Beneficiation of stormwater drainage in urban basins

The case study of Albufeira's catchment

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Abstract

In this essay the issue of flooding in urban areas, which due to their magnitude cause high social, economic and environmental damages, is studied. The occurrence of these events is increasing, due to the expansion of impermeable paved areas resulting of the growing urbanization, but also due to the existing climate changes causing an increase in the frequency and intensity of these events. The city of Albufeira, where a number of recent floods have been registered, reflects the situation in Portugal.

In this context, it becomes necessary to evaluate and select some measures that will benefit the existing rain draining systems in the Albufeira´s catchment. The beneficiary measures under study consist of the implementation of Low Impact Development (LID) solutions that will obtain the maximum efficiency in terms of peak flow decrease, runoff volumes reductions, and of their respective transported pollutants, thus preserving the water quality on the receiving areas. Among these types of solutions, the retention basins deserve special emphasis, due to their high efficiency in what concerns the peak flow reduction. In the framework of this paper, three retention basins to be implemented in the Albufeira´s catchment, located respectively in the in the Albufeira´s, Vale do Paraíso´s and Ataboeira´s basins, are conceived and dimensioned. In order to be able to select the best technical and economical solution, a cost benefit analysis of the three studied retention basins is implemented.

In addition, the evaluation of some beneficiary measures on the main streams of the studied hydrographical basin is carried out, due to the fact that these streams currently present a reduced flow capacity even in recurrent precipitations. Finally, a preliminary evaluation of complementary LID solutions to be implemented along the overall basin area, aiming to promote the infiltration of rain waters, is also conducted.

Keywords: stormwater drainage, urban catchement, LID, retention basin, modelling

1. Introduction

In the recent years the issues with urban areas flooding have increased, raising concerns with local population exposure and vulnerability to this phenomenon (Coelho et al., 2004). The increasing intensity and frequency of extreme precipitation occurrences, possibly due to climate changes, and the expansion of urban constructions, are contributing to increase the surface stormwater runoff, causing floods that due to their magnitude entail huge social, economic and environmental damages and costs (PEC, 2006).

This document discusses some of the consequences of overflow in urban areas, and also evaluates some benefit measures to improve the existing draining system that will allow the mitigation of the consequences of these occurrences. Later, these insights are applied to the practical case of Albufeira's catchment.

It is worth mentioning that due to the magnitude of the losses associated with the overflows registered in the last decade, the firm HIDRA was requested a study by Câmara Municipal de Albufeira – Alfufeira´s municipality - on the possible improvement solutions to the existing local draining system. Within this project it was important to evaluate different options, and this paper presents the author's contribution to the referred study. The reviewed solutions increase the potential for stormwater runoff retention, and also refer to some complementary measures that will promote soil water infiltration and the increase flow capacity of the existing streams.

2. Urban areas overflows

In Portugal, according to the International Disaster Database (EM-DAT) statistics, floods and overflows are the most frequent natural catastrophe. Also a tendency toward their increased frequency and severity has been registered, due to climate changes which is well documented in a study conducted by Lima et al. (2012). The occurrence of very intense and/or increasingly longer precipitation periods, contributed to the intensification of flood episodes, that are no longer exceptional events but a daily constant of the reality of certain populations (Coelho et al. 2004).

On the other hand, the disordered growth of urban areas enabled the occupation of the flooding areas augmenting the flood risk of these infrastructures and making it increasingly difficult to protect them (Tucci, 2008).

Also, the higher construction density in urban areas caused, among other changes, a drastic reduction of the water infiltration rates, contributing to the increase of superficial drainage and preventing the recharge of the ground water aquifers (Yannopoulos et al., 2013, Maus et al., 2007 and Blair et al., 2014). Simultaneously the urbanization process promotes the transportation of sediments, debris and chemical components deposed on the surfaces, which, via superficial runoffs may cause physical, chemical and/or biological impacts on the receiving environment (Paul & Meyer, 2001). It is then necessary, to implement an adequate water treatment in order to prevent negative pollutant effects on the water quality of the rivers and streams where these are discharged.

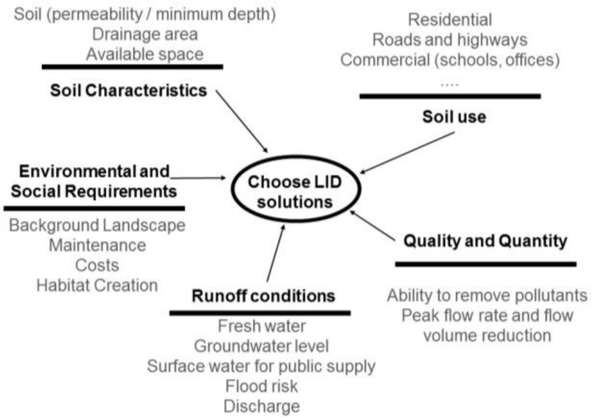
Adding to the problems caused by the growth of urban areas, it is noted that this growth was not supported by the reinforcement or rehabilitation of the existing systems in those areas, which became under-dimensioned to receive new incoming overflows. Frequently also, there are no interceptive mechanisms put in place such as grids and gutters.

To mitigate the problems described, some techniques have been developed in order to promote a source control which, as the name itself indicates, allows the storage and infiltration of stormwater runoff near the point where the precipitation hits the surface. Among these techniques, the Low Impact Development (LID) ones are included.

3. Low Impact Development techniques

According to Yannopoulos (2013), source control techniques are divided in Structural and Non-Structural. The first intercept the flow, and delay, slow down or absorb the pollutants transported by the run-off. The later, involve preventive measures, including a set of rules and regulations that make it possible to stop or refrain the transportation of pollutants in the rain waters flows, promoting the use of a number of good practices, such as the cleaning of the streets and the use of stormwater runoff at municipality level and at building level (Fletcher & Taylor, 2007).

Within the control at the origin measures, the concept of Low Impact Development (LID) techniques was developed. These techniques are studied with the aim of the detention, retention and infiltration of the superficial runoff waters, but also there treatment, reducing the impact of the urban development (Elliot & Trowsdale, 2006) and represent an investment that is lower then the costs associated with the referred flooding events (Tucci, 1999). The choice of the correct LID solution that should be applied depends of a number of existing



Picture 1 - Fundamental criteria in choosing the beneficial system solution.

conditions as sensitized in the Picture 1.

According to the classification recommended by Yannopoulos (2013) the Structural LID can be divided into: a) vegetated systems (filter strips, grass swales); (b) infiltration systems (infiltration basins, infiltration trenches, bio retention systems, sand filters, …); (c) storage facilities (detention ponds, green roofs,…) and (d) pervious paving systems.

In Table 1 the efficiency of the different solutions is compared in what concerns the reduction of the peak discharge and drainage volume, the removal of total suspended solids (TSS), nutrients and heavy metals. The requirements of those solutions in what concerns land occupation, initial investment (capital cost) and maintenance costs is also presented. This classification is based on the study by Woods-Ballard et al.(2007).

As concluded from this table, the resolutions that present high efficiency rates in reducing the water flow are mainly the retention basins and the pervious pavements, and consequently they should be applied in areas which present frequent risk of overflow.

Retention basins are found mainly in areas upstream to high density urban occupation areas because they require a considerable implantation area. Porous pavements on the other hand can present a high urban occupation, which then does not represent a disadvantage, once they do not occupy additional space when compared to the traditional pavements, so they should be used whenever possible.

In what concerns total suspended solids and heavy metals removal, basically all the presented solutions present a high efficiency rate, so they should be recommended in areas where a significant accumulation of these elements occur. In what concerns the removal of nutrients only the pervious pavements present a significant advantage.

It is the coordination of these types of solutions that allows the reduction of the risk of floods and improves the quality of stormwater runoffs.

4. Modelling stormwater drainage systems

The development of dynamic models has made it possible to evaluate in a realistic way the performance of the existing draining systems.

This detailed study of the existing draining system performance, is crucial in order to evaluate the correct improvement measures required. In fact, the only way to do this is to conduct a detailed evaluation of the existing system when it is required to perform upon a specific rainy event, and then evaluate the system performance variations when new system beneficiary solutions are introduced.

	Peak flow reduction	Volume reduction	TSS removal	Nutrients removal	Heavy metals removal	Land take	Capital cost	Maintenance cost
Grass swales	➡	➡	⬆	⬇	➡	🔴	🟢	🟡
Filter strips	⬇	⬇	➡	⬇	➡	🔴	🟢	🟢
Bio retention systems	➡	➡	⬆	⬇	⬆	🔴	🟢	🟡
Infiltration trenches	➡	⬆	⬆	➡ / ⬇	⬆	🟢	🟢	🟡
Sand filters	⬇	⬇	⬆	⬇	⬆	🟢	🔴	🔴
Infiltration basins	➡	⬆	⬆	➡	⬆	🔴	🟢	🟢
Retention basins	⬆	⬇	➡	⬇	➡	🟡	🟢	🟢
Green roofs	➡	➡	⬆	⬇	➡	-----	🟢 - 🔴	🟡
Pervious paving systems	⬆	⬆	⬆	⬆	⬆	🔴	🟡	🟢

Efficiency	
High	⬆
Medium	➡
Poor	⬇

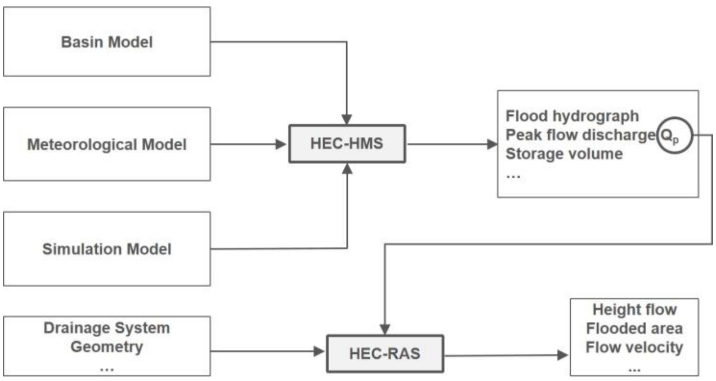
Level	
Low	🟢
Medium	🟡
High	🔴

There are, however, some major obstacles when building a modulation that reflects the real behavior of the existing system when subject to extreme rainfall events. One of these major obstacles is to obtain precipitation values that reflect the actual events. At the same time it becomes very complicated to translate the state of the stormwater catchment at the exact time of the studied precipitation events, namely in what concerns the degree of the soil saturation witch is reflected on parameters that should be introduced in the modulation, such as the curve number (CN).

Not forgetting the uncertainty associated with the above factors, and attempting to reduce them, it is common to use modulation software that allows to take into consideration even the aspects related to the drainage quality. Some of the most used ones are the SWMM (Storm Water Management Model), HEC-HMS (Hydrologic Modeling System) e HEC-RAS (River Analysis System).

A recent study highlights the fact that the HEC-HMS model is more adequate to the modulation of the superficial runoffs in rural basins, while the SWMM model is more adequate to use in urban basins (Souza et al. 2012). This being so, the choice is to use the HEC-HMS to model the present system, once the aim is to find solutions that allow the reduction of superficial runoffs in a semi-urban environment, that is upstream of the urban area.

In fact, as can be seen in Picture 2, it is possible to use the HEC-HMS software to transform a certain precipitation in water runoff, thus estimating data such as the peak flow. Given this parameter and using the HEC-RAS software, it is then possible to estimate flow highs and evaluate the floodable areas, associated with these transported flows. It is then clear, that using these two softwares in conjunction, will enable the mapping of flood risk areas upon rainy events, associated with different return periods, making it easier to identify the areas that should be protected and to evaluate the system beneficiary measures.



Picture 2 – Modelling the existen drainage system

5. Case Study: Hydrological study

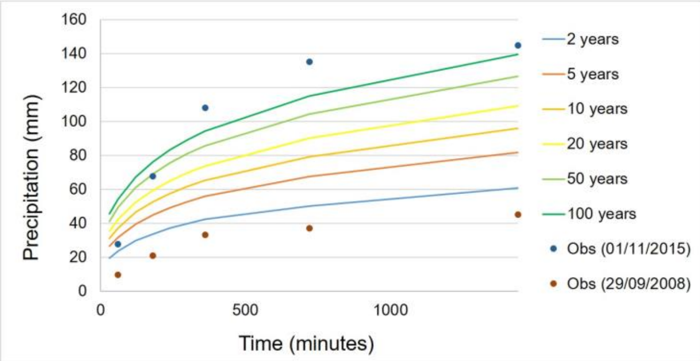
Albufeira’s catchment, as some other Portuguese coast areas, has been subject to different factors that increase their vulnerability to floods. In the last decades there are record of such events that due to their magnitude caused relevant economic, social and environmental costs to the population and the government. In fact, in Albufeira’s catchment the last extreme event took place at 1st November of 2015. This being so it is necessary to predict and implement measures that help mitigate the risks associated with such events.

In order to evaluate the benefits of introducing some benefit measures in the existing system, it’s necessary to study the precipitation regime in Albufeira’s catchment through an hydrological analysis.

In the Albufeira’s catchment there are no meteorological stations that allow the estimation of its udometric possibility curves, so the nearest precipitation station with higher number of registrations is used in this study, namely the Algoz station. Picture 5.1 represents the udometric possibility curves, and also the precipitation registered in November the 1st 2015 and September the 29th 2008, dates in which high floods along the stream were registered.

Based on these curves, and using the rational method, the peak flow is estimated for different returning periods. These flows allow the validation of the results obtained in the HEC-HMS. As it is observed, the floods registered in November the 1st, 2015, correspond to an extreme precipitation level that is associated with a returning period of 100 years.

In the modulation of both existing and future drainage system the different udometric possibility curves are used.



Picture 3 - Albufeiras´s basin Udometric Possibility Curves for different returning periods (T).

6. Case Study: LID solutions

As referred, this document investigates solutions that will allow drainage volume reduction and prevent the occurrence of floods near the Camping Park and at the existing tunnel, both located upstream of the most dense urban occupation zone, while preserving the quality of the receiving environment.

This quality aspect is even more relevant in this case once this catchment drains to beach shores with an important recreational function.

Accordingly, given the high flow reduction efficiency of the retention basins and the existence of available areas near the Camping Park to construct them, it was chosen to study in further detail this alternative, while also studying the drainage capacity of the streams that cross the critical area under study. In order to protect the highest urban occupation area and due to the magnitude of the flows that are generated in this studied catchment, these solutions must be complemented with other solutions that increase the runoff infiltration and retention.

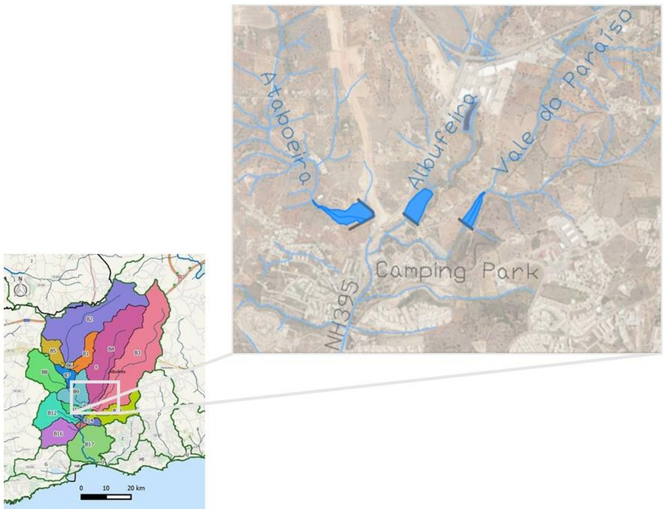
To find the most beneficial technical-economic solutions, a cost-benefit evaluation should be conducted, to identify the minimum required investment needed to reduce 1 m^3 of stormwater peak flow. The cost-benefit analyses of the implementation of the three retention basins analysed demands the estimation of the peak flow degree damping produced by these structures and the evaluation of their initial investment.

The next paragraphs indicate some of the proposed measures to mitigate the flood problem in the Albufeira's catchment.

6.1 Retention solutions studied

As previously referred and as can be observed in Picture 5.2, the efficiency of the construction of three basins in the Albufeira's catchment is studied. These are located in the Ataboeira´s stream, Albufeira´s stream and Vale do Paraíso´s stream, upstream of the Camping Park area. This type of solutions have the advantage of not requiring constant human monitoring, namely in what concerns to their discharge.

These retention basins have two different dischargers: one bottom outlet (with circular section) and one emergency discharge. The first one must guarantee the discharge of current flows while the second one only comes into operation when the storage height reaches a certain height. The design of these two dischargers is made with the software HEC-HMS, ensuring that, for stormwaters associated to a returning period of 100 years, there is a minimum clearance between the maximum level and the embankment of 0.5 m.



Picture 5.1 – Studied retention basins location

The emergency dischargers is equipped with a discharger stepped coated gabions, above the earth embankment, solution that leads to a highest energy dissipation.

After the design of all the analyzed retention basins, using the HEC-HMS program, and the udometric curves obtained to this area, the following 5 scenarios are evaluated:

- Scenario 0: Current situation;
- Scenario 1: Construction of the Albufeira’s stream retention basin;
- Scenario 2: Construction of Albufeira´s and Vale do Paraíso streams retention basins.
- Scenario 2A: Construction of Albufeira´s and Ataboeira´s retention basins.
- Scenario 3: Construction of all the three studied retention basins (Albufeira´s, Vale do Paraíso´s and Ataboeira´s).

Based on the reduction of the peak wave and the estimated initial investment required by each of these scenarios, the chosen solution will be the one with the lower investment that produces the highest efficiency in reducing the peak flow. This solution corresponds to the SCENARIO 2 – therefore the recommended solution is to build Albufeira´s and Vale Paraíso´s retention basins.

Nevertheless, the water lines where these basins are discharged, do not present the adequate discharge capacity to meet the requirements of the current precipitation occurrences, and this being so they also must be improved.

6.2 Waterline improvements

To evaluate the discharge capacity of the main streams, the HEC-RAS software was used in such a way as to estimate the maximum quotes attained by the flow in a flood situation. As it was mentioned before, it is clear that for floods associated with a 5 year returning period, there are already existing overflows in some sections of the studied streams. In spite of the fact that the construction of the retention basins already produces the reduction of the discharge height the overflow continues to exist in some sections. It is therefore evident the need to increase the discharge capacity of those sections, through a geometrical redefinition of their main channel. This redefinition entails for example, the creation of a compound river bed in the area near the camping park, where frequent floods occur. Nevertheless, these measures also require the coating of the smaller river beds with rockfill in the Vale do Paraíso´s area that crosses the Camping Park, and the creation of confinements that should go up to a height of 1.20m, in order to accommodate the flood peaks discharge in the Camping Park area associated with a flood with a 10 year returning period.

To minimize the damages associated with extreme events, it is also recommended to manage the Camping Park occupation by its users in accordance to the times of the year and different associated flood risks. Therefore, in the winter it is recommended that it is only allowed to occupy the areas in which the elevation is above the 45 quote, corresponding to the maximum quote associated with floods approximate to the centenary.

During Autumn and Spring, the occupation can descend to inferior quotes, and in the Summer, when the flood risk is lower, it can come near the river bed.

6.3 Other measures

Given that the mentioned measures will not be sufficient to solve the flood problems in the totality of the basin, a number of additional beneficiary measures are recommended in order to improve the existing system.

The next paragraphs describe some of complementary LID solutions that should be implemented in the urban area to make up for the reduced infiltration caused by increased impervious areas.

- Porous pavements: should be implemented along the National Highway 395 to promote the infiltration of stormwater runoff in that area. Additionally this solution can be used in *Praça dos Pescadores* and in the parking facility near the Ferreiras Football Stadium where a high water accumulation occurred in November the 1st, 2015. This good practice should be used whenever possible once, according to the study, it presents great advantages from the water flow reduction and run off quality improvement perspectives;
- Infiltration trench: applied in townhouses that have area available for its implementation, like the urbanization Clube de Albufeira.
- Grass swales: located in the three main streams, upstream the retention basins. It

should have dykes to promote additional retention of stormwater runoff.

- Green roofs: implement on some public buildings, such as the City Hall, high schools and the parking lot located near the beach, due to the dimension of its roof structure.

Other complementary measures can be implemented, in order to promote the infiltration of stormwater runoff in the most density construction areas, such as:

- Creating a mandatory legal requisitions requiring that all new buildings present a certain amount of green coverage, as already is the case in countries such as the USA, Canada, Australia and Japan;
- Creating a fiscal incentive that allows the owners of plots of land with higher percentage of green coverage to pay a lower tax related to the draining of rain waters.
- Using mechanisms in new buildings, that allow the re utilization of rain run offs, using an additional filtering system, as for example sand filters;

These and other additional measures will potentiate the increase of green spaces in the urban area, reducing the flows generated by high intensity rain events and promoting the removal of pollutant substances.

Nevertheless, due to the magnitude of the flows generated in extreme rain events, these solutions must be complemented through structural storage and deviation solutions.

7. Conclusions

In the latest years the concept of complementary control at the origin, using LID solutions that allow not only to reduce peak point flows, but insure the maintenance/preservation of the receiving environment quality was developed. Upon the analysis of a number of these solutions it's possible to conclude that retention basins and the use of porous pavements are the ones that present greater efficiency in reducing the maximum peak flow. These solutions also present good results in what concerns to the removal of total suspended solids and heavy metals.

The cost-benefit analyses of the implementation of the three retention basins analyzed requires the estimation of the peack flow degree damping produced by these structures and the evaluation of their initial investment. After this analysis it is recommended to build Albufeira´s and Vale Paraíso´s retention basins.

The detailed study and design of the others referred LID measures may be a work to do in the near future, under which it could hold its modeling using, for example, the SWMM software. In this way it would then be possible to quantify the efficiency of each of these solutions. It would also be interesting, as performed for the retention basins, for each of the LID solutions to evaluate the implementation cost per m^3 of reduced runoff.

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