# Attachment_1 Setting up implementations

**Design approach of porous ramp – Lyon case**

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# Design approach of porous ramp – Lyon case

## Analysis and shared identification of the problem to be solved

One of the competences of the river union of the Yzeron basin (SAGYRC) is to reach the good ecological state of the waterways which drain this catchment area. Approximately 60% of the watercourses have low to no flow during the summer period. The ecological status is therefore highly impacted by urban discharges during rainy weather via the CSOs (combined sewer overflow) outlets (Figure 7). These discharges are triggered by summer storms. The reduction of rainfall runoff by retention solutions at the source and the installation of a separate sewerage network are now part of the development strategy of the catchment area carried out by the sewerage syndicate (SIAHVY). The percentage of volume discharged by all the networks over a year remains below 5%, which is compatible with the European directive on urban wastewater. On the other hand, the number of discharges by storm overflows largely exceeds the objective of 20 days with triggering. This is due to the fact that the combined sewer networks are undersized and in poor condition. The economic cost of repairing them requires spreading the work over several decades. This implies the development of alternative strategies for the protection of watercourses in order not to penalize the objective of good ecological status carried by the SAGYRC.

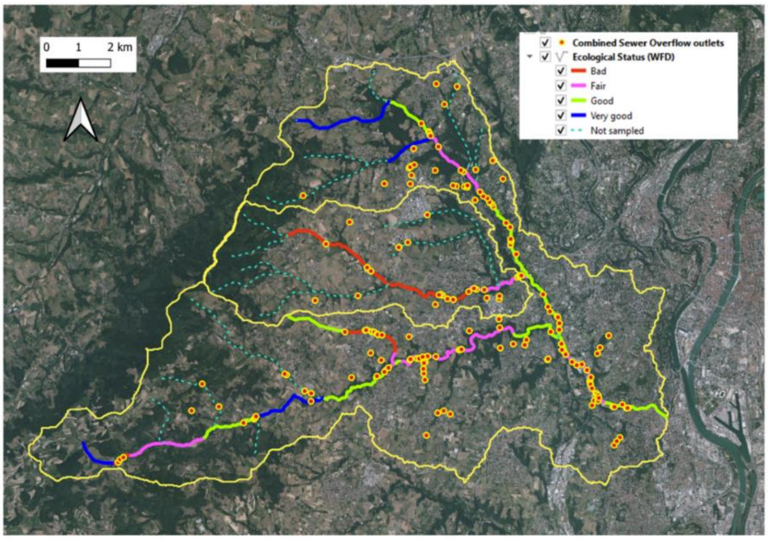



*Figure 7: Watershed of the Yzeron river and sub-watershed of the Ratier river. Ecological status of the main watercourses and position of the wet weather discharge points (CSOs).*

## Choice of NBS

The historical partnership between applied research and the two syndicates has made it possible to evoke an innovative solution based on nature, placed directly in the watercourse because upstream actions on the sewerage system cannot give short-term results. This solution consists in restoring or amplifying the self-purification capacity by promoting the accumulation of porous sediments. In the case of the Yzeron basin, the sediment is essentially sandy. This allows a good capacity of filtration but also of biodegradation by the microbial activity. This natural function has been studied and confirmed on a pilot station (Figure . 8), located in a small stream (1.2m wide) of the Yzeron basin, through several research projects since 2005. The pilot site of the Chaudanne consists of a sequence of two main biofilters, induced by porous barriers (here permeable wooden sills), allows to find downstream (station 4) the quality of the water located upstream of the CSO (station 0). This statistic concerns one year of observation with weekly analyses. The presentation of the operating and maintenance principles of this innovative solution convinced the two unions, which therefore accepted the test on the ATENAS demonstration site. For the unions, this is a "no-regrets" solution because the risk-taking is limited, due to the reduced cost of construction and the low impact on the natural environment. The decision levers here are trust and mutual knowledge of operational and academic constraints.

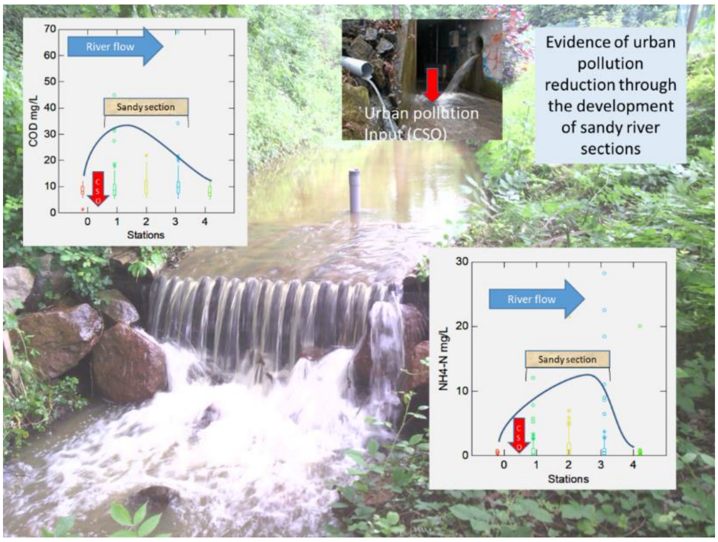



*Figure 8: Demonstration of the amplification of the self-purification function of a small watercourse. Pilot site of the Chaudanne water course.*

Moving from the pilot site to the demonstration site involves taking into account two factors:

- The widening of the stream from 1.2 m to 5 m;
- The number of CSO outfalls, which increases from 1 to 4 in the 100 meters upstream of the demonstration site.

As a first approach, we estimate a ratio of 4 between the two sites. The hypothesis is therefore that a volume of sand 4 times greater than that of the pilot site must be developed to obtain an equivalent result. This would theoretically bring the values of the chemical parameters to their values upstream of the 4 CSOs. The volume of sand on the pilot site is 67m x 1.2m x 0.6 m, or 48 m3. The objective is thus to accumulate 193m3 of sand (48m3 x 4) in the topography of the river using porous barriers and without causing more frequent overflows on vulnerable areas. The expected evolution values of the parameters are calculated from the observations made on the Chaudanne pilot site. They are summarized in *Table 3* (in milligrams per cubic meter of sand volume).

*Table 3: Measured variations of organic parameters per cubic meter of sandy sediment crossed by hyporheic water (Chaudanne pilot site).*

| 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 |

It is noted that all physico-chemical parameters are decreasing except for nitrates. Two reasons are responsible for the increase of nitrates (N-NO3-). The important contribution of agricultural nitrates and the process of nitrification which was highlighted on the pilot site.

The self-purification process is demonstrated through the evolution of the nitrogen (N) percentages of the nitrogen compounds (NH4, NO2, NO3) (Figure 9). Monitoring of gases emitted by bacterial activity has shown a production of 1 liter of gas per square meter per day with a majority composition of 71% nitrogen gas (N2) followed by 26% methane gas (CH4). The rest is nitrous oxide (N2O). The proof of concept is therefore achieved at this stage.

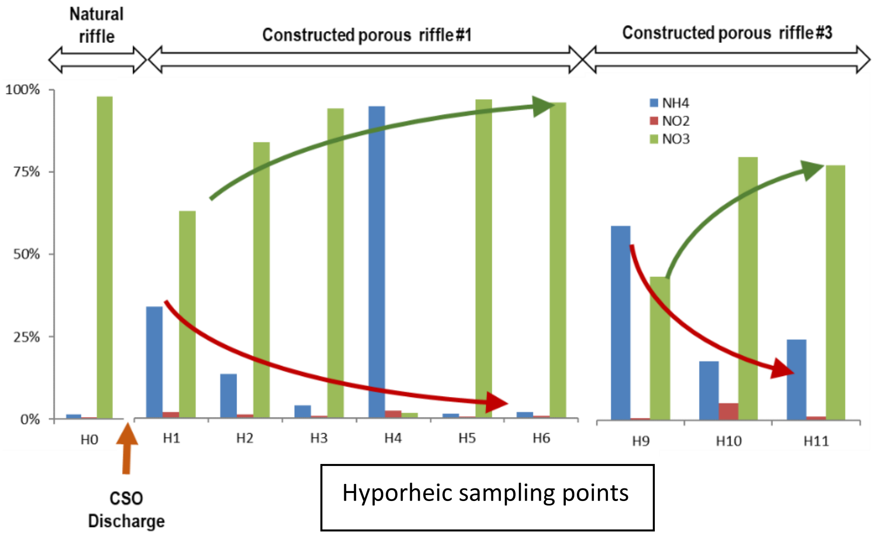



*Figure 9: Demonstration of denitrification and nitrification processes in the sandy zones of the porous ramps 1 and 3 of the Chaudanne pilot site.*

### Pre-location of the NBS

It is from the knowledge of the ecological state of a large part of the network of watercourses of the Yzeron basin that the choice of the location of the demonstration site was made. It was positioned downstream of the Ratier stream which presents a poor ecological state in its upstream part. This is linked to the presence of numerous CSOs, the presence of an urban area located upstream and the existence of a flow of the stream on the bedrock in its upper third. The absence of porous sediments in this part explains the low self-purification capacity. The Ratier stream has returned to an acceptable ecological status in its downstream section, but it disturbs the good ecological status of the Charbonnières stream into which it flows (Figure 10).

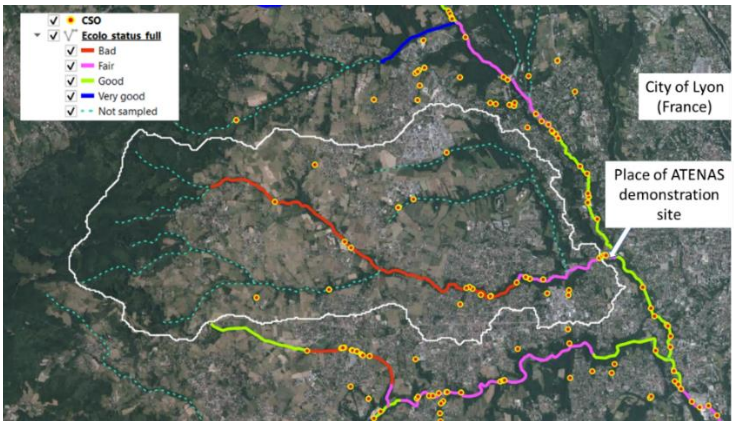



*Figure 10. Location of the study zone for the ATENAS NBS demonstration site - West of Lyon city (France)*

### Feasibility study

The feasibility study was carried out by considering the most suitable areas to accumulate large volumes of sand. For this purpose, the river syndicate provided the precise topographic data of the watercourse. The study consisted in identifying the most favorable zones to accumulate large volumes of sand with porous barriers whose height is the lowest possible. This constraint takes into account a lesser effect on the overflowing water line and a reduced cost of the amount of material to be brought into the streambed to create the porous barrier. The results presented to the river union are shown in Figure11 and Figure 12.

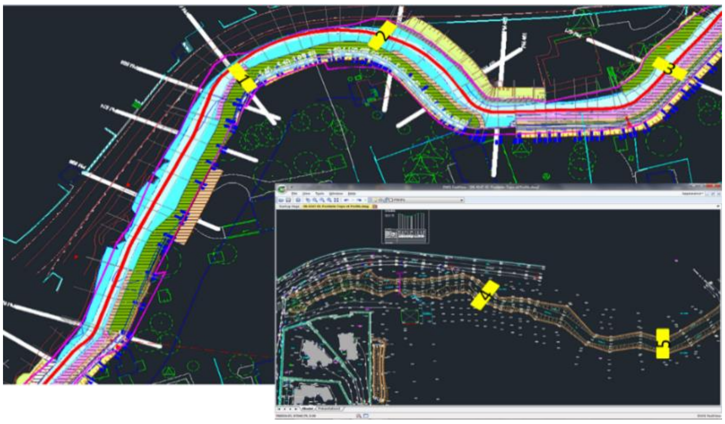


*Figure 11. Five potential location for porous barriers with estimated sand volumes of : (1) 65m3; (2) 45m3; (3) 38m3; (4) 72m3; (5) 48m3.*

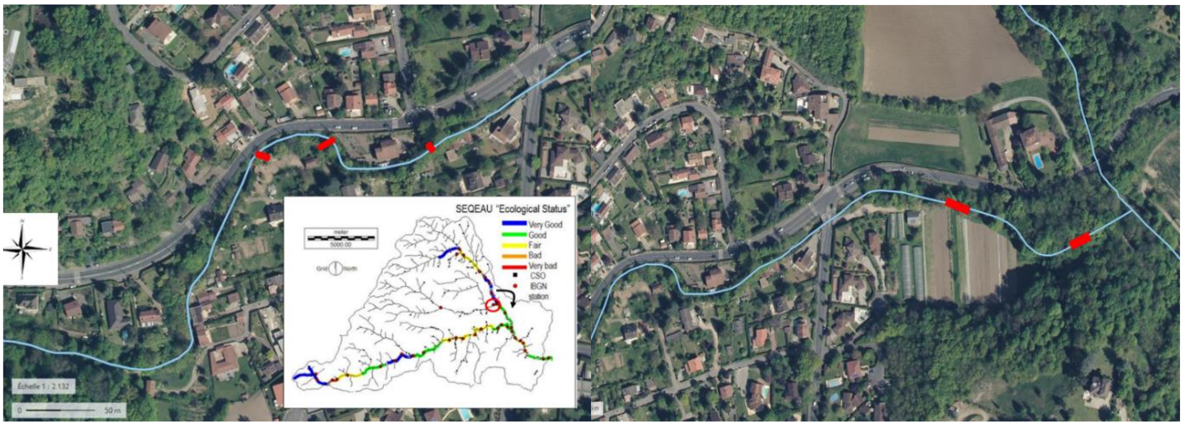



*Figure 12. Upstream (of bridge) possibilities for location of the ATENAS NBS demonstration site and Downstream (of bridge) possibilities for location of the ATENAS NBS demonstration site.*

**Final decision for NBS implementation**

The river union and the fishing federation have retained proposals 4 and 5. This limits the volume of sand to 120m3, which represents 60% of the volume recommended for the pilot site, taking into account the scale factor (X 4). The choice is guided by five conditions:

1. Not to interfere with the flood control and ecological restoration project upstream of the bridge;
2. Do not create an overflow area with the porous barriers;
3. Do not reduce the diversity of aquatic habitats with long sandy flats that are considered unsuitable for brown trout reproduction;
4. Check the accessibility of the watercourse by the earthmoving machines;
5. Verify the right to proceed with work in the riparian parcels of the banks that are partially excavated to install the porous barriers.

Item "3" was discussed with the fishing federation because long sandy flats are natural in this downstream portion of the stream. The average length of the sandy flats is 12m. Point "5" was solved by placing the porous barriers in the parcels belonging to the river union. This shows all the conditions that are necessary to achieve a NBS in a stream.

Figure13 shows the sandy areas, with an average thickness of 0.5m which is imposed by the height of the porous barriers. These visualizations are necessary for decision making.

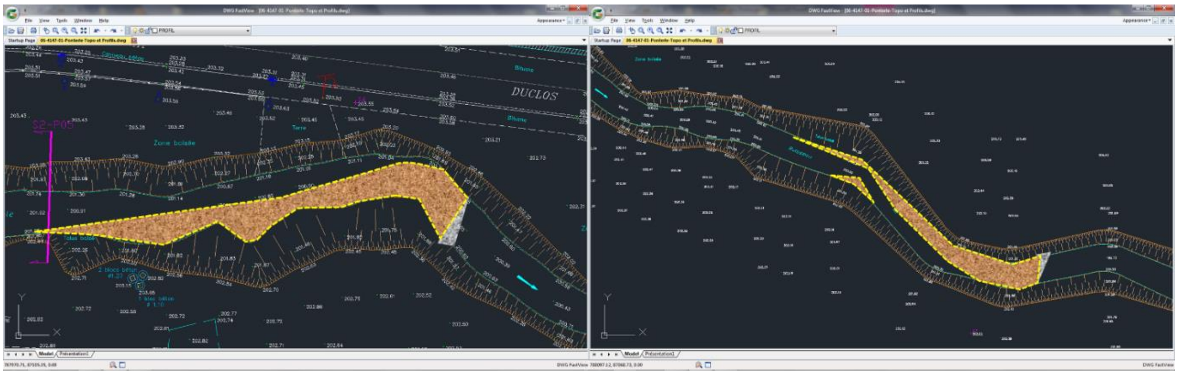


*Figure 13. Delimitation of sandy areas by the effect of porous barriers.*

**Hydraulic study**

The influence of porous barriers is evaluated on the water line. A 1D steady state hydraulic model is used to simulate this influence. The test is performed with the ten-year flood and the 100-year flood (*Figure* 14). For the ten-year flood, a rise of the water line of 0.5m appears at the porous barrier located the most downstream (110m). This causes localized overflows (*Figure* 15), but in a limited way on areas without stakes located further upstream. For the 100-year flood, the whole area between the fields, the forest and the road is flooded, with or without the porous barriers. The water line is raised by about 0.3 m, which is not negligible, but it should be noted that this is a non-constructible zone, dedicated to the expansion of flood volumes, to avoid flooding of houses located upstream of the bridge.

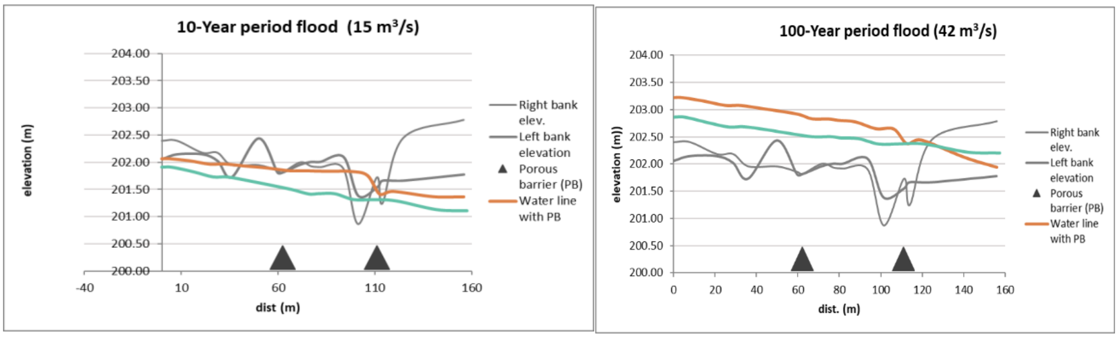
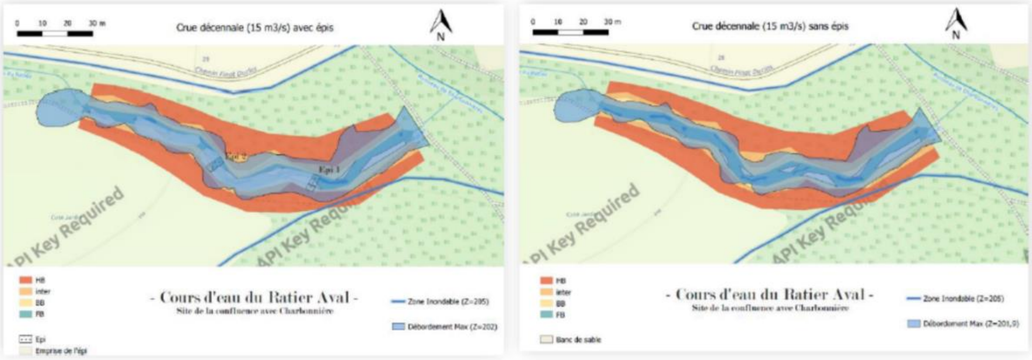
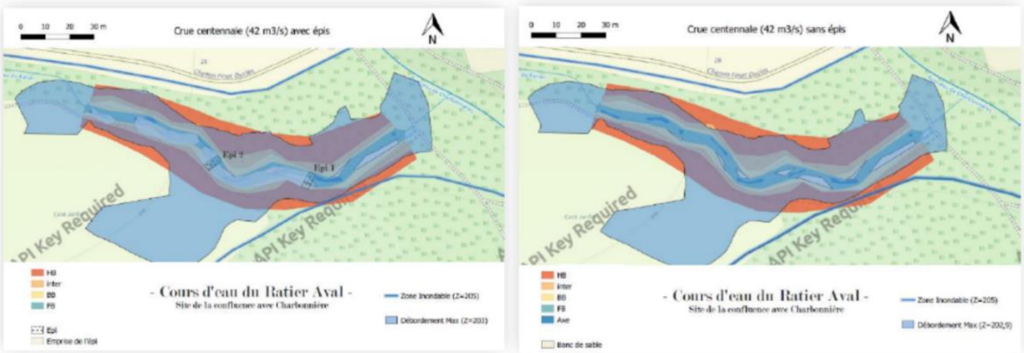



*Figure 14. Evaluation of porous barriers on the water line elevation during 10-y and 100-y flood events.*




Overflow limits for a 10-year flood - with porous barriers (left) and under current conditions (right)




Overflow limits for a 100-year flood - with porous barriers (left) and under current conditions (right)

*Figure 15. Evaluation of porous barriers impact in overflowing  conditions.*

**Field implementation**

The final location is determined during a field visit with the technicians of the river union. Dimensional drawings are used to specify the shapes, dimensions and volumes. The calculation of the volumes is to be carried out at the stage of consultation of the companies of earthwork because that determines the working time and the cost of materials (*Figure*). The works are directed by the INRAE research team which accompanies the earthworks and the installation of the porous barriers. The construction stages are discussed with the drivers of the earthmoving and pebble supply machines.

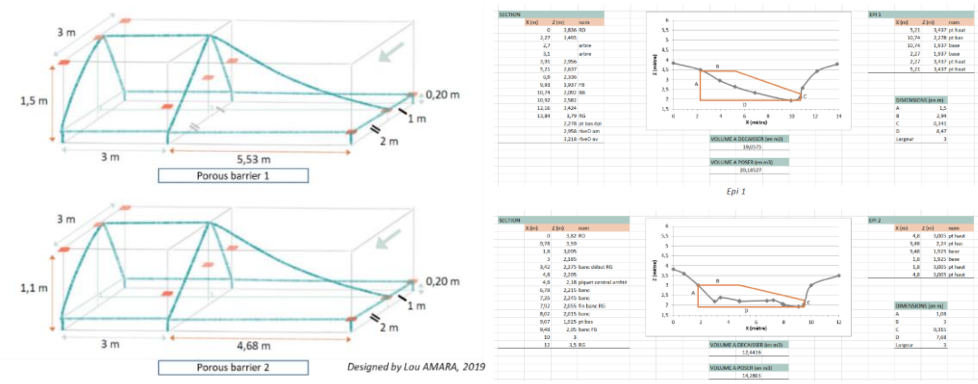



*Figure 16. Calculation sheet of the volumes of earthworks and pebbles to be put in place.*

The first step is to excavate the bank of the intrado over 1m to prevent scouring of the porous barrier and erosion of the bank during major floods. The second step consists in digging the bottom of the stream on its width to be level with its lowest point which is in hydrogeomorphological balance. The work is conducted at this stage by a researcher to assess the problems and list the practical questions to be asked for a future site (Figure ).

*Figure 17. Marking the landmarks of the site on the ground (Left). Stream bed excavation (center). Conducting the site by a researcher (Right).*

The river union imposes the minimum impact on aquatic and vegetal species during the construction phase. The trunks of the trees are protected. The roots are avoided by the construction machinery. A bundle of coconut fiber is placed downstream of the earthwork area to limit water turbidity (*Figure* 18).

*Figure 18. Local biodiversity to protect: crayfish (left). Coconut fiber barrier during the earthwork phase to limit water turbidity that can harm downstream aquatic species (center). Intrusive tree trunk device made by fishermen that helps destroy the porous ramp (right).*

**From the porous barrier to the porous ramp**

The construction of the porous barrier initiates a sediment accumulation process upstream of it. The stock of porous sediment (sand or silt) fills the morphological variability of the bed which then becomes a plane with a low slope. The flow velocities decrease due to the dissipation of hydraulic energy, which favors decantation. The length of this plane determines the trapping capacity of the suspended matters which will be able to infiltrate under the draining effect created by the porous barrier. The organic matter concentrated in the sediment stock favors the bacterial development which consumes and recycles the organic matter by mineralization processes. The mineral forms are again usable by other living forms, plant and microbial. The fluxes of the microbial processes evolve according to the water temperature (the activity increases exponentially with the temperature of the hyporheic water beyond 12°C), the flow rates, the fluxes of water and associated substances. The rapid rises, of short duration (1h) are characteristic of urban discharges of rainy weather, induce strong hydraulic gradients between the upstream and downstream of the porous barrier, which favors the infiltration and circulation of organic matter in the sandy stock. The speed of circulation is thus conditioned by the flow of the watercourse. In periods without water, the hyporheic circulation persists because of the natural slope of the bed bottom. The stock of sand can be renewed in part, on 10 to 20 cm of thickness, at the time of the morphogenic floods. This arrangement, simple in appearance and well integrated in the landscape, is therefore a bio-reactor whose activity is regulated by the hydrology of the watercourse and the substances transported by the water.

The porous ramp is therefore a self-constructed and self-maintained complex by natural processes, which are promoted by the ideally placed porous barrier. Its longitudinal equilibrium profile in the form of a plane and its infiltration function explains the term "porous ramp". Its construction is based on the principle of dual regulation proposed in ecohydrological engineering. The duality characterizes the interaction between the nutrient flows brought by the water flows and the transformation flows operated in reaction by the bacteria of the crossed porous media. Ecohydrology also mentions the existence of hot-spots and hot moments of metabolism. We find these characteristics of amplified bacterial metabolism in the porous ramps (hot spots) whose effectiveness also depends on the seasons (hot moment). *Figure* 19 illustrates these concepts.

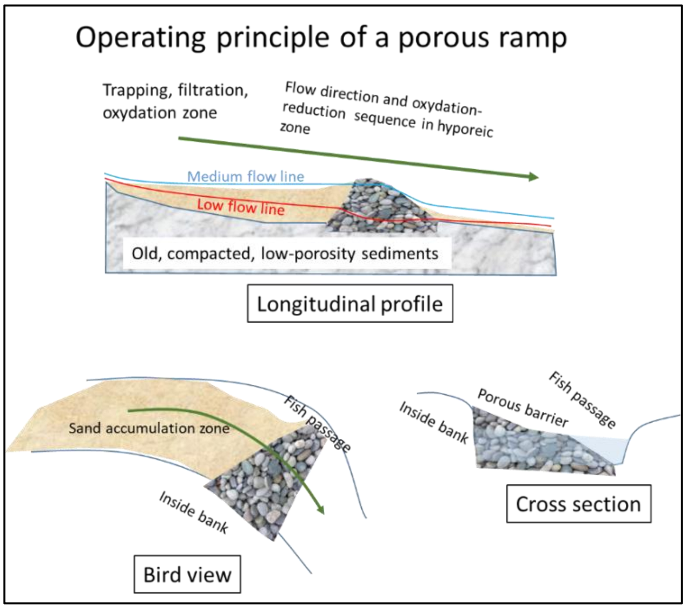



*Figure 19. Visualization of the geometry and water line of a porous ramp (left)*

**Field monitoring / effectiveness indicators / decision to intervene**

The measurement of effectiveness is based on different indicators:

1. The accumulation of porous sediment upstream of the porous barrier. For this purpose, simple wooden stakes with height markers are useful to follow the constitution of the sandy stock and its evolution according to the periods of floods ( *Figure* 20).
2. The stability of the porous barrier under the effect of floods. It is sufficient to monitor the lower part, located on the side of the fish passage, because it is subjected to the strongest erosive constraints during the floods. The loss of pebbles or stones in this part should trigger a repair intervention (*Figure* 21).
3. Observation of the storage process of organic matter in the porous sediment (sand-lime). This process is manifested by a black coloration of the hyporheic water, which indicates active decomposition of the organic matter. Its absence may indicate a problem of water circulation in the porous sediment, such as dense vegetation on the surface. The absence of organic matter, which may occur after a major flood that remobilizes the surface layer (*Figure* 22).
4. Confirmation of microbial activity by stirring the sediment underwater with a stick. This activity is manifested by gas bubbles that rise to the surface. The gases produced are nitrogen gas and methane, both odorless (*Figure* 22).
5. Measuring the concentrations of organic nitrogen and carbon compounds, between upstream and downstream of the porous ramps, in the surface water and hyporheic water. This informs us about the physicochemical and microbial processes involved. Percentage decreases and transformations are indicators of efficiency. They are only to be acquired in a sustained way in a phase of qualification of the installations. This can be integrated into the services of a design office (*Figure* 23).

To summarize: indicators 1 and 2 are sufficient to check the good condition of the porous ramps and decide on an intervention action. Indicators 3 and 4 are useful to check that the self-purification process is working well. In case the self-purification process is not working, it is necessary to involve specialists in ecohydrological engineering to make a diagnosis and propose a reactivation method.

In any case a monthly visit is the guarantee to be able to intervene at a lower cost to maintain the efficiency of the porous ramps by the maintenance services. It is also necessary to verify that post-installation developments of the porous ramps do not contribute to their destruction. This is the case observed with a bundle of tree trunks put in place by fishermen just upstream of the porous barrier number 2, without authorization from the river union. The result was the rapid erosion of the porous barrier by accelerating the flow of the river during floods.

*Figure 20. Wooden stakes with tape indicator to measure sand height. Near the porous barrier (left) and 30 meters upstream from the porous barrier (right).*

*Figure 21. Eroded (left) and repaired (right) porous barrier.*


*Figure 22. Checking the presence of organic matter in the sandy sediment (left) and checking the presence of gas in the sandy sediment (right).*

*Figure 23. sampling point of hyporheic waters in the sandy stock with a piezometer (left) and control of physico-chemical parameters (T, DOx,EC, RP)(right).*

**Construction and maintenance costs**

The costs incurred by the construction of the porous barriers and their maintenance are detailed below, along with the conditions for their construction.
Access conditions to the banks: facilitated by an agricultural road.
Land cost: 0 k€ because the plots adjacent to the river are the property of the river syndicate.
Duration of the work for two porous barriers located at 100m from each other: 1 day
Cost of the work site: 5 k€.
Legal conditions:

- In France, rivers that are not directly managed by the State are under the responsibility of the riparian owners. This implies maintenance and the non-aggravation of flow conditions (Civil Code). This is demonstrated in the demonstration site.
- The water agency imposes to maintain the hydraulic continuity (without fall of more than 0.15m) in the rivers in order to maintain the free circulation of the aquatic species. The porous barrier is designed to meet this requirement.
- The Water Police has given its approval for the implementation of porous barriers in the sense that the amplification of the self-purification process does not fall under the regulations applicable to wastewater treatment plants. Indeed, the treatment conditions impose standards on discharges into waterways. This cannot concern the treatment of discharges already in the watercourse.

After 6 months of operation, the cost of repairing and consolidating the two porous barriers after major floods: 3 k€, duration: 1 day. No deterioration noted since 18 months despite other important floods

**Dissemination and training activities**

The demonstration site serves as a field example to train master students in water science. A two-minute video has been produced to summarize the objective of the ATENAS project and the demonstration site. It is available on the link: https://hal.inrae.fr/hal-03974072

An information panel for the general public on the concept of NBS and its practical application is under construction. It will be placed at the entrance of the demonstration site and will be part of the animation points used by the river union to educate students about the functioning of the rivers. The panel will be inaugurated in the presence of the two partner unions, the river union and the sanitation union. QR codes link to the video and to the ATENAS project website.


Figure 0-1 : Communication and training materials for pupils, students and professionals.

A meeting to present the results is planned with the two unions. The idea is to evaluate the possibility of replicating the solution on other rivers of the Yzeron basin. A presentation is also planned with the Association Rivière Rhône Alpes Auvergne (https://www.arraa.org/nos-missions) which gathers professionals (river managers and technicians) to which the SAGYRC belongs. This guarantees a wide diffusion of the results to the regional actors. A video in French of the results is being prepared.