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# ENERGY RECOVERY FOR SUSTAINABLE URBAN DRAINAGE SYSTEMS (SUDS)

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## Abstract

Urban drainage systems are infrastructures essential in urban areas to control the flooding of roads, properties and infrastructures. A common solution is the storage of the water excess in retention ponds. This work proposes a methodology for the adaptation of energy recovery solutions to drainage systems.

The consideration of urban flooding as a problem caused by excess water that can be harvested and re-used rests on the concept of Sustainable Urban Drainage Systems (SUDS) and provides a comprehensive representation of a water-energy nexus for future urban areas.

The study comprises an optimization of a case study in a small district area of Lisbon down-town through the use of a micro-hydropower converter – a 5 blade tubular propeller. The methodology included the settlement of a power target demand, the sizing of both the volume and the water height in flood control ponds in order to maximize the energy production and on the control of the water discharge.

*Keywords*: Energy recovery, SUDS, micro-hydropower.

## 1. Introduction

The urbanization in Europe has been happening since the mid 1950′ and, recently, the European cities have become less compact. In fact the space occupied by urban areas is increasing faster than the population itself, according to the European Environment Agency (EEA), and even in regions where the population is decreasing, urban areas are still growing. The same trend can also be seen in the United States and China (EEA, 2006; EEA, 2011; PLUREL, 2011).

The growth of urban areas implies an increase of impermeable areas, which as a direct impact on rainwater drainage costs and in the complexity of these systems (Neves, 2005; Tingsanchali, 2011). A less adequate management of urban drainage systems can have serious consequences, such as floods or pollution problems. In fact, the intermittent discharges from combined sewer overflows are a major source of water pollution in urban areas (David *et al.*, 2010).

Hence, the concept of SUDS – sustainable urban drainage system – has emerged to include in the planning of drainage systems other factors such as water quality, social impacts and environmental issues (Santos, 2011).

For each particular location, decision makers must study and select the best combination of practices that result in the most cost-effective and achievable management strategy possible (Lee *et al.*, 2012).

The use of storage ponds is an already frequent solution in SUDS (Santos, 2011). These reservoirs can be build underground or as a lake (Figure 1) and allow a controlled discharge of the inflowing volumes of water, reducing the downstream peak flow. The outflow is usually discharged into the environment or lead to treatment plants. However, these water volumes have potential to be used before being returned to the water bodies. New solutions for improving the elasticity of water systems, i.e. that maximize the exploitation of the available resources inside the system, are currently emerging, such as micro-hydropower.

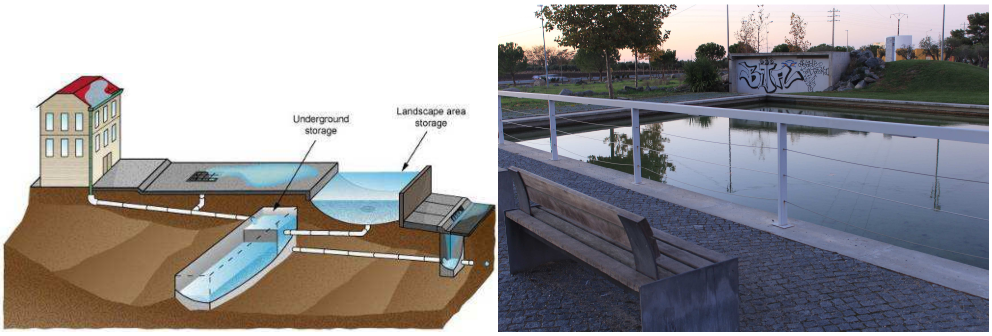

Figure 1. Types of retention ponds. Undergound (left) and lake (right).

By installing turbines downstream one or more retention ponds, advantage can be taken from the high created in retention ponds to produce energy. As the heads created in an urban drainage system are considerably low, the turbines must be appropriate to small-heads. Recently, different projects have developed new technologies for micro-hydro converters, such as the European Project HYLOW (Hydropower converters with very low head differences). In the scope of this project, new hydropower converters for very low head differences and, among them, a 5 blade tubular propeller turbine (5BTP) was designed at Instituto Superior Técnico (Ramos *et al.*, 2012-b, Ramos *et al.*, 2012-c, Ramos *et al.*, 2012-d).

In addition to hydropower production, there are other potential uses for these ponds, such as the storage of water for irrigation or reserve for fire and, in lake type reservoirs, recreational uses and leisure or ecological purposes.

In this study it is intended to study the relevance of using retention ponds to produce energy through micro-converters. For this purpose, a previously calibrated Mike Basin model (Ramos *et al.*, 2012-a, Ramos *et al.*, 2013) was used to simulate the energy production considering an urban area in Lisbon.

## 2. Model description

The studied system was a scheme with two hydropower stations located downstream a retention pond, as represented in Figure 2. With two hydropower stations it is intended to have one operating with some stability and another operating whenever there is enough volume to turbinate in two turbines.

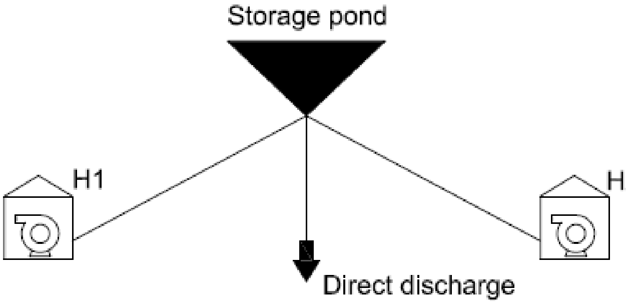

Figure 2. Simplified representation the studied system.

The model was developed in the Mike Basin software, a decision support system to study the water distribution within a basin. The runoff of a catchment is calculated taking into account the hydrological cycle, the type of soil and the provision of water, considering over-land flow, base-flow and inter-flow. The water supply comes from rainfall and snow melt, being also affected by evaporation. Since the studied area is an urban watershed in Lisbon, the surface storage, interflow and base flows were considered negligible. The rainfall was based on data from the meteorological station of Lisbon, belonging to the meteorological institute of Portugal (Meteo.pt, 2012). The daily rainfall series considered was from the year of 2011 – Figure 3.

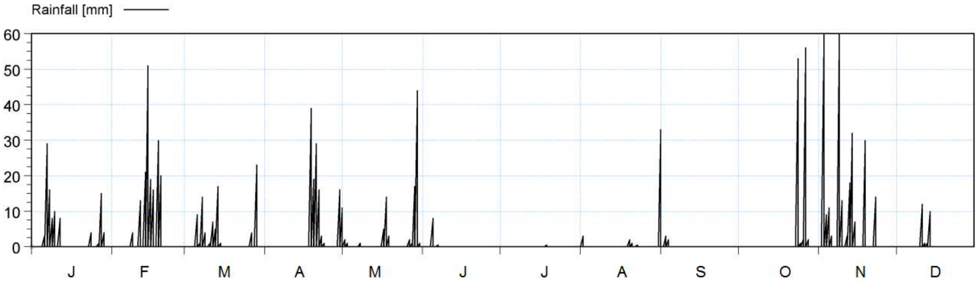

Figure 3. Daily Rainfall in Lisbon' station during the year 2011 (source: Meteo.pt , 2012).

To simulate the retention pond, power target demands were considered for each hydropower station to control the turbinated flow. Hydropower station 1 has priority and its target demand was stated constant. For the Hydropower station 2, the target demand is monthly variable, depending on the season.

A flood control level was set at the maximum height. The power is calculated as function of the turbinated flow and the net head was obtained from the water level inside the pond and the turbine efficiency.

A reference water level, defined reduction level, was considered as the level below which the target demand is affected by a reduction factor (RF) between 0 and 1. This factor attenuated the discharges, keeping a high head in the reservoir for a longer period. The reduction rule was the same for both stations, with the reduction level fixed at two thirds of the reservoir height.

In the water outlets of both hydropower stations was settled a maximum allowable discharge, corresponding to the maximum turbine operating flow.

# 3. Simulations

## 3.1 Set-up

The objective of each simulation is to analyze the energy production, the deficit to the defined target and the flow discharged.

For the case study, the selected maximum head was 10 m, which corresponds to the limit of application of the 5BTP. Simulations were run for different RF – 0.3, 0.5 and 0.8. Two catchment areas were considered, with 0.05 km$^2$ and 1 km$^2$, for pond volumes between 510 m$^3$ and 1 000 000 m$^3$. In both cases, the pond was considered dry at the starting point.

The demand targets were settled as shown in Figure 4.

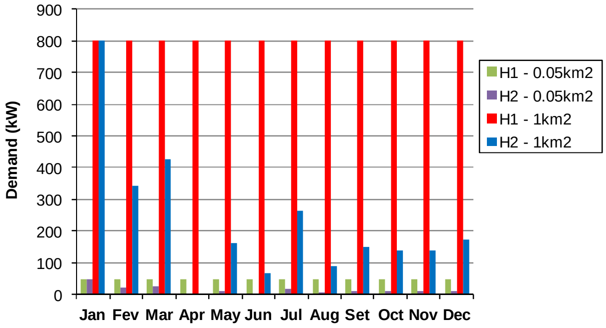

Figure 4. Demand targets for each hydropower station.

## 3.2 Simulation results

The simulation results were plotted as function of the pond volume. Figure 5 shows the average daily generated power achieved in each conducted simulation for the first case – considering a catchment area of 0.05 km$^2$. In Figure 6 is presented the average daily deficit between the generated power and the demand target and in Figure 7 is presented the total volume directly discharged without passing through any power station.

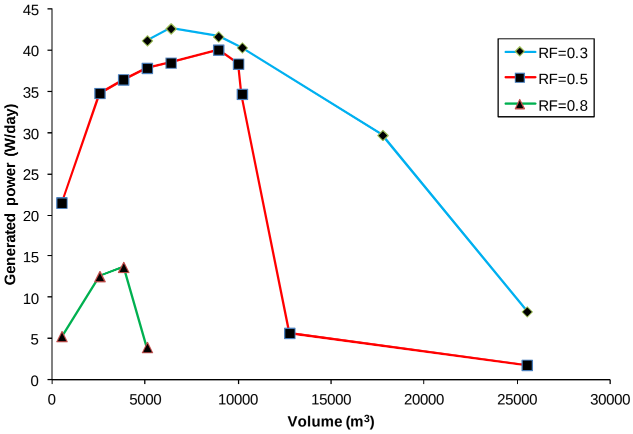

Figure 5. Average daily generated power as function of the pond volume for different reduction factors. Catchment area of 0.05 km$^2$.

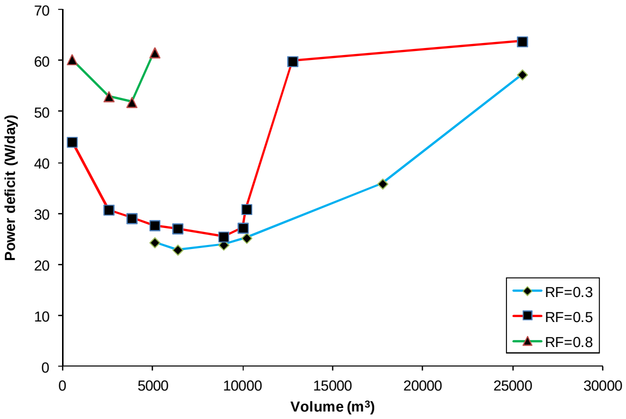

Figure 6. Average daily power deficit as function of the pond volume for different reduction factors. Catchment area of 0.05 km².

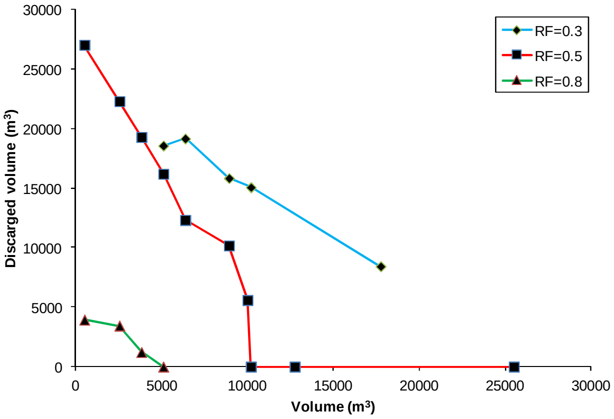

Figure 7. Total directly discharged volume as function of the pond volume for different reduction factors. Catchment area of 0.05 km².

From the analysis of the presented results, it can be concluded that if the water level is kept high for a longer period (lower RF), allowing for longer operations, it results in a higher overall production. Nevertheless, the directly discharged flow is significant when considering a RF=0.3. For a RF=0.5, the directed discharged flow is 0 for pond volumes superior to 10 000 m3, which means that the total stored volume is used. RF=0.8 results in appreciably inferior energy productions.

In Figure 8 is represented the maximum volume stored in each simulation, for the different RF considered. For the higher RF, 0.8 and 0.5, the maximum volume is not achieved with the bigger pond volumes. This indicates that, in such situations, the pond would be overly dimensioned.

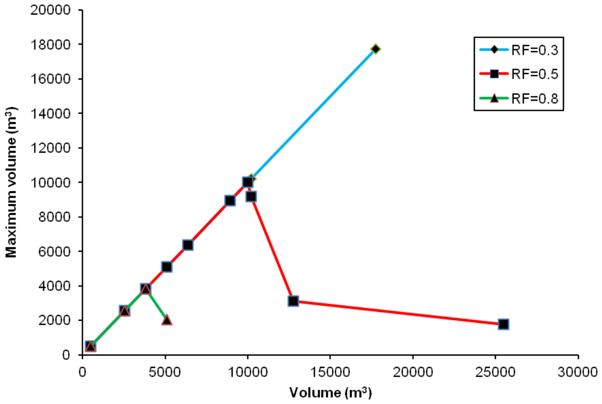

Figure 8. Maximum volume reached for different volumes of pond.

For the second case, with a catchment area of 1 km², Figures 9 to 11 show the average daily generated power, the average daily deficit and the total volume directly discharged, respectively.

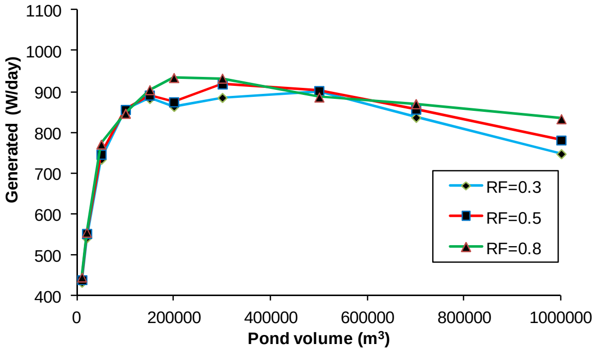

Figure 9. Average daily generated power as function of the pond volume for different reduction factors. Catchment area of 1 km².

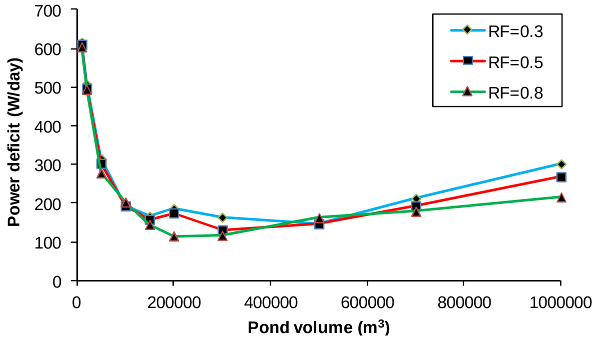

Figure 10. Average daily power deficit as function of the pond volume for different reduction factors. Catchment area of 1 km².

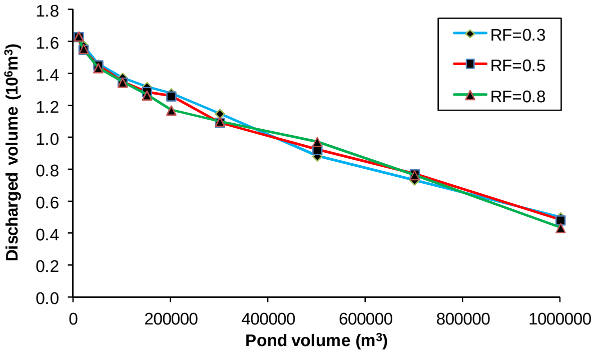

Figure 11. Total directly discharged volume as function of the pond volume for different reduction factors. Catchment area of 1 km$^2$.

From the analysis of the presented results, it can be concluded that a lower RF does not necessarily result in a higher overall production. Nevertheless, the simulations for each pond volume are very similar, indicating that the RF has a low influence in the process. This can be explained by the fact that the pond tends to be kept above the reduction level. In all simulations, the maximum level was achieved.

## 3.3 Best results analysis

### *3.3.1 For a catchment area of 0.05 km$^2$*

The best overall energy production is achieved with a pond with 6 375 m$^3$ when considering RF=0.3 and with a pond with 8 925 m$^3$ when considering RF=0.5. The maximum flow in the system outlet is the same for both cases, of around 18 l/s, which indicates that both cases have similar effects on the attenuation of the flood.

Figure 12 shows the variation of turbinated flow and the directly discharged flow through the simulation for the particular case of a pond volume of 8 925 m$^3$ when considering RF=0.5. The periods with higher direct discharges are related with the maximum pond volume being reached and also with the maximum operating flow of the turbines. Figure 13 presents the daily generated power throughout the simulation time and the total target requested to the system. Figure 14 presents the variation of volume inside the pond.

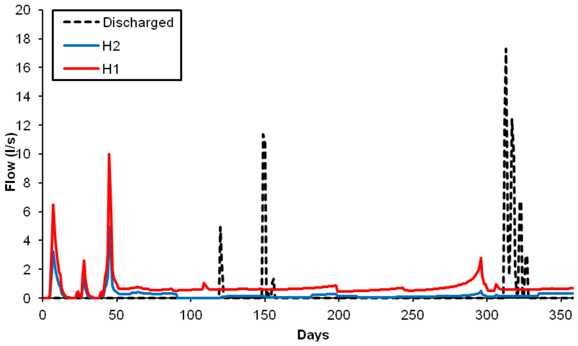

Figure 12. Turbinated flow in both hydropower stations and flow discharged directly into the environment. V=8 925 m$^3$ and RF=0.5.

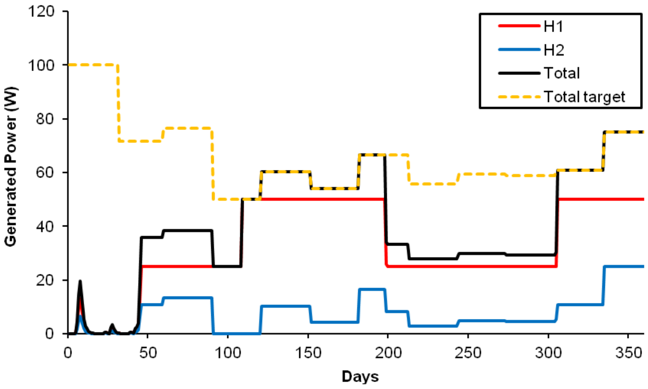

Figure 13. Generated power. V=8 925 $m^3$ and RF=0.5.

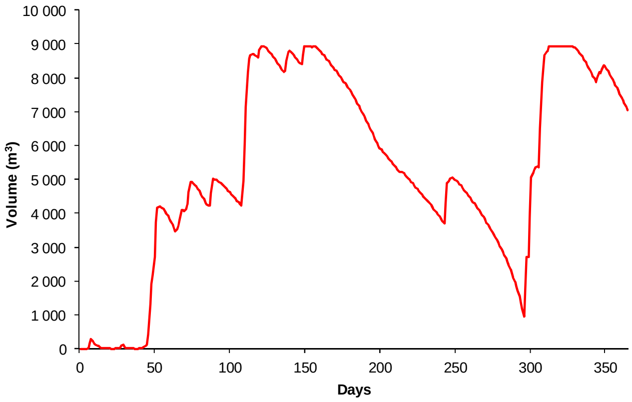

Figure 14. Variation of volume inside the pond for V=8 925 $m^3$ and RF=0.5.

### 3.3.2 *For a catchment area of 1 $km^2$*

The best overall energy production is achieved with a pond with 200 000 $m^3$ for all three considered RF. Figures 15 and 16 show the daily generated power and the variation of volume inside the pond through the simulation for the case of RF=0.5. The maximum discharged flow is approximately 53 time the maximum turbinated flow.

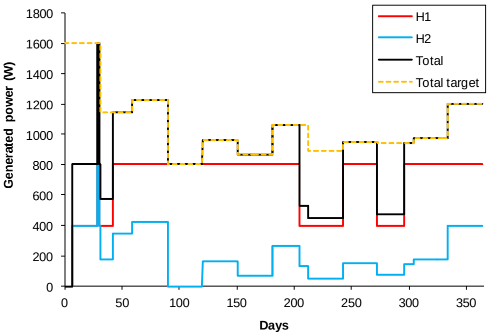

Figure 15. Generated power. V=8 925 $m^3$ and RF=0.5.

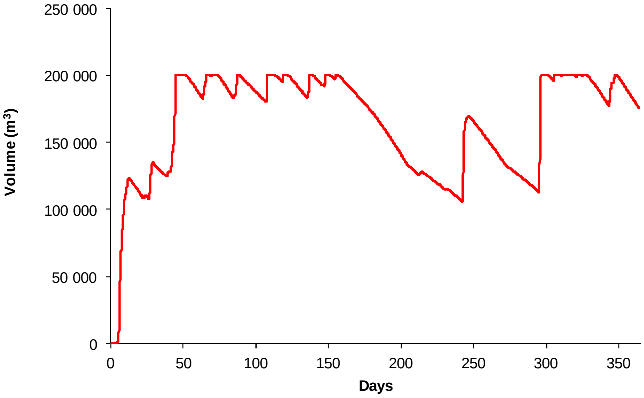

Figure 16. Variation of volume inside the pond for V=200 000 $m^3$ and RF=0.5.

## 4. Conclusions

This study presents a possible solution for a SUDS considering hypothetical urban watersheds in Lisbon, Portugal. With two micro-hydro turbines downstream a retention pond, an average of around 40 W/day can be generated for an area of 0.05 $km^2$, and an average of around 930 W/day can be generated for an area of 1 $km^2$. The amount of energy is considerably small, but the area of watershed in the model is also very small. Also, the size of the considered catchment area strongly influences the results.

To be viable, such system must be collocated downstream a much bigger catchment area. Higher inflows will need bigger storage ponds and bigger micro-hydro converters, but the energy production would also increase. It is also important to notice that the simulations were run starting with the retention pond empty. Considering that there is continuity in the process, and since the simulations ended with the water level inside the pond above the reduction level, the average daily production would increase in the following years.

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