D2.2 Report describing design, implementation, construction phases and monitoring strategy of performances for the new build NBS.
Part 2

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Contents

1. General introduction to NBS

According to the IUCN's shortened definition, "nature-based solutions leverage nature and the power of healthy ecosystems to protect people, optimize infrastructure, and preserve a stable, biodiversity-rich future."
In the ATENAS project, the focus is on improving urban stormwater runoff management by use of NBS, both in a dense, constrained urban environment and in the urban fringe where the implementation of NBS can be part of urban planning. The use of natural functions aims to better manage the quantity and quality of urban runoff in order to best conserve this resource rather than discharging it in a polluted form to natural outfalls. NBSs aim to protect and improve the quality of receiving water bodies by cleaning up the water they receive through a variety of natural processes that include biodegradation, bio-assimilation or sequestration taking place in stagnant, running or groundwater.
The richness of the ATENAS project lies in the diversity of cultures, techniques, climates and geologies that interact with the potential of NBS to better manage the water resource related to urban runoff.

1.1 How to make use of the natural processes and where to act?

A good understanding of natural processes key features is required overall. A main feature is the quantity of water that can be processed by a natural process in a given duration time. This is a natural limit, which can only be increased by enlarging the volume or the treatment area of a NBS, and to some extent by favoring a type of physico-chemical environment. It is therefore a question of identifying in a catchment area where a balance can be found between the quantity of water (and the associated pollution) to be treated and the available space in which to implement the NBS. To this must be added the constraint of gravity flow which defines the places where water accumulates naturally.
Two scales of action should be distinguished here. One is to insert a NBS into a dense urban system where stormwater runoff is directed by modified topography and artificial surface and subsurface drainage systems. In this case, the location of the NBS cannot be optimized as the area of runoff collected relative to the area allocated to the NBS is most of the time a major constraint, in addition to the capacity of the natural receiving system to receive this amount of water without generating urban flooding. The other scale refers to the periurban context where urban planning is still in action. This context offers more opportunities to develop the full potential of NBSs. Crop land and natural environment are out of scope for ATENAS project but they must be included in a watershed scale analysis to ensure a coherent action between NBSs implementation and existing natural systems preservation. This refers to landscape management. Guiding principles can be found in the EcoHydrological management principals, as proposed by UNESCO-Intergovernemental hydrological programme.

2. Constraints and levers for the implementation of some NBS projects in the metropolitan area of the city of Lyon (France)

Four development operations linked to NBS are presented in the peri-urban area of Lyon. These operations have been selected according to an urbanization gradient that highlights the constraints and objectives that can be assigned to NBS according to their environment. The points of interest were analyzed through key questions referring to the feasibility factors and the determinants of the choices made. This covers the purpose, used natural processes, design, maintenance, evaluation and monitoring aspects that condition the choices. The innovative character is particularly analyzed for the demonstration site (number 3) realized in the framework of the ATENAS project.

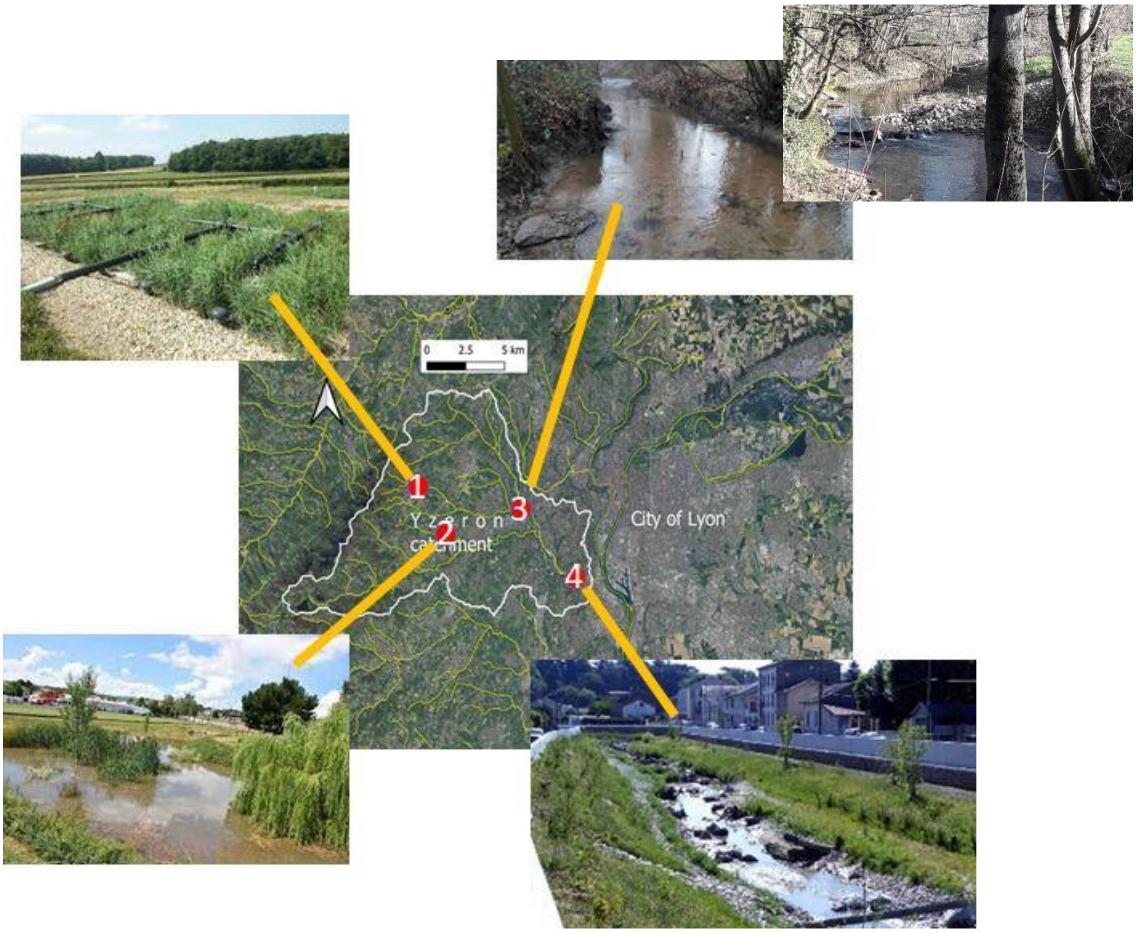


Figure 2.1. Four types of NBS analysed in the vicinity of Lyon city (France).
1 : Planted biofilter to process urban waste water from small upland villages (1000 inhabitants).
2 : Wetlands designed to treat combined sewer overflows before they are discharged into small streams or groundwater.
3: Induced sand biofilter (porous ramp, inner river channel) to process combined sewer overflows loaded of organic pollution.
4 : Removal of a concrete urban riverbed to reduce flooding, restore natural biodegradation processes by reconnecting groundwater, allow wildlife to move through this restored blue-green corridor, and provide recreative space for citizens.

In order to detect river stretches that are not well functionning, data on the biological and chemical status at different points of the river network and over several years are necessary. Their combination allows to describe a gradient of "ecological status". These indicators are the response variables to pollution and hydromorphological alterations linked to the urban environment. This competence is generally the responsibility of the regional water agencies in the various countries. In Europe, monitoring of water bodies is mandatory. The following figure illustrates how the natural capacity of bio-degradation allows the recovery of a good ecological status, despite urban discharges during rainy weather that degrade this quality from their injection points.

a. Enabling factors analysis

We make here a feedback on the conditions of realization of the porous ramps in the ATENAS project

What is the reason for the innovative solution "porous ramp" in small intermittent streams?

The question of the innovative solution followed an observation made between the river and sanitation syndicates with the researchers. It can be summarized by the fact that urban runoff is the main reason for pollution of small intermittent streams in the western peri-urban watershed of the city of Lyon. Faced with this observation and following studies of the sewerage systems and urban development, the usual solutions appeared to be unfinanceable to correct this problem. In addition, the syndicates have formulated, to adapt to climate change effects (long dry periods with sporadic intense rainfalls) the central objective of limiting as much as possible the loss of rainwater resources that transit through the sewerage networks and leave the catchment area to reach a treatment plant. Indeed, the consequences of this current management are twofold: the loss of water resources for the watershed's aquifers and rivers and the cost of treatment for the citizens by the wastewater treatment plant. Several solutions are then considered:

- repair of the most problematic networks (state of degradation X proportion of lost resource);
- disconnection of rainwater that arrives in the combined networks;
- management at the source of rainwater;
- reuse of wastewater by using planted filters.

These solutions are to be combined according to the technical, environmental, economic and existing or to be built condition of the building stock. Stormwater management solutions that reach waterways imply that they are of good quality. In some cases it is possible to direct this water to dedicated structures to facilitate settling and bacterial purification. However, the overflow points of the combined sewer system are numerous, the segregation impossible or the space to develop purification basins is not available. This means discharges of rainwater mixed with wastewater that cannot be controlled upstream of the discharges. In this case the solution is to be found in the waterways. This is the origin of porous ramps.

What are the relationships that allowed the realization of the demonstration site of the porous ramps?

The first factor to consider is that of a pre-existing partnership between research and the river and sanitation syndicates of the watershed. This partnership takes several forms of interaction:

- the participation of the researchers in the review and evolution of the technical specifications proposed by the unions to launch studies. This is a free service provided by the researchers who, in return, benefit from a good knowledge of the issues and constraints of the territory studied;
- participation in technical committees organized by the syndicates to evaluate the intermediate results of the studies. This makes it possible to point out shortcomings and to propose methods to resolve them. This is a free service provided by the researchers, who in this case communicate innovative solutions to the engineering offices and the unions;
- participation in collaborative research contracts, which are private partnerships specific to the development of innovative solutions that engineering firms cannot propose and guarantee due to lack of experience. In this case, researchers are funded for the time spent on the projects;
- the participation of trade unions in research projects carried out by researchers. In this case, the unions are not eligible for funding but offer their skills and resources to benefit from the innovative results of the research. This is the case of the ATENAS project for which the sites for the implementation of porous ramps were discussed with the unions and the users of the rivers.

These practices have created a climate of mutual trust between the researchers who propose innovative solutions and the field of operational application that is necessary for the activity of the unions. In addition, the syndicates are in contact with many interlocutors and users of the territories and functions they manage. This is an important point to avoid conflicts of use, in particular when innovative solutions are developed in environments already used by other groups of actors. The syndicates are therefore essential mediators for identifying the interlocutors and organizing information and decision-making meetings.

What are the criteria of the operational actors to choose an innovative solution?

The principle of porous ramps was first tested in a pilot field project over a ten-year period. During this period, the porous ramps were tested on an intermittent 2-meter-wide stream, impacted by a single combined sewer overflow unit. This pilot project was followed by several national and international research projects in which the unions signed letters of interest, indicating that they would provide field sites, verify legal constraints and transmit data of interest to the research.

In general, operational actors are wary of the time it takes for research to provide solutions. The participation of unions in research projects that do not claim to provide short-term solutions is therefore essential. To do so, it is necessary to have identified common issues such as the search for innovative solutions to problems that cannot be overcome by the current approaches proposed by the consulting offices. This is a long-term dynamic that cannot strongly involve the operational actors but that must provide them with a technological watch and the possibility of specifying their constraints. This develops their confidence in the results of the research. Collaboration in the form of "technology watch" is therefore a determining factor in their agreement to go to the scale of the demonstration site. Beyond the provision of test sites, their financial contribution to the construction of the porous ramps confirms their commitment to support this transfer.

The choice of an innovative solution is always seen as a risk for a decision-maker because he does not know if he will be able to manage the unintended consequences in case of malfunction or unforeseen side effects. The ATENAS project contract is that if the research demonstrates the effectiveness of the porous ramps at the demonstration site, then the unions will take responsibility for replicating the solution at other sites. Moreover, the unions consider the risk to be minimal because the solution is low cost and in the event of failure, the elements introduced into the river will be taken up by the natural environment without any consequences for it. This is a "no regret" decision.

Important points

The writing of the letter of interest for a research project is a decisive step in the level of involvement. It must stipulate the means and prerequisites that the operational partner will manage to carry out the project in its territory. Thus, the choice of the site will be the subject of meetings and discussions.

b. Theme of interest for NBS deployment

Small streams in urbanized areas are subject to two types of constraint: the contribution of pollution linked to rainy weather discharges and the rectification of their shape, sometimes with concrete banks and even the bottom to limit overflows. These constraints considerably alter the natural self-purification capacity of these rivers. Biodegradable pollution is then transferred downstream to watercourses, which can have an impact on fish farming, swimming and aquifer recharge.

The objective of a porous ramp is to create conditions that will restore and even amplify the purification capacity of a small watercourse in an urbanized area. To achieve this objective it is necessary to understand how sediment transport occurs and where biodegradation is active under natural conditions. These specialized skills exist in the design offices, but they must be organized to achieve the objective.

Figure 2.2. Example of stone and concrete walls to protect a road and houses against flooding. View taken upstream of the ATENAS demonstration site, near the city of Lyon. The result is a deepened and straightened riverbed.

c. Nature in action

It is important to identify the factors that favor certain natural processes, in order to understand how human action contributes to reducing their effectiveness, and where to act to rehabilitate, compensate or amplify these natural processes in a targeted manner.

The term self-purification in a watercourse covers various processes such as filtration, dilution, mineralization, biodegradation and bioassimilation, which is the process of reintegrating the organic matter thus transformed. Under natural conditions, unaffected by human activity, a balance is established between natural inputs of biodegradable matter and the capacity of the natural environment to digest these inputs. Human activity alters these balances through excessive inputs, concentrated in specific locations in the case of urban rainwater discharges. Human action also reduces the capacity for self-purification by constraining and sealing the beds of small streams (Figure 2.1).

The map in Figure 2.2 illustrates a "watershed scale" approach to understanding the interactions between natural processes and human pressures. The indicator chosen to summarize the natural process of biodegradation is the ecological status (in the sense of the WFD) of river sections. This synthetic information is based on numerous physico-chemical and biological analyses carried out over several years [Wagner & Breil, 2015]. Black spots represent the locations of urban wet-weather discharges. Their positions and densities determine the degradation of ecological quality in certain areas of the watercourse.

To interpret this map, you need to know how to read it. The three main factors affecting the natural biodegradation of a watercourse are as follows:

- The slope of the riverbed. The steeper the slope, the more effective the aeration process that brings in dissolved oxygen. This facilitates the oxidation of organic matter present in the water.
- The thickness and permeability of the sediment that makes up the river bed. Surface water flows through this environment, bringing with it organic matter. It's an environment conducive to the development of bacterial films, which have the capacity to biodegrade organic matter, either through oxidation or reduction processes, depending on the dissolved oxygen content of the water.
- The connection of the watercourse with groundwater, which can dilute surface water.

These factors interact at different spatial scales. Areas with steep slopes erode and transport sediments without accumulating them. In this case, oxidation is the main factor in biodegradation. Medium slopes temporarily store transported sediments, and in places offer zones for aerobic and anaerobic bacterial biodegradation. Depending on the variability of local topography, biodegradation capacity can range from high to low. Low-gradient areas accumulate sediment and develop biofilters that are efficient for anaerobic biodegradation. Low flow velocities reduce biodegradation fluxes, but the connection in downstream areas between streams and groundwater dilutes organic loads, thus promoting biodegradation

On the basis of these factors, we can interpret the map in Figure 2.2:

- Ecological status is generally rated as very good to good in headwater areas where human pressure is low. In this case study, steep slopes also favor the renewal of dissolved oxygen through aeration of the water, which promotes the oxidation of organic matter. This compensates for low sediment thickness, which cannot be maintained on steep slopes. In this way, a high organic load at the head of a basin can be completely biodegraded on 5 km of steeply sloping watercourse (Figure 2.2, zone 1).
- On intermediate slopes, quality can be poor if human pressure is too great, as sediment thickness may be insufficient and aeration limited (Figure 2.1, zone 2). Downstream improvement (Fair quality) is linked to the presence of an underground water table and local geology.
- In low-gradient areas, quality is improved by the presence of a 10 to 20 m thick water table (Figure 2.2, zone 3), which produces dilution. Quality is also improved by sand deposits 0.5 to 1 m thick, which facilitate bacterial biodegradation.

Small natural watercourses therefore have a variable defence capacity along their course.

Topographical gradient is the then primary factor controlling biodegradation.

NBSs require open space at the edge of watercourses (see case 2 of NBSs on Figure 2.1). This is due to the fact that biodegradation rates are not easily influenced by water temperature. Large surfaces must therefore be used to treat large pollution flows. In France, small rivers are not managed by the state, and many are surrounded by private land. This hampers the use of NBS along these watercourses, as landowners are generally unwilling to sell their land for a low price in the collective interest if the land is in an urban development zone.

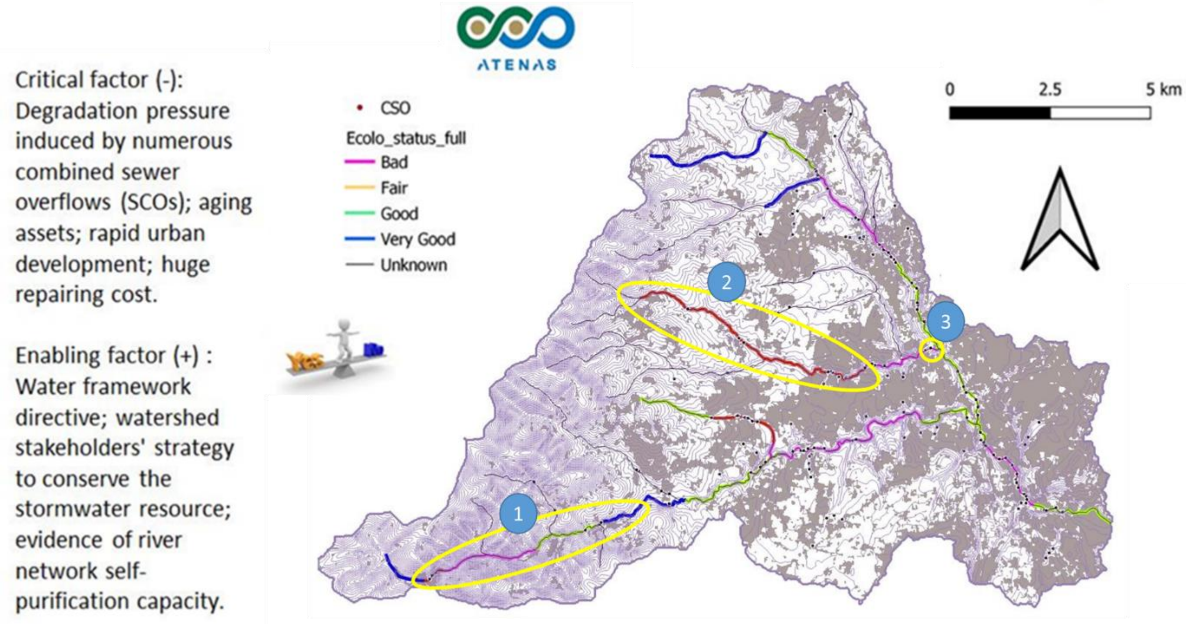


Figure 2.2. Ecological status variation along small watercourses impacted by urban storm water overflows (from biological and chemical water data collected over 20 years). (1) regeneration zone - from poor to fair to good to very good; (2) poor quality area with numerous CSO points; (3) location of ATENAS demonstration site.

d. Design

The design of the porous ramps was inspired by experience accumulated over several years of observation from a field pilot. The principle is to create an accumulation of sediment over a fairly long length in a small watercourse in order to increase the interception surface for particulate and dissolved pollution during low-water periods. Sediment accumulation is encouraged by a porous barrier that does not completely block the watercourse. This allows the free movement of aquatic species. The barrier must be porous to facilitate water circulation in the sediment and within the barrier. The accumulation of sediment raises the water line in relation to the downstream side of the barrier, encouraging infiltration and circulation of water in the accumulated sediment. The whole system finds a form of equilibrium, sloping slightly from upstream to downstream. This combination of sediment and porous barrier is referred to as a porous ramp. This system is illustrated in Figure 2.3.

The porous ramp functions differently according to the flow rate, which in turn is influenced by the seasons. During low-water periods, when the river's capacity to dilute rainwater discharges from summer thunderstorms is low, the flow of pollution increases upstream of the groin as a result of the constricting effect of the flow, which favours deposition and infiltration of the pollution carried in the accumulated sediment. Urban rainfall discharges are intense and short-lived. A large proportion of the pollution flow can therefore be captured if the sediment is of sufficient length and volume. The organic matter accumulated in the sediment is then biodegraded by bacterial activity. This activity can alternate between reduction and oxidation processes, depending on the water level in the permeable sediment.

In high water, most of the pollution is transported beyond the porous ramps, but with a dilution that is often sufficient not to impact ecological status. On the other hand, the flow of slightly polluted water continues to cross the porous ramp with a flow of dissolved oxygen that favors rapid biodegradation and cleaning of the porous ramp. Finally, in the event of a major flood, the sediment can be partly renewed by erosion and deposition. This rejuvenates the biofilter. We're talking about an ecohydrological device here, as it uses the different phases of the hydrological regime to perform various natural functions such as sedimentation, biodegradation and regeneration.

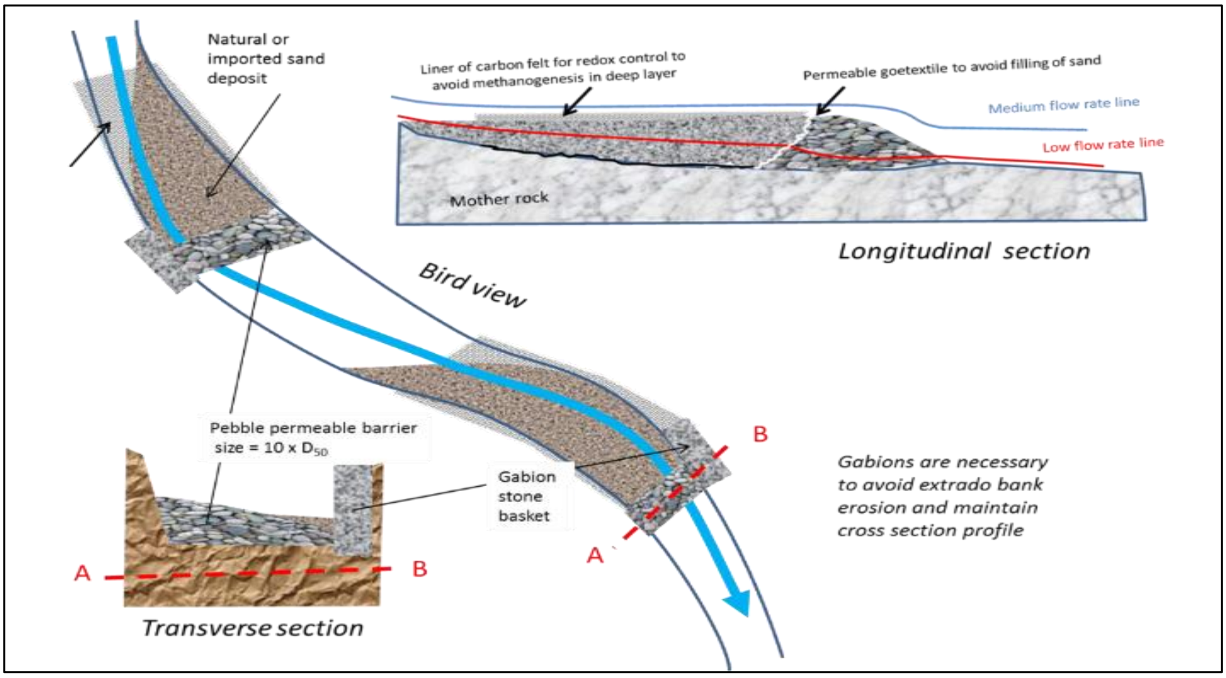


Figure 2.3. Functioning principles of constructed porous ramps

Figure 2.4. appearance of a porous ramp after construction. Left: sand accumulation upstream of the porous barrier; right: porous barrier, here made of pebbles.

e. Site selection

The study area is determined by the objective of improving the ecological quality of the downstream watercourse. One strategy would be to place a system of porous ramps downstream of each urban wet-weather discharge point, but this may be impossible for a number of reasons: unsuitable topographical conditions, complicated access for earthmoving machinery, private land, a fish breeding area, the repetition of dispersed work sites is more complicated to monitor and maintain over time, and vulnerability to local overflows generated by porous ramps. The main idea is to reduce the impact of a lower-quality tributary flowing into a main watercourse. One siting criterion is therefore to be close to the confluence, in order to deal with the cumulative effects of upstream flows in the tributary of poorer quality. This was the choice made for the demonstration site after consultation with the river syndicate that manages the watercourses in the catchment area.

Once the study area has been identified (Figure 2.2, zone 3), a topographic survey of the riverbed is required. This is carried out by a topographer, with centimetric accuracy. The longitudinal profile of the watercourse must then be studied in order to assess the most suitable areas for creating a sediment accumulation over a length of more than 20 m, with an obstacle of around 50 cm in height. This implies an average gradient of less than 2%.

Once these zones have been identified, a sediment volume can be calculated by integrating the width of the watercourse and the average height of the porous ramp. A number of different locations are proposed. The selection criteria are, in order: length of accumulation zone, width and thickness. Length, taken in the direction of flow, favors interception by landfall of particulate organic matter, which is the desired goal. The quantity of water infiltrated depends on the surface and thickness of the sediment, which averages between 20 and 40 cm.

Five sites were initially selected on the basis of the above criteria. Accumulated sediment volumes were estimated at between 25 and 100 m3, depending on the site. The three most upstream sites were associated with a program to widen the river to contain the 100-year flood. This program included the development of a varied ecological habitat. The local fishing association preferred not to retain the three sites in this zone, as the long sandy flats of the porous ramps are considered unfavorable for Fario trout reproduction. Despite the existence of long natural sandy flats in this watercourse (there were 12 with an average length of 16 m in the study area), the opportunity to offer 400 m of watercourse with a diversified habitat prevailed over the objective of enhanced self-purification. It was therefore decided to build only the two porous ramps located downstream, outside the widened section (figure 2.4).

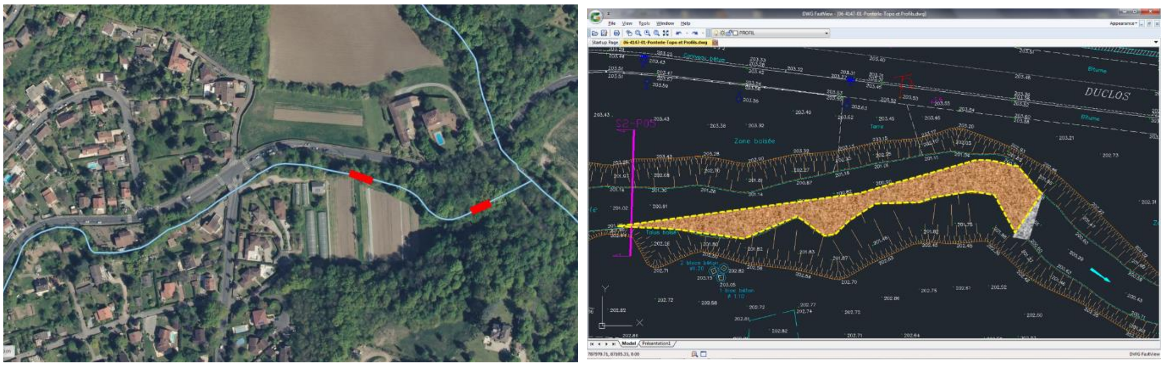


Figure 2.5. (left) Locations of the two porous ramps selected for the ATENAS project. (right) An example of how to visualize the right-of-way of a porous ramp using topographic profiles.

Several sites are proposed and presented to the river syndicate (or manager). In our case study, two of the five proposed sites were excluded due to recalibration for flood protection purposes.

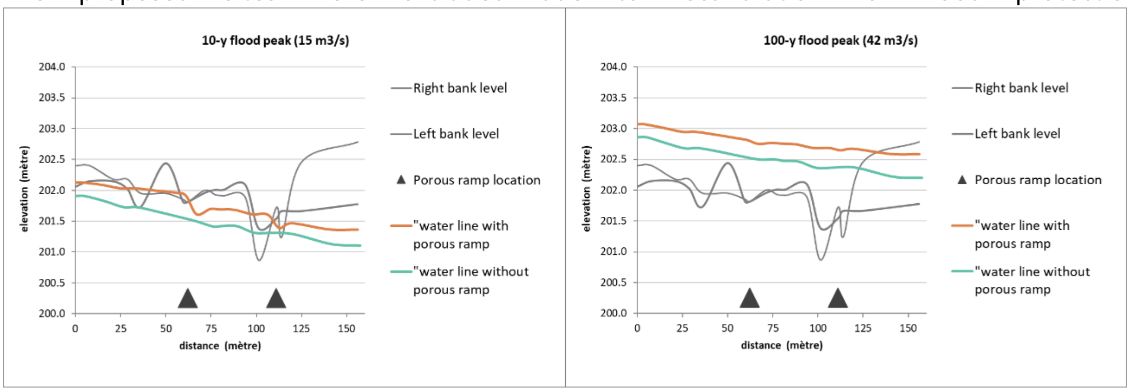


Figure 2.6: Hydraulic simulation of the impact of porous ramps on the overflow water line for 10-year and 100-year floods.

Once the sites have been validated, it's time to assess the influence of porous ramps on river overflow. A 1D hydraulic model may suffice to assess the position of the water line for a frequent (10-year) and a rare (100-year) flood (see Figure 2.6). Choosing an overflow area with no issues at stake is an advantage when it comes to installing porous ramps. In our case study, the overflow induced by the porous ramps remains very localized for the 10-year flood and has no appreciable influence on the flooded area for the 100-year flood.

f. Sizing

In an uncontrolled or non-servoed environment, as in the case of NBSs, characterization of self-purification performance is based on empiricism, since self-purification processes interact around an equilibrium zone. It would be costly and perhaps even impossible to measure the numerous spatial and temporal variations of such a system. At this stage, the results of a study carried out on a field pilot downstream of a single discharge point provide orders of magnitude of pollutant reduction per unit volume of a porous ramp. The following table gives indicative values per cubic meter of porous sediment through which water and associated pollutants pass. It should be noted that nitrates increase as a result of the nitrification of nitrogenous organic matter brought in by urban rainwater discharges. This mineralization makes nitrates available for the creation of new bacterial and plant biomass.

Table 2.1: Indicative rate of reduction of pollution indicators per cubic metre of porous ramp.

Electrical Conductivity (µ.S/cm)	Dissolved Organic Carbon (mg/l)	Ammonium N-NH4+ (mg/l)	Nitrite N-NO2- (mg/l)	Nitrate N-NO3- (mg/l)	Ortho-Phosphate PO43- (mg/l)
-0.786	-0.038	-0.011	-0.003	0.087	-0.008

The porous ramp operates within the hydrological regime. The device is designed to intercept the organic matter produced during storm overflows and then biodegrade this organic matter the rest of the time. It is therefore not a question of sizing the system according to an average flow calculation, but rather according to its length and interception surface. The question arises as to what % of the pollutant flow is not intercepted, especially during summer low-water periods.

Although based on one year's observation from a pilot site on a 2m-wide stream, the use of table 2.1 enables us to estimate the volume of porous sediment required to reduce a mass of pollution. This mass is calculated as the product of the pollution flow (in mg/l) multiplied by the duration of the urban wet-weather discharge. This data is also complex to acquire and will depend on the urban environment. In the case of the demonstration site, we used a simple scaling ratio based on the assumption of an identical pollution flow between the study site and the demonstration site. As the watercourse receives four points of urban discharge during rainy weather, we consider that four times the volume of porous sediment is needed to reduce the pollution introduced into the watercourse. This equates to a volume of 160 m3. As the stream is 4m wide, sediment accumulation should be encouraged over 80m if the average thickness is 0.5m. The installation of the two porous ramps at the demonstration site enabled us to accumulate 60m by 0.3m, i.e. a volume of 72m3. It's not enough, but it enabled us to verify the partial reduction effect as well as several aspects of the implementation and monitoring of such a layout.

g. Maintenance

The plunging shape of the porous groin encourages sediment accumulation, creating a point of weakness where it meets the natural river bed. This is the area of highest velocity during floods. During the two years of testing carried out as part of the ATENAS project, it became apparent that this area of the groin needed to be rebuilt and reinforced. This required the use of a small mechanical shovel to set large stone blocks into the riverbed. This area should be checked after each major flood.

Figure 2.7. Reconstruction of the porous barrier nose. Condition after major flooding (left) and after more resistant reconstruction (right).

h. Monitoring

The indicators of a porous ramp's efficiency are its capacity to store sediment and organic matter. Sediment storage is easily monitored using wooden stakes placed in the accumulation zone (Figure 2.8, left). After each flood, the distance between the top of the stake and the sediment surface can be measured. If the stakes are installed at the start of the development, the volume of sediment present can be assessed and its fluctuation evaluated by regular corroding of the stakes, in order to identify the original bottom of the watercourse.

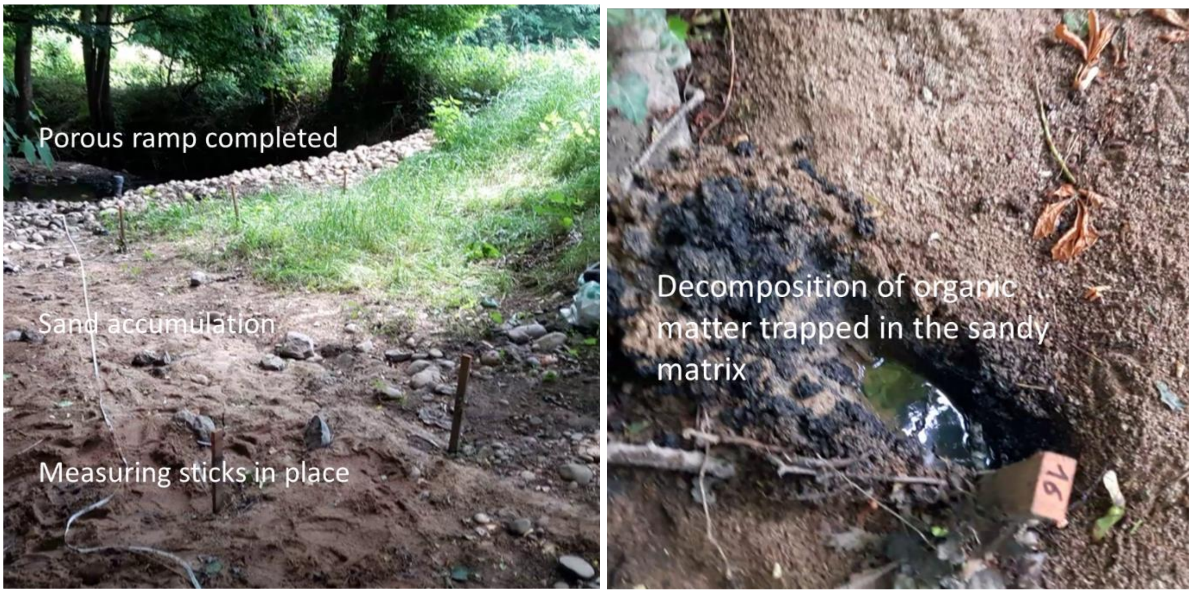


Figure 2.8: Indicators of sediment accumulation and biodegradation of organic matter.

The presence of organic matter is easy to verify: simply dig into the sediment and observe its color and that of the interstitial water (Figure 2.8, right). Decomposing organic matter turns black. This indicator shows that the sediment is acting as a trap for organic matter circulating in the watercourse. This must be observed during low-flow periods, when the porous ramp floods the sediment deposit during rapid overflows from sewage systems. During high-water periods, the organic matter is diluted and degraded by higher flows of water and dissolved oxygen. The black coloration then disappears. The following photos illustrate the operation of the measuring sticks and the presence of trees that provide shade and limit the development of vegetation in summer and winter on the sandbars created by the porous barrier, up to 30 metres upstream.

i. Results of 1-year measurement campaign

To confirm the effectiveness of the system on the demonstration site, specific measurements of water quality indicators are required. The idea is to confirm, for example, the results of Table 1, which were used to size the surfaces covered by the porous ramps. This is achieved by measuring these indicators in shallow piezometers, to gain access to the quality of the water circulating in the sediment (between -30 and -60 cm). These piezometers are installed in the upstream and downstream zones prior to the installation of the porous ramps. The parameters monitored continuously (every 10 minutes) using probes are dissolved oxygen, redox potential, pH, temperature and electrical conductivity. Water samples are taken weekly at the surface and in the piezometers for more detailed analysis of the concentrations and forms of organic compounds - nitrogen, carbon and phosphorus. This enables us to verify the mineralization process linked to self-purification and the upstream-downstream effect of porous ramps on the concentration of organic matter.

j. Results of water quality measurements

The experimental design to assess the effectiveness of the porous ramps (PR1 and PR2) consisted in measuring surface water quality (SW) upstream of the device on the equipped river (station C), as well as upstream and downstream of the main receiving watercourse (SW, stations Y and X). Stations Y and X can indicate the potential effect of porous ramps on the quality of the main watercourse, based on upstream-downstream differences.

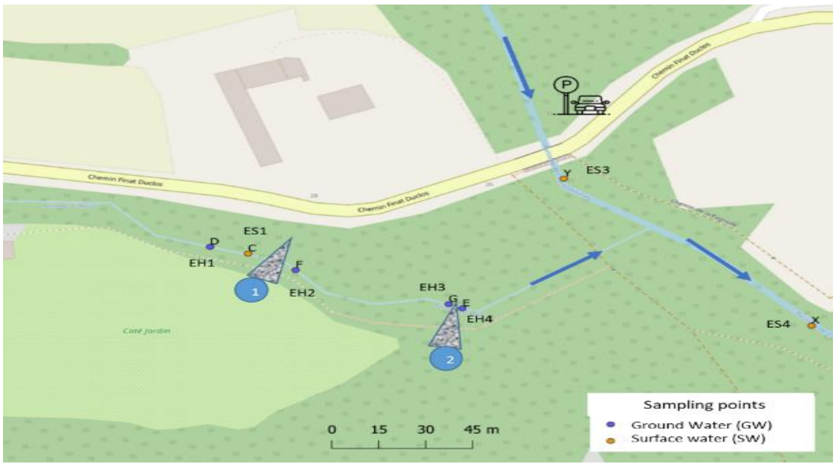
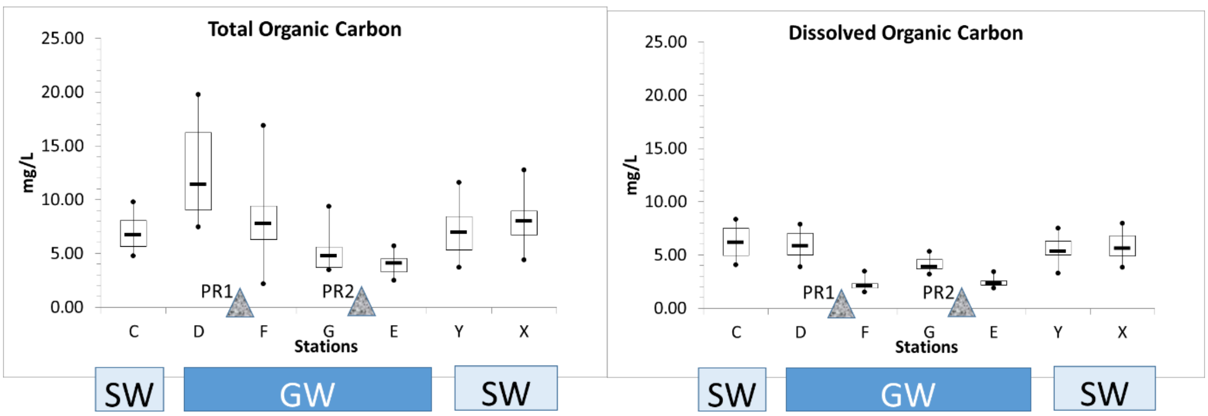


Figure 2.9: Sampling and measurement plan developed at the ATENAS demonstration site.

The other measuring stations are located upstream and downstream of each of the porous ramps (PR1 and PR2). Samples are collected from piezometers at a depth of 30 cm below the sediment surface. This water is called "groundwater" (GW), as it is the site of infiltration and biodegradation caused by the porous ramp systems. The results presented are based on the analysis of 30 samples collected from surface water (SW) and sediment (GW) between 02/23/2021 and 12/16/2021. Concentrations are calculated in C and N equivalents.

The measurement of total organic carbon (TOC) shows two effects: TOC storage in the sediment of the first porous ramp (P{x=X} <= 1.2% between station D and the other stations) and the decrease in TOC from upstream to downstream of the two porous ramps RP1 and RP2. Dissolved organic carbon (DOC) in surface water (SW) and sediment water (GW) is no different upstream of PR1, demonstrating the good circulation of water from SW to GW, as this is the dissolved fraction. Next, we note a significant drop in DOC as we move from PR1 to PR2. We can see that both TOC and TOC are biodegraded (assimilated) by oxidation as they pass through the porous ramps.



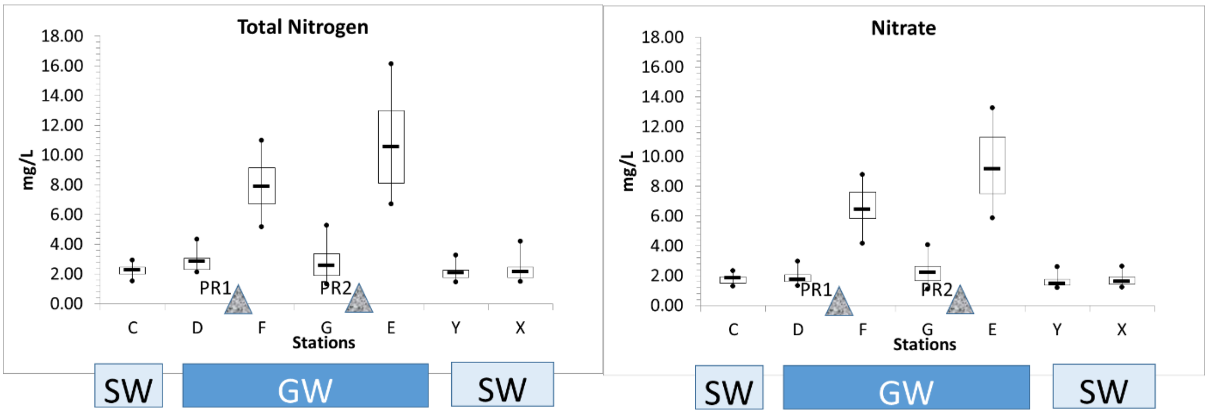


Figure 2.10: TOC, DOC, nitrogen and nitrate concentration distributions over the monitoring period for the performance evaluation of two porous ramps.

Total nitrogen and dissolved nitrogen (not shown here) show very similar concentration distributions. It can be seen that most of the nitrogen is nitrified (oxidized), probably by nitrifying bacteria, at the outlet of the two porous ramps, with a concentration process. As the concentrations of all physico-chemical parameters fluctuate over time, a dynamic equilibrium is established between upstream infiltration and downstream exfiltration. This physical mechanism is verified by comparison with stream flows for intermediate flows. At high flows, dilution seems to be superimposed, leading to a general drop in concentrations. Low flows favor biodegradation due to the slow circulation of fluxes in the sediments. This results in a decrease in TOC and an increase in Nitrate in the sedimentThe origin of the organic pollution seems to clearly indicate the influence of urban discharges on this small stream. Ammonium content decreases from station "C" to station "E" across the 2 porous ramps. Phosphate (ortho-phosphate) does the same. However, the agricultural origin of nitrates cannot be ruled out.
The influence of the device on TOC and Nitrate in surface water is not detectable in surface water. The surface ratio of the two watersheds (which is close to 1) cannot explain any significant dilution by the arrival of the "Y" station. Only phosphate, which is a good tracer of wet-weather urban discharges and is heavily consumed as it passes through the porous ramps, shows a significant drop (P{x= X} = 0.02) between its value in surface water (SW) at station C and its value at station "X".
At this stage, we can conclude that the porous ramp system is capable of effectively collecting some of the pollution from storm overflows.

k. Early Warning indicators

If the size of the rock elements making up the barrier mass is insufficient, it is the narrowest and lowest zone of this barrier that can be washed away (figure x-right) during a flood that submerges the barrier (figx-left, high deposits following submergence). However, the rock elements must not be too coarse, as this would prevent the sediment from accumulating efficiently. The solution is to stabilize the barrier by embedding boulders 5 times as large in the river bed, just around the low-lying area. This is the solution that worked on the ATENAS demonstration site. This point must therefore be anticipated when the boulders are first placed, to avoid the need for a second machine intervention.

Figure 2.11: Example of erosion of the nose of porous ramp number 2 (left = before; right = after).

After a few years, the sediment bank may be colonized by vegetation, encouraging the storage of fine particles on the surface. This phenomenon is delayed if the porous ramps (porous barrier and sediment accumulation zone) are located in a shaded area in spring and summer. This will limit infiltration and biodegradation. In autumn, this vegetation should then be cut back (and used as green manure for the associated agricultural area) to allow the natural flow of water to redistribute fine particles into the porous sediment matrix. Sediment maintenance can be reduced in the event of heavy flooding, which scours the surface layer and regenerates the sediment mass. An annual visit in early autumn allows us to assess the vegetation and condition of the porous ramps.