Smart water management (SWM): flood control and water uses

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Abstract:
The main objective of this work is to analyse a study area, in Seixal, regarding flood risk and flood mitigation techniques. This analysis was performed by computational modelling using DHI software, MIKE SHE. Several scenarios were compared regarding flood risk and SUDS efficiency. To obtain a more accurate analysis was also determined the economic viability of each technique, stablished in two ways: the first one through life cost analysis and the second one taking into account the damages caused by a certain type of flood. The results present that the best scenario is the one who will minimize the effects of great urbanization and consequently the increase of flood risk, which combines two different measures: permeable pavement and detention basin. This alternative allows to fully explore the mitigation capacity of each technique. The installation of this system proved to be viable, demonstrating a very important improvement in the flood mitigation system in Seixal.

Keywords: Urban flood, flood, modelling, sustainable urban drainage systems, economic viability.

1. Introduction

Floods are the most common type of natural disaster in Europe (EEA, 2015). Europe is one of the continents with the highest rate of urbanization, with about 75% of the population living in urban areas, and recent studies reveal that this scenario could increase to 80% in 2020. The EEA also states that the space occupied by urban areas is increasing faster than the population itself. It is expected that, between 2000 and 2030, the world population will have increased approximately 72%, while, for the same period, it is expected an increase of 175% of urban areas with 100 000 or more inhabitants.

Flooding often occurs as a result of high rainfall intensity in the catchment area, insufficient storm drainage capacity, river overflows, storm surge or as a combination of these phenomena. The risks of flooding are amplified by the expected effects of climate change and by the increase of impervious areas. The use of sustainable urban drainage systems (SUDS) can reduce urban surface water flooding as well as the pollution impact of urban discharges on receiving waters.

The main objectives of this work are to give an overview of urban water issues and smart water management as well as the information about possible implementation of sustainable urban drainage systems towards a more sustainable water management. To achieve the proposed goals is performed an analysis of a case study assisted by a model simulation software (MIKE SHE, by DHI) that allows to represent the benefits of these innovative and sustainable systems. The current research work aims to demonstrate the susceptibility to flood of an area in the old city center of Seixal, ways to prevent these extreme events in the area using sustainable urban drainage systems and a cost/benefit analysis of its implementation.

2. Sustainable urban drainage systems

In urban areas where many surfaces are sealed by buildings and paving, natural infiltration is limited. Instead, drainage networks consisting of pipes and culverts, divert surface water to local watercourses. In some cases, this has resulted in downstream flooding and deterioration in river water quality caused when foul sewers are overwhelmed by surface water leading to a release of dirty water into rivers. Drainage systems need to adapt to and manage extreme events including flooding and periods of drought, while helping to reduce carbon emissions. Storage of runoff within a SUDS system is essential for providing the extended detention of flows for water quality treatment, as well as for peak flow attenuation of larger flows for flood protection downstream of the site. Runoff storage can be provided within an on-site system through the use of structural controls and/or nonstructural features and landscaped areas.

Attenuation storage is used to store runoff to enable a reduction in the peak discharge from the site.

Retention storage facilities are designed to contain a permanent pool of water (in stormwater ponds and wetlands) which are used to provide water quality treatment.

The differences between a conventional drainage system and a sustainable drainage system is shown in Figure 1.

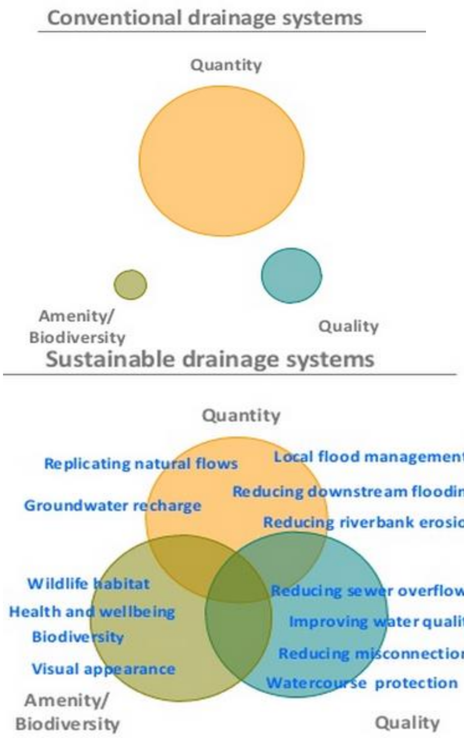

Figure 1 – Differences between a conventional drainage system and a sustainable drainage system

It is important to determine which SUDS techniques are best suited to the proposed land use of the area draining to the system. CIRIA C697 presents the following criteria: 1. Land use characteristics.

2. Site characteristics.
3. Catchment characteristics.
4. Quantity and quality performance.
5. Amenity and environmental necessities.

SUDS, may be divided in the following classifications: Source control, Swales & conveyance channels, Filtration, Infiltration, Retention & detention and Wetlands and Inlets/outlets/control structures.

3. Simulation model

MIKE SHE is a physically based model, based on physical laws which are derived from forms of the laws of conservation of mass, momentum and energy. The evapotranspiration model is calculated using the Kristensen and Jensen methods, although user input reference ET can be calculated in different ways. Channel flow is handled using one dimensional (1-D) diffusive wave Saint-Venant equations and overland flow is calculated using two dimensional (2-D) diffusive wave Saint-Venant equations. Water infiltrating into the unsaturated zone can be modeled using the 1-D Richards flow or gravity flow. The saturated zone is modeled using a three dimensional (3-D) Boussinesq equation which uses finite difference methods to solve the partial differential equations (PDE's).

4. Case Study

The Tagus estuary has a high potential to flooding from different sources along its margins, due to the intense occupation. This study was conducted in a restricted area (Figures 2, 3 and 4) located in the southeastern margin of the estuary, that was selected due to past record of flood episodes and relatively diverse land use occupation, with a total area of 491127m^2 and 1170m of margin length. The territorial occupation of this area is associated to relevant industrial sites that were built in Seixal (steel industry). Due to this important industrial presence urban areas grew nearby. These local industrial developments went into decline in the late 1990s and most of the facilities closed. At present, some management territorial plans indicate the intention of transforming a large part of these abandoned industrial sites into urban areas (which includes residential, services and logistics facilities).

Figure 2 – Study area location

Figure 4 - Risk index in Seixal Bay (Project Molines)

Figure 3 - Study area

Marginal flooding in the Tagus estuary can have adverse effects. Some urbanized marginal areas, such as Seixal, are low-lying, so that the potential human and material costs of a flood are high. One of the most severe historic episodes described was originated by the combination of extreme storm surge levels and locally generated waves during the February 15, 1941, windstorm, causing high human casualties and property damages along the estuarine margins (Muir-Wood, 2011).

The ongoing rise in sea level affects tidal propagation and circulation in estuaries, and these changes can have far reaching consequences on the sediment dynamics, water quality and extreme water levels. The increasing of population is also causing a major impact, the induced erosion may cause accelerated siltation and the urbanization will increase the runoff. The consequences will be the growth of water's turbidity, the acceleration of sedimentation and the spread of silts, muds and clay throughout the estuary, which leads to a major vulnerability of its margins.

5. Model testing and validation

MIKE SHE allows users to easily visualize the parameters that are being introduced and to create output image data.

Background: In order to place the visual data at the geographic site, it was used a georeferenced google satellite image of the study area. To create an readable image by MIKE SHE was used the software QGis 2.12.0 which allows to georeference a normal google satellite image with Google OpenLayers plug in. This is necessary once MIKE SHE uses georeferenced inputs such as shapefiles and gridfiles. Every input and output data is shown over this image, giving the geographic information.

Foreground: With the software QGIS 2.12.0 was created a polygon shapefile of the study area. The shape acts as a boundary within which every calculation is made. This appears represented in every output image given by the software and allows the user to study a specific area.

One of the necessary inputs to define the simulation is the duration of the simulation and time step period. The simulation period chosen was 2 months. The time steps used in the model for efficient simulation were: initial unsaturated zone time step 6 (hours); maximum unsaturated zone time step (1 hour); maximum saturated zone time step (4 hours); maximum overland flow time step (1 hour).

The meteorological data consisted in three main inputs: precipitation rate, net rainfall fraction and infiltration fraction. Precipitation rate was set as uniform and with a constant temporal distribution. The value assumed was 3.5 mm/day (i.e. average precipitation in the rainiest month, November). It was considered that precipitation was equally distributed in the study area and only 10% of the rain was infiltrated. The digital elevation model (DEM) that was acquired with a 7.5 arc-seconds resolution GeoTIFF data (with a RMSE range is between 26 and 30 meters) was converted into a point file suitable for MIKE SHE using QGIS 2.12.0. The elevations in the point file were triangularly interpolated into a 10 by 10 meter resolution inside MIKE SHE. Figure 5 shows the topography as it appears in MIKE SHE in the study area.

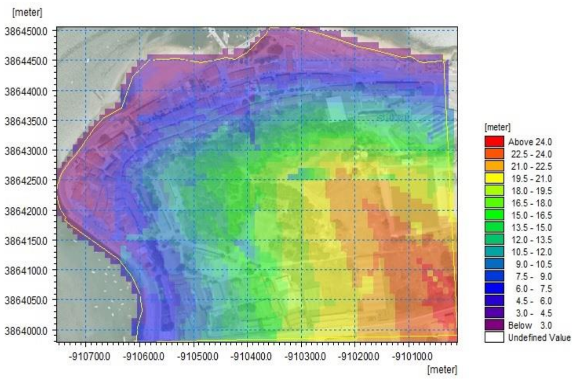

Figure 5 - Topography map of the study area as an input file in MIKE SHE

The MIKE SHE model was run under various land management scenarios to investigate the effect that land use has on the hydrological model. There are two main land uses on the study area: green areas (Figure 6) and paved areas (Figure 7).


Figure 6 - Green areas adopted in the study area


Figure 7 - Paved areas adopted in the study area

Several simulations were analyzed and performed in order to verify if the outputs given by MIKE SHE model were the same has the flood data registered in the study area. Modeled flood outputs from these simulations were compared and adapted to real and observed conditions. In Figure 8 it is presented the MIKE SHE model used for final testing of the different scenarios.

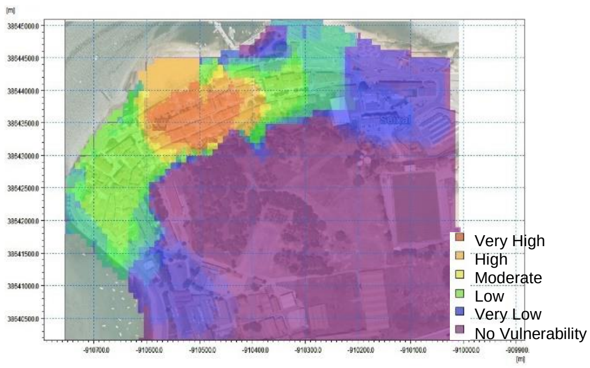

Figure 8 - MIKE SHE model used in the flood scenario simulations

The results showed that the model simulated flooding much like what would occur in nature. After the model definition it was possible to start the scenarios simulation for each SUDS alternative.

The study area is a built-up area among the most densely inhabited around the estuary's margins. The area totals 672,016 inhabitants in 670.39 km2. For this study it was considered as a Residential and Commercial area. It was determined whether there were any site characteristics that may restrict or preclude the use of a particular SUDS technique. The area is almost impermeable due to the roads and buildings, has 491197m^2 (>2ha) and gentle slope (nearly flat). There is a lack of space for new facilities. Analyzing the characteristics it was concluded that only these techniques were valuable at this point: retention pond, wetland, infiltration trench, soakaway, filter strips, filter trench, detention basin, green roof and permeable pavement. Construction and maintenance costs can vary widely between techniques and the long term costs of SUDS should be considered at an early stage. In selecting a design from a series of options, both capital and operational costs should be considered using a whole life costing approach. To select the techniques with more acceptance by the community was used the matrix presented next in Table 1.

Technique	Maintenance	Community Acceptance	Cost	Habitat creation potential
Retention Pond	Medium	High	Medium	High
Wetland	Medium	Low	High	Medium
Infiltration trench	Low	Medium	Low	Low
Soakaway	Low	Medium	Medium	Low
Filter strip	High	High	Medium	High
Filter trench	Medium	Medium	Medium	Low
Detention basin	Low	High	Low	Medium
Green roof	High	High	High	High
Permeable Pavement	Medium	Medium	Medium	Low

Table 1 - Community and environmental factors selection matrix, CIRIA, 2015

Under this analysis it was concluded that the techniques valuable for the study area were infiltration trench, detention basin and permeable pavement. After the mentioned analysis the techniques were applied to the study area, Figures 9, 10, 11, 12, 13 and 14.

Figure 9 - Infiltration trenches technique applied in QGIS

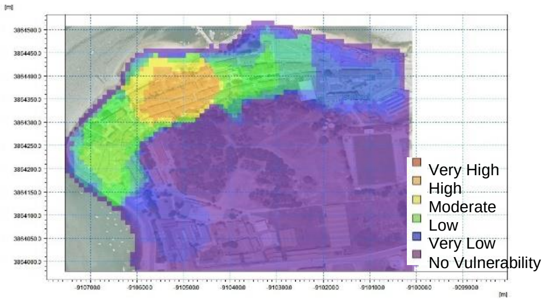

Figure 10 – MIKE SHE model with infiltration trench application

Figure 11 - Detention basin technique applied in QGIS

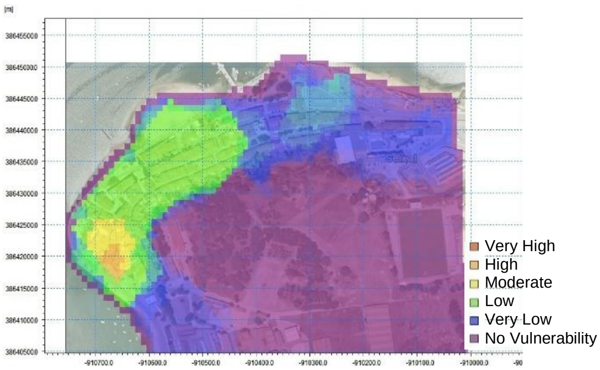

Figure 12 - MIKE SHE model with detention basin application

Figure 13 - Permeable pavement technique applied in QGIS

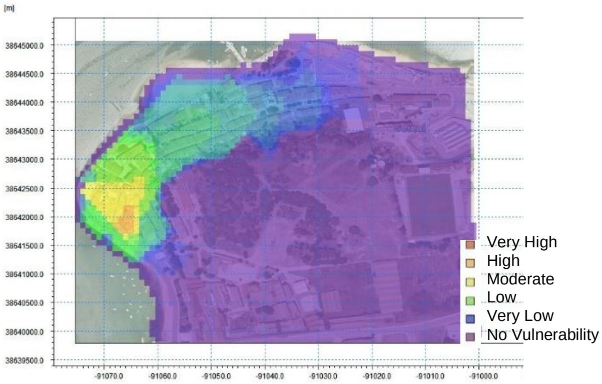

Figure 14 - MIKE SHE model with permeable pavement application

Taking into account the simulations performed for the different scenarios the flood risk areas were calculated for each situation. First it was evaluated the flood risk of the MIKE SHE model (Figure 8) and the results obtained are shown in Table 2.

Table 2 - Flood risk of the study area

Risk	Affected area
No Vulnerability	53.47%
Very Low	18.67%
Low	18.47%
Moderate	1.10%
High	4.09%
Very High	4.20%

The results showed the probability of flooding like what would occur in nature. After the model analysis it was possible to do the same assessment for the scenarios simulation for each SUDS alternative. While visualizing the graphic models it was noticeable that the risk Very High was mitigated, so it was not considered on the following calculations. The calculations showed that both techniques - detention basin and permeable pavement, have a major impact in flood risk attenuation. Although the results are acceptable, the intervention areas are considerable and may reduce the community acceptance and the economic viability. For this reason it was simulated another scenario that combined both techniques (Figures 15 and 16).

Figure 15 - Combination of detention basin and permeable pavement techniques applied in QGIS

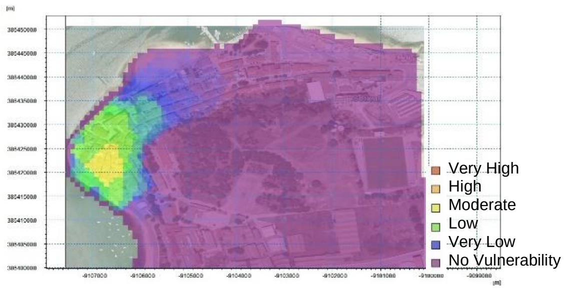

Figure 16 - MIKE SHE model for flood with combined techniques applied

After the model analysis it was possible to do the same comparison between the other scenarios. While visualizing the graphic model it was noticeable that for the combined scenario the risk Moderate was mitigated, so it was not considered (Table 3).

Table 3 - Comparison of flood risk between no intervention scenario and best scenario

Risk	Affected area without intervention	Affected area with combined techniques
No Vulnerability	53.47%	81.74%
Very Low	18.67%	9.65%
Low	18.47%	7.26%
Moderate	1.10%	1.35%
High	4.09%	-
Very High	4.20%	-

When considered only the first three scenarios, infiltration trenches was the worse alternative and permeable pavement was the most effective technique. For both economic and viability reasons, was considered a scenario with the combination of detention basin and permeable pavement techniques, which revealed that could be a reliable option.

6. Economic viability of SUDS in the case study

6.1 Life cost analysis

Life Cost analysis consider all relevant and identifiable financial cash flows regarding the acquisition and use of an asset. In order to compile whole life costs, the following parameters may be required:

- Procurement and design costs;
- Capital construction costs;
- Operation and maintenance costs;
- Monitoring costs;
- Replacement or decommissioning costs.

For the life costs analysis were considered only the techniques tested in the MIKE SHE model, using the data given by the simulation scenarios, the results of this analysis are shown in Table 4.

Table 4 - Total costs

Component	Cost
Infiltration trench	172,077.13 €
Detention basin	63,756.61 €
Permeable pavement	492,783.75 €
Combined techniques	255,002.53 €

Under this analysis it was concluded that the detention basin technique is the most economical even with one of the largest area. Although infiltration trench shows to be an economical technique, it was concluded previously that its capacity to reduce flood risk is inferior to the others, therefore it is not a reliable option. As presented previously the scenario with the combined techniques (combination of detention basin and permeable pavement techniques) is the best scenario for mitigate flood risk, for this reason the relation between cost/effectiveness appears to be acceptable.

6.2 Damage analysis

The damage analysis considered three main aspects: flood cost/m^2, data given by MIKE SHE model over flood risk and influence risk area. The three referred aspects were combined in order to calculate the damage cost for each scenario. All the scenarios were compared with the MIKE SHE model that simulates flooding much like what would occur in nature (Figure 8).

Table 5 - Comparison between estimated damage costs for different simulated scenarios

Risk	Affected area without intervention	Affected area with combined techniques
No Vulnerability	-	-
Very Low	€6.514.259	€ 4.794.334
Low	€5.337.568	€ 2.296.978
Moderate	€628.090	€ 1.049.828
High	€1.931.644	-
Very High	€5.417.045	-
Total	€19.928.607	€ 8.141.142
Saving	-	€ 11.687.464

Under this analysis it was concluded that all the techniques are valuable for the study area since all of them have a lower cost comparing with the scenario without intervention (Table 5). When considered only the first three scenarios, infiltration trenches was the worse alternative and detention basin was the most effective technique. For both economic and viability reasons, was considered a scenario with the combination of detention basin and permeable pavement techniques, which revealed that could be a reliable option and less expensive.

7. Conclusions

The simulations undertaken in this study show that SUDS application in the case study would have significant effects on flood mitigation. In the case of a combination of two techniques this effects would be particularly substantial due to the decrease of prone to flood areas. Concerning the case study area it would be relevant in future works to prepare a model of the riverside area around the municipality of Seixal in parallel with a model that simulates the Tagus river behavior and its impacts in the area. An analysis with a major scale might be a study with potential to be submitted to the authorities being led to appreciation as a possible investment in flood mitigation.

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