Setup of an in stream treatment facility for urban creek revitalization, Belo Horizonte (Brazil).

Martin SEIDL */***, Marcos VON SPERLING**, Paulo CASTRO**, Filipe LIMA DORNELAS** and Nilo NASCIMENTO***

* Université Paris-Est, ENPC Cereve, 6-8 ave B.Pascal, F77455 Marne la Vallée cedex 2 France (E-mail: martin.seidl@cereve.enpc.fr)
** UFMG DESA, Universidade Federal de Minas Gerais, Av. do Contorno 842, 30110-060 - Belo Horizonte, MG, Brazil
*** UFMG EHR, Universidade Federal de Minas Gerais, Av. do Contorno 842, 30110-060 - Belo Horizonte, MG, Brazil

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Abstract
This paper aims to present a detailed setup for the future treatment facility of Vilarinho, where a detention pond in a poor peripheral area of Belo Horizonte (Brazil) will be revitalized and combined with a constructed wetland and public leisure area. The paper discuss the technical aspects like concentrations and pollutant load during dry weather and wet weather periods, needed for the wetland design, without forgetting the social implementation of the future public service.

INTRODUCTION

The cities of industrialized countries are generally using a sewer system to collect and transport their wastewaters to a common point outside of the urbanized area, where a treatment system removes the nutrients and the carbon in excess, preserving the natural water resources. In less industrialized countries there may exist only a collecting and intercepting system to transport the wastewaters out of the city. In the worst case, in the absence of intercepting lines or wastewater treatment plants, a direct discharge to urban streams or canals occurs and the creeks turn out to be a part of the collecting system.

Belo Horizonte is one of the largest cities in Brazil, with a population around 2.5 million inhabitants. One of the biggest public works projects in the city is the Program of Environmental Recovery and Sanitation for Belo Horizonte (Drenurbs). Its aim is to clean 73 polluted streams (30% of total), equivalent to 140 km of watercourses, integrating them into the natural landscape of the city. The program includes action on basic sanitation, flood control procedures and habitation replacement. These works will benefit 49 per cent of the population and represent the greatest financing project ever undertaken in the history of Belo Horizonte, being co-financed by the Inter-American Development Bank (IADB). Drenurbs has established a priority scale for all urban creeks based on general environmental situation, necessity of reallocation of dwellers due to the environmental risks caused by the occurrence of water-transmitted diseases or floods. The watershed used for our study (see below) is on the priority rank 36 for revitalization established by the master plan for sanitation of Belo Horizonte for the 256 urban watersheds (PBH 2006).

In many areas of Belo Horizonte the main limitation is the lack of interceptors, to transport the collected sewage to the existing waste water treatment plant (WWTP). From the necessary about 600 km of sewers, around 300 km have already been implemented. The existing WWTP capacity is actually greater than the flow collected. The existing sewers collect the wastewater from about 93% of the population, but only half of it is treated. The investments, including sanitation, revitalization of urban creeks and flood control foresee for the 10 priority watersheds about 350 million US$ (PBH, 2004). To preserve the water resources a big effort is needed to double the natural water ways by collectors and interceptors, or less effort might be spent to constructing a (temporary) in stream facility. In Belo Horizonte such an in stream facility already exists to protect the lake of Pampulha, the city's main reservoir. An air flotation plant with a capacity of 1 m^3/s was built, at the entrance of the lake to treat the most important incoming stream.

Within the European project SWITCH (Managing Water for the City of the Future) and the Brazilian Research Program on Basic Sanitation (PROSAB), two small urban watersheds have been chosen to test alternative technologies for the treatment of diffuse pollution and run-off. In the Quaresma watershed it was chosen to implement an artificial wetland treatment of diffuse pollution. The principal objective of the project is the evaluation of the dry weather and wet weather fluxes and the effectiveness of their treatment by the constructed wetland.

Because of lack of open space it was decided to use an existing detention pond and to use it partially for the construction of a small-scale horizontal subsurface-flow wetland preceded by a sedimentation pond. The facility should regulate at the same time the hydraulic flow during wet weather, treat the flux of pollutants during dry weather and serve as open green space for the inhabitants.

The difficulty of the project is not only the space limitation, but also the presence of shanty towns upstream, accompanied by an important flux of solid waste (garbage), presence of domestic animals (cows, pigs) and insecurity (drugs), creating additional difficulties for the sampling procedures and the management of the facility. To improve the community compliance with the new urban equipment, a social screening was done with the inhabitants living within a perimeter of 1 kilometre from the detention pond. More than 100 households were visited with a questionnaire about the living conditions, the perception of the detention pond and the willingness to contribute to its management (Seidl et al 2007). The results, showing an important involvement with the area and the desire to use the detention pond as a safe community space, were defined with the community during a half-day of public mobilization. The wetland construction should be accompanied by a yearly campaign of community mobilization to help the management of the future urban area. Nowadays the inhabitants are already participating in the water quality sampling campaign, making it possible to install and use safely the sampling devices.

The future treatment facility will be a "pilot" on a real scale to test the functioning in difficult environmental and social condition. The behaviour of the subsurface units will be tested with different filling materials, high levels of organic and solids loadings and possible flooding periods. The wetland will serve the local authorities to learn to manage a new type of waste water treatment equipment and to learn to manage it within a community. Far more the whole area should be accessible to the public to serve for environmental education and space of leisure.

The objective of this study is to evaluate the pollutant fluxes of the watershed to be treated and to verify the feasibility and efficiency of constructed wetlands using sub-surface flow under local conditions.

MATERIAL AND METHODS

The realisation of the wetland can be divided in 5 different phases :

1. A social economic study to know the desires and acceptance of the local community
2. Evaluation of the pollutant load of the upper watershed
3. A pilot test to verify the technical feasibility of the proposed technology
4. Mapping and design
5. Construction of the system

Social compliance

The social mapping of our study was done using the regional network of Brazilian public health care SUS (Sistema Único de Saúde). A part of this system are free public medical centres run by teams of community health agents ACS (Agente Comunitario de Saúde), doctors and technicians for disease vector control. The ACS's were elected for the data collection for their familiarity with the area and community, making it possible to access all sectors even under difficult social circumstances like, extreme poverty, use of drugs and presence of organized criminality.
During two weeks (June 2007), a team composed of local ACS and university students applied a questionnaire to more than 100 households within 1 kilometre distance from the detention pond, corresponding to 1% of the circumscribed population. Within a household, the questionnaire were applied simultaneously to the household representative and one adult of opposite sex. The questionnaire of 55 questions was divides in 5 parts i) identification of habitants, ii) general environmental knowledge and perception of urban waters, iii) satisfaction with sanitation services, iv) public health related to water born diseases and v) community compliance with the future wetland / landscape zone. A simplified questionnaire was applied to the children in the local elementary school (Seidl et al 2007).

Evaluation of the pollutant load

The urban creek Quaresma is situated at the south limit of the urban area of the city of Belo Horizonte and is a tributary of the more known creek of Vilarinho. The creek of 1500 meters drains a watershed of 120 hectares, containing principally residential habitation and a low income population of about 15 000 inhabitants (122 inhab/ha). The upper part of the creek is closed and canalised, whereas the lower part is open in semi natural bedding. The sampling station is situated at the upper end of the detention pond, about 1000 meter from the creek origin (Figure 1).

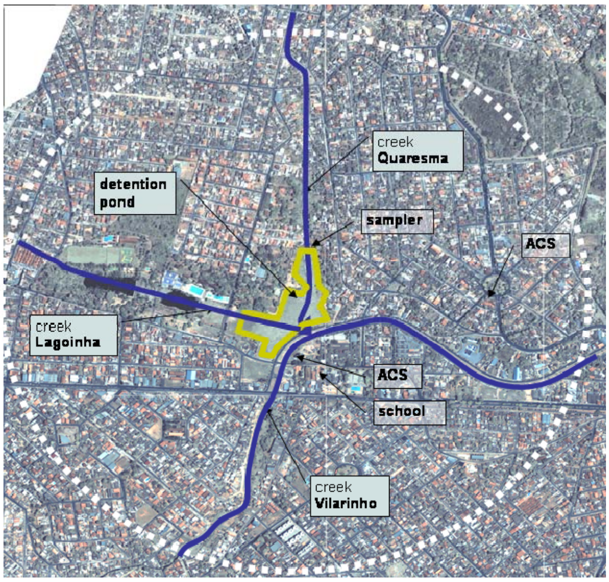


Figure 1: Position of the watershed and study area. The red line indicates the limits of the watershed

Standard water quality parameters were monitored from June 2007 to June 2008 to estimate the pollutant load during dry weather and wet weather periods. The samples were taken on working days, by an automatic sampler (ISCO 3700) triggered by time or by level impulse. During the dry weather period the sample was cooled by ice. The sampling was proportional to time, during 24 hours with a 2 hour frequency during the dry weather period and during 2 hours with a 10 minutes frequency during wet weather events. The samples were transported immediately after the end of sampling to laboratory for treatment and analysis (De Castro et al 2008).

For each sampling 12 samples were analysed for solids and main pollutants : carbon (BOD, COD) nitrogen (NH4, NO3, NKj) and phosphorus (Ptot) and two subsequent samples were mixed for analysis of pathogens (E. Coli), organic micro-pollutants (PAH) and heavy metals (Zn, Cu, Cd). The organic micro pollutants where analysed after solid extraction according to Zgheib et al (2007). The chemical species were analysed according to AWWA (2005), colorimetry for the nutrients, AAS flame/ ICP (Perkin) for the heavy metals and GC/GCMS (RTX-5 SilMS) for the PAH. The PAH measured correspond to the 16 priority PAH established a proprietary by the EPA (1984.)

Pilot test

The horizontal subsurface filter technology was tested with urban wastewater during one year in pilot scale at the local waste water treatment plant. A small UASB (Up flow Anaerobic Sludge Blanket) reactor fed with raw wastewater from the city of Belo Horizonte was connected to two horizontal constructed subsurface-flow wetlands in parallel. The UASB with a volume of 7 m^3 had a hydraulic flow of 30 m^3/day and residence time of 6 hours. Each wetland was 22 m long and 4 m large, and received 7.5 m^3/day of UASB pre-treated wastewater. As filter medium was used a layer of 30 centimetres of medium diameter furnace slag. The slag was previously tested for (heavy) metal release. One filter was grown with *Typha latifolia* and the other was left blank (unplanted) (Lima et al 2008).

Parameter	Value	Unit
Bed height	0.4	m
Liquid height	0.3	m
Length	24.1	m
Width	3.0	m
Surface area	72.3	m^2
Wet volume	21.7	m^3
Flow	7.5	m^3/d
Surface hydraulic loading rate	0.1	$m^3/m^2.d$
Hydraulic retention time (V.porosity/Q)	1.2	d

Figure 2: View of the planted and unplanted subsurface-flow wetlands treating the effluent from an UASB reactor.

RESULTS AND DISCUSSION

Social compliance

The results of table 1 below show that a low income community, living in a periphery of an extended urban area, with relatively good sanitation services, but with lack of public security, choose for safe community space if the occasion is given. This occasion is in our case the revitalization of a detention pond. Despite the mediocre living environment perception, the inhabitants are keen to (re)appropriate the new urban space by means of community action and environmental education. There might be significant difference in opinion as function of geographical location of habitat, the age or the sex of the habitants involved. ***The local authorities should take into account these aspects and put accent on the educational function of the future wetland, its accessibility to scholar public and give an important role in the management to the women and the local health community agents*** (Seidl et al 2008).

Table 1: Preferences or management scenarios issued from the socio-environmental survey (PBH : local government, ACS : community agents)

Scenarios	1st preference		2nd preference		3rd preference	
Public	Adults	young	Adults	young	Adults	young
Equipment desired	Square	Square	Walking lane	Walking lane	Park	Football playground
Priority after the works	Security	Security	Maintenance	Maintenance	Tranquillity	Accessibility
Best administrator	PBH	---------------	Community	---------------	private enterprise	---------------
Best leader	ACS	PBH	Church	ONG	PBH	School
Best mean of appropriation	Environmental education	Environmental education	Set up of community association	Education of children	Education of children	Set up of community association
Best educational action	Cultural activities	---------------	Meetings	---------------	Information campaigns	---------------

Pilot experiments

The pilot experiments showed that the by-product of steel industry, the furnace slag, release only small quantities of metals (except of calcium), comparable to those found in wastewaters and that this ***slag can be used safely as filling material for waste water treatment***.

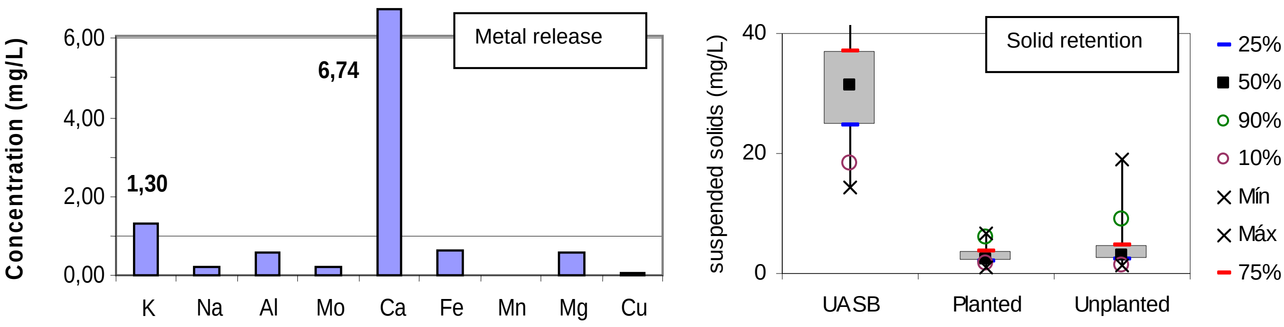
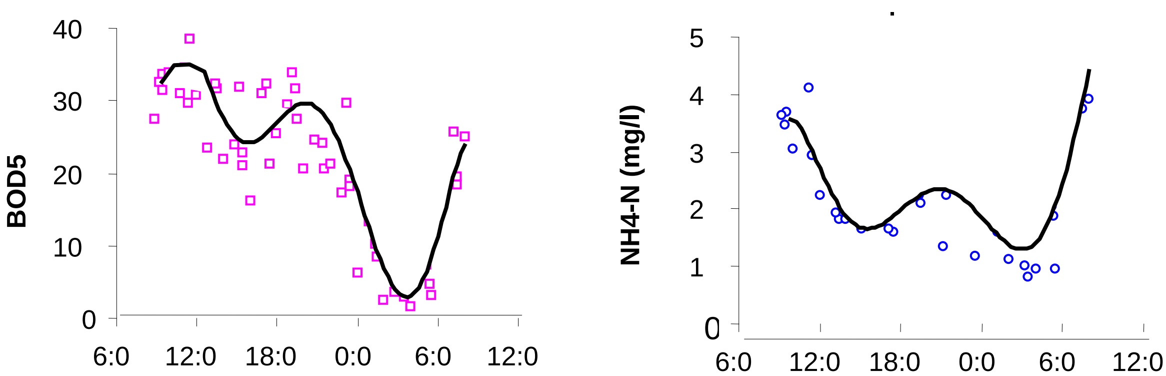


Figure 3: Result of release of (heavy) metals during solubilisation experiment (left) and the retention capacity for the horizontal filter (right)

On the other hand, the medium slag gave an excellent efficiency for solids retention, where the *Typha* planted filter gave better results than the unplanted. Though the *Typha* contributes significatively to the treatment, but it may possible contribute to clogging of the filter medium and a coarser medium and eventually a smaller plant would be used.

Watershed characteristics

During the dry weather the water quality parameters show for the Quaresma creek a clear day-night cycle with the very high means of 226 mg BOD_5/L and 17.8 mg NH_4-N/L. N. The impact of discharge of the waste water is underlined by the almost constant concentration of pathogens indicators like *E. coli* with a mean above 10^8 MPN/100 ml (Figure 3, Table 1).



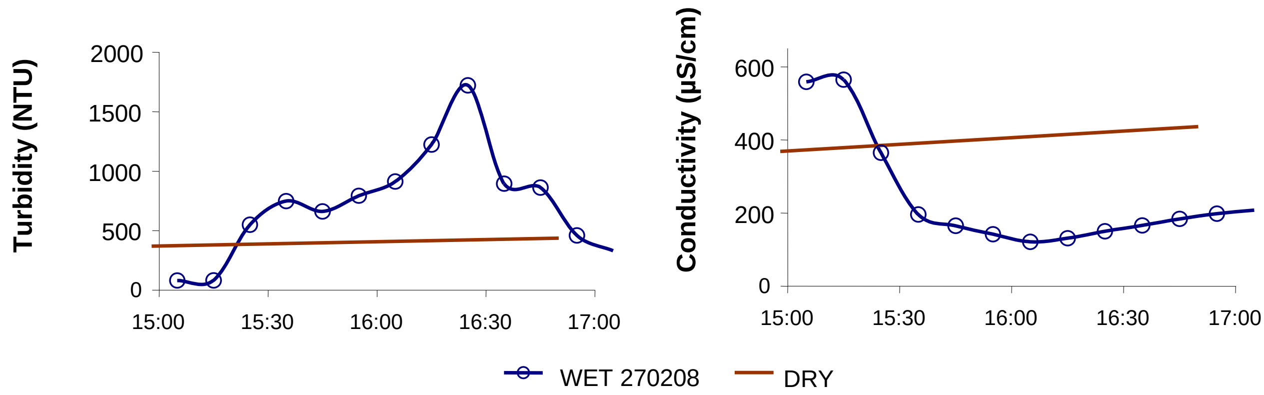


Figure 4 a, b, c, d: Water quality parameters for the urban creek Quaresma, during dry weather from June to December 2007 (above) and during a wet weather event of 27 February 2008 (below). The dry weather figures represent 5 dry weather campaigns of 24 hours. The dry weather solid line represents the polynomial regression. The wet weather solid line represents the evolution of concentration during the dry weather at the same moment.

Using the mean conductivities of local drinking water (170 µS/cm), of a reference creek Lagoinha (274 µS/cm), of our creek Quaresma (550 µS/cm) and that of waste water (660 – 778 µS/cm) we can estimate that the proportion of waste water is between 55% and 70%. Assuming that no waste water is collected in the watershed of Quaresma and that most of the drinking water consumed (150 L/hab/day) returns to the creek as waste water, we obtain that 60% of the flow is due to waste water.

The solids transported are about 58 % composed of organic matter, but there is no relation with the day / night cycle. The composition of the organic matter remains the same during the day, about 50 % of the organic matter is biodegradable, but there is no correlation between organic matter content and its biodegradability. The N/P ratio is about 5.7.

Table 2: Mean concentrations and flow for the Quaresma creek, based on 8 dry weather campaigns of 24 hours and 4 rain events between June 2007 and April 2008

	Periods	CE (µS/cm)	SS (mg/l)	COD (mg/l)	BOD5 (mg/l)	$N\text{-}NH_4^+$ (mg/l)	P-tot (mg/l)	*E.coli* (/100ml)	Peak flow (l/s)
DRY	8	566	235	394	186	20,1	2,65	1,10E+08	40-100
WET	4	326	582	148	70	3,63	1	8,00E+07	1600- 4500

The suspended solids content during the dry period is very high for an urban river, even if the wastewater contribution is taken into account. The relatively low organic matter content of the suspended solids indicates a mineral contribution, most probably from the land erosion in the open channel.

The contribution of the erosion is more evident during wet weather events when the solids contents goes up to several grams per litre (Figure 4) and the dark colour of water becomes red coloured by the laterite present in the region. The cumulative rain fall for this event was about 29 mm, causing a peak flow of 2.7 m^3/s bringing up to 1700 mg/l of suspended matter. The biodegradability estimated as BOD /COD is almost the same during this rain event, suggesting dilution of the waste water flow.

From the above results we can calculate that the BOD_5 load is about 1200 kg/day which gives, with 50 g-BOD_5 per inhabitant, a treatment capacity needed of 24 000 habitants. The solids flux is almost 2 000 kg a day, bringing about 800 kg of mineral matter a day during dry weather. During wet weather the flux might be 10 or 100 fold (figure 5).

The high level of the wet weather solids flux and the area available makes it not possible to treat the rain events.

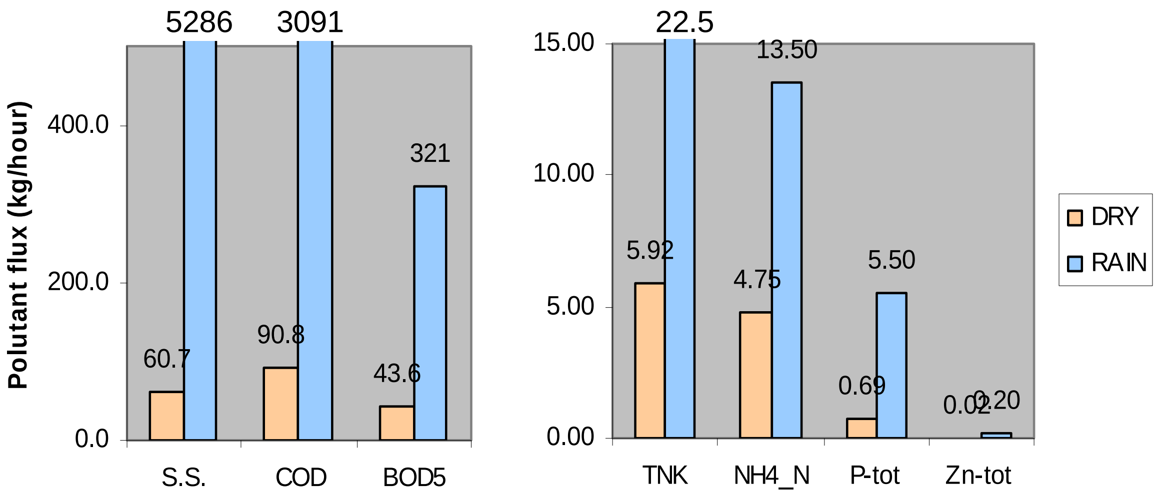


Figure 5: Pollutant fluxes based on flows modelised for the rain events sampled (De Castro 2008.)

Tables 3 and 4 show results of metals and PAH at the Quaresma creek. During the dry weather period the heavy metals show a slight impact of the urbanisation on the water quality which can be found generally in urban rivers. The relatively low levels reflect the absence of industry and high traffic in the watershed. The rain periods show an effect of dilution, also visible for conductivity.

TABLE 4: Total metal contents for 3 dry weather diurnal cycles in 2007 and 3 wet weather events at the beginning of 2008.

total metal (µg/L)	cadmium	copper	nickel	zinc
DRY weather	<2	24	17	95
WET weather	2.0	14	4.9	58

From the organic micro pollutants analysed until now, the PAH results show relatively low contamination during the dry weather. The results of heavy metals suggest that the concentration to expect during wet weather events will be lower.

The levels measured are sufficiently low to permit eventual reuse of water or vegetal biomass produced.

FINAL CONSIDERATIONS

The conditions put forward by the administration of Belo Horizonte and issued from the socio environmental survey for the revitalization of the detention pond are summarized in the table below.

Table 5 : conditions for the design and management of the constructed wetland system

Limiting condition	Design / management solution
The existing detention pond should keep mainly its **function of flood detention** (The wetland should not diminish the detention capacity and should withstand flooding)	The ponds and filters will be only 50 cm above the flooding plane. All the works will be reinforced by stones. The filter will have a top layer of fine gravel and will be operated during wet period with water level above the gravel. No tubes will be used, only open channels. Coarse slag will be used as main filter material.
The area should also be used as a public green area (The area should be **safe for public**).	The access to ponds should be limited. The ponds depth will be limited to 2 meters and the area will be protected by nets /grids. The bio filters will have subsurface flow to diminish exposure and preventing mosquito breeding and human contact.
The treatment plant should have an **education** role	Public access to the treatment plant. Reinforcement of collaboration with local schools. Creation of educational programs about urban waters. Launch of a new research program.
The treatment should be efficient	Mixture of settler and anaerobic pond and a coarse filter. Use of aquatic plants. Bypass during wet events. Creation of collectors for excess of waste water to limit overloading.
The treatment facility should be "**maintenance free"** for several weeks (The treatment facility should not use external energy source and limit the necessity of labour)	The system will use gravity for water transport and when necessary manual force for cleaning. No tubes will be used, only open channels. Keen design to limit clogging and floating material deposit.
The construction should be easy and **"low cost".**	Use of low cost technology like ponds and filters, use of clay for sealing, use of slag as fill material, keen design to limit the volume of soil re(moved). Surface treatment limitation.

The only technology which may partially satisfy the requirements listed above is a waste stabilization pond or an artificial wetland. The settling pond does not really satisfy the public safety criteria because of free water space and possible breeding place for mosquitoes. Even if the pond is the best low cost means for settling it may also serve as uncontrolled swimming place for the children in neighbourhood, bringing problems of contamination or drowning. The solution is to use planted filters and to avoid contact with waste water by protecting free water surface by grids or floating plants.

The actual proposition is a pre-treatment by means of septic tanks or protected anaerobic ponds, followed by a series of planted filters with horizontal sub-surface flow. Two lines of treatment are proposed one planted and one unplanted for reference.

During the dry weather the water quality parameters show a strong relation with the waste water discharged by the inhabitants of the watershed. The creek Quaresma contains about 60% of waste water. The BOD_5 load of 1200 kg/day is equal to 20 000 equivalents of inhabitant. The full load cannot be completely treated by wetland within the space available.

The globally available space for treatment is about 14,000 m² (Figure 6), from which effectively 10,000 m² can be used for treatment. The treatment surface available is about 0.5 m²/inhabitant against 1 or 2 needed for natural systems and will result in lower efficiency if the full load is going to be applied.

The wet weather flux can not be treated because of the high hydraulic load and the extremely high flux of solids. The most effective measure, on mean term, to diminish the solid load during wet weather, is better erosion control in the upper area.

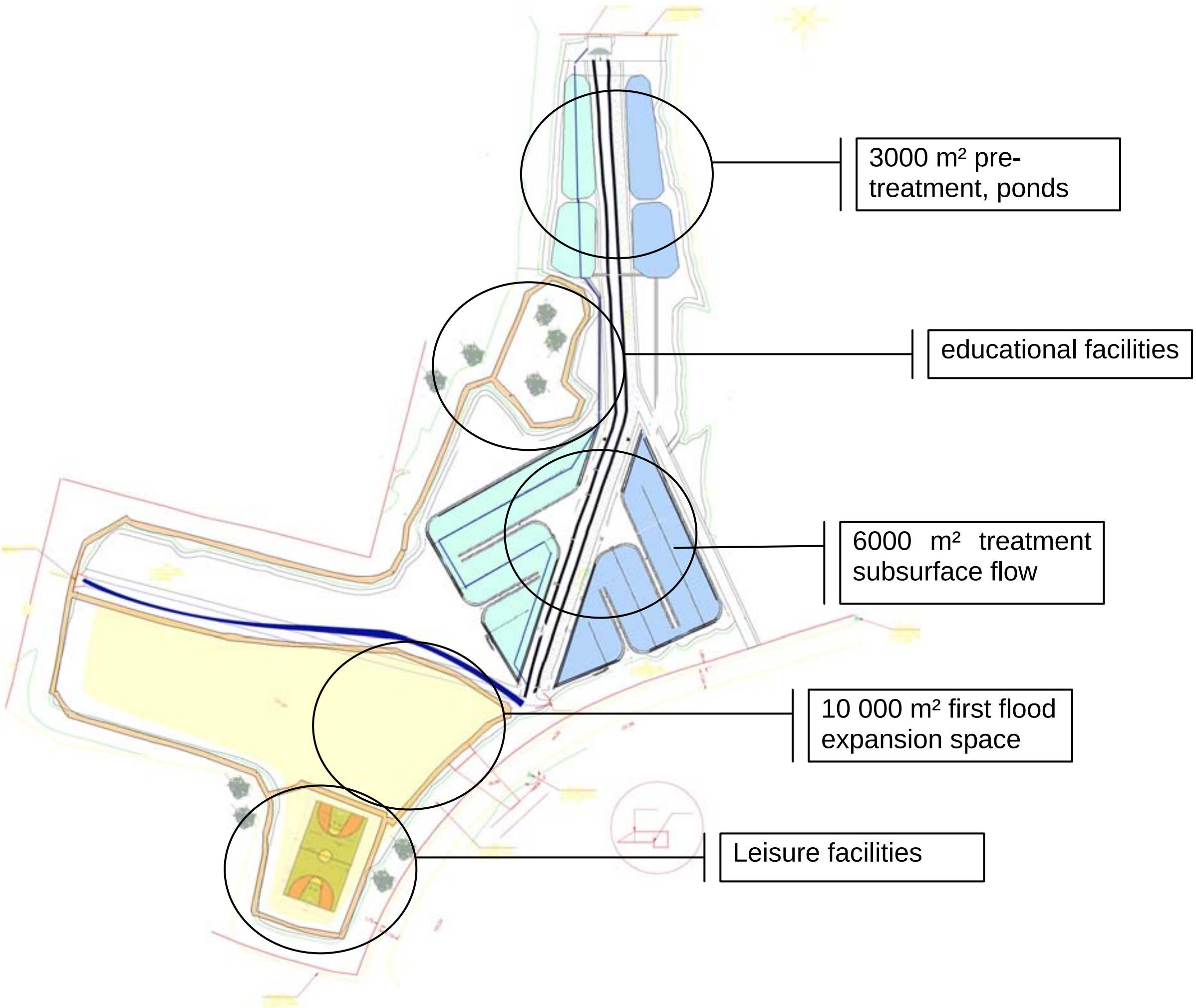


Figure 6: Sketch of the area with the proposed treatment facility. Approximate scale 1:3000

The plant should be operated with precautions to test its maximum treatment capacity. It is important to stress that the treatment facility is a pilot installation to test the functioning in difficult environmental conditions like high loadings, possible flooding, degradation or mismanagement and has an important educational function. A good management will be only possible if all parties will work together especially the local government and the inhabitants of the area. An educational program along with the scientific research might be the best way to link all parties.

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