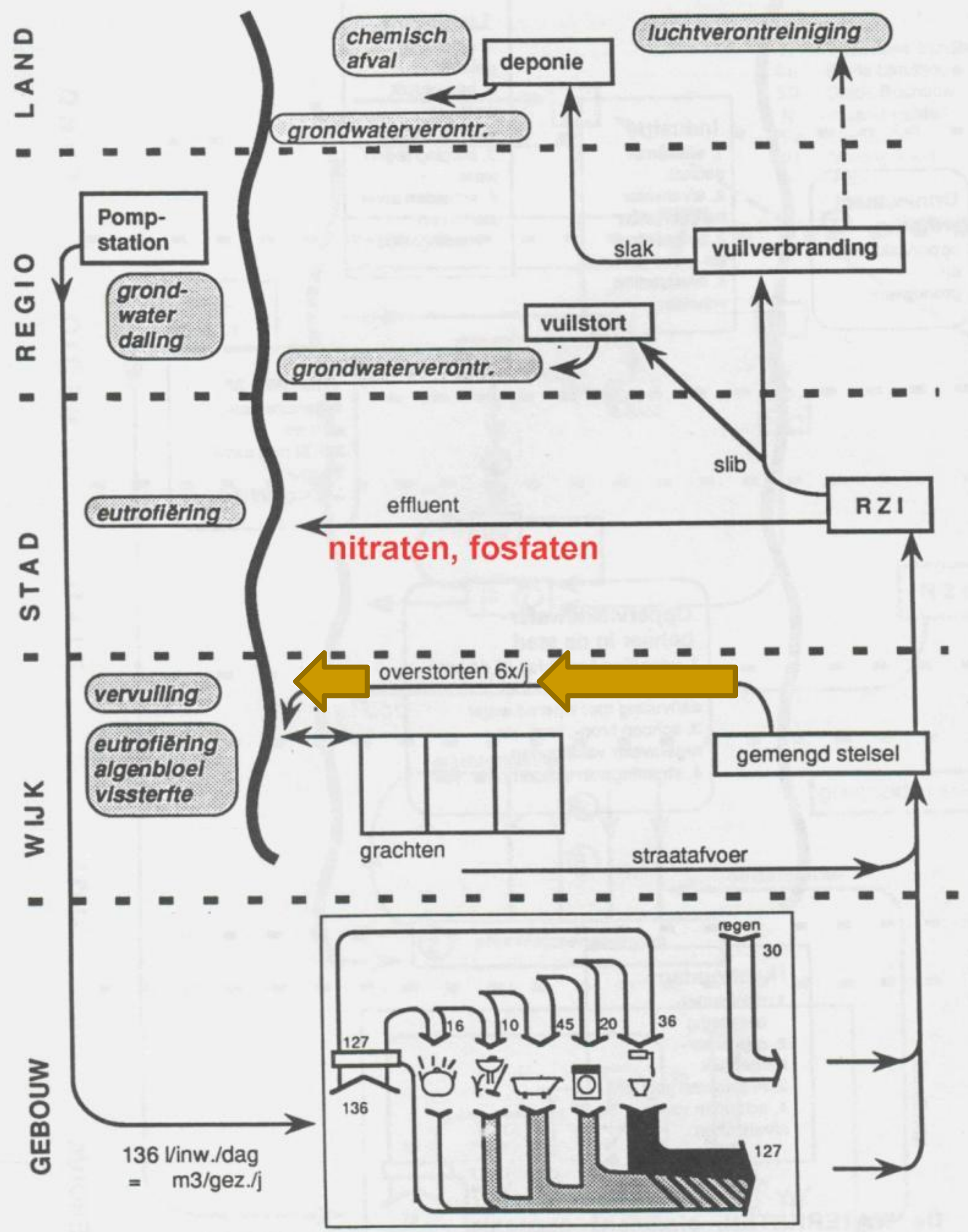
Mechelen (B). Parking Planckendael (Muizen)



Sint-Niklaas (B). Parking Recreation area ‘De Ster’.

Unsustainable use of water causes severe problems.

Mixing black, grey and white water in sewage systems causes capacity problems in the purification plants, in periods of heavy rainfall: **<u>overflows</u>** bring polluted water directly into the river.

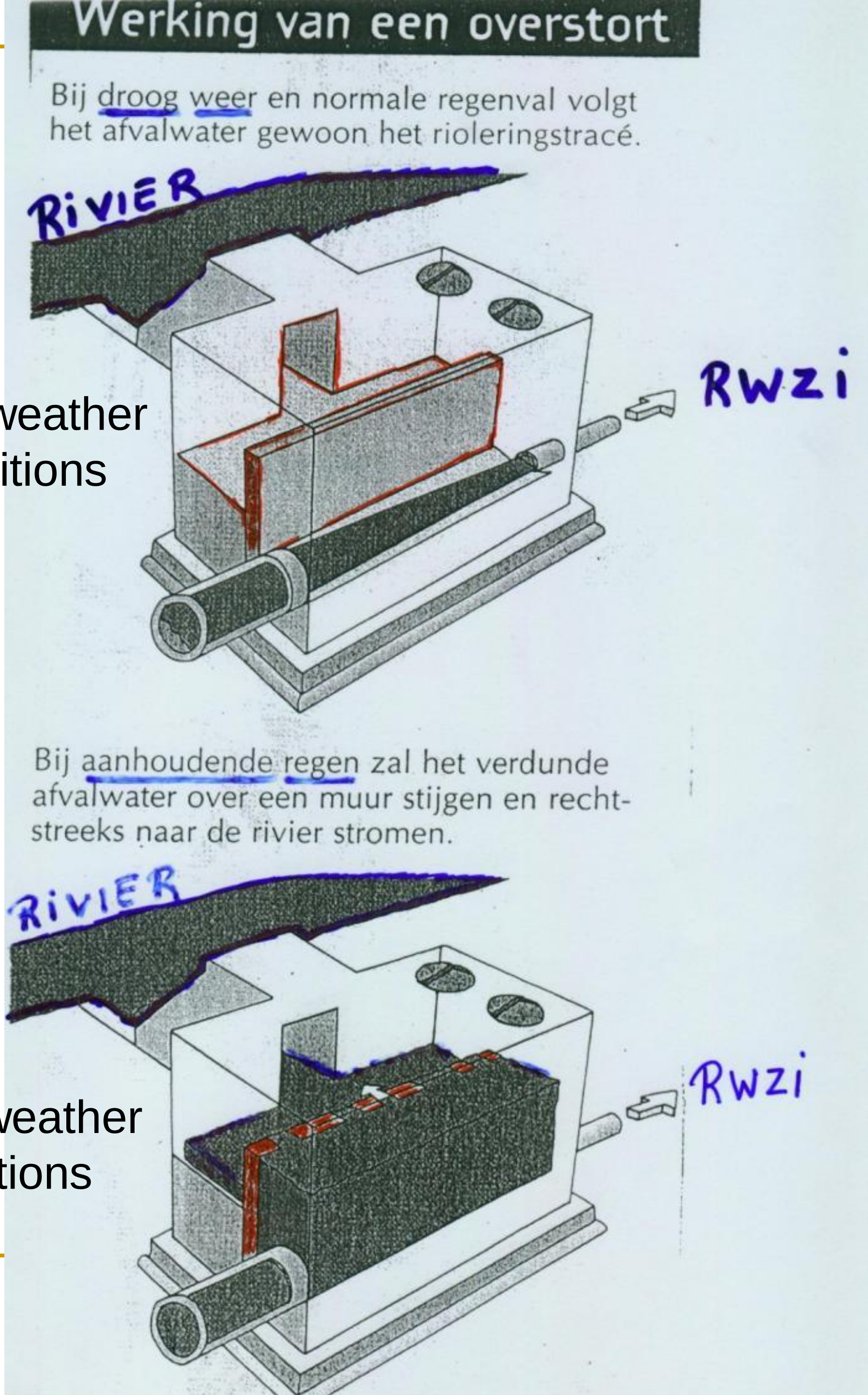


Figuur 2.3.1 De WATERKETEN, bestaande systemen en milieuproblemen.

Overflow is causing flooding

Dry weather conditions

Wet weather conditions



Disconnecting rainwater from roofs from the sewage system is necessary

Church of Ronchamps (Fr)

The presbytery has a green roof

Design **water neutral**:
Green roofs are minimising run-off amounts.

Eidfjord (N). Hardangervidda national park

Use succulent plants (such as *Sedum sp.*) for green roofs.

Boxtel (NL). De Kleine Aarde

Green roofs are interesting for biodiversity, summer cooling and water management, …

Westerlo (B). Kamp C

Technical features of a green roof.

Hovden (N): water neutral ecoquarter.

Amsterdam (NL): designing with rainwater on the roof of the ING Bank.

Water neutral retirement home (Pelgromshof Zevenaar ,NL)

Green roof and infiltration pond.

View from inside a room

Water management
on city quarter level

Separating sewage systems
Disconnecting rainwater from sewage
Collecting and **re-using** rain water
Infiltrating superabundant rainwater
(figure from TJALLINGII, 1996)

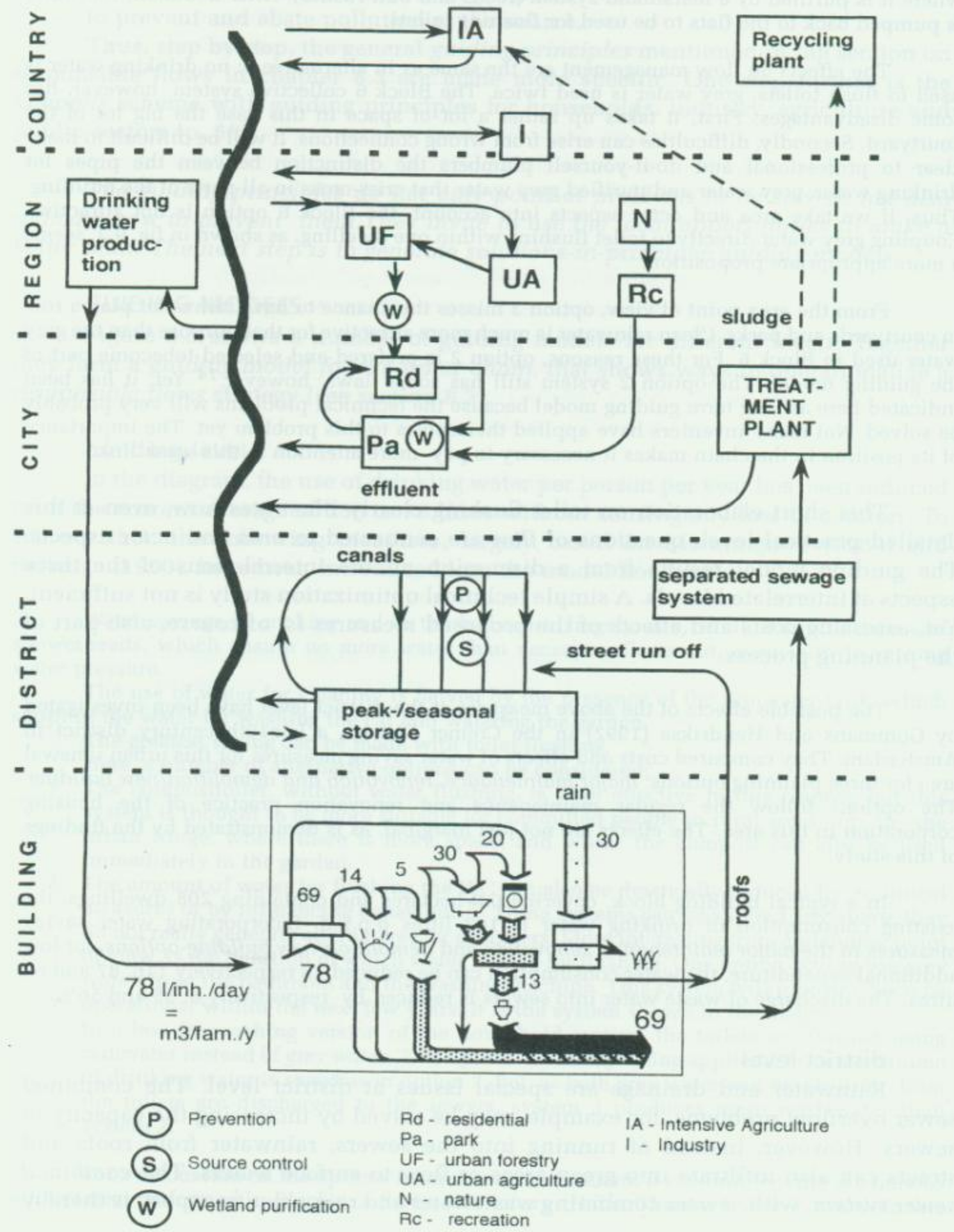
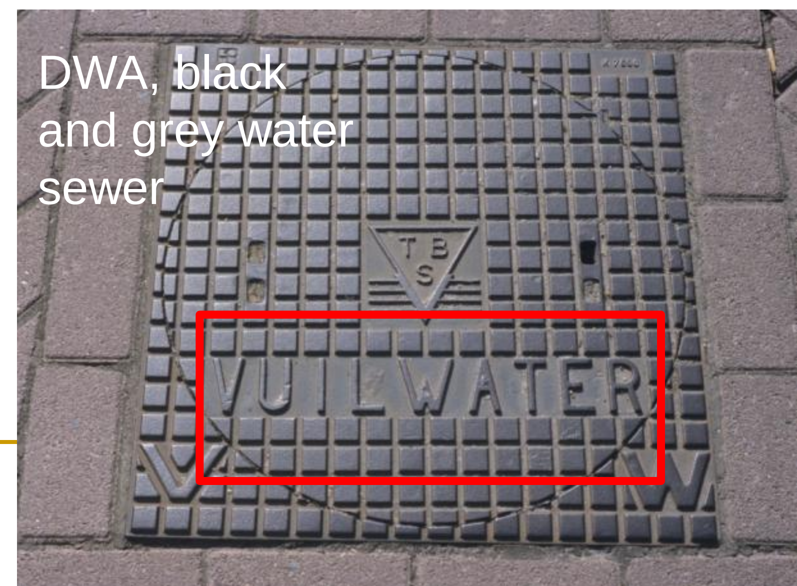


Figure 9.3:
Guiding models for the water chain (lowland situation).
source: Ecopolis.

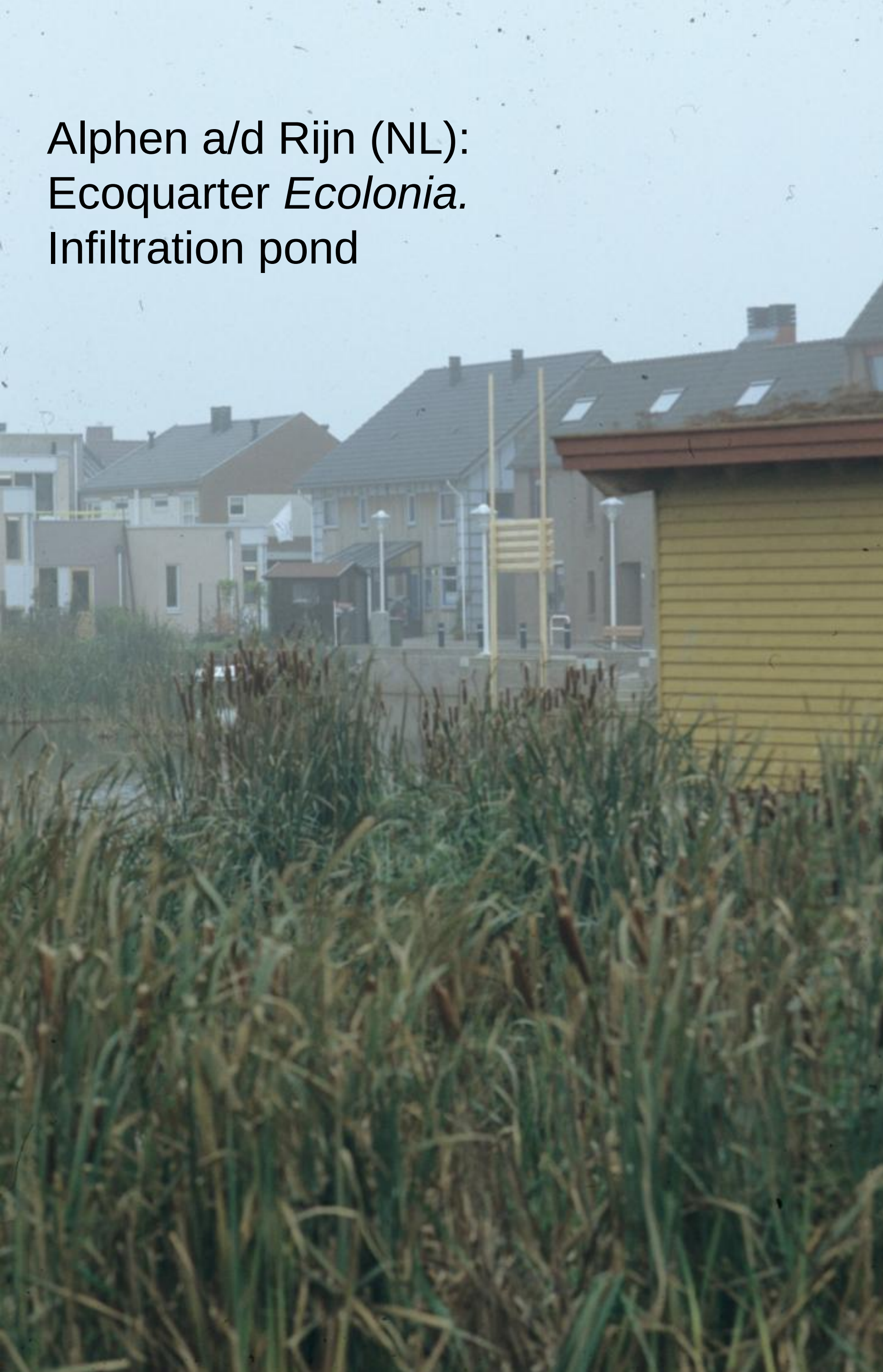
Separate sewage systems **on city quarter level**

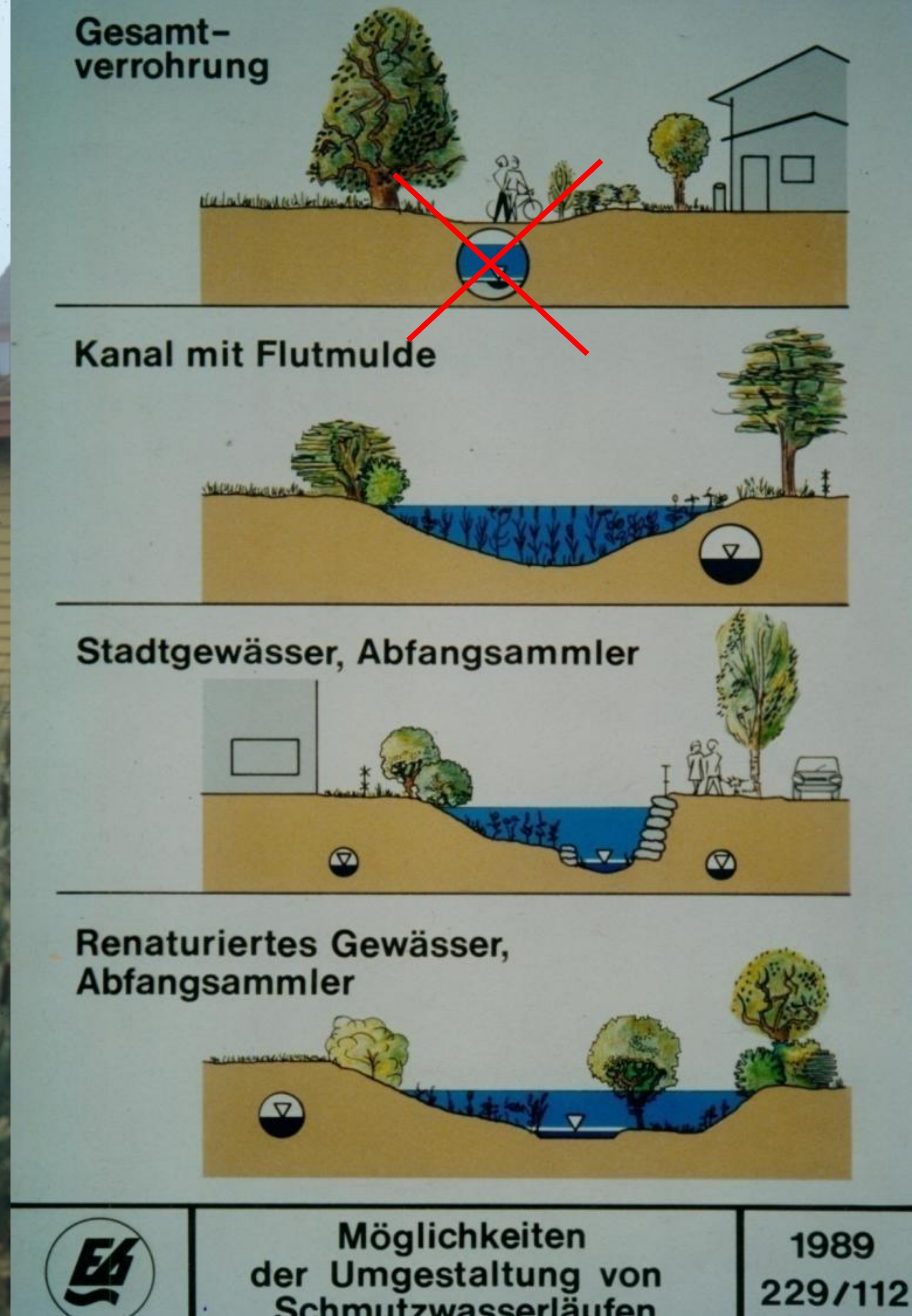
Culemborg (NL)



Belfort Bethoncourt (F)

Alphen a/d Rijn (NL):
Ecoquarter *Ecolonia.*
Infiltration pond





‘s Hertogenbosch (NL): city quarter ‘De Vliert’

Children playing in the water playground of the ecoquarter.

Delft (NL)

Gelsenkirchen (D)

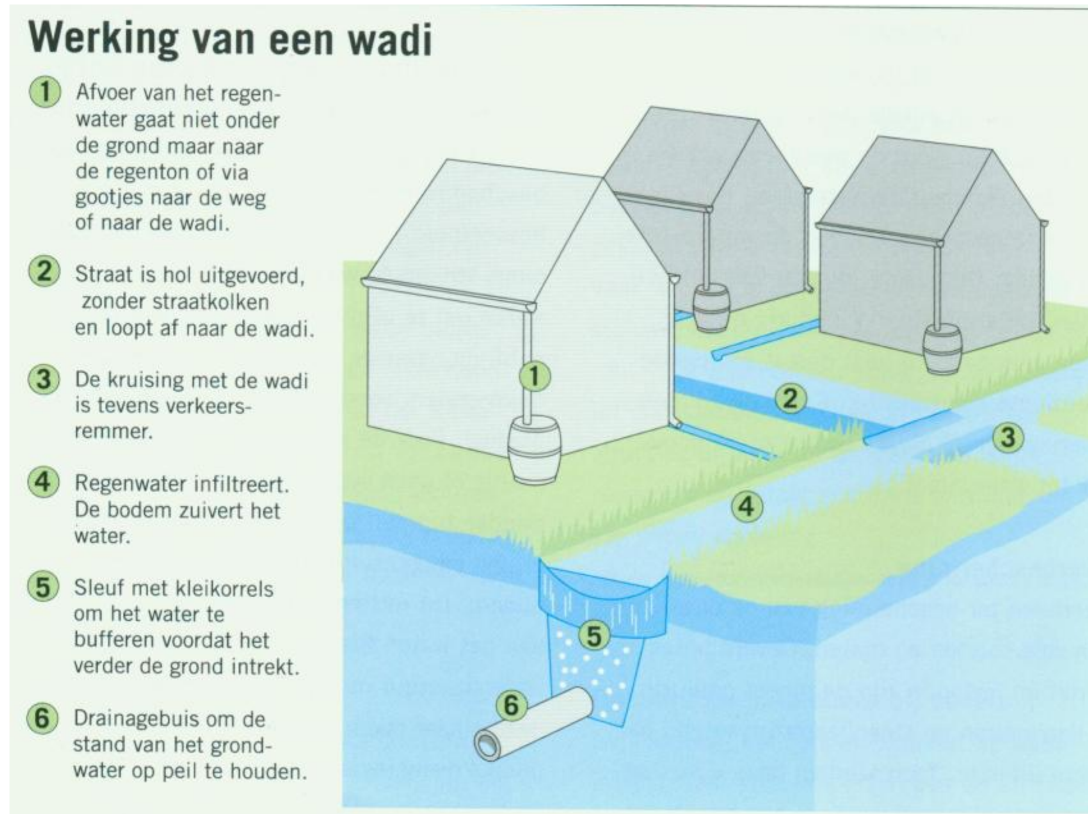
Culemborg (NL)

Infiltration zone in Gelsenkirchen (D).

Infiltration zone in the ecoquarter *Kuppersbusch.*

Gelsenkirchen (D) eco quarter *Schüngelberg.*

WADI technique.



WADI: a natural regulation of rainwater

Enschede (NL): eco quarters

Oikos and Ruwenbosch

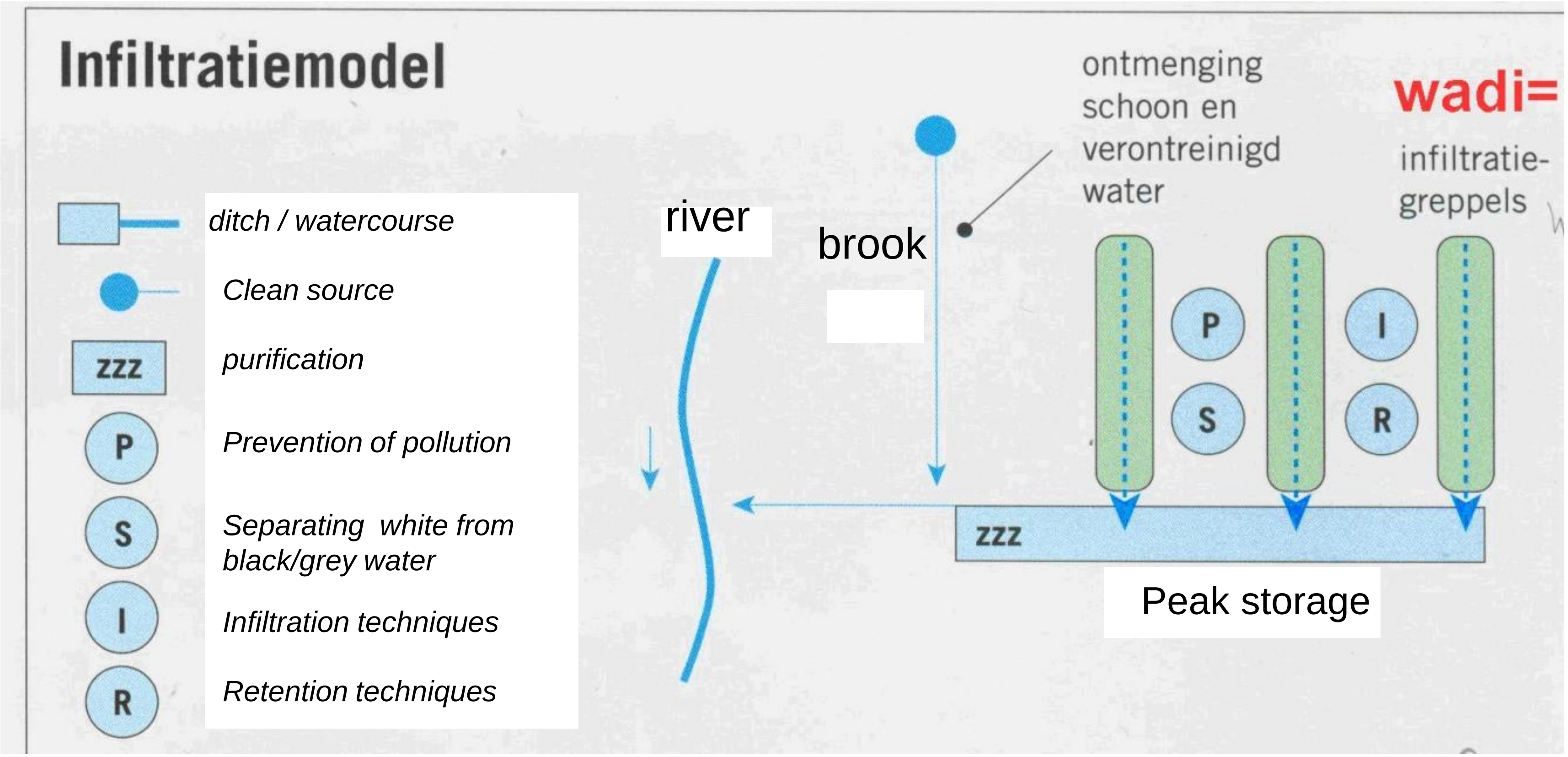
Enschede (NL): eco quarters

Oikos and Ruwenbosch

‘SLOKOP’

The ‘slokop’ is connected with the sewage system and prevents flooding.

THE INFILTRATION MODEL is a guideline for residential areas. Do not discharge rainwater in sewage systems. The aim is **retention** and **infiltration** of clear rainwater in urban areas. This is also important for the creation of wet conditions for plants and animals, while the groundwater level in urban areas often is very low.



STOWA. STICHTING TOEGEPAST ONDERZOEK WATERBEHEER. 2001. Levende stadswateren: werken aan water in de stad. STOWA, ill. ISBN 90 5773 096 3. www.stowa.nl

Wadi's in the eco quarters !

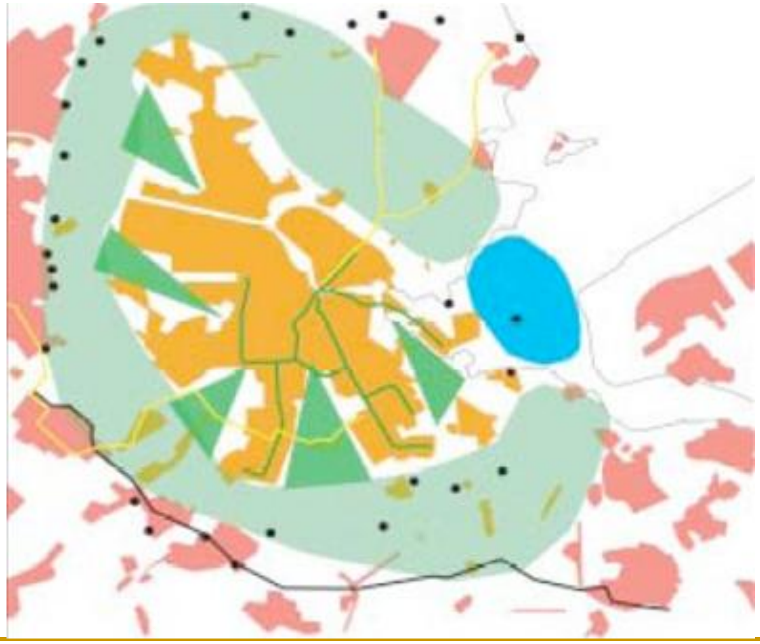
Culemborg (NL)

Malmö (S)

Malmö (Sweden): ecoquarter *Västra Hamnen (western Harbour)*

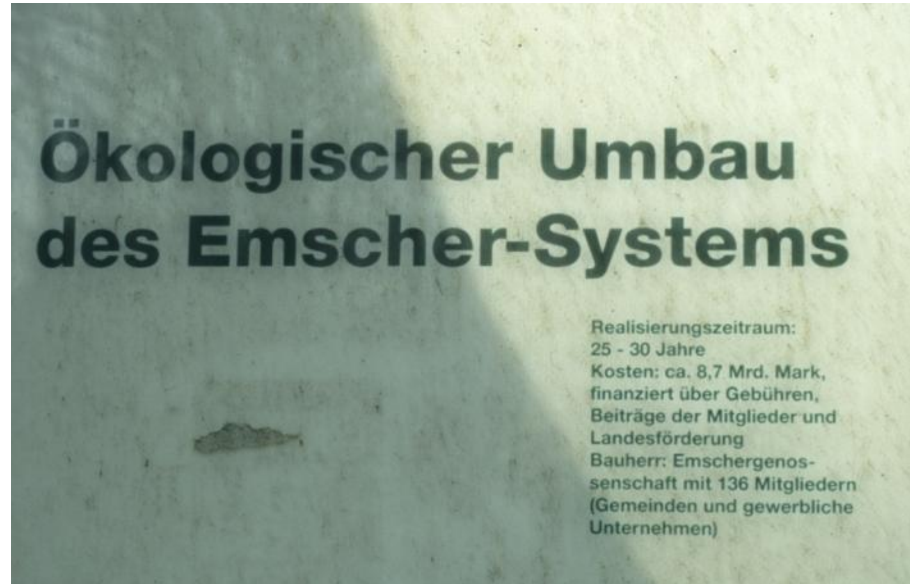
<u>On the city level</u>, the lobe city (see Theme 5) is a very good model for combining it with ecologically sound water management.

In the blue-green fingers, storm water can be stored and infiltrated, which is preventing flooding of the built-up city lobes, and is cooling the cities down



Amsterdam as a lobe-city (From Gieling, 2006)

Germany: Ruhr area



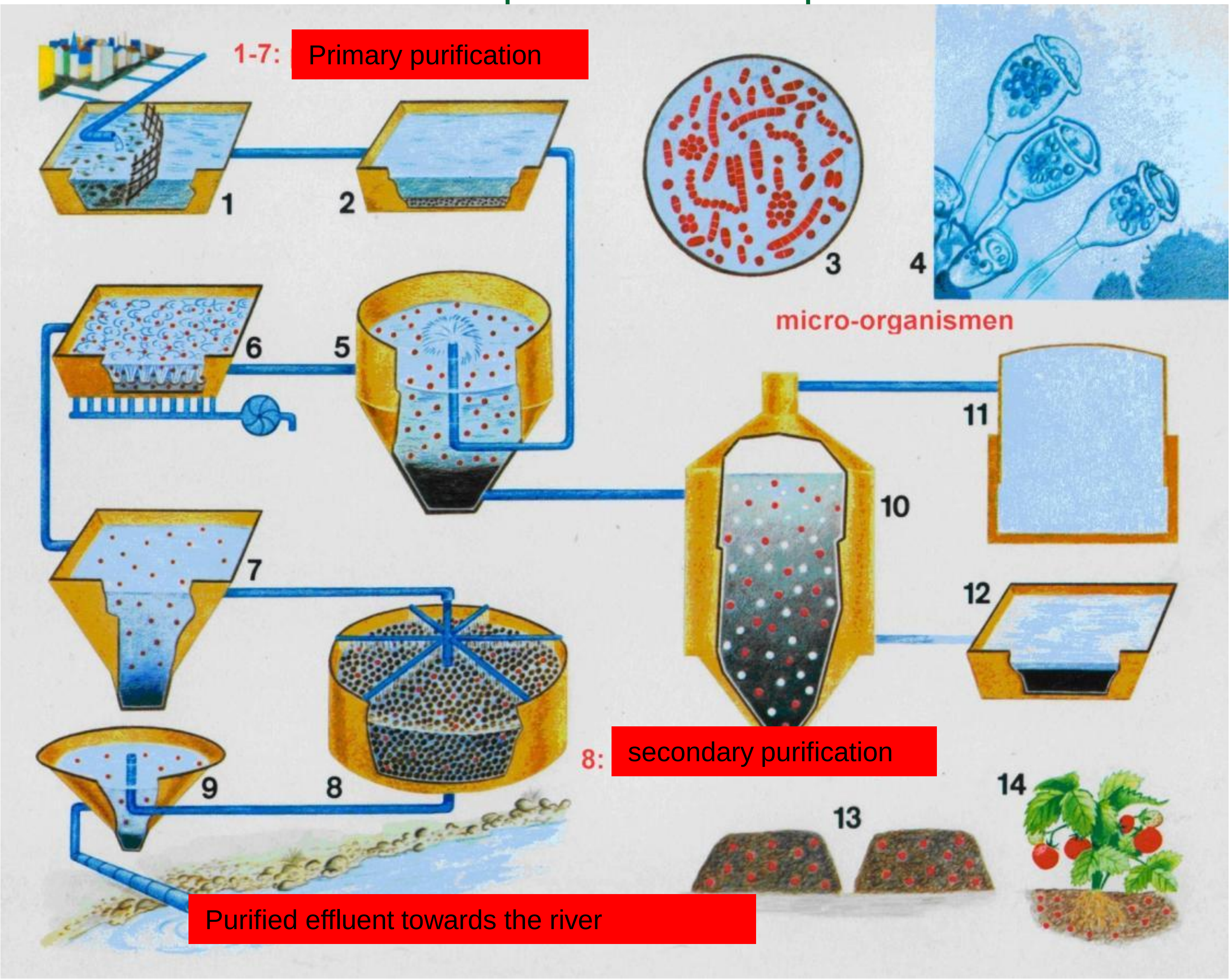
Before and…

…after 're-naturierung'

Structure of this presentation.

- 1. The cooling effect of the vegetation.
- 2. Some climatological backgrounds.
- 3. Climate-proof architecture, city expansion and urban planning.
- 4. Small scaled marsh plant purification systems

How a central water purification plant is functioning.



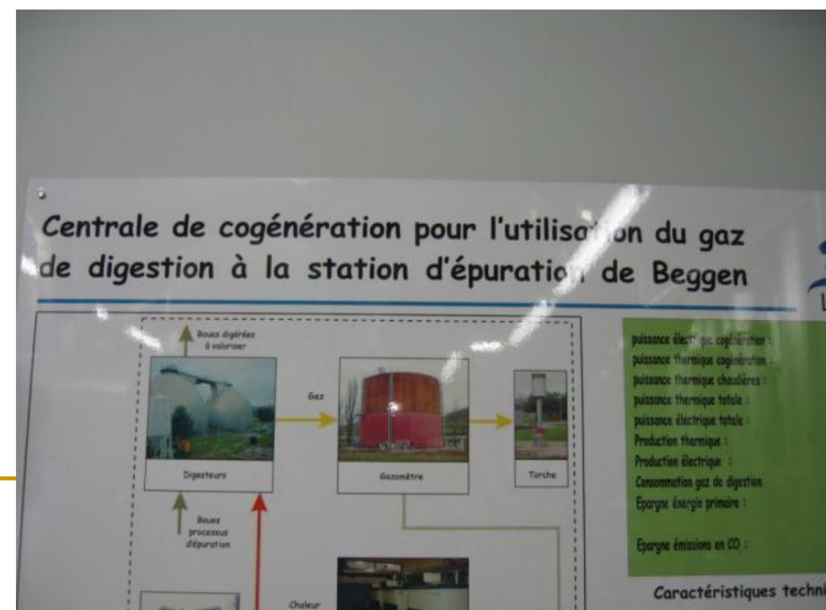
Treatment methods used in a central water purification plant

- **PRIMARY (Mechanical) PURIFICATION:** Sieving and settling coarse material.
- **SECONDARY (biological) treatment**: Bacteria & Micro-organisms
- **TERTIARY TREATMENT:**
  Removing the inorganic salts (mainly nitrates and phosphates). Is very expensive and is not applied often, so *eutrophication* remains a major problem (see theme 4). The purified water (= effluent) is denitrified only in very few stations throughout Europe.

Secondary treatment (= biological treatment by micro-organisms)

Sludge tanks in the purification plant.

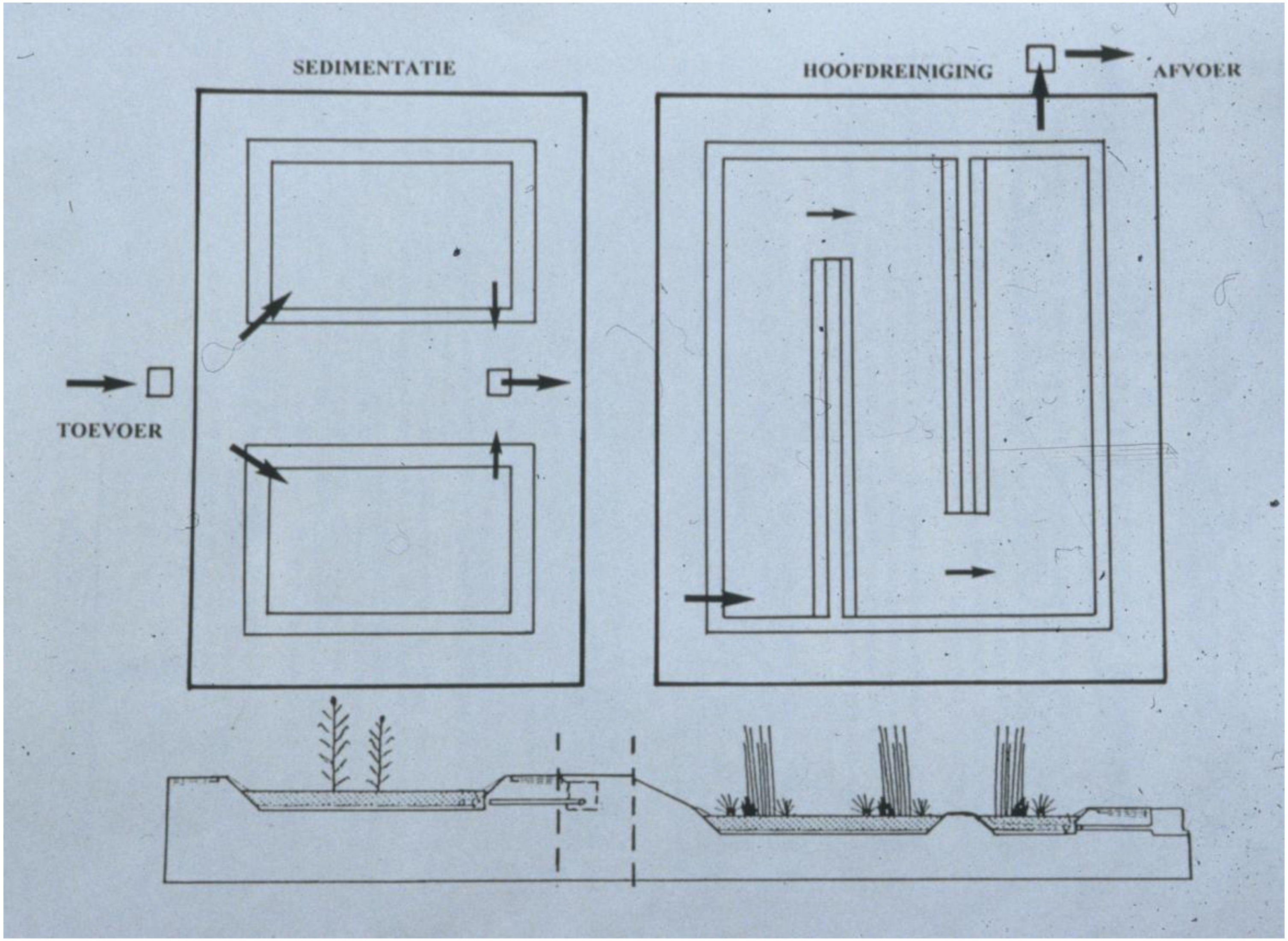
Sludge from wastewater treatment can also be used to extract **biogas** for energy plants (municipality of Luxemburg)



Small scaled marsh plant purification systems (PPS).

De kleine Aarde, municipalities Boxtel (NL) and in Puurs (B)

PPS: principle.



PPS. Hof Van Coolhem, Puurs (B)

The clean effluent might be re-used….

PPS: A solution for isolated dwellings

The purification system has been integrated within the garden (regio Aarschot, B.).

PPS. An appropriate system for do-it-your-self ….

Hamlet hoogheide (Puurs, B) has its own marsh plant purification system.

The municipality of Puurs (B) bought a farmland, removed the soil , placed an EPDMfoil, built a pumping station, planted reed for the PPS and promoted bio-degradable cleaning products

The Flemish Land Agency has built a larger purification system in the municipalities of Huise and of Kruishoutem.

Kolding (DK) Glass pyramid with a marsh plant water treatment system in an urban context

Kolding (DK)

Wadi for infiltration of **<u>white</u>** water

<u>Black</u> and **<u>grey</u>** water are purified in a plant purification system.

Plant purification system in Kolding (DK), in a glass pyramid in the middle of the semi-public garden.

The concept of the waterfootprint.

- See separate ppt presentation (Theme 7)
- www.waterfootprint.org
- Thanks to Professor Hoekstra and Dr. Winnie Gerbens-Leenes from the university of Twente (The Netherlands).
- Thanks to Shabbir H Gheewala, Professor at the Joint Graduate School of Energy and Environment (JGSEE), King Mongkut's University of Technology Thonburi, Thailand