Integrated Blue and Green Corridor Restoration in Strasbourg: Green Toads, Citizens, and Long-Term Issues

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Abstract The Ostwaldergraben is an urban stream located in Strasbourg (northeast of France). Mostly fed by groundwater, it was enlarged some forty years ago, which led to a radical alteration of the flow dynamics and a strong siltation. According to the European Water Framework, the stream displayed a bad status with sediments polluted by discharges of former tanneries. Hence, a project of restoration—both of the stream and the adjacent wasteland—was launched by the City of Strasbourg in 2010 to solve these issues of environmental degradation in accordance with the European regulation. The stream bed was redesigned to energize the flows and to create meanders and vegetated benches. To improve the connectivity between two adjacent wetlands, new habitats and a network of ponds have been created. A hybrid type of stormwater treatment system—a pond followed by a constructed wetland—was implemented to complete the restoration project. In this chapter, we propose to study this project from its construction to its current development, through the lens of ecological engineering and a perspective on long-term issues. We aim at illustrating the facts that nature-based solution management can differ from technological management and that the ecosystem services provided by a nature-based solution result from trade-offs, which requires a global analysis of such restoration project. To reach this goal, the project will be studied from ecological, engineering, and sociological perspectives. Our study shows that the restored socio-ecosystem works on a rustic basis and provides several ecosystem services: supporting services (habitat for

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amphibians), regulating services (water quality enhancement), and cultural services (urban landscape greening).

Keywords Stormwater treatment · Ecosystem services · Green toads Urban landscape · Restoration

1 Introduction

The main target of the Ostwaldergraben restoration's project (2010–2015) was to create an ecological corridor in an urban area by restoring a length of about 600 m of the Ostwaldergraben stream and its floodplain. The main ambition was then to rebuild the stream's function as a blue and green corridor for a target species (*Bufotes viridis*, commonly referred to as the green toad) between two upstream and downstream sites that were previously restored. In 2008, the upstream zone originally composed of an agricultural area was turned into three ponds located in a compensatory afforestation north of a large one called 'Etang du Bohrie' (Fig. 1). This area is surrounded by a mosaic of different habitats. In 2009, on the downstream area, a wetland was restored around the Ill River at the confluence with the Ostwaldergraben. At this location, the restoration consisted in the creation of various environments (wet meadows, woodlands, reed beds) and a flooded island enclosed by arms with various depths. In less than one year, the site was colonized by at least 12 regionally declining species, of which 7 are listed as endangered (birds, reptiles, and insects such as *Odonata* and *Lepidoptera*). But the stream stretch that connects these two wetlands was preventing these species from spreading or freely moving, especially the green toad. The green toad is a patrimonial species, an important and emblematic element of the regional fauna. The species easily colonizes early successional habitats within its area of occurrence as long as the vegetation is not too developed. This species depends on two major types of habitat: ponds as suitable habitats for breeding and larval development and terrestrial pioneer habitats for juveniles and adults (foraging, hibernating, and/or traveling). Several indications of the presence of *B. viridis* were observed upstream (recurrent use of breeding sites) and seldom downstream the restored area along the Ostwaldergraben in a large pond called 'Etang Gerig.'

In that context, the main aims were (i) to provide *B. viridis* with a corridor to reach and leave reproduction sites, allowing exchanges between two close subpopulations; (ii) to reinforce habitats available to complete its life cycle. Organisms that require two different habitat types to fulfill their life cycles, such as pond-breeding amphibians, are especially vulnerable to habitat loss and degradation (Becker et al. 2007). For them, landscape complementation can be defined as the process by which the proximity of two critical habitat patches of different types essential for a major ontogenetic niche shift complements occupancy, abundance, or persistence in each patch (Dunning et al. 1992). The project was designed to both allow displacement of individuals along the river and increase the landscape complementation in an urban context for the green toad.

Fig. 1 Location of the restored section (white double arrow) between two adjacent sites previously restored for environmental purposes (view extracted from Google earth). The flow direction is from west to east

2 Issues and Potential of the Socio-Ecosystem at Stake

2.1 What Alterations Have Motivated the Restoration Program?

The Ostwaldergraben is an urban stream mostly fed by groundwater. Forty years ago, it was enlarged which led to a radical alteration of the flow dynamics and a strong siltation. The environmental characteristics change along the course of the stream from the upstream part (‘Etang du Bohrie’) to the downstream one. Before the confluence with the Ill, the stream flows under a bridge dedicated to the trams’ and cars’ traffic. The wet bed occupied the entire width of the bridge deck, meaning there were no banks at this point. The passage of terrestrial fauna was impossible there, while the bank vegetation continuity was interrupted and fish passage restricted because of a very low water depth (Fig. 2a). An earthen bund contained the river on the left bank; it abruptly severed the aquatic compartment from the terrestrial one.

In terms of nuisances, pylons of power lines are placed overhang from the stream on the left bank. A regulation obliges the landowners to manage the vegetation that develops under and around the pylon within a radius of 5 m. Since these lines cannot be moved, regular vegetation management operations (cutting of trees and shrubs, mowing) are scheduled.

Before the restoration program, a monitoring highlighted that the stream displayed a bad status, notably because of polluted sediments due to the former tanneries. The district's stormwater was directly discharged into the watercourse without any prior treatment, and the ducts were overhanging the natural environment.

In this context, the challenge was (i) to revitalize the stream in an environment with fine sediments of very poor quality, (ii) to allow the creation of a mosaic of environments favorable to the movements and reproduction of the green toad, (iii) to decrease the negative effects of the passage under the bridge in terms of longitudinal continuity.

2.2 First Project, Public Inquiry, and Social Adjustments

From the aforementioned alterations, the Ostwaldergraben project was first imagined as a three-pronged approach:

1. Stream restoration and creation of an ecological continuum allowing animal species to come back, among them the green toad (*B. viridis*);
2. Stormwater depollution performed by treatment systems (we will explain in the next part why this was included);
3. Creation of a bike lane along the restored stream.

Closing the whole area to the public was also an option considered in the project. A public inquiry was carried out in 2011 as a prior step to the whole project. A public inquiry is a regulatory and mandatory step (French regulation) that takes place prior to any land use planning project. It is meant as a democratic consultation tool, where any citizen or environmental/local associations can freely express their view on a given land use project. Three environmental associations answered the inquiry and insisted mainly on the creation of the bike lane, perceived as in total contradiction with the species comeback. Public meetings were held in 2012 in Strasbourg and Ostwald (the two municipalities at the border of the Ostwaldergraben). The organization of public meetings is the second mandatory requirement in the process of public consultation in a land use planning project. Following the public inquiry and the public meetings, the local authorities gave up

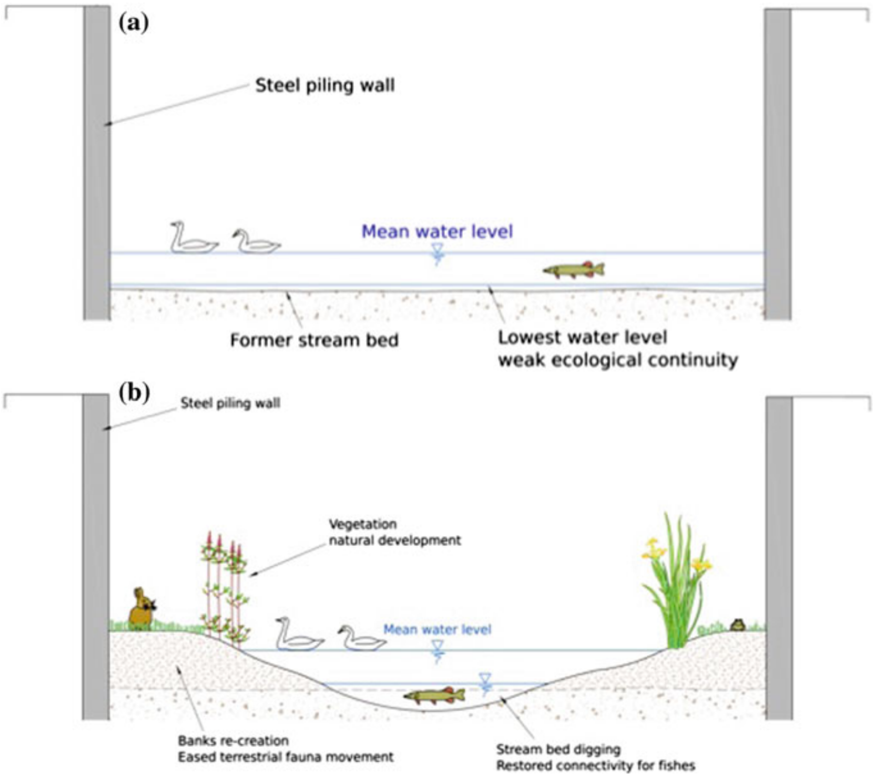

Fig. 2 **a** Former situation. The space under the bridge breaks the terrestrial continuity (banks severed) and the aquatic continuity (low water depth). (Modified from a document produced by the engineering consultant SINBIO), **b** Restored situation. The space under the bridge was modified to tighten the width of the streambed, revitalize the flows, and avoid siltation. The tightening of the minor bed and digging of the middle part of the channel make it possible to obtain water height and flow velocities compatible with fish continuity. The naturally vegetated side banks allow the passage of the terrestrial fauna. (Modified from a document produced by the engineering consultant SINBIO)

on the bike lane project and concluded also that the comeback of given species (e.g., mosquitoes, amphibians, etc.) subsequent to the stream restoration was an issue for some citizens. The stream flow was very low at that time, so mosquitoes were largely able to nest in even before restoration. The report also highlighted that the residents preferred closing the site to avoid burglary or potential nuisances.

The project was eventually carried out in two phases to restore the site (stream and flood channel) over more than 600 m (2015) and setup stormwater treatment systems (2012).

2.3 The 'Dirty' Stormwater Problem and the Way It Was Solved

The restoration of a stream relies on its morphologic features, but also on the various water inputs, mainly stormwater in this case. Two main effects are at stake: (i) banks physical alteration due to water discharge and (ii) water pollution through contaminant transports by stormwater.

The first effect is caused by stormwater collection in separate networks and direct discharge into streams; the resulting peak flows during storm events create a physical effect of digging on the riverbanks. This at least disturbs the morphology of the stream, if not reshaping it and may generate suspended solids resuspension in the stream; the consequences unveil very quickly. Additionally, in the case of the Ostwaldergraben stream, the outlet pipes of the separate network were positioned overhang and discharged directly into the water bodies, which increases the physical impact of runoff.

The second effect results from a quite complex chain of processes. When it rains, rainwater loads with airborne pollutants, such as heavy metals, hydrocarbons, pesticides, and gaseous species (Azimi et al. 2005; Scheyer et al. 2007; Fenger 1999). As it reaches the roofs, roads, gardens and if there is enough rain to start runoff, it will collect other compounds either by transport or dissolution. In the case of urban systems, these main compounds are (Barbosa et al. 2012): solid particles from dust, traffic, and animal feces (becoming suspended solids when carried in the water), heavy metals coming mainly from gutter, road and car material, PAHs from traffic, pesticides from gardening activities, bacteria from animal feces and miscellaneous compounds from light-headed point discharges. In the case of the Ostwaldergraben stream, the typical pollutant concentrations for eight runoff events analyzed in 2013 are listed in Table 1. As can be seen from the table, these are low but significant levels, and of course highly variable values. Urban streams are thus directly contaminated by polluted stormwater in case of untreated discharge. Eventually, even at these low levels of contamination, stormwater was shown to display ecotoxicological effects on aquatic ecosystems (Gosset et al. 2017; Chong et al. 2013); stormwater treatment is mandatory to keep the stream in a good state once restored.

To alleviate this environmental degradation and help maintaining the stream at a good status, many options can be chosen, from the most classically engineered ones to ecologically engineered ones, sometimes called nature-based solutions (NBS) (Erickson et al. 2013). Classically, engineered systems are generally characterized by a large environmental footprint due to the use of exogenous material and of their complex structures arranged with the intensive use of machines powered with fossil fuels. Eventually, the recycling of the materials at the end of their lifecycle is not neutral. Although the environmental footprint of NBS exists as well, it is greatly reduced compared with classically engineered systems (O'Sullivan et al. 2015). In the case of constructed treatment wetlands (CTWs), a large part of the ecological footprint is due to the fact that the basin

Table 1 Contamination levels in the Ostwaldergraben stormwater for eight runoff events in 2013 (adapted from Schmitt et al. 2015). COD = Chemical Oxygen Demand, TSS = Total Suspended Solids, TN = Total Nitrogen, TP = Total Phosphorus

	COD (mg_{O2}/L)	TSS (mg/L)	TN (mg_N/L)	TP (mg_P/L)	Cu (µg/L)	Cr (µg/L)	Pb (µg/L)	Zn (µg/L)
Minimum concentration	25	5	0.8	0	9.6	1.1	1.7	176
Maximum concentration	400	110	11	1.2	42.4	10.6	94.4	640
Number of detections	5	7	8	6	7	5	7	3

must be filled with sand of a given particle size, that is sometimes sampled and transported from afar.

Apart from their ability to clean stormwater and to protect the stream (feature of any stormwater treatment system), the reduced ecological footprint of NBS and the will to create green/blue connections with the to-be-restored stream were the main reasons these systems were set up along the urban stream. More specifically, constructed wetlands were set up. Among the ecosystem services provided by this type of system (Moore and Hunt 2012), regulating services were guiding the construction of a hybrid system composed of a pond and a constructed treatment wetland (CTW). The potential peak flows are buffered by the succession of a pond and a CTW, while the pollutant load is reduced by the combination of settling, photodegradation, physical filtration, biodegradation, and sorption phenomena happening in the pond-CTW system. This system is typical of an ecological engineering approach, as defined by Mitsch (2012): 'the design of sustainable ecosystems that integrate human society with its natural environment for the benefit of both.' It is (among others) characterized by reduced engineering during the construction phase, reduced compulsory maintenance and energy costs and use of natural properties from a complex ecosystem to provide ecosystem services—in this case, regulating services.

3 Tackling the Issues: The Restoration of the Ostwaldergraben Socio-Ecosystem

The implementation of this restoration program, the technical choices, and the construction resulted from the work of a consortium with an owner (City of Strasbourg), a contractor (the engineering consultant SINBIO), an engineering school (Ecole Nationale du Génie de l'Eau et de l'Environnement de Strasbourg), a research laboratory (ICUBE lab.), a water agency (AERM—public establishment of the Ministry for Sustainable Development), a NGO (BUFO—study of Amphibians and Reptiles of Alsace), and citizens. This co-construction exercise involved a participatory approach that marked the different stages and accomplishments that we describe here.

3.1 Technical Itinerary to Achieve the Restoration Objectives

In order to stimulate the flow and limit the siltation, the bed width was reduced to 2 m. Gently sloping banks likely to be naturally vegetated by helophytes were created as well as windings and meanderings (Fig. 3). Shrub willow cuttings were planted.

The first operations to improve the diversity of the habitats were devoted to the creation of a pond network in the upstream sector where the sediments were not polluted. These ponds have three main functions: They serve as potential breeding habitat for amphibians, they contribute to the habitat diversity available to wildlife, and they collect the water discharging from the stormwater treatment system (see next part). The excavation/embankment operations were conducted to erase the bund; this reconnected the river and its major bed, while removing an awkward feature in this landscape context.

Management operations (mowing) of the vegetation under and around electric pylons must be conducted regularly. These interventions allowed artificially rejuvenating the environment on the left bank where breeding ponds were created, the right bank being left in natural evolution. The fauna and flora thus have a mosaic of aquatic/terrestrial habitats at different stages of plant succession. Mowed habitats are banks of alluvium and sand adequate to the displacements of many species.

Fig. 3 Restored stream. A dead arm can be seen on the left side of the picture, and a meander on the right (*Source* ICube Laboratory)

The biological quality of the Ostwaldergraben was evaluated with biological indicators based on aquatic macroinvertebrates. The biotic index applied highlighted the bad status of the stream stretch. Deposits made during the period of the tanneries' activity resulted in sediment contamination with highly toxic metal trace elements, such as chromium (Table 2). These observations led to remove the bund and dispose of this part of the polluted materials in a nearby dump (the one from the old tanneries). The remaining contaminated sediments corresponded to finer fractions, with sludge dredged from the stream bed. They were confined on created mudflats in a part of the old bed (three sections short-circuited by the re-meandering). The objective was to confine all the polluted muds extracted from the reduced minor bed and the ponds created on the right bank. The mudflats were covered with a geomembrane and a geotextile to avoid contact with the air in case of a drop in the water table. The containment of polluted sediments enabled the project to stay economically realistic compared with an export-and-treatment option. Additionally, it avoids for humans as for animals any possibility of contact or ingestion of the pollutants when visiting the area.

Vegetated embankments were created under the bridge to ease the passage of wildlife under the structure and restore the ecological corridor function for terrestrial species (Fig. 2b). The flow was tightened in a dug channel to promote aquatic continuity, in particular for fish. This panel of technical options was chosen thanks to the property right of the site by the owner builder, the City of Strasbourg.

Table 2 Sediment quality of the stream observed at two locations in 2006. All measured organic compounds are polycyclic aromatic hydrocarbon (PAH). The limit values provided correspond to French guideline values for soil and water pollution

	Units	Location 1	Location 2	Limit value
Dry matter	%	23.5	41.0	/
Cd	mg/kg DM	5	5	<10
Cr	mg/kg DM	**1,600**	**5,700**	<65
Cu	mg/kg DM	**150**	53	<95
Hg	mg/kg DM	1	0.23	<3.5
Ni	mg/kg DM	34	15	<70
Pb	mg/kg DM	190	70	<200
Zn	mg/kg DM	1,100	190	<4,500
Benzo(b)fluoranthene(3,4)	µg/kg DM	1,200	400	/
Benzo(k)fluoranthene(11,12)	µg/kg DM	550	190	/
Benzo(g,h,i)perylene(1,12)	µg/kg DM	700	280	/
Indéno (1,2,3-c,d) pyrène	µg/kg DM	1,300	390	/
Fluoranthene	µg/kg DM	2,200	640	/
Benzo(a)pyrene(3,4)	µg/kg DM	1,100	410	/
Sum of the six PAH	µg/kg DM	7,050	2,310	/

3.2 Setting up the Nature-Based Solutions to Treat Stormwater

Three urban watersheds are discharging runoff water into the stream on the study site, so three nature-based systems were set up; each one collecting and treating the water from one watershed. The sizes of the watersheds are pretty alike (ca. 2 ha) but in order to test the effect of different configurations on treatment efficiency, the constructed wetland varied in size. The choice of the CTW being the variable was somewhat arbitrary, as the pond might have been another variable of choice for different setups. Thus on the location of the initial wasteland were eventually built these treatment systems (Fig. 4), made of (from upstream to downstream):

- An artificial pond followed by a vertical subsurface flow wetland (#1 and #3, with differences in the size of the porous media that were used) followed by a discharge pond;
- An artificial pond followed by a horizontal subsurface flow wetland (#2) followed by a discharge pond.

Of the three systems, only two (#1 and #3) have been studied so far, so we will not develop further on #2. The main geometric, hydraulic, and upstream watershed characteristics of the systems are summarized in Table 3. For each watershed, the {pond + CTW} combination area is around 1–2% of the watershed active area.

As the groundwater table is close to the surface on the premises, the whole system was conceived to be impervious, in order to prevent infiltration of untreated water. As the available soil was not watertight, the main question that arose was how to ensure such imperviousness? The choice was finally made to coat the bottom of the pond and the wetland with 30 cm clay to achieve this at a reasonable cost; luckily this was the most environmental-friendly solution (other solutions were geomembrane or concrete).

The pond is fed through a concrete duct that is the outlet of the separate network collecting runoff water from the urban watershed (Fig. 5). The water flows from the pond to the CTW through a floating weir, whose triggering depends on the initial pond water level and rain events characteristics (intensity, duration, dry period, water level, and return period) and that works only for large enough rain events. The constructed treatment wetland is fed through several PVC pipes reaching different parts of the system to try and feed the system homogeneously. After vertical flow in the CTW, the stormwater is discharged into the last artificial ponds that are hydraulically connected to the stream. Moreover, the first pond is equipped with overflows—made of concrete pipes, which increases the ecological footprint of the system—that discharge directly into the final pond in case of extreme events. This overflow system caused a temporary failure in the system. It is indeed sealed with clay on the edge of the pipe to remain watertight, but a too low water level in the pond at first caused the clay to dry and subsequently retract. When water filled the pond back at a higher level, it started leaking at the joint and the pond drained. More clay was added to solve the problem.

Fig. 4 Hybrid treatment system just after construction. The settling pond is on the lower side of the picture; the constructed treatment wetland is on the upper left side of the picture. A bit further behind, a discharge pond can be seen (*Source* ICube Laboratory)

Table 3 Stormwater treatment system characteristics and hydraulic features (adapted from Schmitt 2014)

		#1	#3
Watershed	Surface (ha)	2.7	1.8
	Active surface (ha)	0.9	0.52
Pond	Size (m × m)	11 × 9	5 × 4.5
	Maximum hydraulic load ($m^3/m^2/day$)	10	10
	Permanent water volume (m^3)	28	2
	Maximum temporary water volume (m^3)	56	10
CTW	Area (m^2)	90	100
	Surface/watershed active surface (%)	1	2
	Maximum hydraulic load ($m^3/m^2/day$)	60	30

From the surface to the bottom of the CTWs, the porous medium is distributed as follows: The top layer is made of 20 cm (CTW #1), respectively, 30 cm (CTW #3) of sand (particle size from 0 to 4 mm); for both CTWs, the intermediate layer is made of 25 cm of fine gravel (particle size from 4 to 8 mm), and the drainage layer is made of 25 cm of gravel (particle size from 16 to 22 mm). The choice and the arrangement of these layers are a crucial and delicate point for CTWs, as it controls the infiltration rate and subsequently the hydraulic residence time, determining the absence or prominence of clogging in the system.

Finally, as the system feeding is by essence stochastic, a minimal water level is maintained at the bottom of the CTWs to reduce the water stress that vegetation, especially wetland plants, could endure during long dry periods. The ponds were

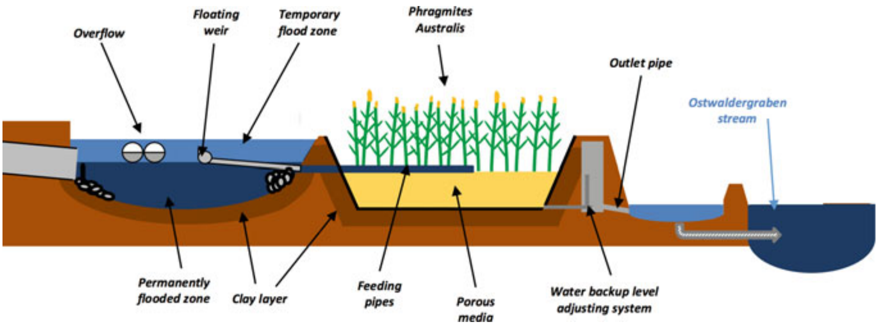

Fig. 5 Side view of the treatment system. From left to right (corresponding also to the water flux), pond, constructed wetland, discharge pond, stream (adapted from Schmitt 2014)

built free of vegetation, while the constructed wetlands were planted with *Phragmites australis* (9 plants/m^2).

4 The Ostwaldergraben's Response: Aftermath of the Restoration Project

4.1 The Creation of a Haven for the Green Toad? A New Face for the Corridor

The operations on the natural environment showed positive changes in a very short time after achievement. For example, the first ponds were created between March and August 2012, and as early as in September immature individuals of green toads were observed in these newly created habitats. In April of the following year (2013), egg clutches of several green toads were observed. The creation of a network of ponds at the upstream site (Bohrie Pond—2008) produced the same trends (Michel and Zrak 2015): a very fast colonization and a rise in the number of use of these environments, at least before the vegetation development (2011). These few results given as examples show the rapidity of spread in new environments by organisms whenever source populations are around.

The notion of a mosaic of habitats has also a central place in this type of project. The amphibian species *Bufotes viridis* acts here as an umbrella species that needs fallow and even cultivated soil to find suitable habitat during its terrestrial phase. This pioneer environmental species needs a constantly rejuvenated environment. Working gravel pits on both sides of the restored site allow the maintenance of pioneer habitats, while the restored site can be considered as a secondary habitat favoring connectivity between subpopulations. To keep this passage interesting and functional for the green toad, vegetation must be managed to avoid too great development and keep this system at a pioneer stage. The maintenance needed to manage the vegetation under and around the power lines pylons also helps rejuvenating the vegetation along the dispersal corridor, in particular on the bare soil surrounding the artificial breeding ponds. The obligatory status of this management compensates the absence of self-sustaining natural processes to maintain each adequate habitat available in the mid- and long-terms.

4.2 *Sustainability of the stormwater treatment: evolution of the hybrid system over 5 years*

The responses of the treatment system were observed from the beginning of operation (back in 2012). The hybrid system was meant to provide regulating services on peak flows and water quality. First, less than 20% of the runoff events discharging into the pond actually discharge from the pond to the CTW. Thus, the sizing of the pond provides a strong buffering effect on runoff water discharge into the stream. Second, the pollution of the stormwater is clearly mitigated for both watersheds: major pollution (COD, TSS, TN, TP) (Schmitt et al. 2015) and micropollution (heavy metals and polycyclic aromatic hydrocarbons—PAHs) drops from the inlet to the outlet of the systems. These performances are sustained in time, as sampling sessions from 2013 to 2017 gave similar results.

The ecosystem services expected for the hybrid systems are well provided. The way the system works is also interesting: For instance, in case of runoff a strong shortcut is created by the floating weir because of its arm's length, which largely reduces the hydraulic residence time in the pond—and thus the efficiency of the settling phase (Laurent et al. 2013). This could be easily enhanced by installing a static weir leaving the whole pond surface available. In the CTW, the flow distribution is heterogeneous unlike what was expected: very little water reaches the end of the longest feeding pipes, which creates a feeding gradient.

The accumulation of sediments progressively fills the pond; the organic layer depositing at the surface of the CTW is around 4 cm after 6 years for the most covered CTW and 0 for the less covered. Ponds are colonized (2 out of 3) by macrophytes or algae and transform slowly into wetlands. In the CTWs, a gradient of organic deposit according to the feeding gradient is observed. In both constructed wetlands, trees and grass are appearing and sometimes taking over on macrophytes.

After 6 years of operation, the pollution mitigation is still working. As the pollution that is treated is mainly due to heavy metals and PAH, that are either non-degradable or highly stable compounds, their removal from stormwater means they migrated from the liquid phase to another phase. These pollutants are then logically found in the solid phase (sediments from the pond and organic matter and sand from the constructed wetland)—in the pond sediments, heavy metals were detected at a few mg/kg_{DM} to more than 2,000 mg/kg_{DM} for zinc, and around 1 mg/kg_{DM} of PAHs—and in the vegetation of the constructed wetland—from 1 to 22 mg/kg_{plant_DM} of heavy metals were measured in the reeds growing in the CTW

—(Schmitt et al. 2015). The contamination level in the sediments will rise steadily with time, which makes it first a sink for pollutants, but could also create a source of pollution under changing physicochemical conditions (Semadeni-Davies 2006).

When we look further ahead, the hydraulic functionality is likely to remain as long as sediments' accumulation is not too important. Yet, as the system keeps on retaining suspended solids from stormwater, accumulation will go on and call for sediment dredging, at least in the pond. With a minimal maintenance, this ecosystem service can be easily sustained over time. It is less crucial in the CTW, as the accumulation of mainly organic matter on its surface is much lower than in the pond, as the latter is the first in the system to retain such pollutants. If we look now from an ecotoxicological perspective on this system, the handling and disposal of these sediments appear to be of utmost importance: The toxicity of stormwater sediments was shown for much lower metal concentrations (Hatch and Allen 1999; Snodgrass et al. 2008). And as the treatment system is bound to stay and continue working, this long-term question is critical for the sustainability of the system. Eventually, the issue of the sediment behavior and fate should be carefully thought after.

4.3 Nature-Based Solutions and Citizen Representations: Sociological Aspects of the Project

To study the way this freshly built socio-ecosystem is perceived by the local residents and surveys were carried out during spring 2017. As a first step, seven people living in close proximity to the site were interviewed about their perception of their neighborhood. These semi-structured interviews were focused on the representation of their living environment and the potential nuisances, the representation of the Ostwaldergraben and its utility and on their own practices in terms of water pollution. This step was meant to define precise questions before individual questionnaires would be created. The individual questionnaires summarized the main issues of the interviews and were addressed to all the inhabitants living in the street right next to the site and to the inhabitants living in the street right behind (147 households). The questionnaire contained 23 questions (including 7 questions on the social characteristics of the respondents). It was self-administrated, and the principle of answering to the questions was built on the Likert scale: Respondents had to choose between five modalities (from 1 = 'not at all' to 5 = 'absolutely'). Of the 147 questionnaires mailed, 66 answers were received (45%—without any reminder). The sample was quite similar to the population living in this area: In our sample, we had 53% men and 47% female, the average age was 52 years ($\sigma = 15.1$) and there was a strong percentage of retired people (30%). Fifty-eight percent of the respondents had a direct look upon the zone. The questionnaire allowed us to test three main hypotheses: (i) The distance to the Ostwaldergraben site influences the residents' representation of the Ostwaldergraben; (ii) the knowledge of the functionality of the site (depollution) modifies the inhabitants' behaviors linked to their own pollution in the rainwater network collection; and (iii) there is a typical profile of inhabitants who show a stronger awareness of the link between pollution in the stormwater network collection and the pollution of the Ostwaldergraben stream.

The results showed that distance to the site influenced the representation of pollution of the Ostwaldergraben: The respondents with a direct look on the site preferentially think that the stream is polluted [F (1.61) = 4.0334, $p = 0.05$]. Likewise, the respondents with direct look on the site wish that the site remains closed to the public [F (1.60) = 7.1361; $p = 0.01$].

To check the link between the respondents' understanding of the site and their own behaviors (hypothesis #2), further questions were asked (Figs. 6 and 7). The answers to the question on the system's functioning (Fig. 6) showed that the reintroduction function is the most understood, followed by the aesthetics enhancement. On the contrary, the regulating service—pollution mitigation—is poorly understood and the gutter products do not seem to be associated with pollution. To precise things a bit more, the question of the origin of the water entering the pond-CTW system was asked (Fig. 7). These answers showed that people think of the system as only designed to treat 'rainfall,' which means actually direct rainfall, as shows the answers to the last question '[…] gutter-discharged products.' People are aware that this system is not meant to treat wastewater as shows the answer to the second question (…domestic wastewater). Eventually, the understanding of the stream restoration conforms to reality but there is a gap between the {pond-CTW} function and its perception from the respondents. Additionally, an analysis of the variance (ANOVA) of the results shows that reading the information panel does not make a significant difference in the understanding of neither the treatment function of the hybrid system nor the origin of the water discharging in the system. We can conclude that the panels failed to explain the function of the treatment system, and that if deeper understanding of the people is wished by the city of Strasbourg, additional measures should be taken.

To understand the weight of the communication and information in the respondents' understanding of the site functionality, we tested the part of the communication implemented by the city of Strasbourg (public meetings, visits of the site once restored and information panels). Ninety-one percent of the respondents did not attend the public meetings, and 82% did not visit the restored site. Apart from these formal information sequences, 55% of the respondents read the information panels that are displayed on the access doors to the site, but the impact of the panels on the level of understanding is clearly questionable. It also seems that the respondents did not feel informed enough on the site and its functionality (52% of the respondents). Only 31% think that they are informed on that point.

Concerning a typical profile of inhabitants that were more aware on the link between the stormwater pollution and the pollution of the Ostwaldergraben site (hypothesis #3), it seems that the representation of a level of pollution was not linked with social characteristics.

We also tested the future of the site, trying to answer the question of the Ostwaldergraben sustainability and a kind of 'appropriation' of the site by the

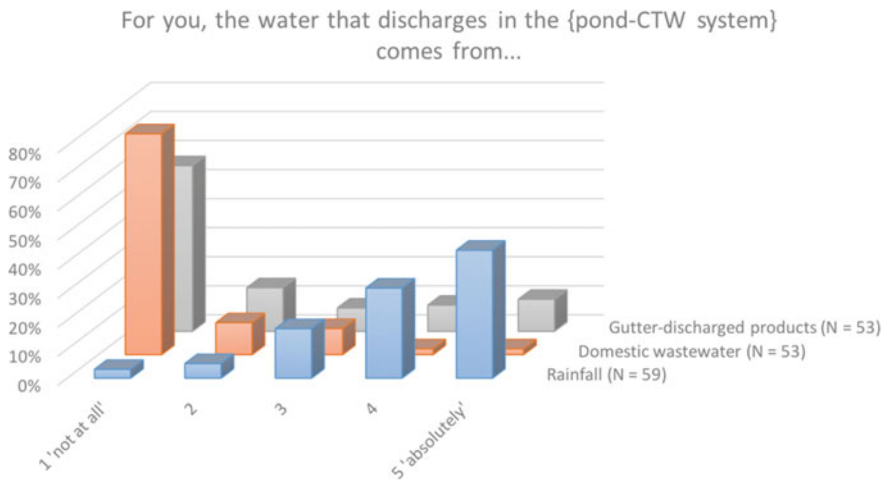

Fig. 6 Results from the questionnaire sent to local communities. The questions were related to the pond and constructed treatment wetland (CTW) in operation phase. Here the origin of the water that flows into the {pond-CTW} system

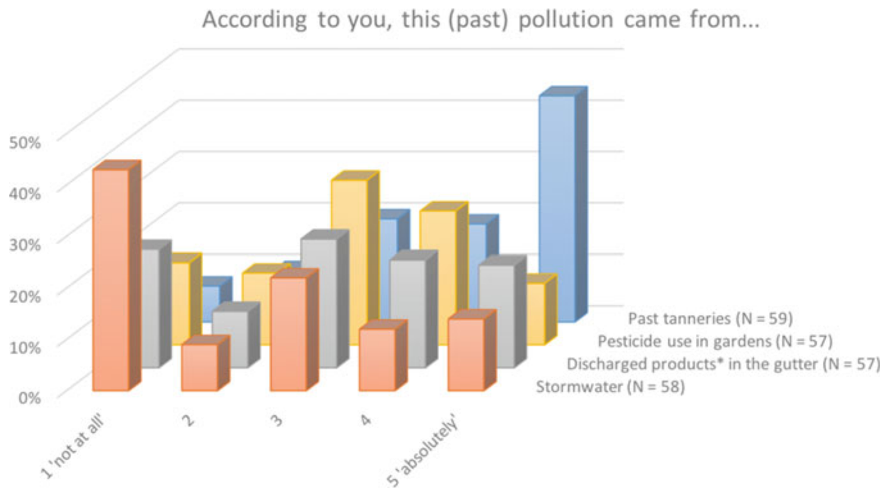

Fig. 7 Results from the questionnaire sent to local communities. The questions were related to the pond and constructed treatment wetland (CTW) in operation phase. Here the origin of the water that flows into the {pond-CTW} system. * paint, oil, water from carwash

inhabitants. A majority of the respondents (56%) wanted it to remain closed, while 30% wanted the opening to be restricted and 14% wanted it to be open. Eventually, we tested the interest of the local community about getting more active in the life of the site and the future vision of the site they had (Table 4). In accordance with the will of having it closed to the public, 46% of the answers about tours open for the

Table 4 Results of the questionnaire sent to residents on the social aspects of the project. The question was: « About the future use of the site, you would like to… » (response expressed in %). 1 = 'not at all,' 5 ='absolutely'

	1	2	3	4	5
Use it for educational purpose (N = 66)	23	3	12	14	48
Get involved in the stewardship of the site (N = 62)	58	10	13	8	11
Have it more used for tours open to the public (N = 65)	46	6	20	8	20
Make it an example for other sites in Strasbourg (N = 65)	20	2	14	11	53

public are 'not at all.' A clear tendency also showed that the inhabitants did not want to get involved in the stewardship of the site (68% of the answers between 1 and 2). They did believe, however, that this system is valuable, in terms of use for educational purpose or as an example to be replicated across Strasbourg.

To summarize, the Ostwaldergraben site seemed mostly 'accepted' and well perceived by the inhabitants. Indeed, the first source of perceived nuisance in the neighborhood was actually youngsters hanging out (20 occurrences at the open question '*In your neighborhood, what kind of nuisances do you perceive (noise pollution, olfactory pollution, visual pollution)*' N = 53). The second nuisance is linked to the amphibians (18 occurrences). Let us remember that the respondents who perceived the most negatively the amphibians are located in one spot, just across the natural pond. Yet, the results showed that the respondents who perceived the amphibians as a nuisance were significantly not favorable to wetland habitats [$F(1.49) = 10.576$; $p = 0.002$].

5 Conclusion: The Trade-Offs of This Project

The target species of this program was *B. viridis*, an endangered amphibian. Many amphibian species have populations structured as patchy networks or metapopulations. Urbanization reduces the ability of these networks of populations to function due to the construction of roads and urban infrastructure that inhibit or discourage amphibian dispersal (Hamer and McDonnell 2008). Stormwater wetlands and their neighboring terrestrial habitats may play an under-appreciated role in the conservation of urban amphibians (Scheffers and Paszkowski 2013). The construction of stormwater ponds is recognized as a useful tool both to mitigate the loss of wetlands, to retain water runoff from impermeable urban surfaces and to treat them, but their ecological value, in particular as breeding habitat for amphibians, remains poorly known (Chester and Robson 2013; Scheffers and Paszkowski 2013). Habitat surrounding stormwater sites also merits attention and preservation considering the importance of small-scale connections between the habitat of immatures and that of adults (Scheffers and Paszkowski 2013).

Controversial views of urban small water bodies are related to their water quality, even if in recent decades the quality of many urban aquatic habitats has been significantly improved. In green toad, heavy metals like copper and lead have been shown to increase the frequency of morphological malformations (Dorchin and Shanas 2010) but *B. viridis* was already found in heavily contaminated water bodies (Adlassnig et al. 2013). Further, analyses are required to investigate the potential cost for the species of a putative lack of water quality.

The great removal efficiency of the treatment system provides benefits, but the cost of the sediments pollution and long-term solution to this is not to be underestimated. Additionally, taking into account local communities advices could help replicating this type of project and improve its acceptability among the population.

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