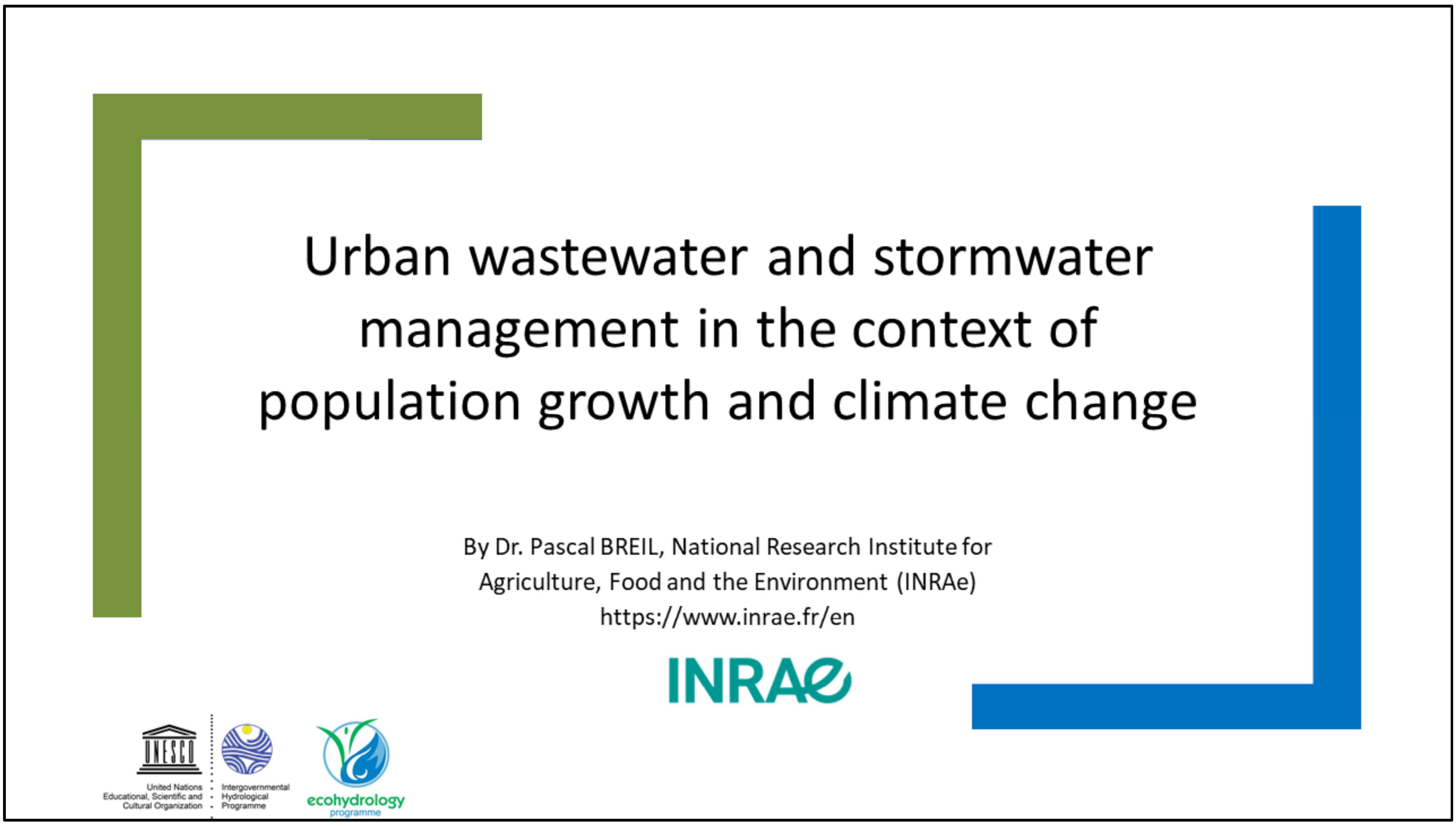
Urban wastewater and stormwater management in the context of population growth and climate change.

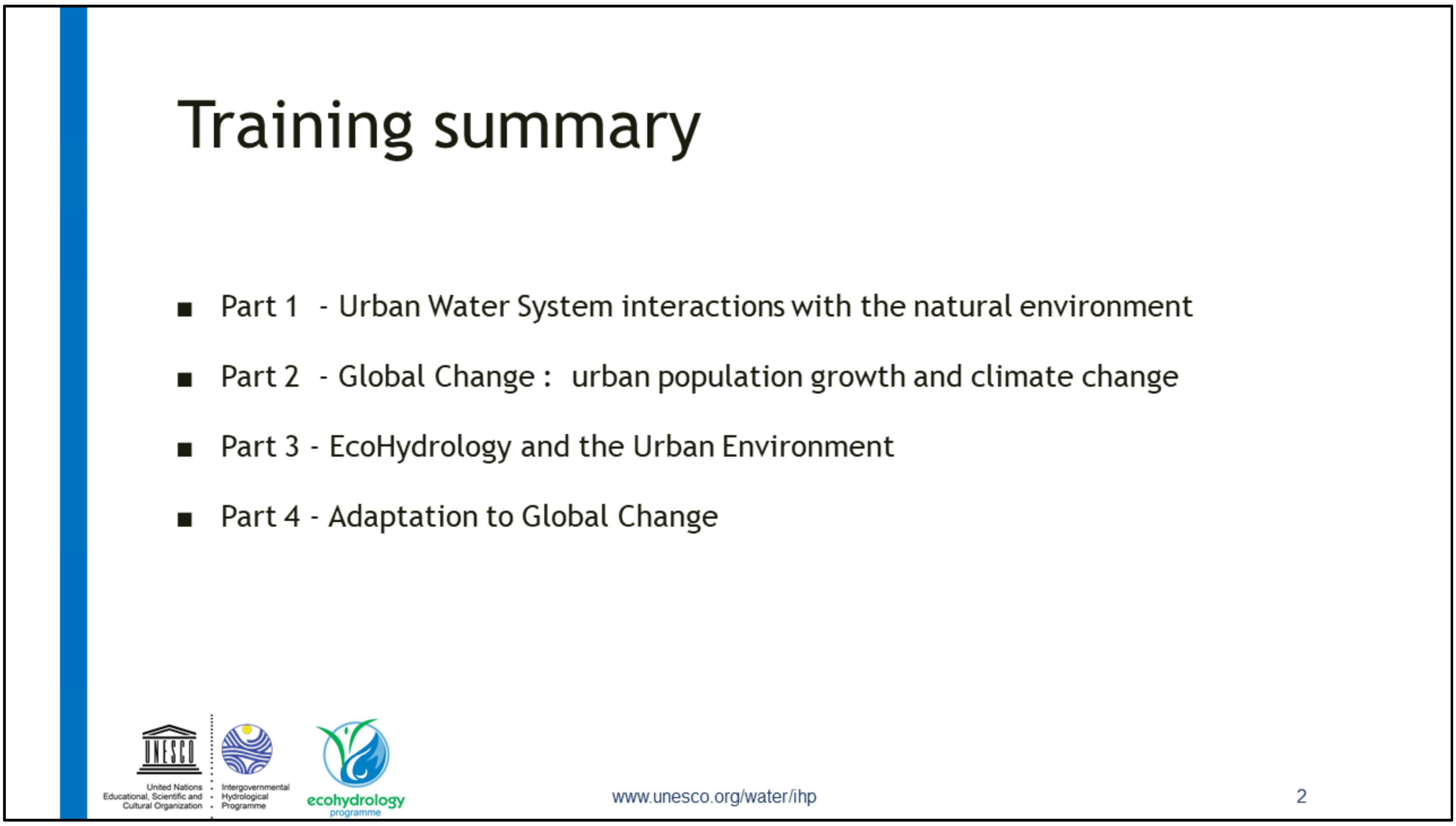
Pascal Breil



Welcome to this training session in Urban Ecohydrology.

My name is Pascal Breil. I am a researcher at INRAe, a French government institute.

I am going to talk to you about problems related to rain and wastewater management in urbanized areas.



The training is organized in 4 parts as follows:

Part1

Urban Water System interactions with the natural environment

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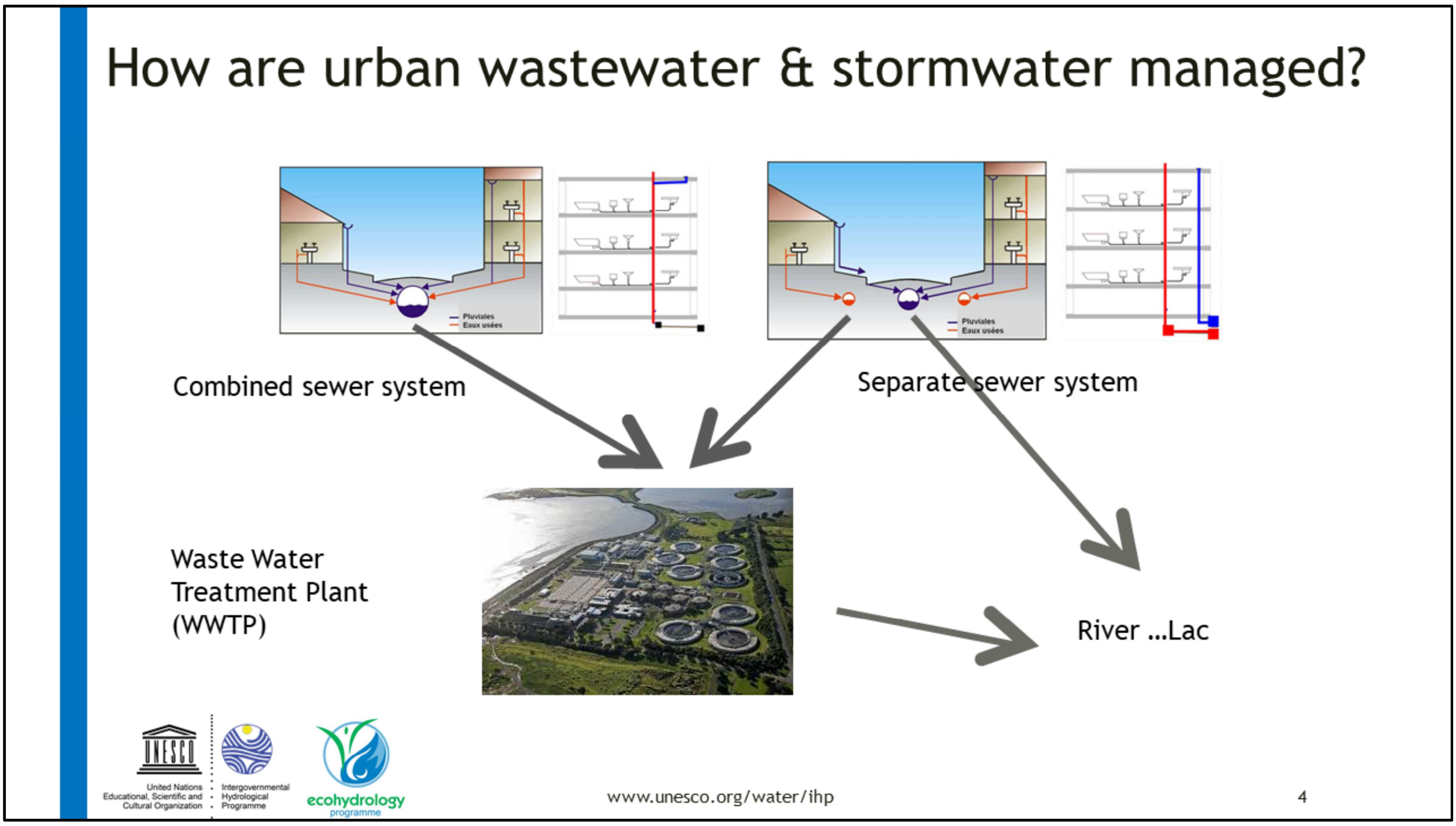
We begin by describing the urban wastewater and stormwater management system



The first thing you need to know is how rainwater and wastewater are managed in the city.

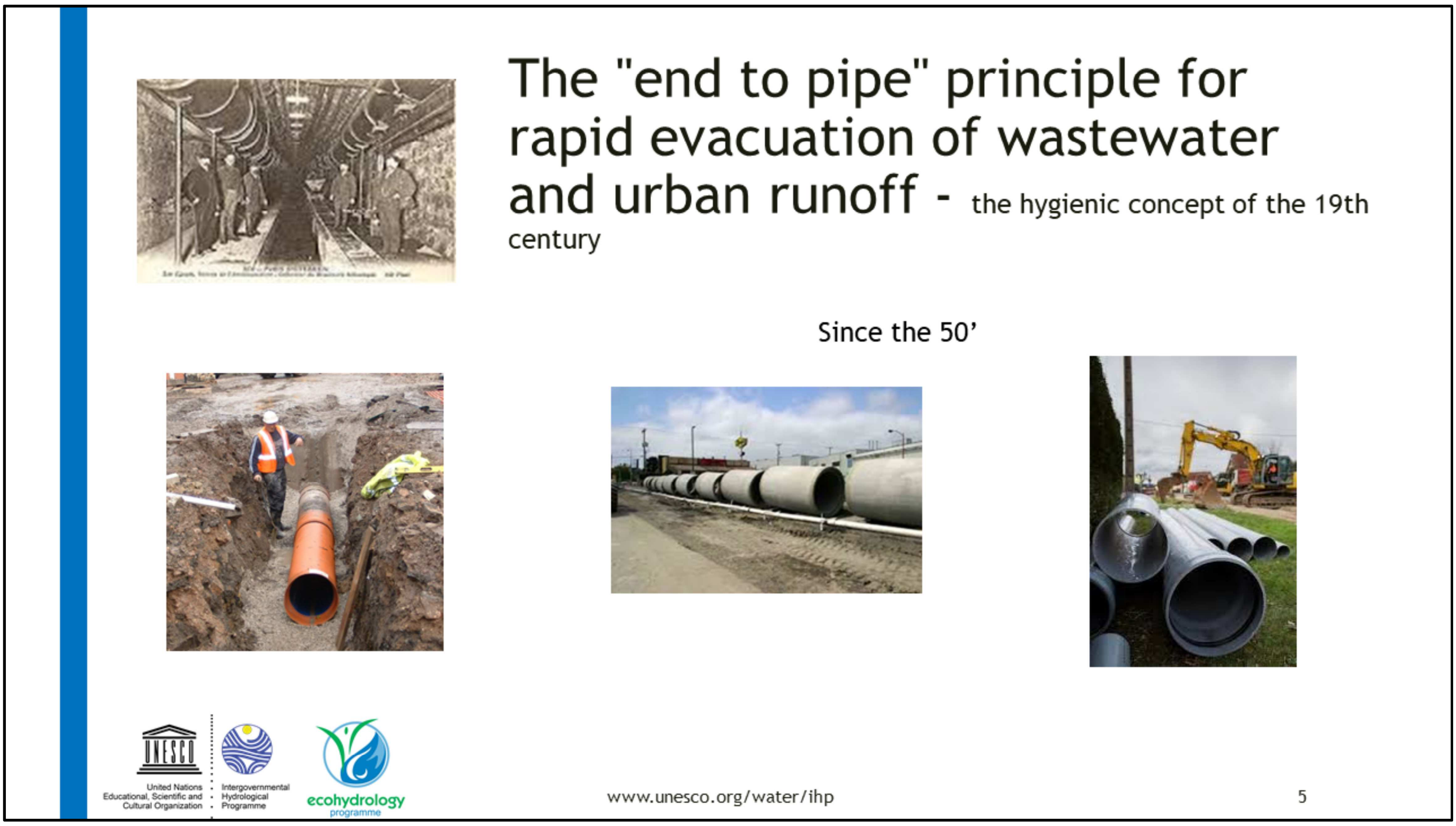
There are two systems of networks that can co-exist:

-The separative network which allows wastewater and rainwater to be collected in two different pipes.

-The combined network that collects rainwater and wastewater in a single collector. It has been the dominant solution during the industrial era for hygienic reason because waste evacuation was facilitated pluvial runoff. It was also the cost effective solution for numerous villages and small towns.

The sewerage network, like the combined network, now usually arrives in wastewater treatment plants.

Strictly rainwater from the separate network is discharged into the natural environment but a settling treatment before discharge is recommended to lower its pollutant load.



Sewerage networks have existed since the 19th century. According to the hygienic principle, the aim was to evacuate urban water as quickly as possible to limit water-born diseases and flooding consequences.

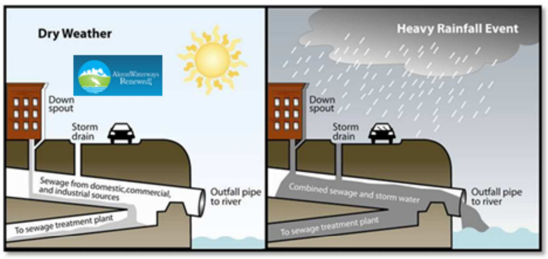
A basic principle in use to convey sewage water and runoff has been the gravity force. The consequence is large pipes are placed in the lowest parts of a catchment, which means along the river network.

Their design has evolved with the passage of time.
The first ones were made of masonry. They were big enough to allow their maintenance by human.

Then in reinforced cement and then in materials more resistant to deformation. The pipes can be buried several meters deep under cities which explain how difficult would be their replacement.

To give an idea, in France the total length of the sewerage network is ten times around the earth (400,000 km). And half of it was laid more than 50 years ago.

Combined Sewer Overflow system (CSO)



As to avoid pluvial flooding of the urban area......
we created CSO systems

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In order to prevent the sewerage networks from overflowing during heavy rains, overflow devices have been designed on the combined sewerage networks.

The principle is as follows: During heavy rainfall urban runoff mixed with wastewater overpasses the pipe designed carrying capacity. As to avoid urban flooding, CSOs' system allow exceeding water to overflows outside of the pipe before it becomes full of water.

The outfalls commonly reach watercourses. They are sometimes equipped with non-return valves to prevent flooding of the network during river floods.

CSOs Problematic

- Combined sanitation systems carry both domestic polluted and rainfall waters during wet weather
- Combined Sewers Overflows (CSOs) are known to impact both biological and physical quality of receiving systems.
- CSOs increase with rapid periurban development where small tributaries are then used to convey polluted overflows
- CSOs are identified as a major degradation source for aquatic ecosystems in USA (Water Act), UK, Canada
- CSOs transfer human pathogens that can persist and alter aquatic life
- The world's Urban population rapid increase (UNEP) in conjunction with climate change is expected to reinforce CSOs overall impact.

- *Refer to publications 8, 9 & 10*

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The general trend of cities expansion has led and will lead to more urban runoff, which in turn require more CSO systems.

This has led to the following problems:….

Point 1: Combined networks convey wastewater but also rainwater soiled by urban surfaces during rainy events.

Point 2: Combined networks overflows in small rivers therefore have a chemical, biological but also morphological impact due to the high peak flows discharged and their low sediment load.

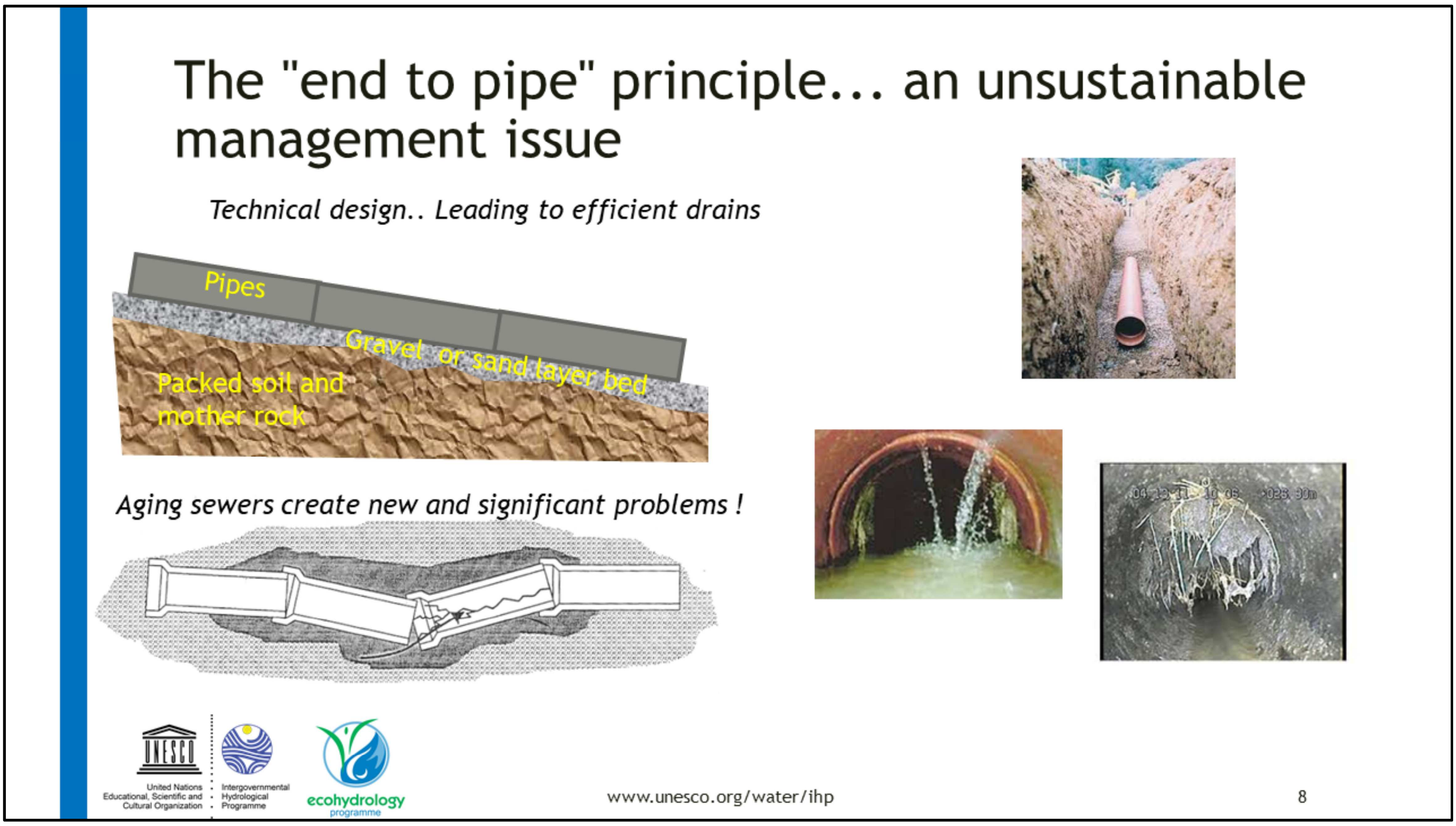
Point 3: Overflows in the combined sewerage system are increasing in frequency and intensity due to urban expansion, as more water has to be passed through the same pipes.

Point 4: Combined sewer overflows are considered major sources of degradation of aquatic ecosystems in several developed countries (USA, UK, Canada).

Point 5: Overflows from combined sewer systems inject human pathogens into small streams with low persistence if dilution is sufficient. Chronically polluted waters become vectors of disease.

Point 6: In some regions of the world, climate change will lead to less but more intense rainfall, which will increase the overflow of combined networks. It should also be considered that longer periods of drought will reduce the dilution capacity of small rivers. As a consequence, CSOs ecological impact should also increase.

To sum up, urban expansion combined with climate change will aggravate the impact of overflow in sewerage systems.

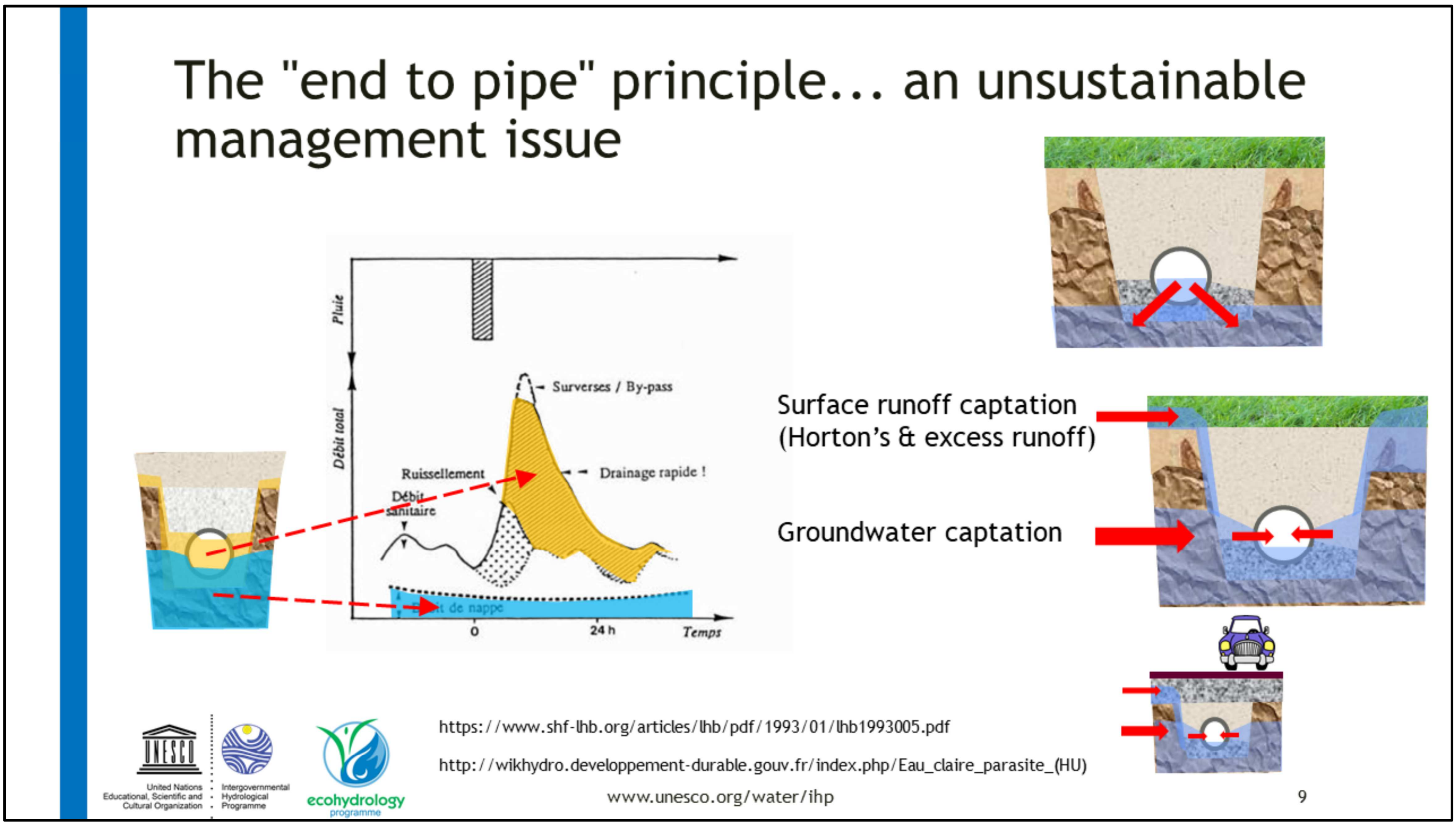


Another element to consider is the ageing of sewerage systems.

Aging sewerage systems are inevitable. With time and the variable stresses on the soil and roots, disjunctions appear between pipe elements. Other leaks are linked to unconventional connections.

Finally, mechanical or chemical corrosion can attack the cement of the pipes that have made up the networks in recent decades.

Roots contribute to limiting the flow capacity. With the loss of watertightness, sewerage networks become drains whose effect is either to pollute the groundwater or to drain it.



It should also be considered that by construction the pipes are laid in trenches whose bottom is filled with sand and gravel to facilitate laying and reduce the risk of breakage.

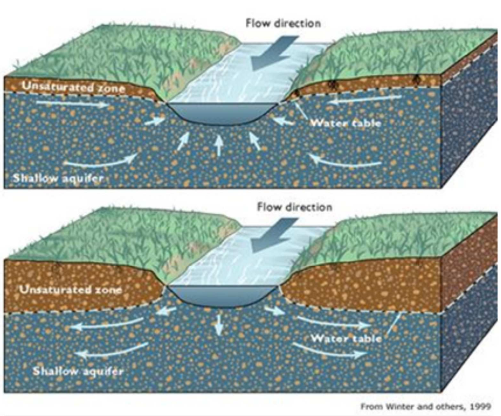
The laying trenches themselves are therefore effective drains for capturing the water table that crosses them. The conditions are such that porous pipes are often pressurized by groundwater.

In these conditions the drainage capacities of the networks are further reduced, which favours overflow during rainy weather.

Moreover, the dilution of wastewater by groundwater and dry weather is detrimental to the operation of the treatment plant.

The cost of rehabilitating sewerage networks is very expensive for urban communities. The "end to pipe" paradigm has therefore lived and a new management paradigm is needed. This will be the subject of the second part of the course.

Urban rivers' fate....what do "we" lost ?



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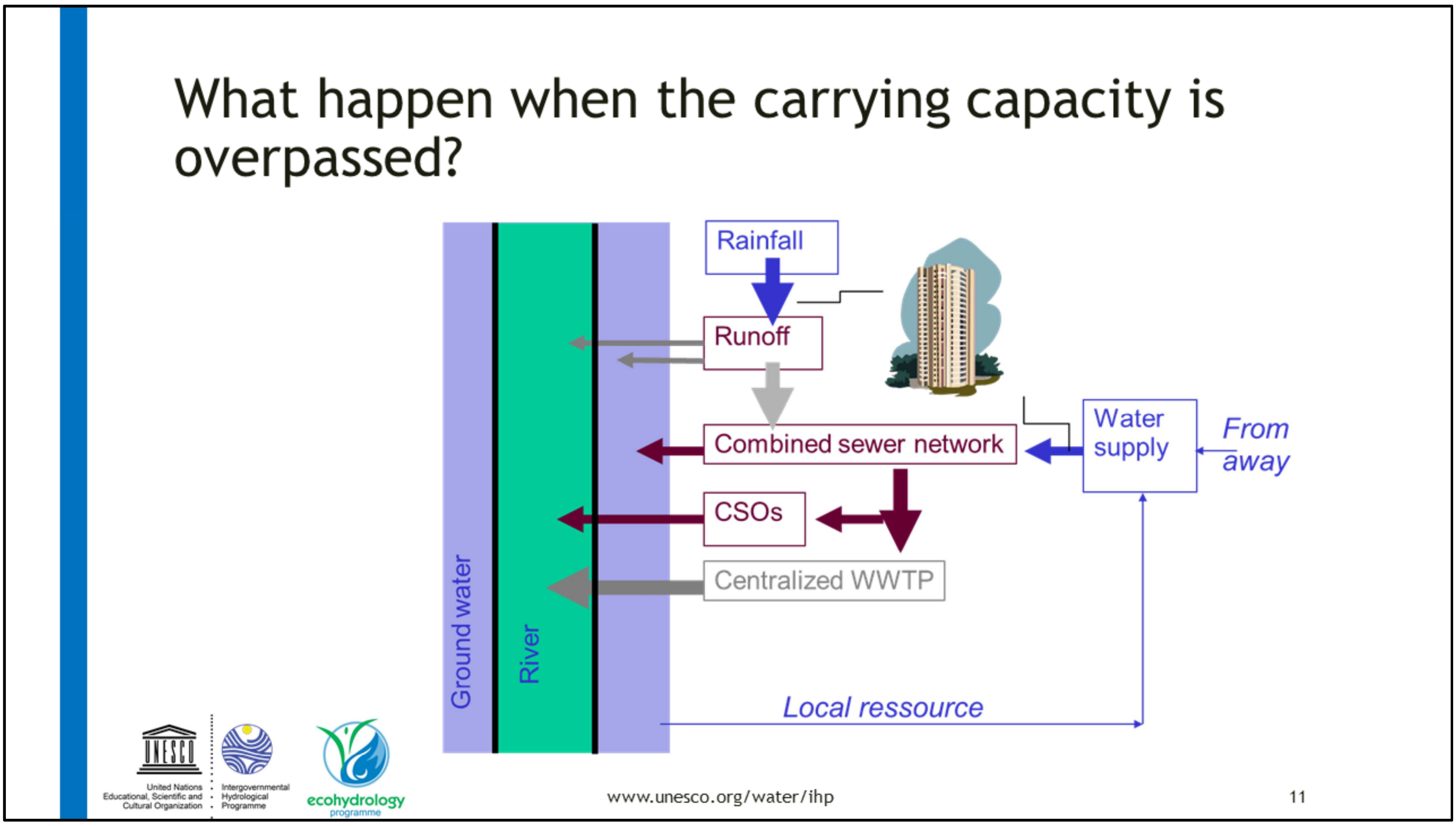
We must also consider the alterations to rivers in urbanized areas:

A natural river is in contact with groundwater. A natural river feeds the groundwater during flood periods.
Groundwater supplies water to the river during low water periods, thus preventing the river from drying up.

To save space, urban rivers have been buried.
To limit their overflows, they were rectified and their beds were concreted. This allowed the flow of water to be accelerated ...
If we compare a concreted river to a natural river, we see that there is no longer a connection with the groundwater.

This has ecological and hydrological consequences.



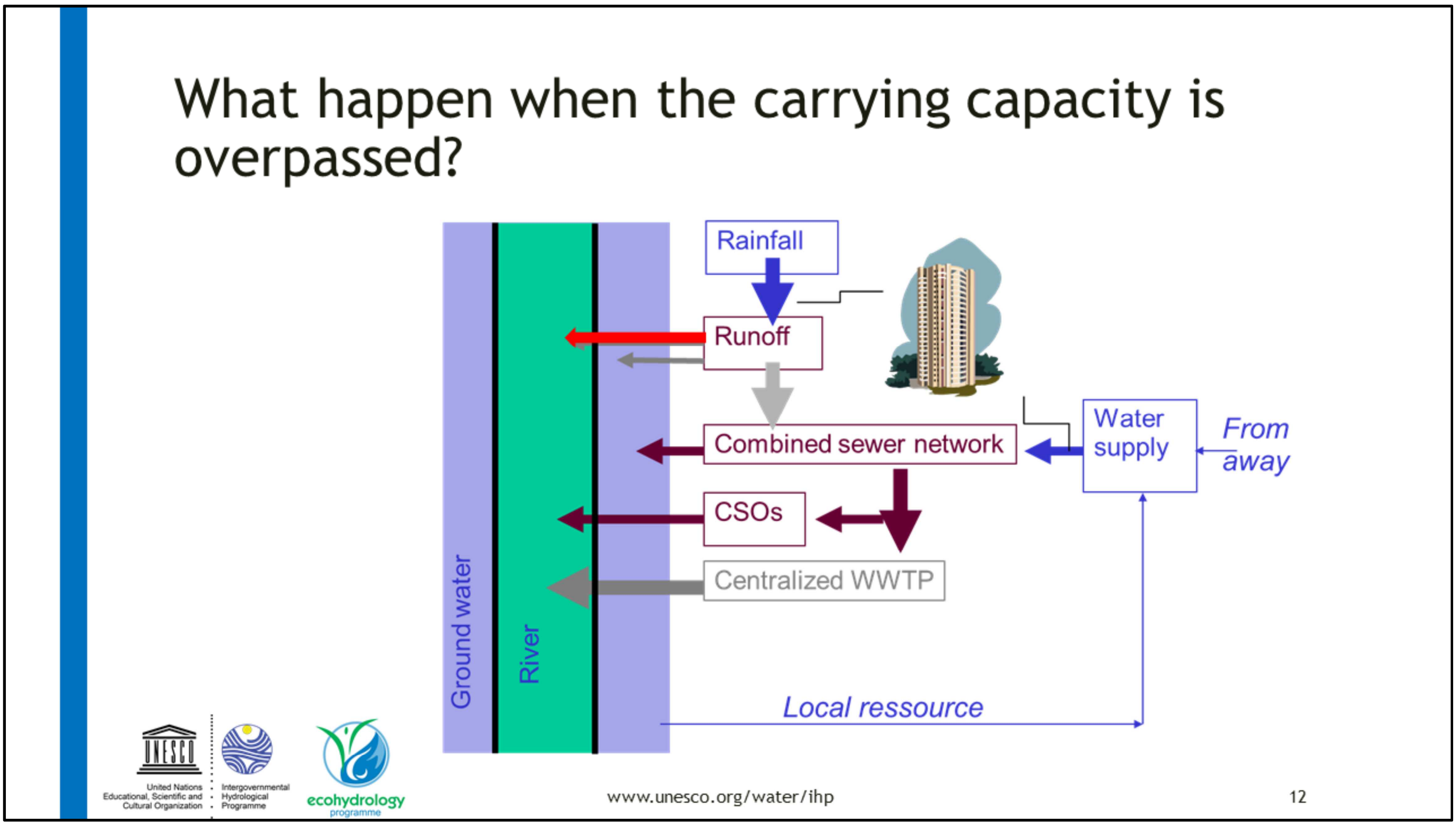
We can see here a diagram representing an urban sewerage system, an urban river and possible sources for drinking water supply.

What happens when the transmission capacity of the sewer system is exceeded?

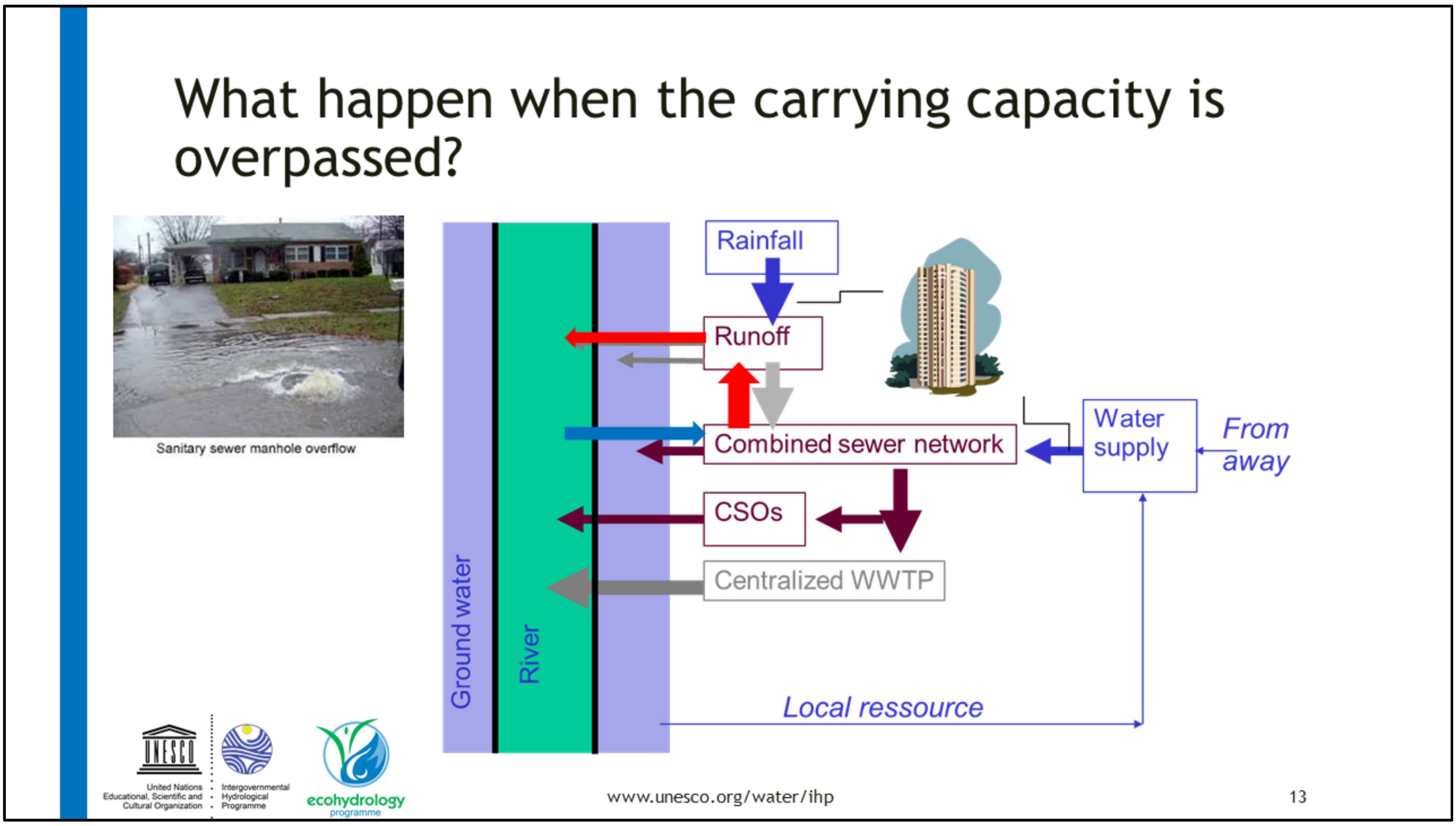
There are three possible causes of overflow, which can be combined:

- intense rainfall
- the reduction of transport capacity by the entry of groundwater into the network
- increased urban runoff

We are going to imagine what happens when the capacity of the sewerage system is exceeded.



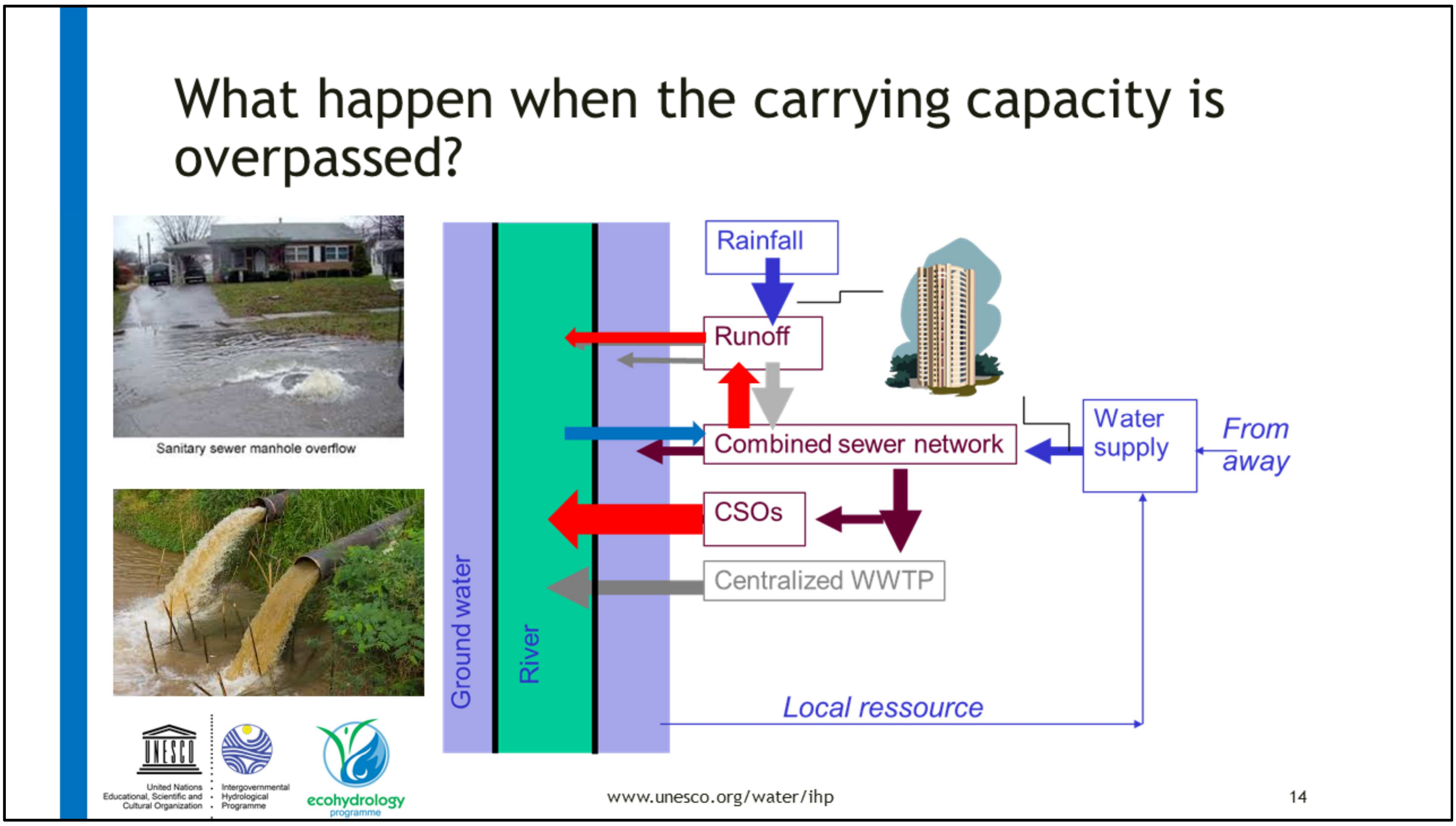
Firstly, urban runoff is increasing and can either reach the river directly or infiltrate into permeable areas and reach the groundwater.



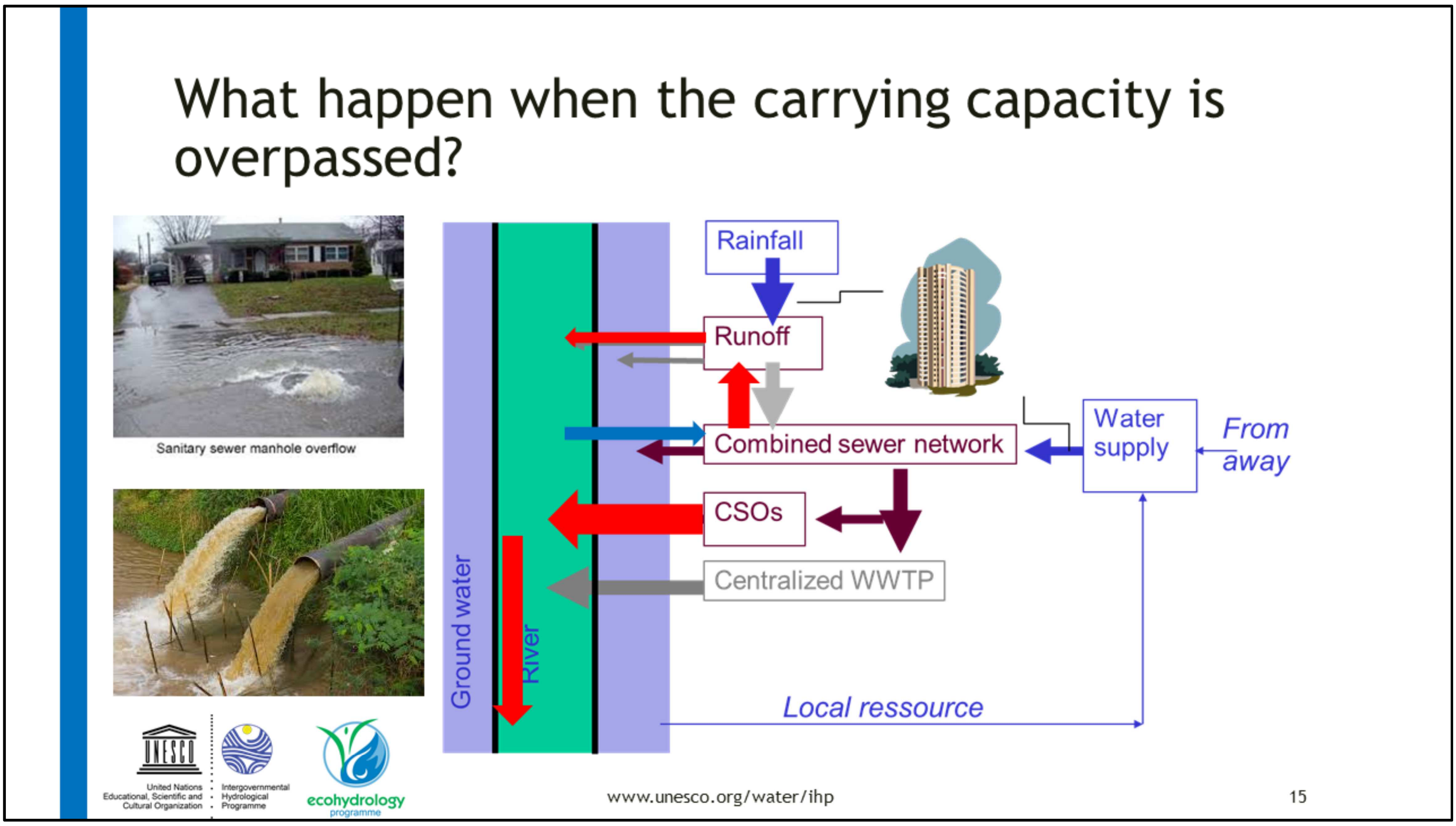
Secondly, the sewerage network overflows:

The runoff mixed with wastewater is discharged directly onto the roads through manholes.

In the event of a concomitant dredge in the river, river water can invade the network and limit its drainage capacity. This has the effect of increasing the rain flood which can no longer be evacuated.

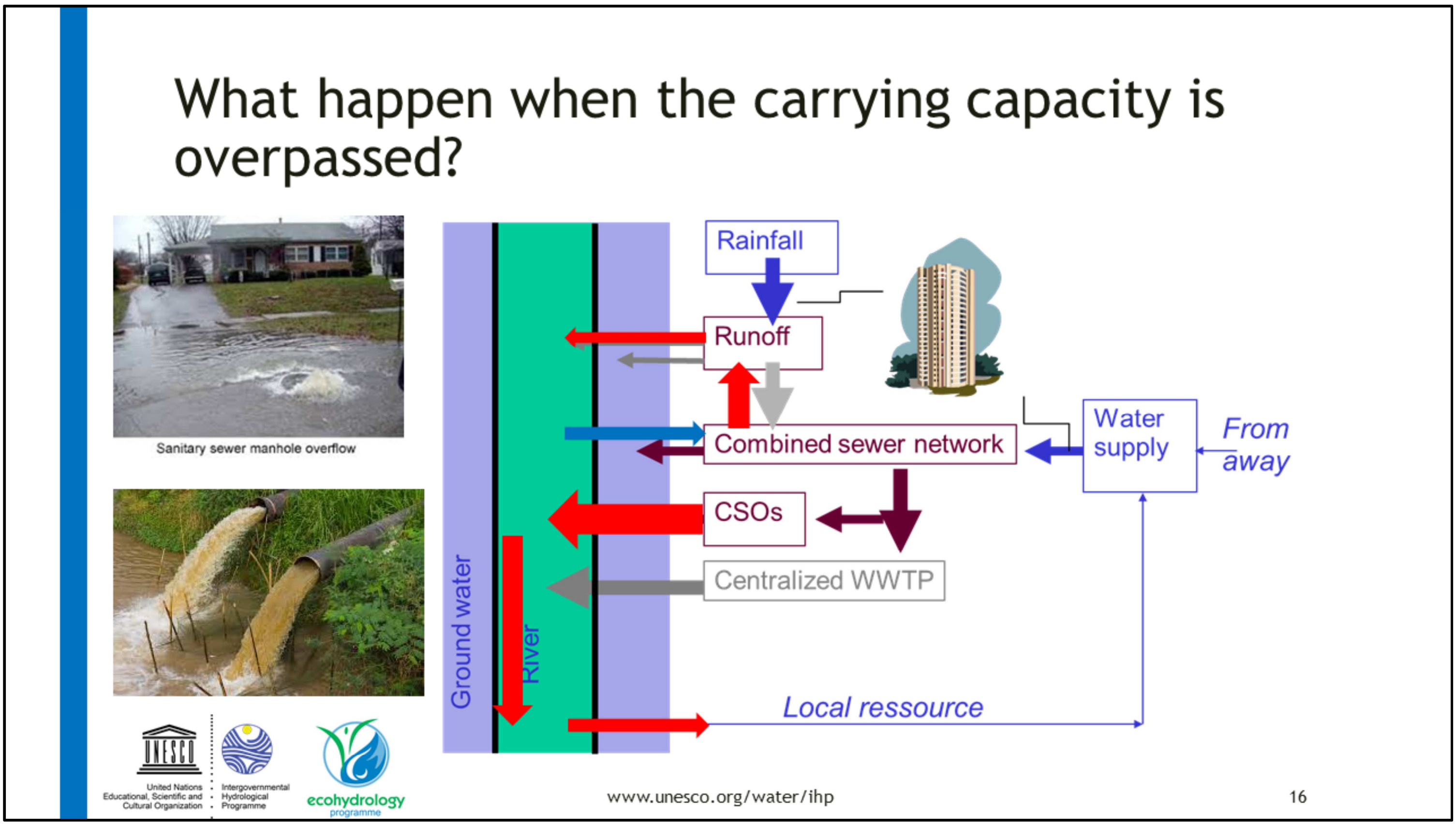


Thirdly, runoff mixed with wastewater is discharged by the CSOs directly into the river.



Fourthly, the polluted water drifts downstream with the current.

It impacts the ecological functions of the river.



Finally, the polluted river water can also reach a catchment of drinking water on the bank located further downstream.

Part 1 : conclusion

Vincent Callebaut's 2050 Vision of Paris

We can summarize the first part of the course as follow:

“the management of urban water by pipes and centralized treatment plants is unsustainable, both economically and in terms of environmental impact.”

The second part of the course is devoted to the analysis of the effect of climate change and urban population growth on pipe-based management.

Part 2

Global change : urban population growth and climate change

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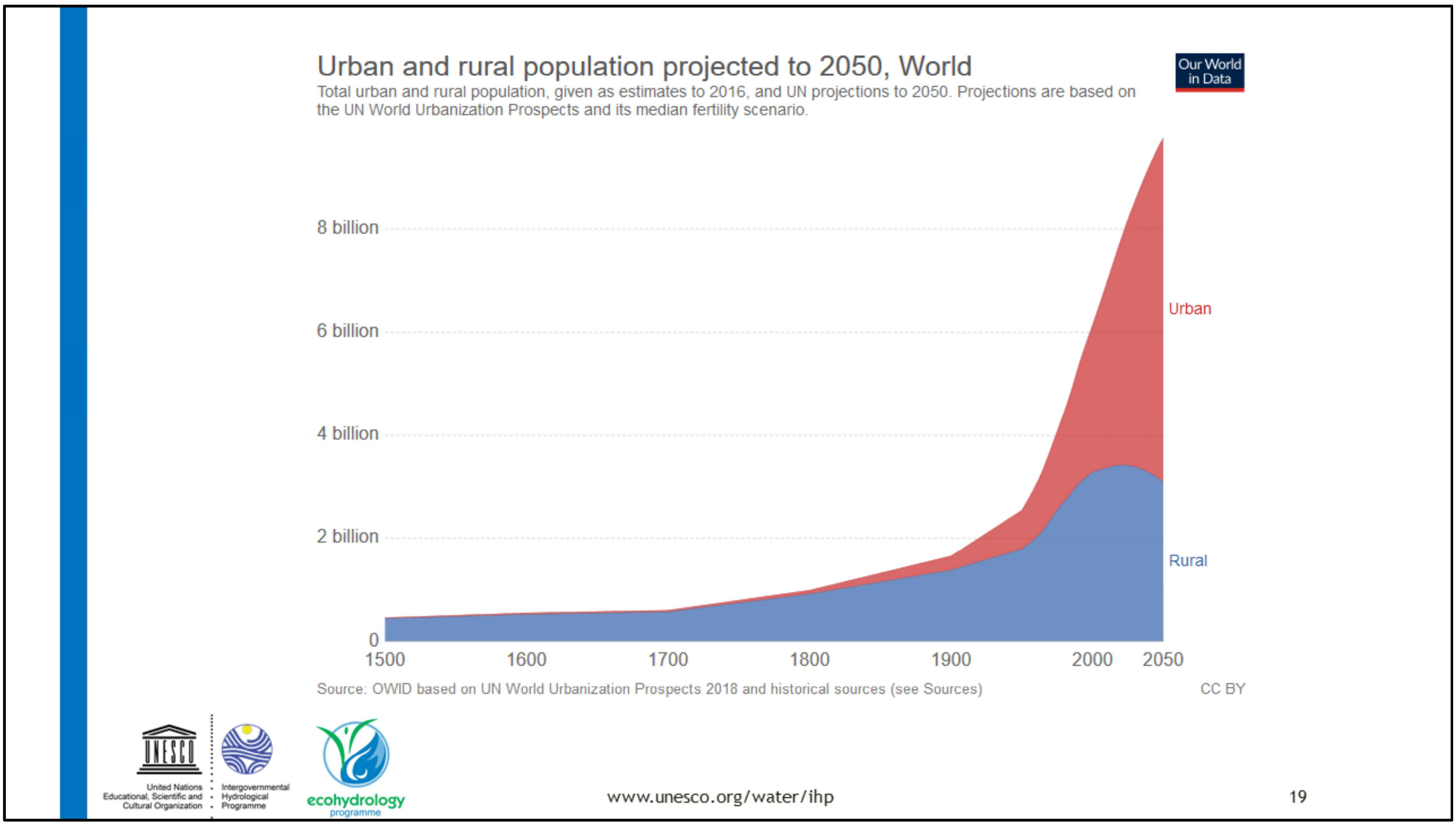
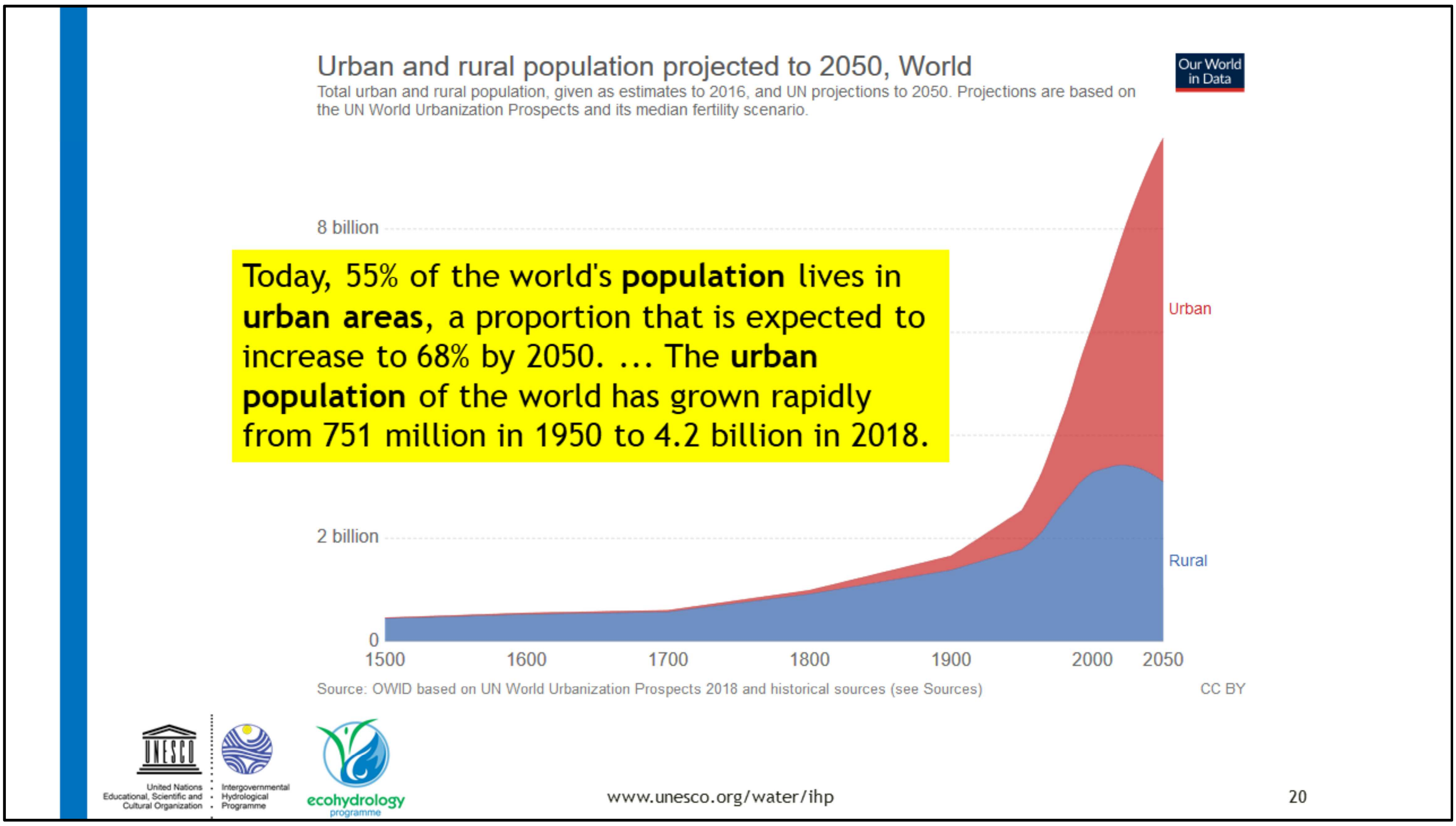


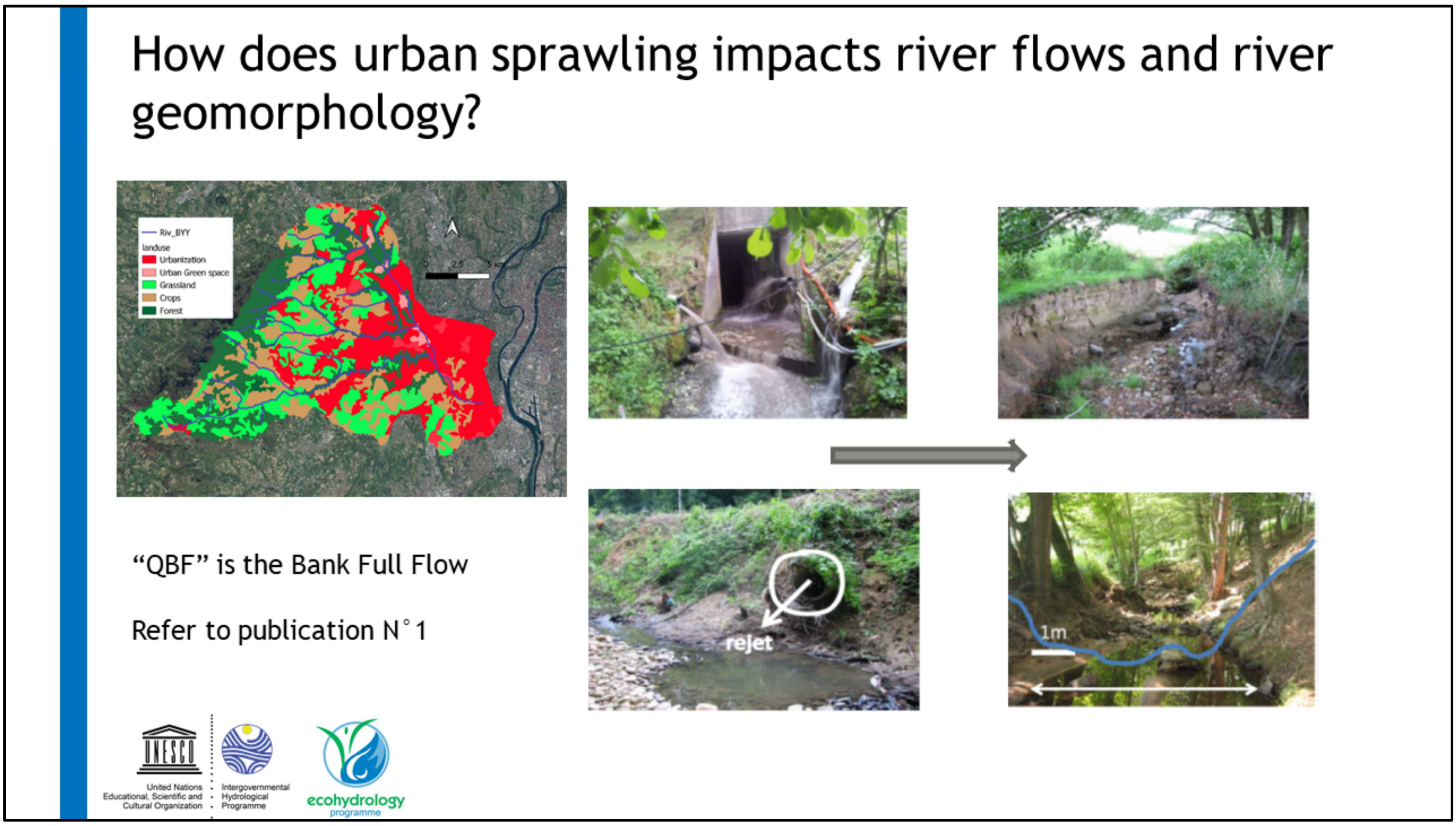
This figure illustrates the world demographic growth distributed in rural and urban population.

We thus see how the problem of urban water management should be considered for the future.



And more precisely:

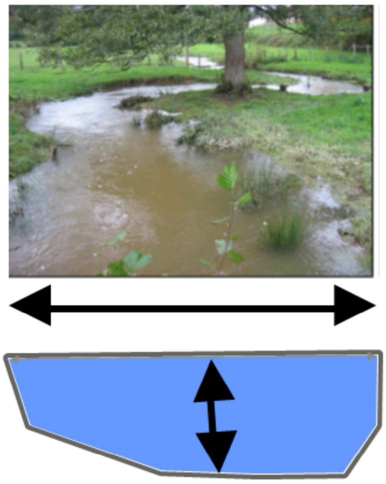
It is predicted that 68% of the world's population will live in urban areas by 2050 !!

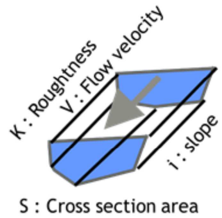


Urban expansion impacts the network of small rivers. This network can represent from 50 to 90% of the length of the hydrographic network depending on the region.

The geomorphological impact reduces the self-purification (ie biodegradation) capacity of rivers. Here we consider some experimental results.

How does urban sprawling impacts river flows and river geomorphology?

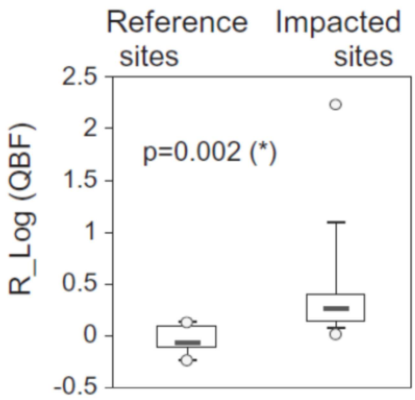




"QBF" is the Bank Full Flow Calculated using the Manning-Strickler equation

$$V = K * Rh^{(2/3)} * i^{(1/2)}$$

$$QBF = S * V$$



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We conducted a hydromorphological study on around forty sections of watercourses. Some were influenced by an urban environment and others in a non-urbanized environment.

One feature of interest is the bank full flow rates. This is the maximum flow that a watercourse can transfer before overflow. The values are normalized by the area of the watershed that is drained by the river section.

The bank full flow without urbanization is very significantly lower than that with urbanization. This shows the strong impact of urban runoff on the geomorphological adaptation of a watercourse.

The associated problem is that this leads to erosion processes that are not in equilibrium with the solid load produced by the non-urbanized part of the watershed.

The consequences are the loss of the hyporehic zone in certain places or the clogging of the bottom by the fall of the banks in other places. The biodegradation capacity of urban rivers is consequently reduced.

Climatic Change ..consequences on urban sewer system and receiving water

- Expected effects
  - *More intense rainfalls*
    - More CSOs
  - *Longer drought periods*
    - Less water into rivers = less dilution capacity*
    - Nutrients flux >> biodegradation capacity!

Refer to publication N°10

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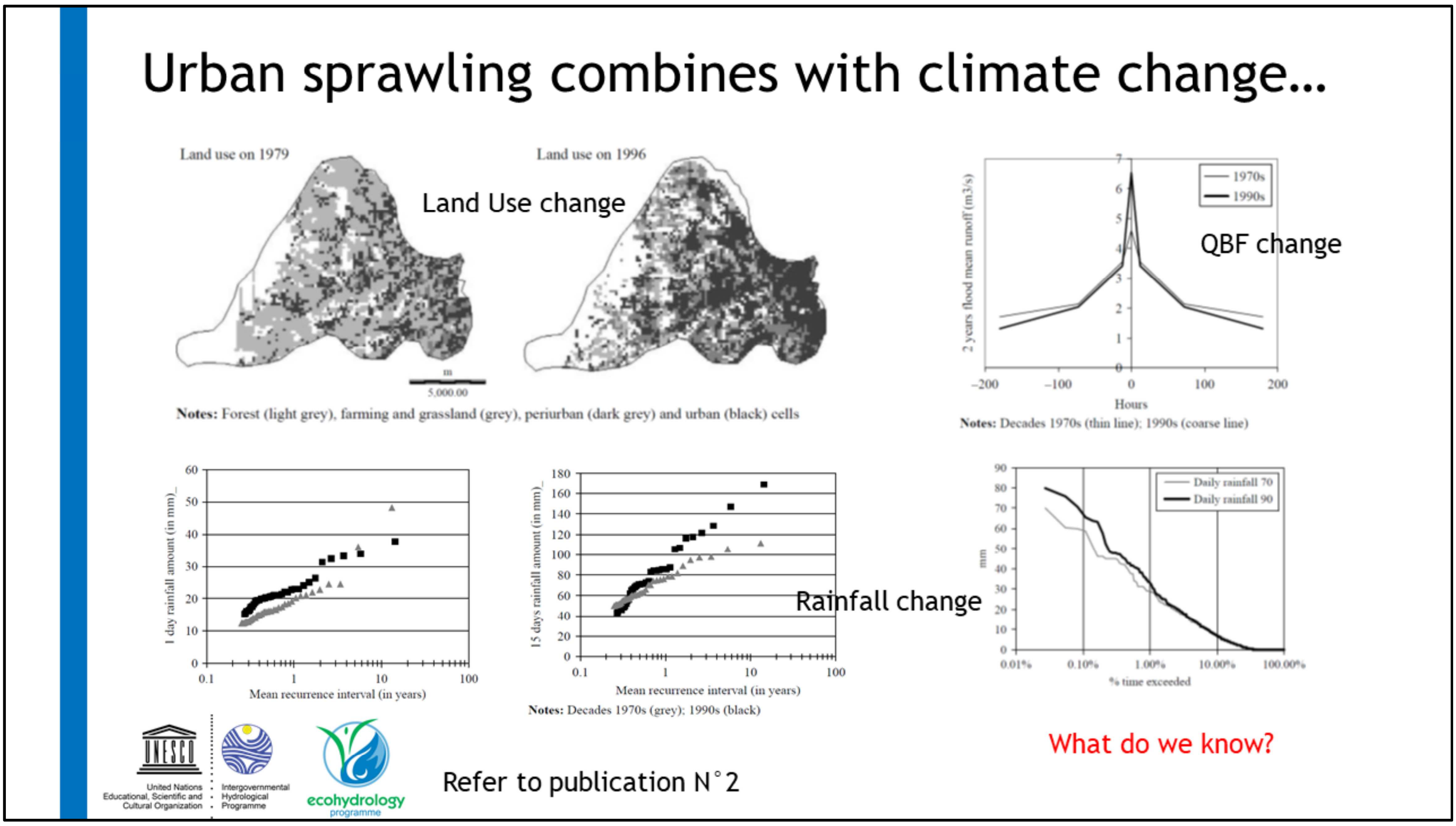
The expected effects of climate change on urban sanitation networks are as follows:

- more intense rains will induce more frequent CSOs because the transport capacities of the networks will be quickly exceeded.

- - longer dry periods will reduce the dilution capacities of polluting flows such as CSOs.

Nutrient inputs will be greater than the biodegradation capacities of small urban rivers.



The consequences of urban development combine with those of climate change.

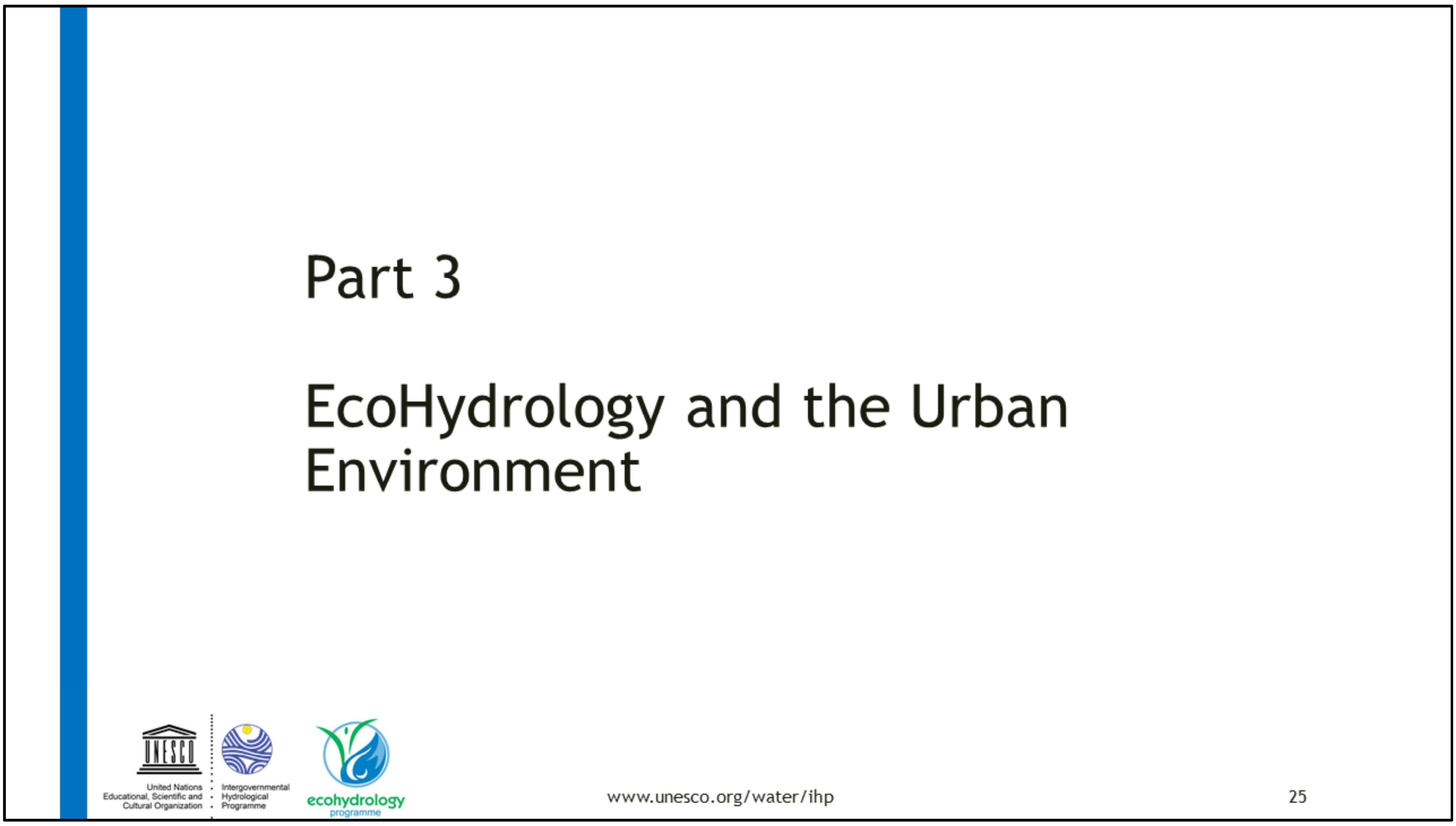
We see here in a watershed of 150 km2 located near Lyon in France how the urabine expansion developed between the 70s and 90s.

We see the evolution of maximum daily rains and maximum cumulative rains over 15 days between the 70s and 90s.

We see that the difference concerns less than 1% of the rains in the 1970s and 1990s.

However, these urban and climatic effects combine together to increase the peak of the full bank flow from 4.5 to 6.5 m3 / sec.

It is difficult to say in what proportion each factor of evolution acts but the geomorphological response of the rivers reflects higher flows for comparable amounts of rain. It is therefore the distribution of rainfall over time and the intensity of urban flows that are the probable causes of this development.



You are probably familiar with the principle of dual regulation which is the basis of operational ecohydrology.

This principle translates the relationships of dependencies and feedbacks between water flows, and what they carry, with the bio-chemical reactions of living systems.

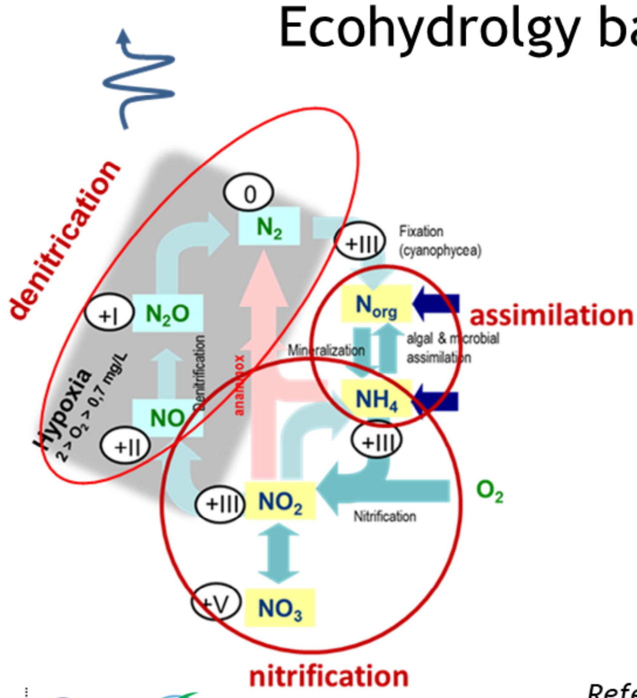
The principle of dual regulation also emphasizes that the directions, intensities and timing of flows condition the dynamics of continental and aquatic ecosystems.

In a natural environment, a dynamic equilibrium is established between the flows, the geomorphological forms that guide the flows and the biocenoses that use and transform the flows.

Human activity modifies these components and creates imbalances as is the case with the impact of CSOs on small urban streams. In order to restore balance in a watershed, it is necessary to identify locations where eco-engineering actions can restore or increase carrying capacity.

This is what we look at in this third section.

Ecohydrolgy basics (I)



Microbial activity depends on ..

- Bacterial concentration
- Nutrient flux & water flow
- Biotransformation kinetic
- Temperature
- Dissolved oxygen
- ....

Refer to publications N°8 , 9

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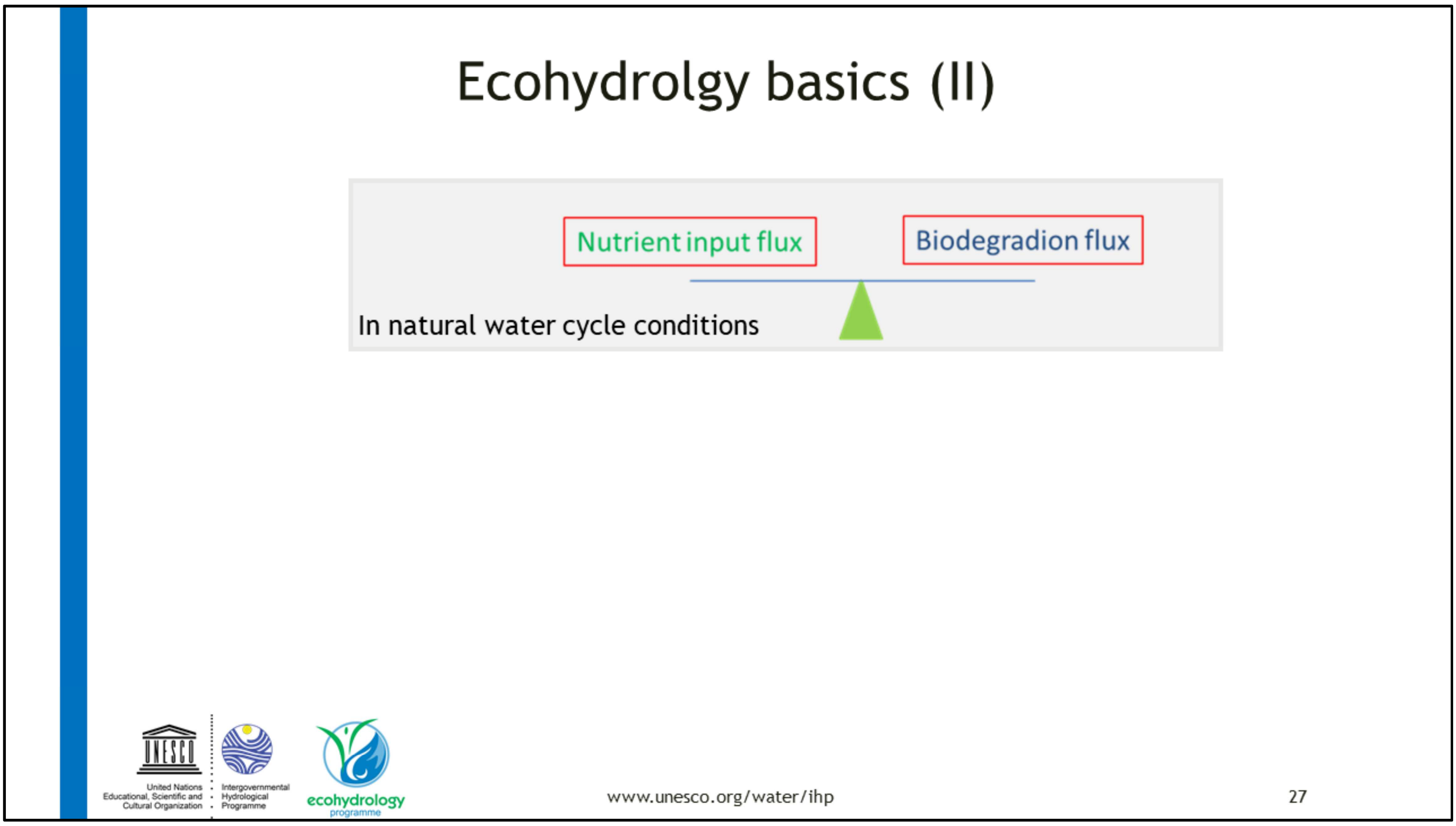
Ecohydrology is based on molecular processes that govern the dynamics of ecosystems.

We look here at the nitrogen cycle. Organic or mineral forms are metabolized by microbial activity, for example to create plant or bacterial biomass.

These organic forms can undergo mineralization which makes them available again in gaseous form with a possible return in the atmosphere.

The dynamics of bacterial metabolism depend on several factors on which eco-engineering actions can more or less act.



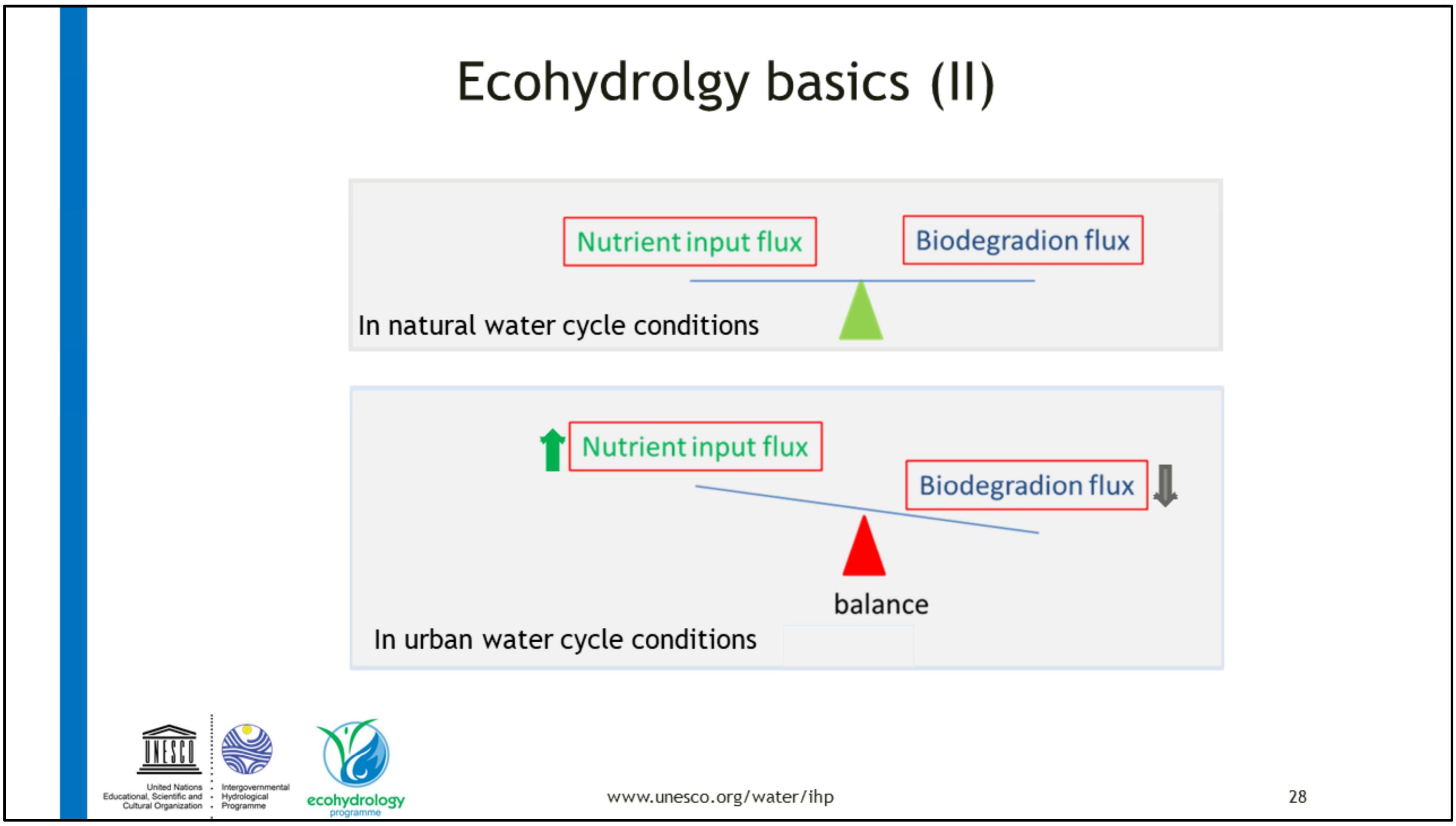
To illustrate the principle of dual control, it is useful to return to the flow equation.

I will discuss it here in an illustrated form.

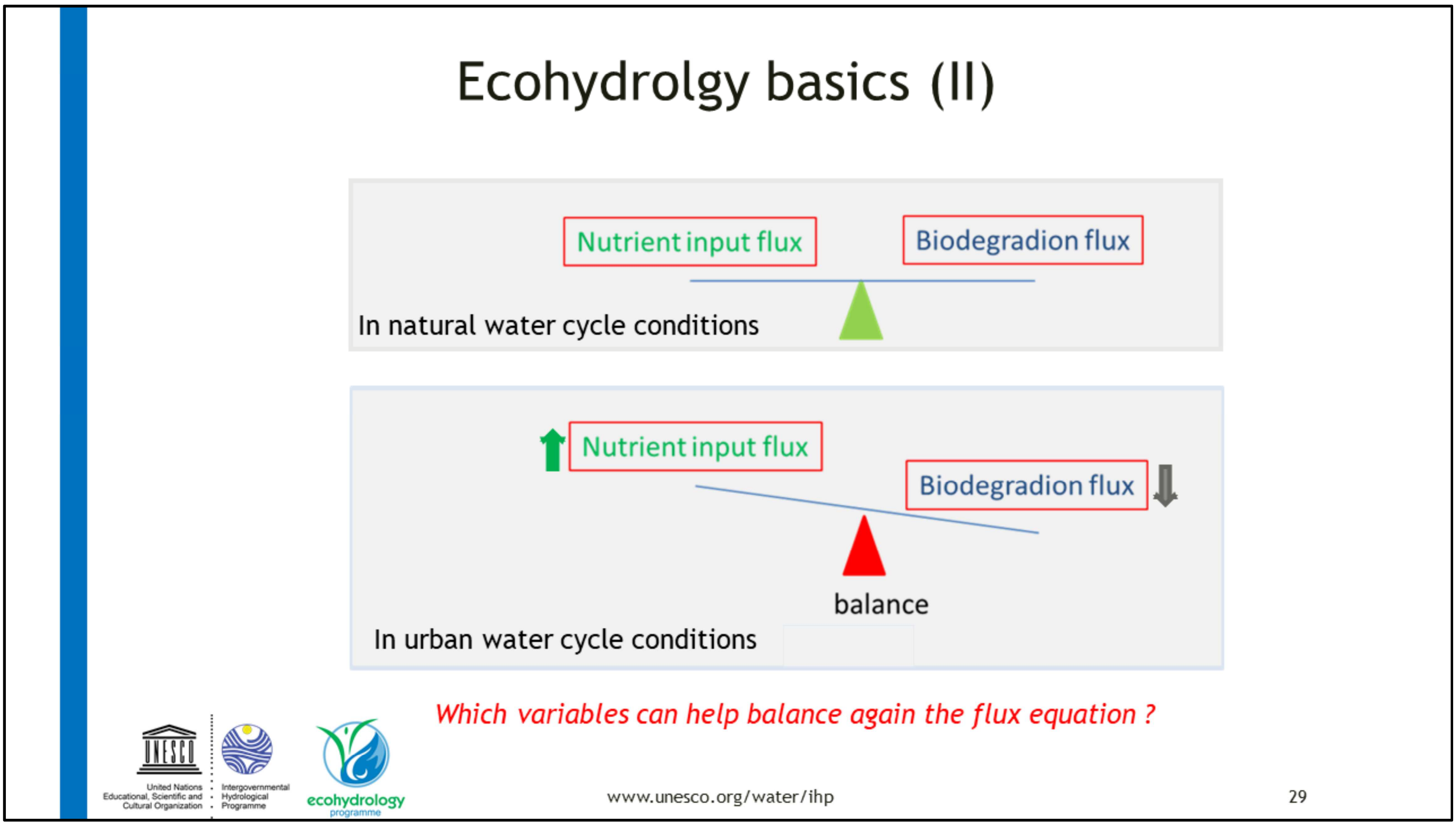
Let's take the example of the biodegradation of organic matter: in urban streams, the massive input of organic matter by CSOs is a factor of imbalance of the dual regulation.

The other factor is the morphological deterioration of urban watercourses due to calibration and rectification.

Under natural conditions, nutrient fluxes are in balance with biodegradation fluxes.



Now if we consider the excess of nutrients and the alteration of the biodegradation capacity for geomorphological reasons, an imbalance appears.



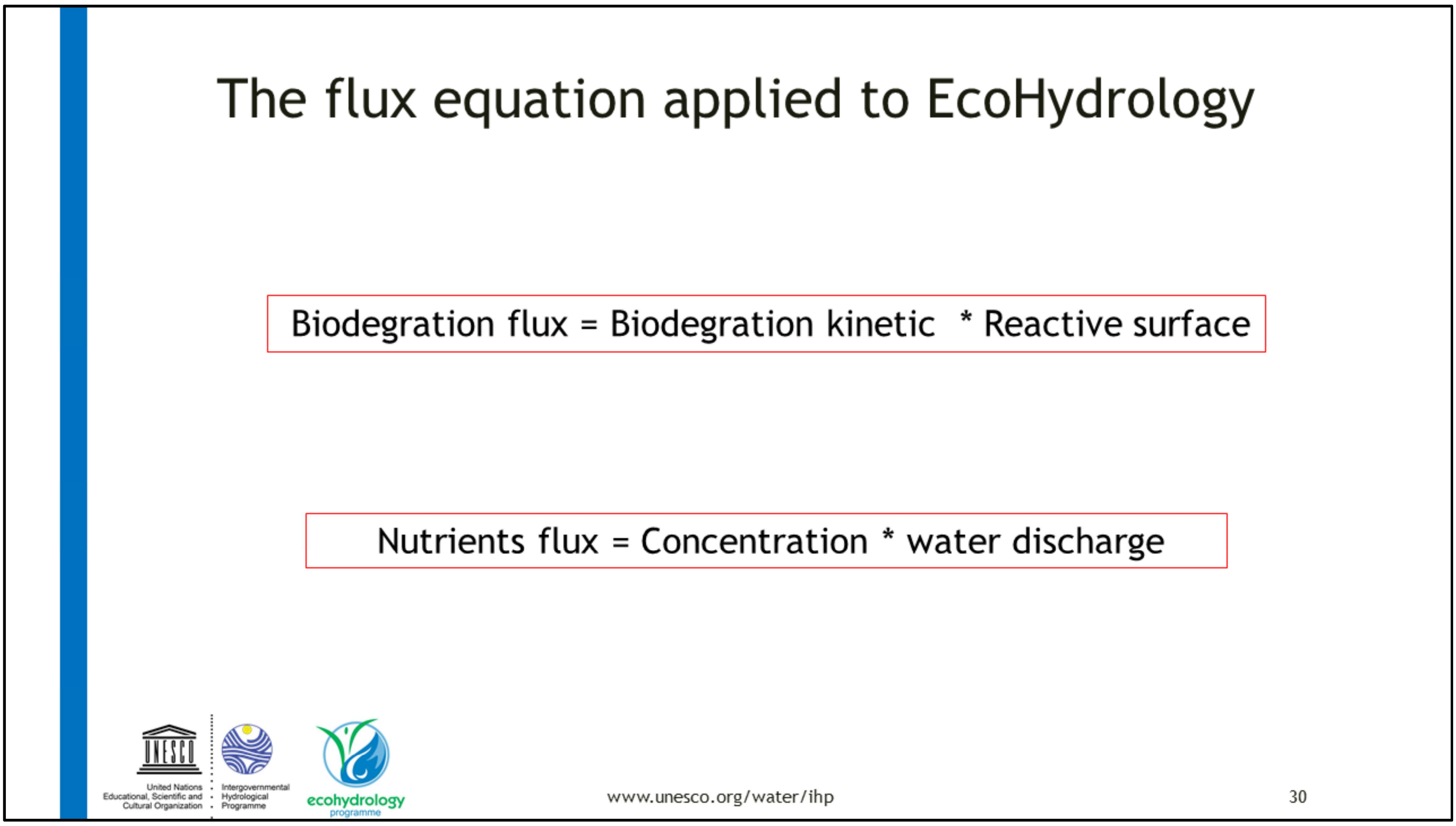
The question is what variables or factors we can act on?

We can also imagine reducing nutrient inputs.
This is a long term solution because the restructuring of degraded sewage systems is costly.

The other way to reduce nutrient inputs is to develop water eco-engineering solutions at the source, but this requires changes in regulations and land management practices.

Finally, global change, as we have seen, tends to accentuate imbalances.

We therefore consider solutions closer to the watercourse.

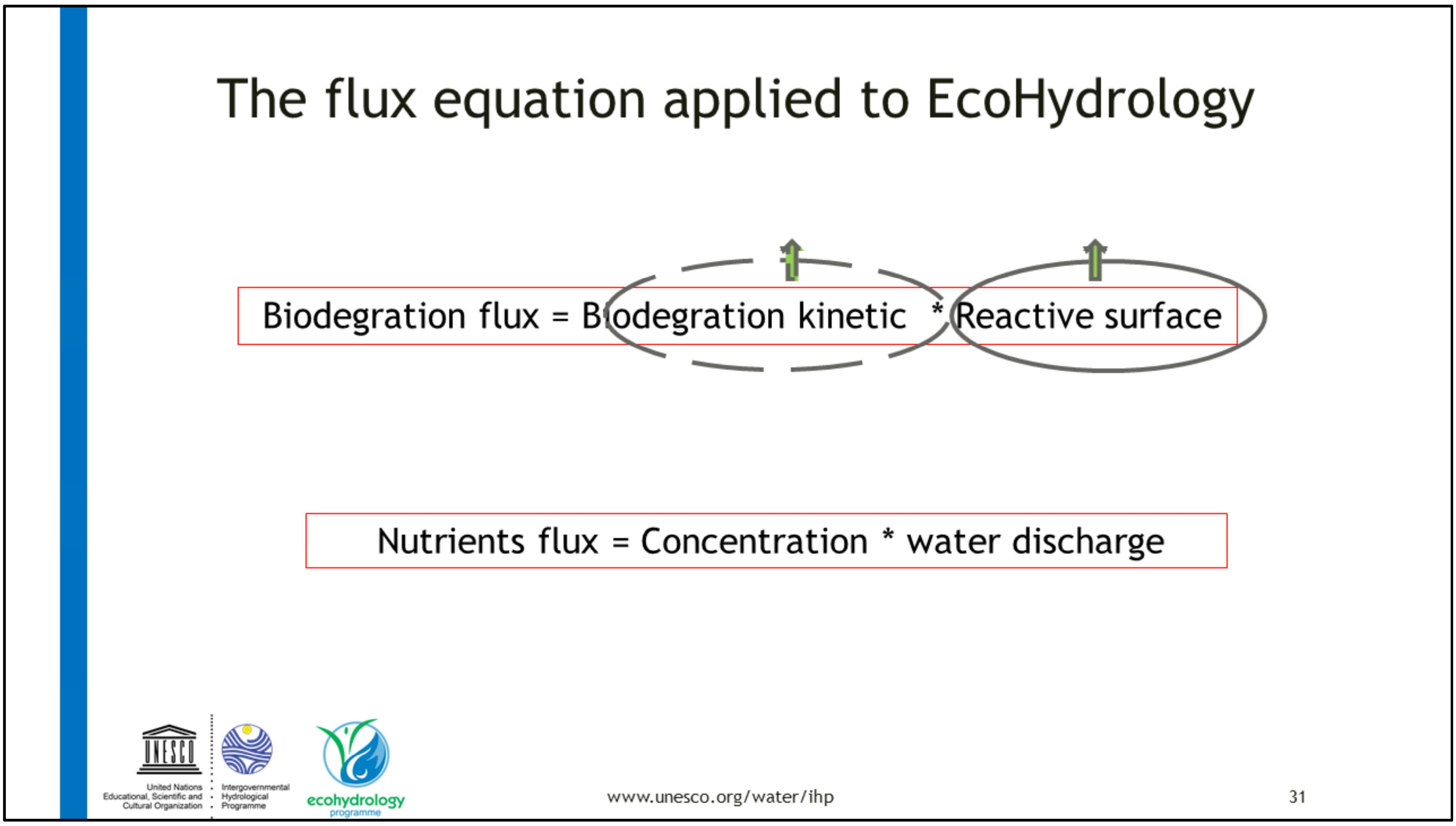


The flow equation applied to ecohydrology can be summarized as follows:

The biodegradation flux is equal to the product of biodegradation rate and biochemical reaction area.

The nutrient flux is equal to the product of the nutrient concentration and the water flow.

The water flow rate is itself a flow rate resulting from the product of the water velocity by the surface crossed by this velocity.



o return to the equilibrium...

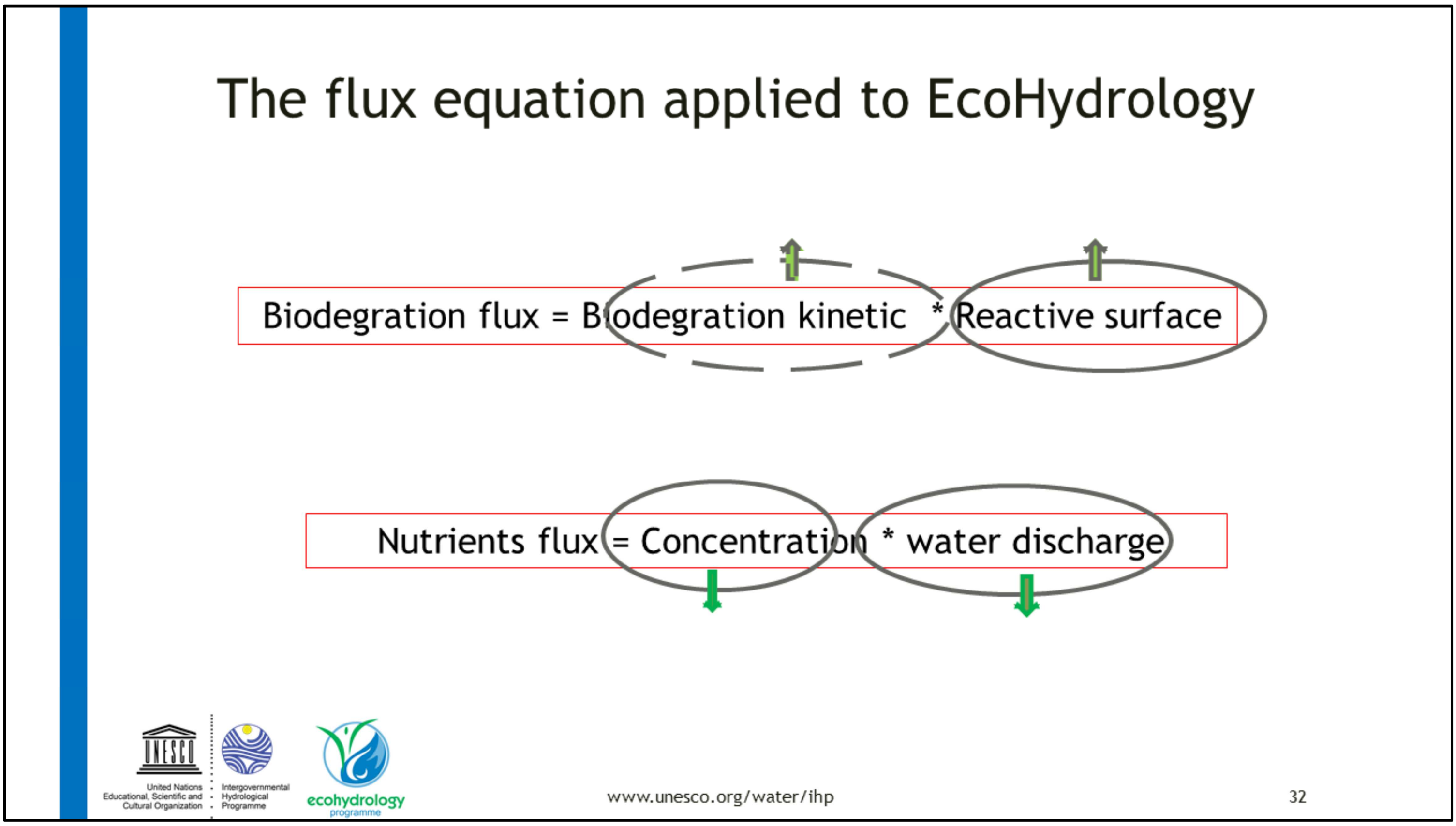
We can increase the flow of biodegradation, for that we can increase the kinetics of biodegradation and , or , the surface of biochemical reaction.

The kinetics of biodegradation depends essentially on the temperature. The bacterial activity is slow below 12°C . Above it grows exponentially. We cannot act directly on the temperature in natural environment.

However, the urban environment influences the temperature of the water discharged by the CSOs. In winter, rainfall runoff on cold surfaces will lower the temperature of the river water. In summer it will be the opposite.

One way to delay this effect is to use the hyporheic zone of the streams as a biodegradation device. This is already the case in natural operation but it is possible to amplify the passage of nutrient flows in the hyporheic environment by acting on the morphology of the watercourse.

We can thus increase the surface of biochemical reaction and take advantage of a more stable temperature in winter and more quickly warm in summer because of the temperature of the CSOs.



To return to equilibrium...

We can reduce the flow of nutrients, for that we can decrease the concentration and, or, reduce the water flow.

These actions are related to the management of runoff at the source.

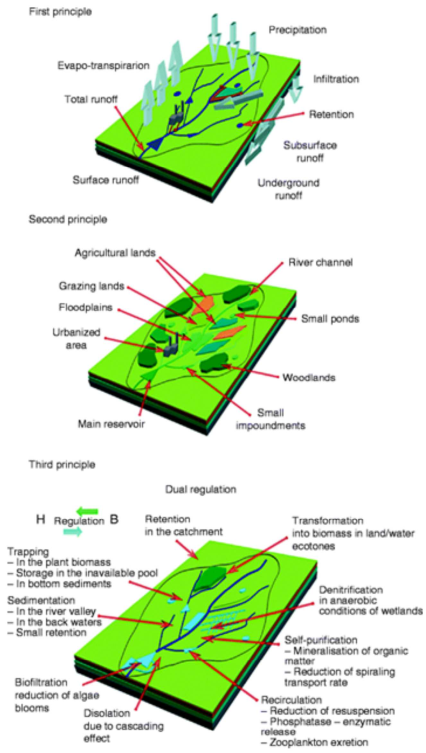
The objective is to reduce the flow of water in combined sewer systems.

Urban runoff is infiltrated as soon as possible or returned to the watercourses through a strict stormwater network but after treatment by bio-filters to reduce urban pollution.

From molecular to basin scales

The fundamental principles of EcoHydrology are to balance, at the watershed scale, the flows of water and nutrients (and pollutants) associated with natural bio-transformation flows. In the case of a bio-transformation capacity degraded by man, it must be restored or amplified by eco-engineering devices placed along the water's paths.

The main natural bio-transformation systems are wetlands, riparian corridors and the hyporheic zone. They are called metabolism "hot spots" (ref@end).The identification of these "hot spots" in a catchment area is an important factor in developing a management plan for the river basin.



Refer to publication N° 4, 5, 6, 7

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We focused on the ecohydrological approach of urban rainy weather discharges. Balanced management must however be understood at the scale of a watershed identifying areas of imbalance and areas of natural recovery.

To do this, it is necessary to understand the circulation of flows in time and in the space of the watershed (first principle).

Then, it is necessary to identify the functionalities of the various ecosystems, natural and human influenced, which will be sources either of imbalance, or of restoring balance (second principle).

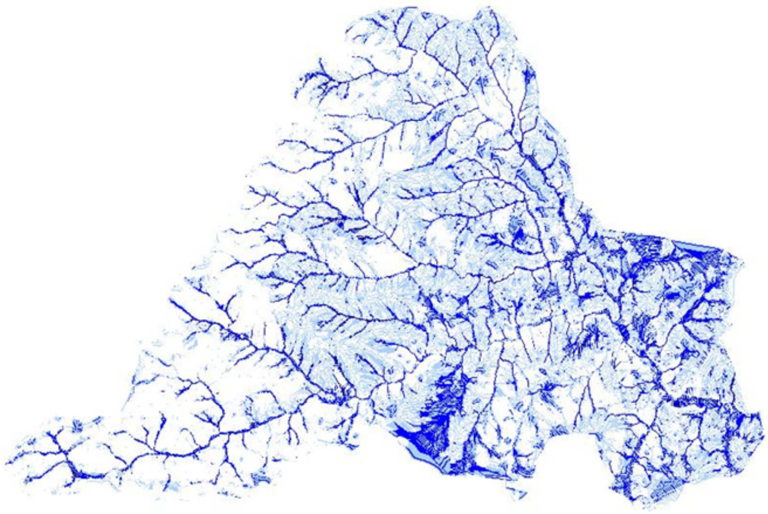
Finally, the crossing of the two previous maps makes it possible to identify the strategic places of action to develop actions of :

- restoration or amplification of natural functions
- - or reduction in the flow of nutrients and excess pollution,
- - or protection of natural recovery systems.

This is the principle of dual regulation.

Urban EcoHydrology : Basin scale vision

A PLUVIAL RUNOFF MODEL CAN HELP IDENTIFY WHICH PART OF THE BASIN IS MORE PRONE TO ACCUMULATE WATER; POTENTIEL HUMID ZONE CAN BE IDENTIFIED



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To illustrate this approach, we take the case of a peri-urban watershed, already seen in this presentation.

In order to understand where the surface water passes, it is useful to have a vision of the runoff flows in the watershed.

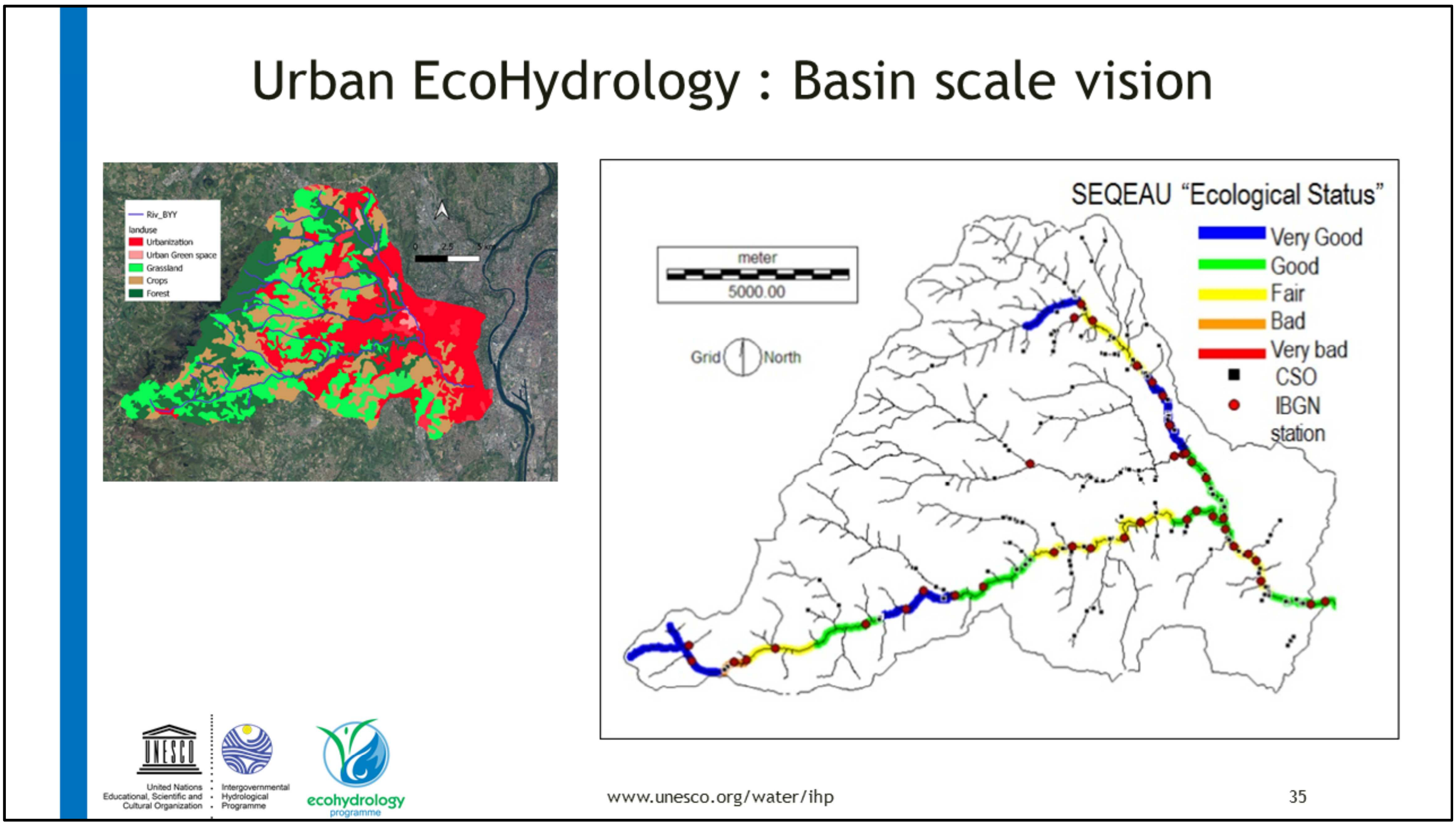
The following map illustrates such a result. Some part of the watershed will run off little due to forest cover or permeable soils.

Others will run off heavily like urbanized areas.

Others will concentrate the runoff in rural areas and will thus favor wet areas and wetlands.

Wetlands are powerful reactors of biodegradation. Their identification and protection are part of the dual regulation in a watershed.

This illustrates the first principle.



To illustrate the second principle, is it interesting to consider land uses and river ecological status.

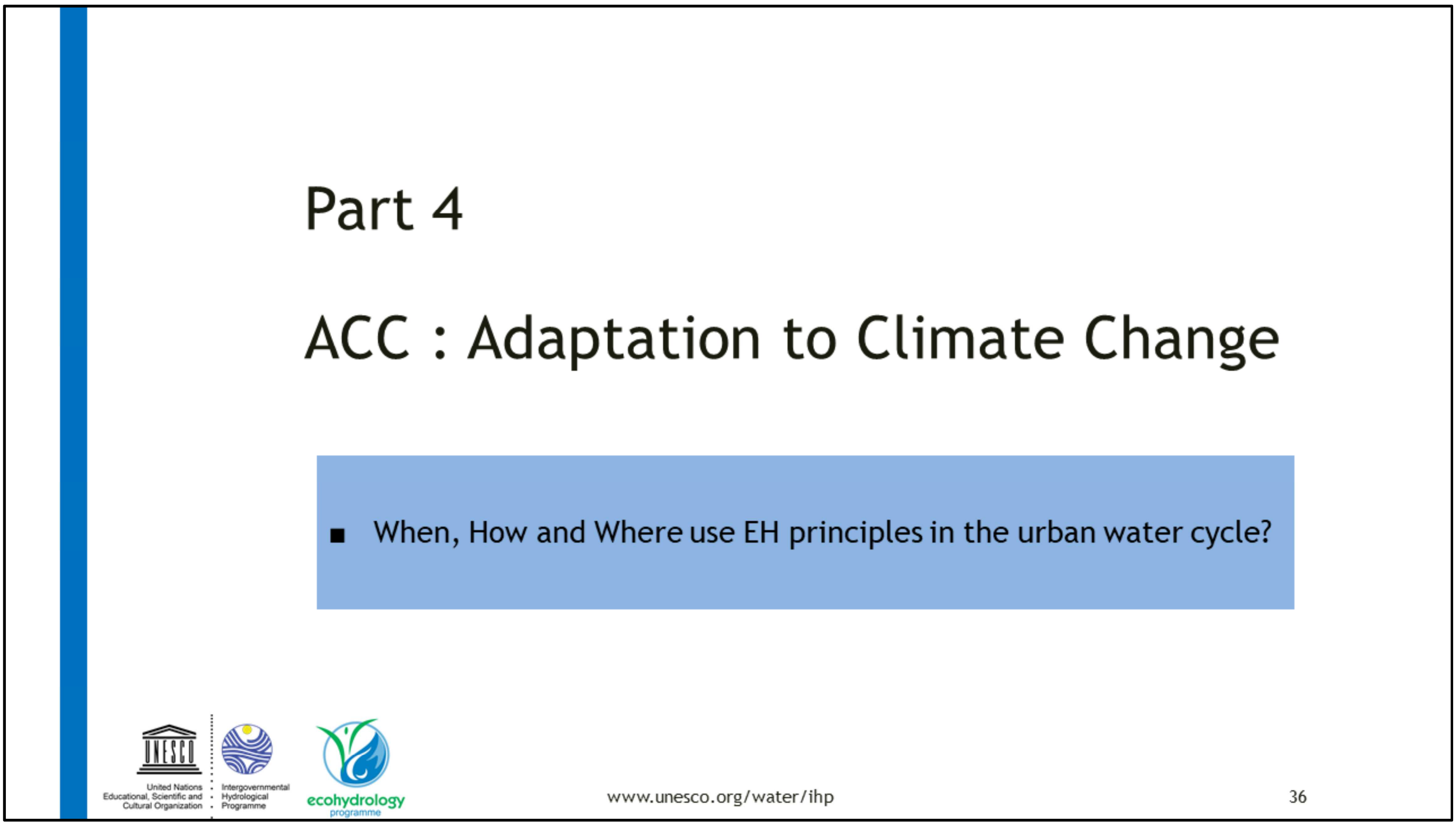
The natural and disturbed environments can initially be considered according to the land uses.

-Urban and agricultural areas are pressure areas. Forests are places of restoration.
-Forested river corridors are protection systems against agricultural pollution.

Knowledge of hydrogeology provides information on the contact zones between rivers and groundwater, which contributes to increasing the capacity for biodegradation, for example.

The ecological status of river courses is an important information to understand:
- where are the imbalances and
- where are the areas of recovery.

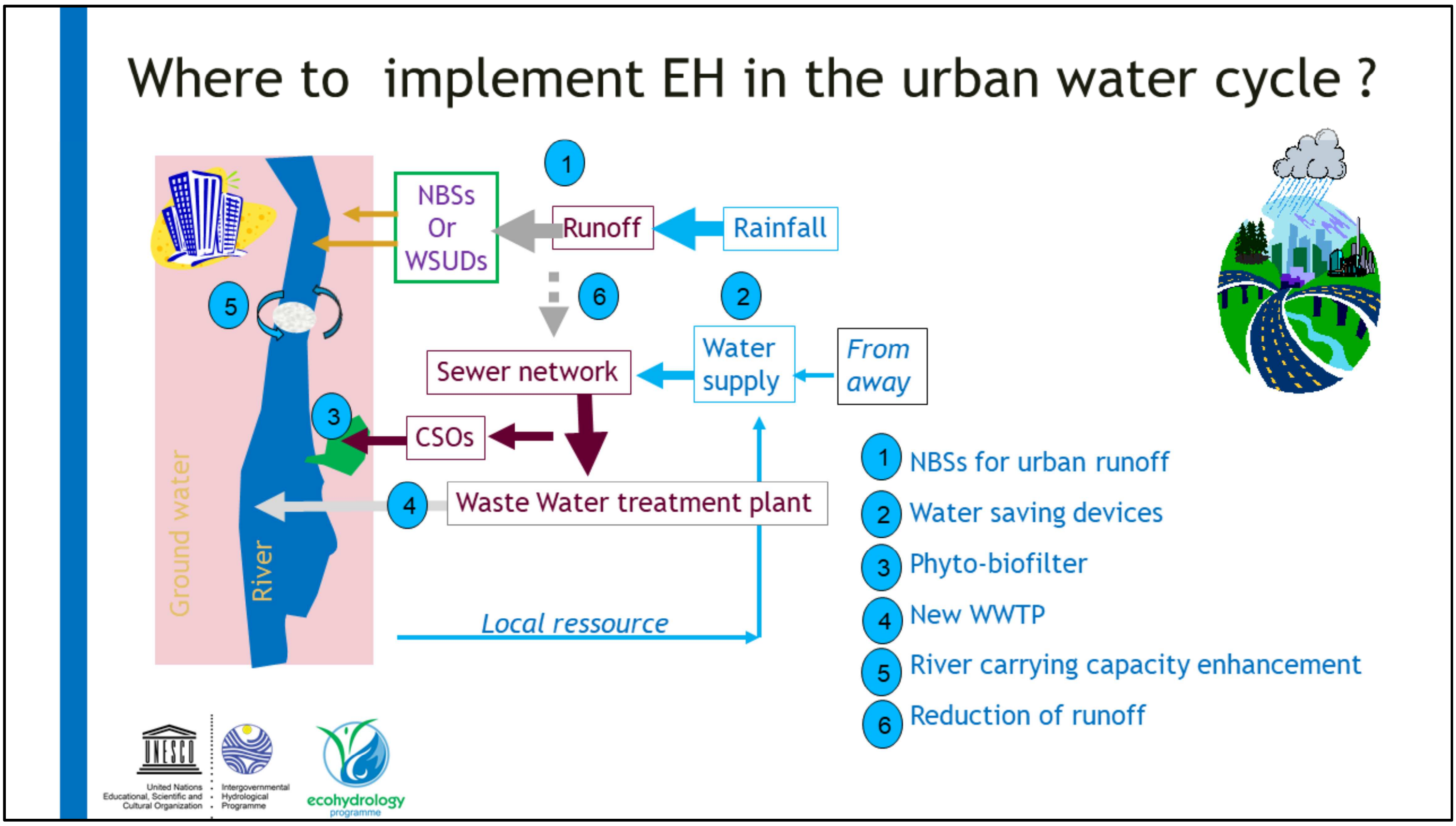
The nature of the bottoms of watercourses provides information on their biodegradation capacity.



The crossing of the first two principles is a matter of expertise which makes it possible to relate the factors of imbalance with the states of degradation observed.

The levers of action are not only scientific, but regulatory and political.

For example, we are dealing here with the issue of imbalances caused by inappropriate CSOs management in small rivers.



Here we take again the schematic diagram of the functioning of the urban water cycle. We indicate in this diagram where different solutions can be developed.

The order of the solutions is not an order of importance.

Number one: treatment by NBS or SUDS of urban runoff before return to the watercourse.

Number two: reducing the consumption of drinking water;

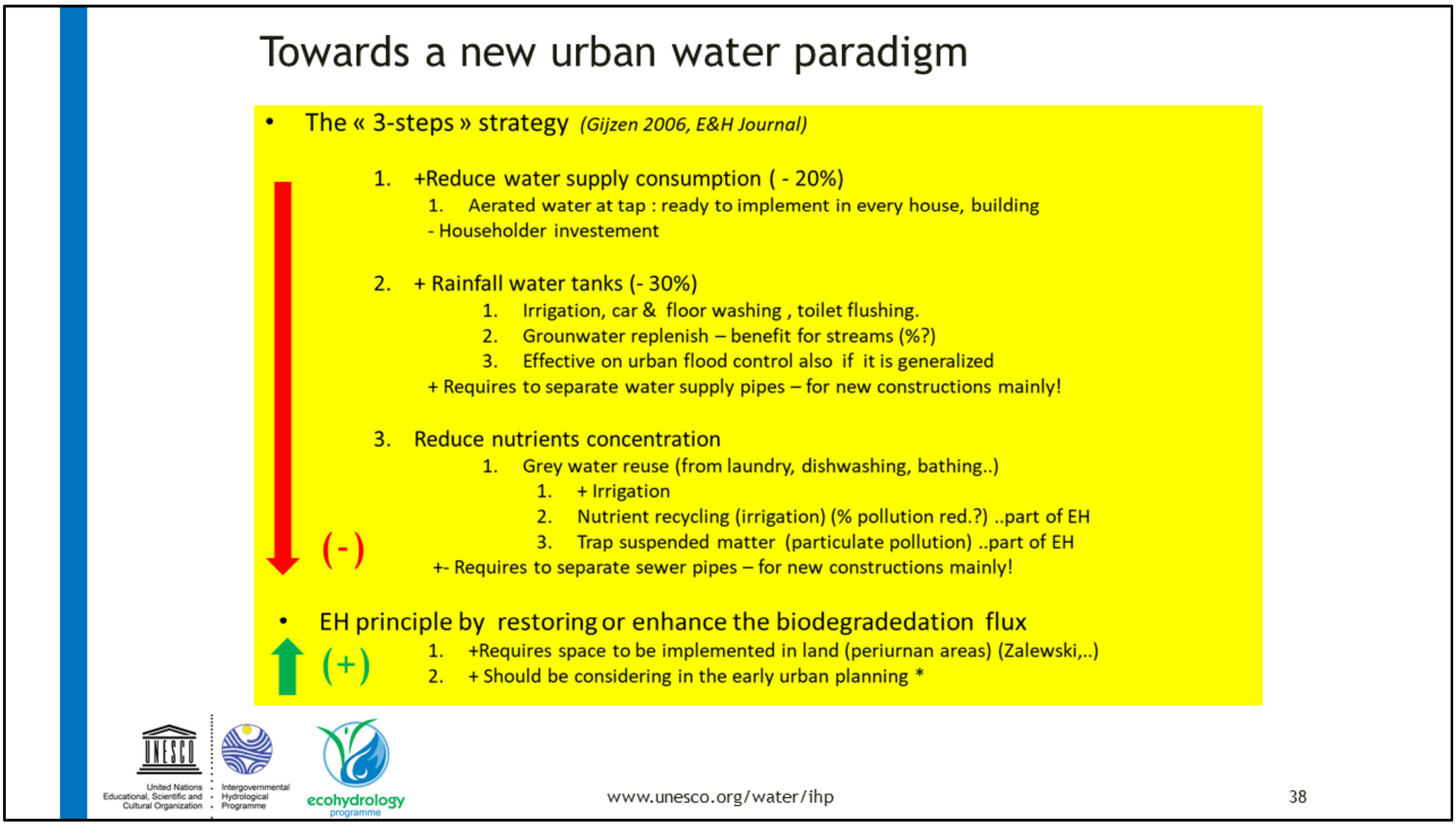
Number three: phyto-remediation which infiltrates non-waterproofed banks.

Number four: improvement of the sewage treatment plant.

Number 5: amplification of the biodegradation capacity of the river.

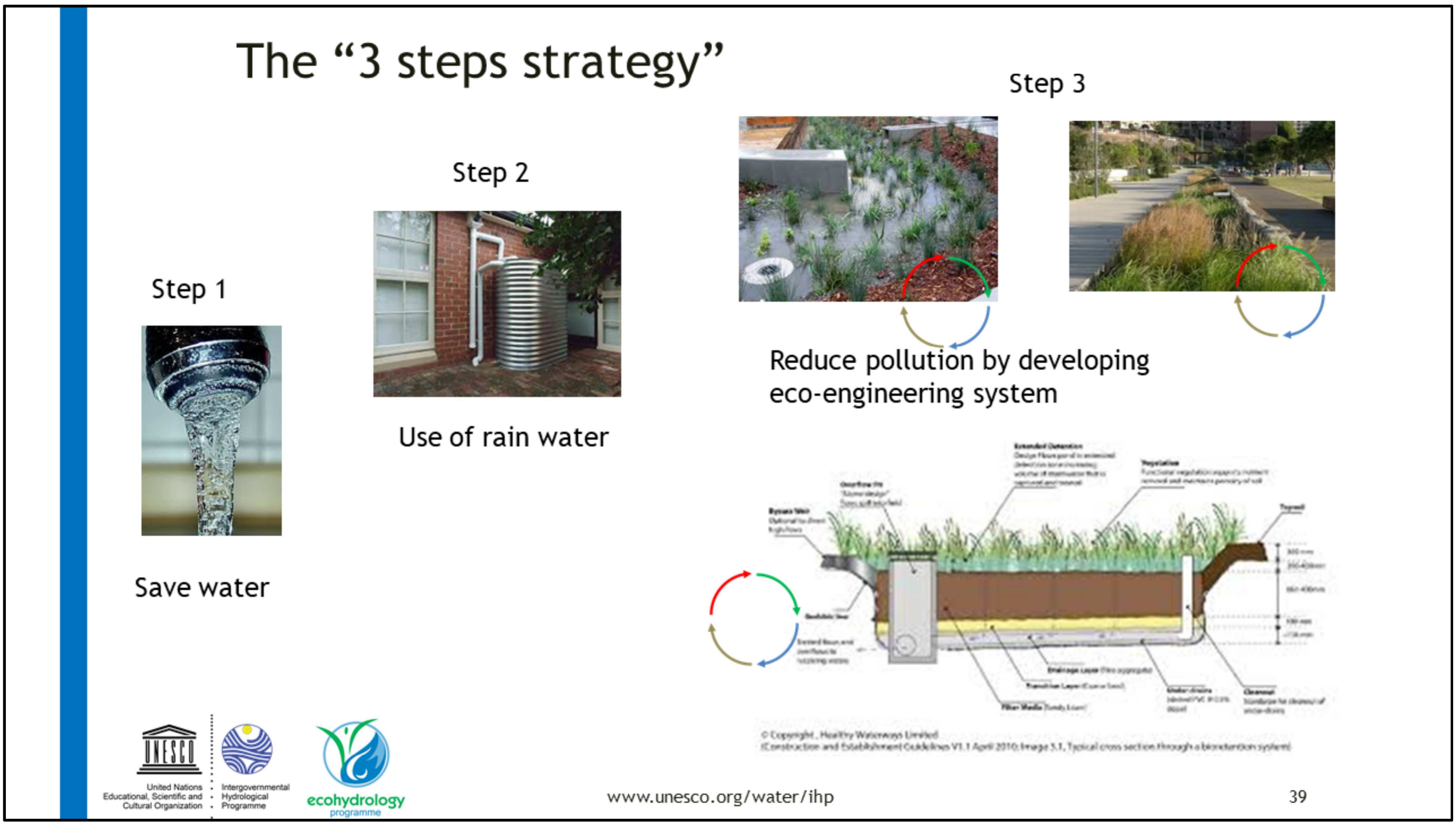
Number 6: reduction of impermeable surfaces in the urbanized area.

We now illustrate these different solutions.



This figure illustrates the results of an article published in the journal E&H.

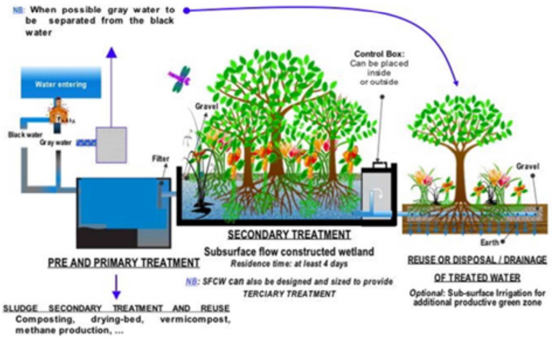
It shows how solutions for reducing the consumption of drinking water, the storage of rainwater for different uses, and the reuse of gray water (non-pathogenic) substantially reduce water consumption (by 50%) and nutrient concentrations.



These images illustrate the various technical means and nature-based developments that contribute to these two objectives:

- reduction of drinking water consumption and
- reduction of nutrient concentrations.

More effective WWTPs



Decentralize WWTP

Centralized WWTP

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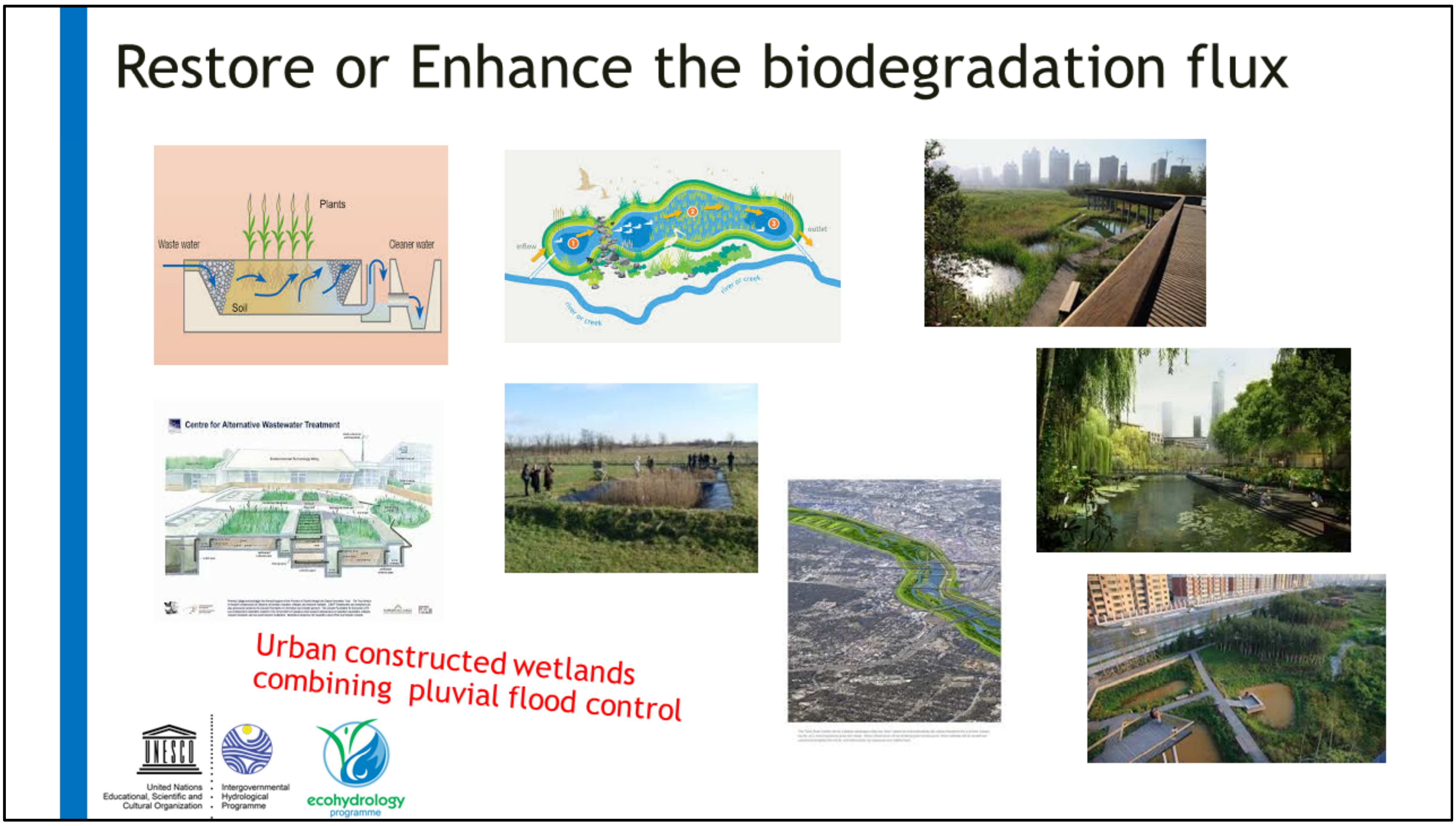
40

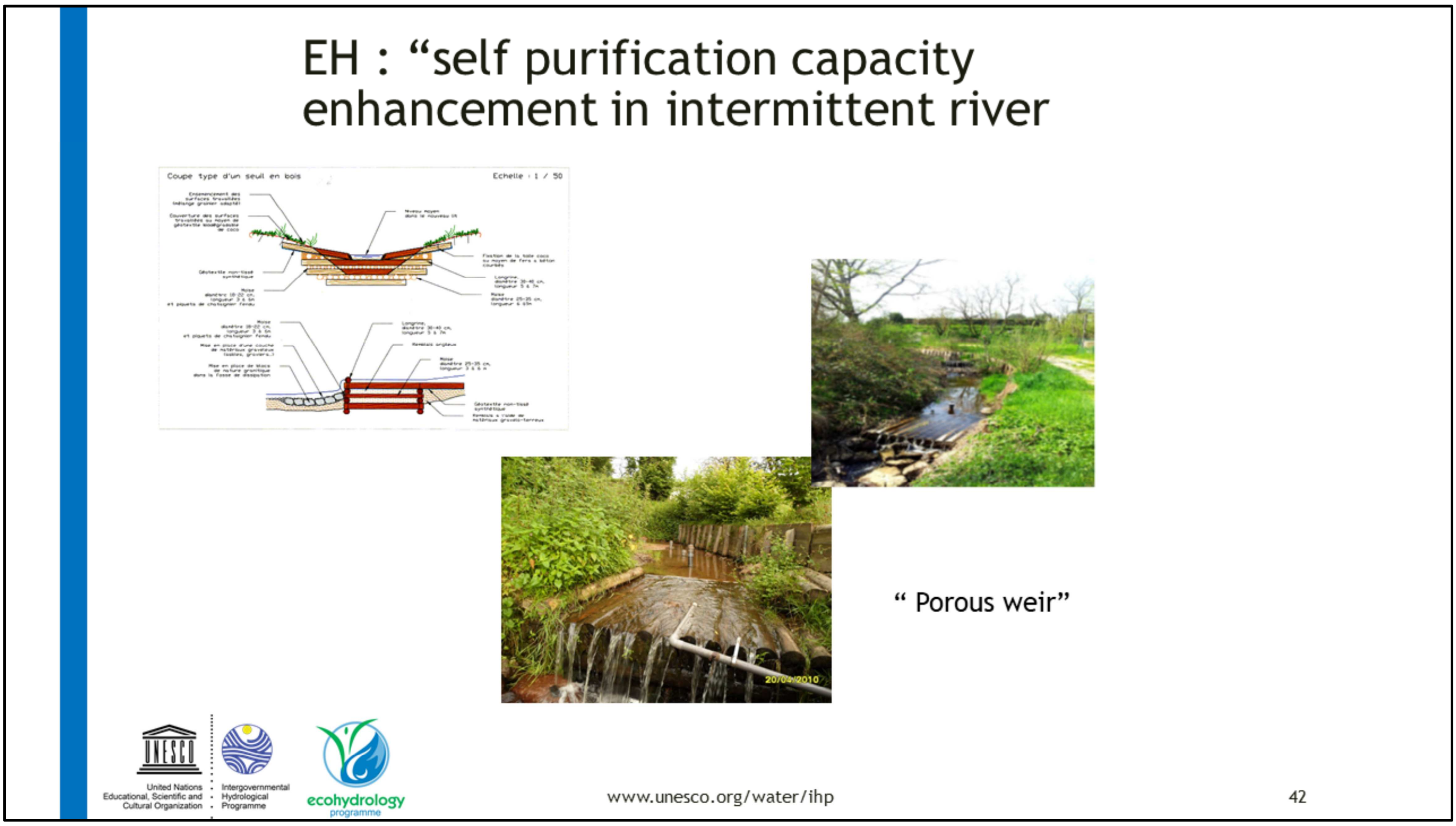
High-performance WWTPs are based on the production of plant biomass, animal (fish) or in core biogas.



Solutions based on biofiltration must also respond to other services such as the management of rain or river flooding. However, the geometry of the devices must be well thought out so that floods do not destroy ecological functions.

This amounts to protecting biofiltration zones of excessively high flow velocity or from excessive sediment deposits.

Hydraulic simulations are necessary to properly size the structures and their shapes.



How to increase the biodegradation capacity of a watercourse?

The device tested for several years consists of promoting the accumulation of porous sediment. For example with a small wooden dam or unsealed block of stone. The dam must be permeable over its entire height to allow water to filter through the accumulation of sediment and then exit through the dam.

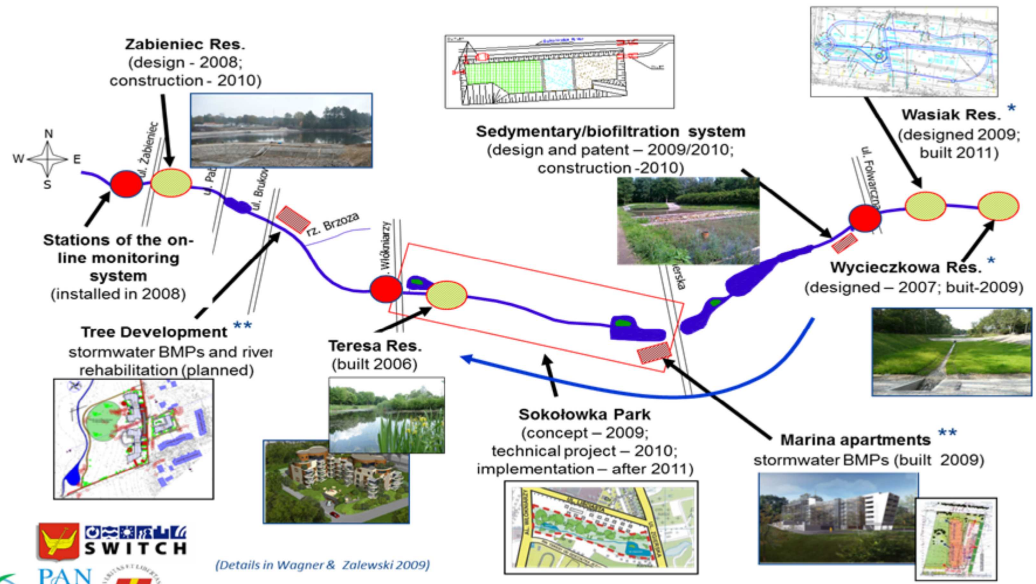
The flat area of sediment accumulated upstream of the dam facilitates the deposition of particles suspended in the water. The porosity of the sediment and the waterfall created by the dam facilitate the infiltration of water and substances dissolved in the sediment. The system is very effective in capturing pollution from CSOs during the low flow period.

This system promotes the development of biodegradation microbial activity. It locally amplifies the biodegradation capacity. The results of analyzes over several years have shown its effectiveness in handling all the pollution generated by a CSO device located immediately upstream.

Once again, it must be said that the choice of location and the sizing of the device are important to consider. Likewise, it is necessary to take into account the fact that the device evolves according to the seasons with the hydrological regime.

This is the illustration of a dual regulation that takes advantage of both the flow conditions and the biocenoses induced by the flow of nutrients and their paths oriented by the design of the device.

EH : “self purification capacity enhancement in a periurban river”



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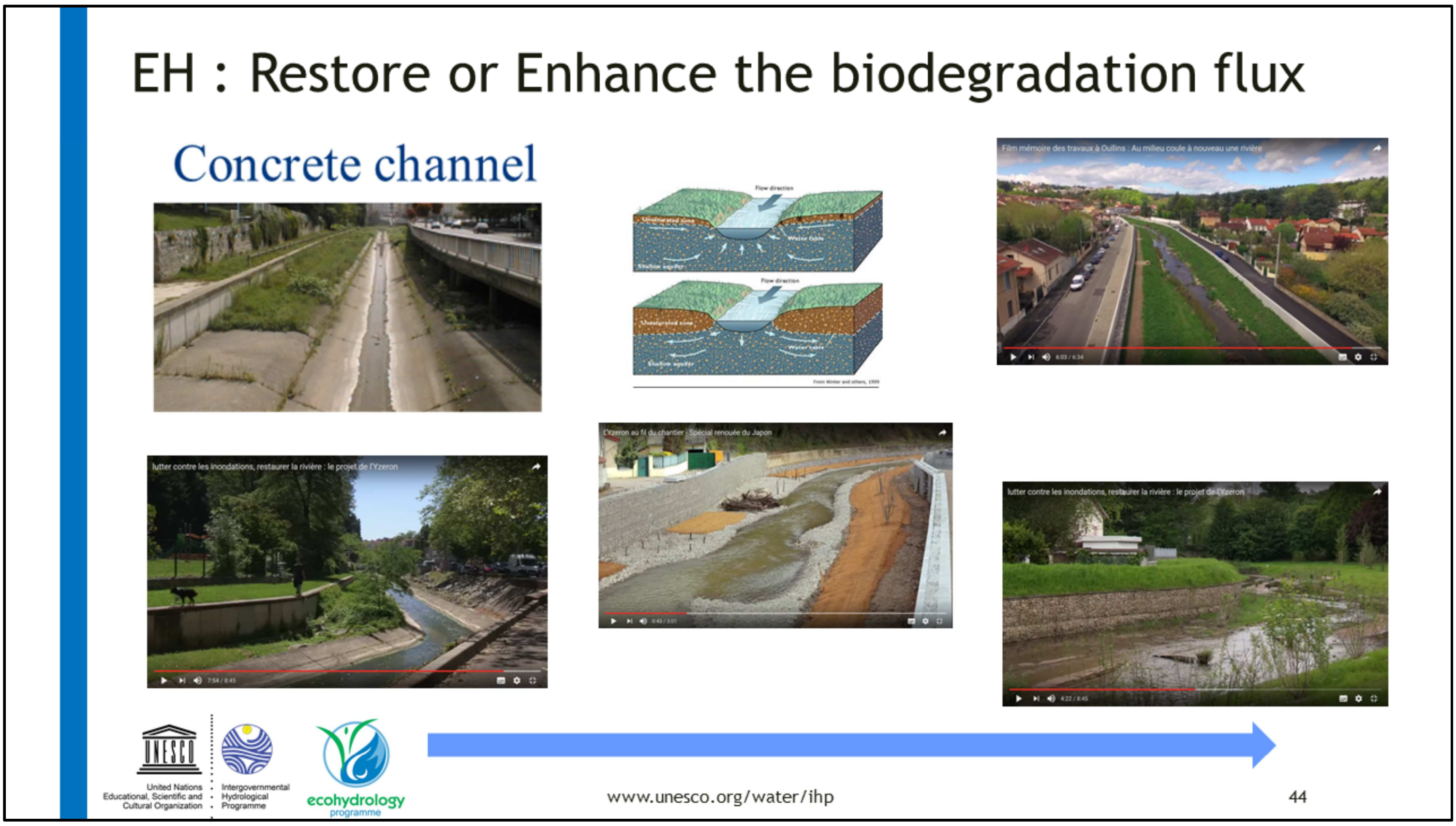


The application of dual regulation can be designed very locally or even be developed over kilometers of watercourses.

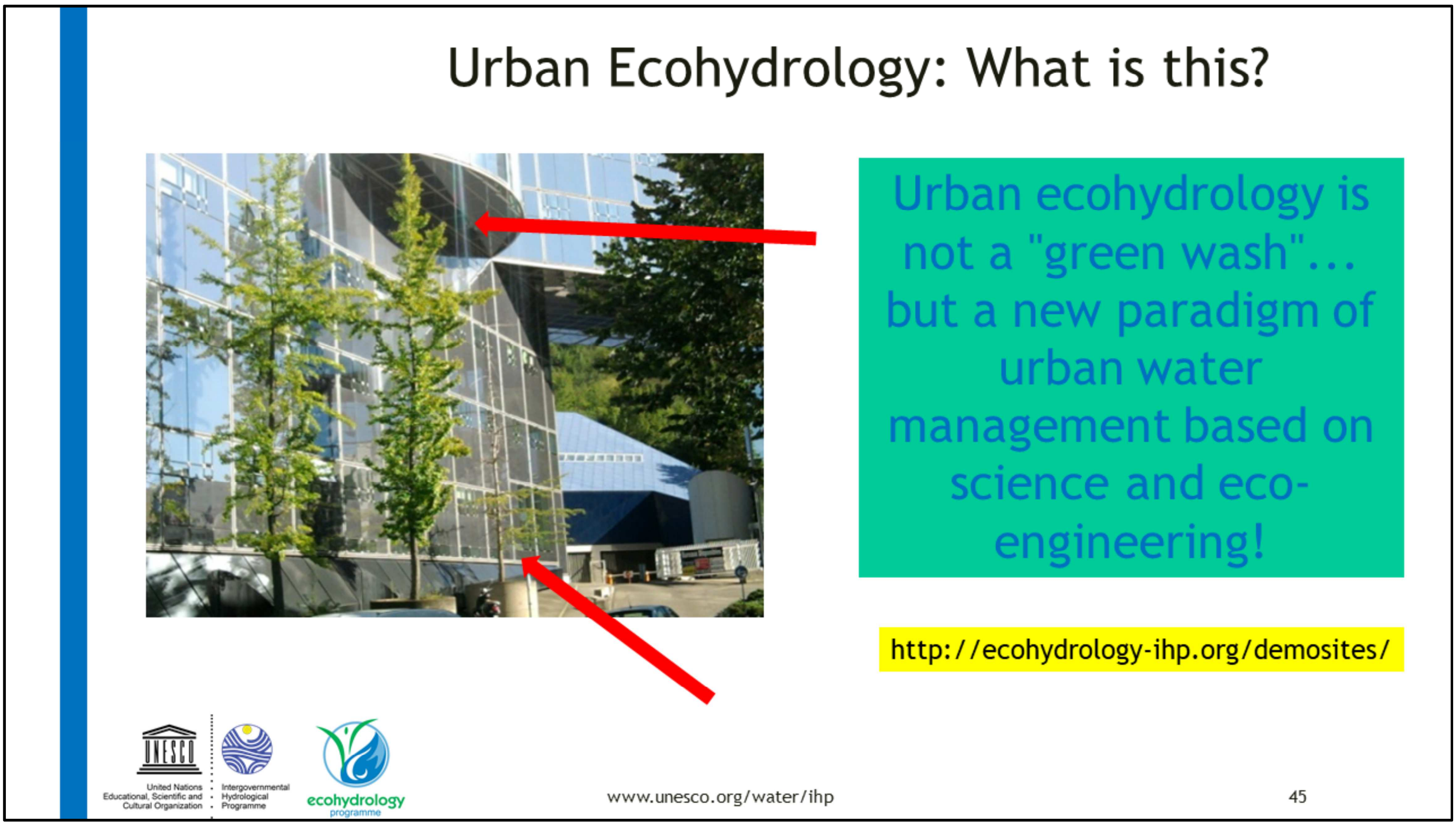
The case presented here is located downstream of the watershed of our study. The project had two main objectives: to widen the river to better manage the floods, and to restore an ecological functioning of the watercourse. Indeed, this watercourse had been channeled and concreted in the 1970s to accelerate the evacuation of flood flows.

This had isolated the river from its tablecloth, created a barrier for fish migration, totally reduced the biodegradation capacity in a highly urbanized area with many CSOs.

The restoration was accompanied by the restructuring of the unit network to reduce CSOs. The objectives of flood control and ecological restoration have been achieved.

It should be noted, however, that reconnecting the river with groundwater was not initially considered as a decision factor in a classical restoration approach.

Ecohydrology can therefore provide more precise arguments in the development of these major restoration projects.



You can see a design blunder from this photo.

One of the trees has been placed under the roof of the building.

As a result, it does not receive rainwater. Ecological engineering is a specialist's business. Operational ecohydrology is one of the methods that allow you to ask the right questions!

Some additional online references to complement the this training course

https://www.researchgate.net/publication/225673886_Biogeochemical_Hot_Spots_and_Hot_Moments_At_the_Interface_of_Terrestrial_and_Aquatic_Ecosystems

http://www.hydrologie.org/hsj/470/hysj_47_05_0823.pdf

https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1002/2016WR019516

https://link.springer.com/content/pdf/10.1007/s10021-015-9878-5.pdf

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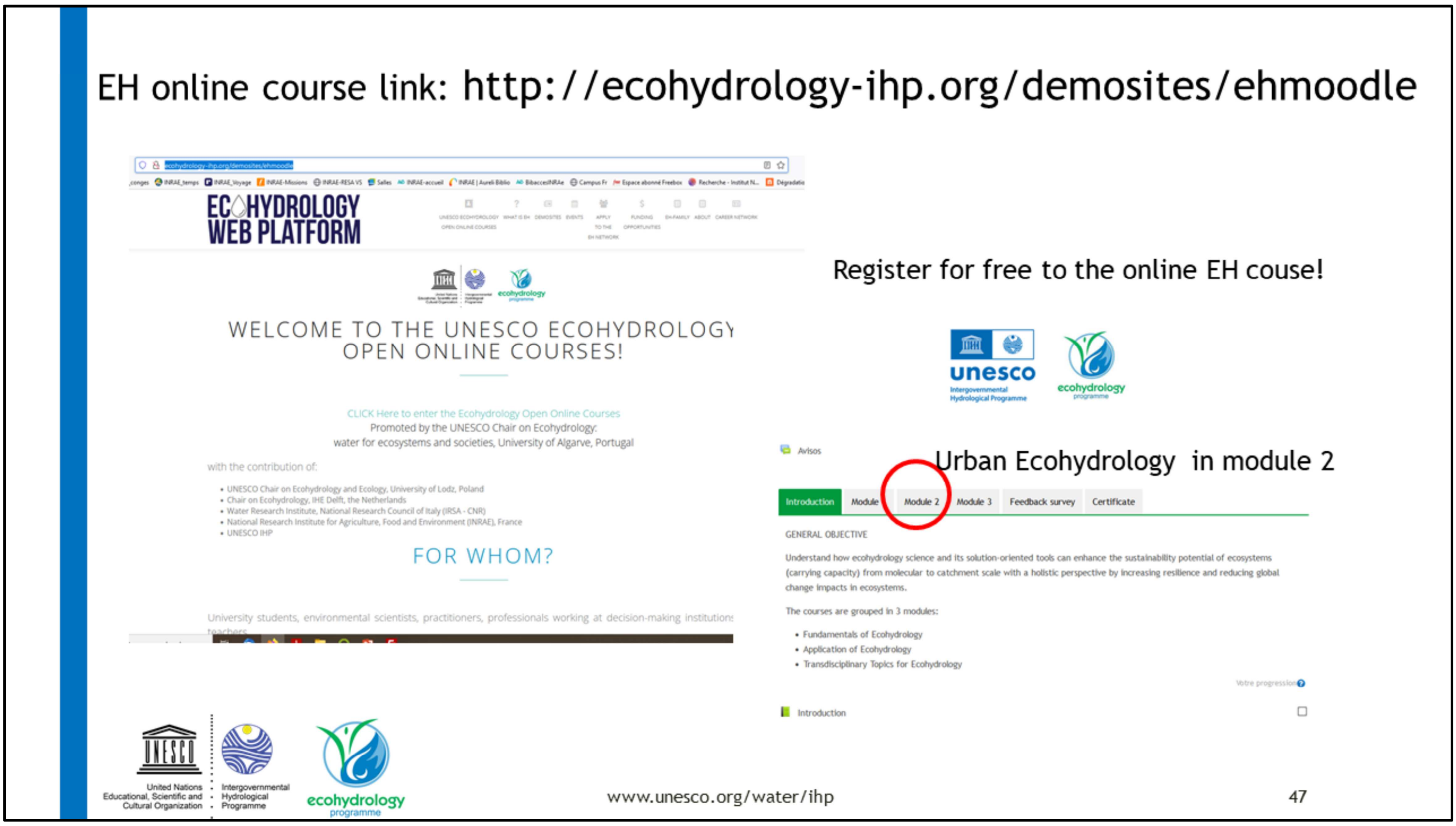
https://www.researchgate.net/publication/225673886_Biogeochemical_Hot_Spots_and_Hot_Moments_At_the_Interface_of_Terrestrial_and_Aquatic_Ecosystems

http://www.hydrologie.org/hsj/470/hysj_47_05_0823.pdf

https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1002/2016WR019516

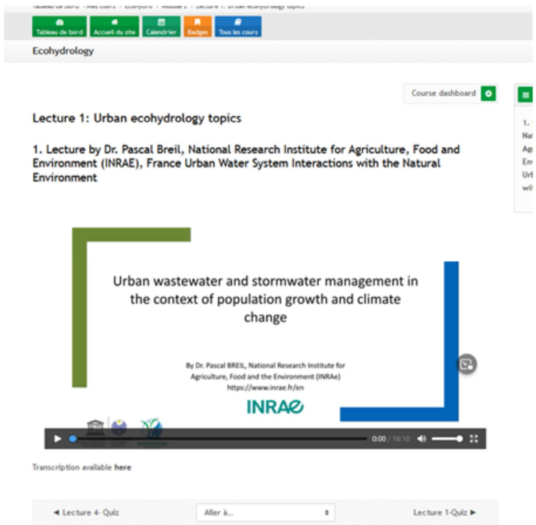
https://link.springer.com/content/pdf/10.1007/s10021-015-9878-5.pdf



http://ecohydrology-ihp.org/demosites/ehmoodle

EH online course link to urban ecohydrology, direct access : https://hidroinformatica.itaipu.gov.py/aulavirtual/mod/book/view.php?id=1010&forceview=1

You can replay the presentation
and test your newly acquired knowledge
with the quiz at the end.



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48

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