Integrated flood management in urban environment. A case study.

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ABSTRACT

During the last decades, the urban creek of the Portuguese city of Guimarães was subjected to strong anthropogenic pressures, resulting in its water quality degradation, and the increasing occurrence of downtown floods. Worldwide, the paradigm of flood protection is changing to one of flood risk management, recognising that managed flooding is essential for a sustainable flood strategy, which success depends on integrating defence structures and early warning systems with improved understanding of the river systems.
The *Guimarães European Capital of Culture 2012* project supports strategic investments in knowledge, technology and innovation, aiming to improve citizens' life quality, through the urban requalification of the historic centre; which includes the revitalization of the Couros creek and a new *living with floods* approach.
Hydrological studies were performed to understand the rainfall/runoff process in order to mitigate the uncertainty of flood flows definition of rivers in urban environment. A hydrodynamic model was developed and applied to simulate the creek's hydraulic behaviour, under different management scenarios, integrating all the main urban constraints. Simulation results allowed to prioritize the chirurgical structural interventions and to assess the impacts of the rehabilitation measures in this urban catchment, contributing as a key factor to enhance the attractiveness and sustainability of this historic city.

Key-words: urban flood management; hydrodynamic modelling; Couros creek requalification.

1. INTRODUCTION

Water management in urban areas must be performed in an integrated approach, considering its two main components − water supply and sanitation systems and flood control – as well as with land use and urbanization dynamics. Flood risk management has to deal with considerable challenges faced by the increased uncertainties due to climate change and the incapacity of the collection systems to respond to all rainfall- runoff events due to the complexity and singularity of the urban processes. Indeed, much of the design principles on which flood management has been based cannot be applied if time series are scarce and/or non-stationary. Such insights strengthen the change in flood management from "control of floods" to "living with floods", integrating flood and landscape management.
Some of the most critical flood problems occur in urban areas where values at risk are high and damages tend to be heavy. Mitigation and even elimination of natural risks are brought about by the introduction of long-term measures. One way of improving the preparation for natural disasters is by investing in the *digital city* concept (Price & Vojinovic, 2008). In this context, the application of hydroinformatic technologies, like advanced geographic information systems (GIS) and remote sensing, in urban water systems should be increased and integrated on decision support systems (DSS), designed to provide better judgements and improved decisions of city disaster managers.
Most cities were founded on high sand banks along the river shore and had expanded in time towards the river. Flood plains are often not present and the city fronts cause bottlenecks in the river systems which cause higher water levels during flood discharge on a local scale. Heightening of the quay wall would solve some flooding problems in the urban areas but is in general not accepted as a solution, because it will damage the historic city view and would cause degradation of the city front (Stalenberg & Han Vrijling, 2005).
A more subtle approach in flood control is needed which is in harmony with the city front, using multifunctional flood defences, in order to stimulate modern city life.
A realistic approach to flood management requires the consideration of urban growth scenarios and the simulation of the corresponding flood conditions (Correia *et al*., 1999). Due to migration of the population from rural areas, urban flood management cannot be dissociated from land-use management, and non-structural measures for flood control can play a crucial role when supported by the increasing of hydrologic and hydrodynamic modelling capabilities.
During the last decades, the city of Guimarães was subject to strong anthropogenic pressure due to increasing urban and industrial occupation, giving rise to the visible deterioration of existing buildings and the

environmental degradation of the Couros river basin. This water body has been part of the population's life and a vital element for the development of the former leather industry. Through several decades this river has been subjected to severe pressure due to the urban growth and the intensive leather industry activity that led to high level of pollution and contamination in the Couros creek, as well as to control the effects of the increased flood events in the historic center of Guimarães. The rehabilitation of urban water resources has an added complexity not only because the multidisciplinary approaches needed, but also due to the strong historic constraints, the lack of space for the implementation of structural measures, and the high value of the available land (Ramisio, 2010).

The European Water Framework Directive demands a good ecological status for natural water bodies and, therefore, there is an urgent need for controlling the detected sources of pollution. The restoration of urban watersheds is a multidisciplinary task involving, hydrology and hydrodynamics, biological and political knowledge. Since a restoration program can only be effective when the main processes involves are fully understood, a preliminary study was done in this creek, focused on the morphology and ecology processes at a watershed scale, incorporating insights from recent research in fluvial geomorphic and ecology, and developing connections between requalification strategies and physical actions.

A field survey was performed in order to understand and detail the morphological and hydraulic characteristics of this creek and related wastewater existing infrastructures. Based on these elements, some research objectives where established: to minimize the flooding of the downtown areas; to mitigate the negative effects of some canalized creek sections; to stabilize the banks with higher erosion risk, allowing to improve the creation of riverside recreational areas; to eliminate pollutant point sources and to increase the control of diffuse pollution.

This paper presents the Couros creek characterization and some results of the hydrological study, the hydrodynamic modelling development and its application to different management scenarios in order to assess the mitigation effects of some typical river restoration procedures and control measures.

2. METHODS

2.1 Study area

The Couros creek has its spring in Serra da Penha (Guimarães), and presents a total length of 6.2 km with a catchment area what about 11.23 km^2. It belongs to the Ave river basin located in the northwest of Portugal (Fig. 1).

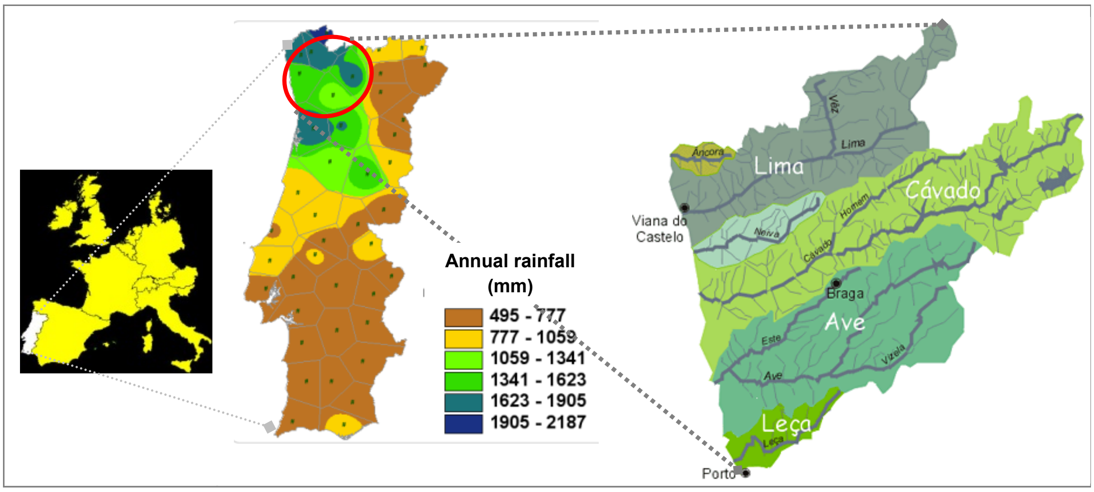

Figure 1 – Portuguese annual rainfall distribution and the River Ave basin location

In Figure 2 a tracking map of *Couros* (leather) creek along the urban area of *Guimarães* is depicted. The three major hydromorphological of this small river are clearly identified: in its upstream section, the river flows inside the *City Park* (Fig. 2a), constituting a natural river system in a leisure urban area.

From the *City Park*, the stream becomes partially channelled crossing all the downtown urban center of *Guimarães* (Fig. 2b), where the former mills, tanneries and public tanks are still visible and anthropogenic pressures are highest.

The downstream section of *Couros* creek crosses the *Veiga de Creixomil* plain, an extensive agriculture area, where this water body reappears again as a natural system (Fig. 2c) before flowing into the river *Selho*.

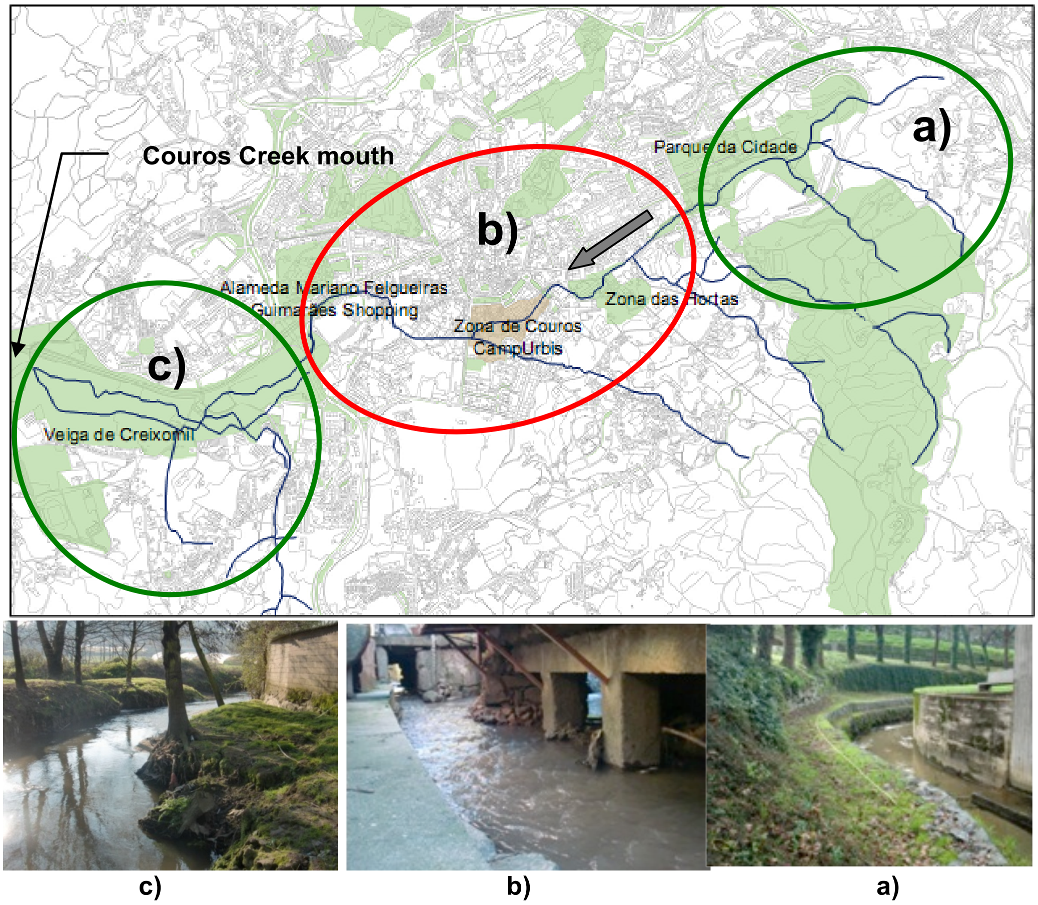

Figure 2 - Couros creek tracking along Guimarães urban area and major hydromorphological zones: a) City Park green area; b) Channelized reaches in downtown city; c) Creixomil plain (rural area).

An extensive field survey was done (Fig. 3) in order to characterize the river sections and the related drainage and sanitation infrastructures (domestic and industrial wastewater networks) The resulting information was organized in a database and as cartographic data, being preliminary task for a future GIS, as useful tool to integrate a desirable DSS implementation for the Couros creek water quality management.

Figure 3 – Field work for river morphological characterizing and riverside infrastructures survey

Concluded these preliminary tasks, a comprehensive hydrological study was performed in order to upgrade the understanding of the rainfall/runoff process complexity in urban environment, and to characterize its hydraulic behaviour based on flood and dry-weather flows estimation.

A hydrodynamic model was also developed for an integrated river system analysis, computing the hydraulic characteristics of this creek, under different management scenarios. Aiming to evaluate the related environmental impacts of these scenarios, water level ranges were simulated for support the proposals of corrective management measures (operational, structural, mitigation and ecological) implementation. Urban runoff pollution load estimation is also being evaluated but is not presented in this work.

3. RESULTS AND DISCUSSION

3.1 Hydrological study

The Couros creek flood flows were estimated applying empirical, statistical and cinematic methods. The empirical methods usually lead to very high specific flow values. These methods are mostly based on geometrical data and, therefore, this calculation process can only represent a rough estimate of the flood flows.

Since there is no historical data of previous flood flows for this river, statistical methods were applied with the pondered correlation of the flow data of a downstream watershed. The obtained results depend on this oversimplification.

Several cinematic methods were also computed in order to estimate the flood flows for the same recurrence period. These methods require representative precipitation data sets or a definition of plausible design hietograms. Three design hietograms where considered, based on the intensity-duration-frequency relations established for this rainfall region.

As expected, the results obtained using this different kinds of flood flow estimation methods showed a very high variability (Table 1). Since they all depended on different morphological and hydrological parameters, the qualitative comparisons of this should not be performed.

Table 1 – Synthesis of flood flow ranges estimation in the Couros creek basin

Methods		**Recurrence time** (years)		
		RT = 10	RT = 20	RT = 50
Empirical	*Scimeni* *Forti* *Gotmann* *Pagliari* *Ganguillet* *(...)*	10 – 383		
Kinematic	*Rational (Chow, Kirpish, Ayres)* *Giandotti* *Soil Conservation Service (SCS)*	18 – 240	22 – 270	29 – 305
Statistical	*Loureiro* *Foster-Hazen* *Gumbel-Chow*	4 – 40	5 – 49	6 – 55
Proposed values		***35***	***45***	***55***

The estimation of flood flows, based on methodologies applied in much bigger watershed, do not represent these specificities, and, for this reason, should be evaluated when applied to small urban watersheds.

The routing of runoff has also a singular behaviour in small urban watersheds and seems to be controlled by their inclination and land cover. The simple estimation of the basin concentration time using distinct kinematic methods led to a very large range of obtained results (Table 2).

Table 1 – Synthesis of flood flow ranges estimation in the Couros creek basin

Kinematic methods	**Concentration time** (minutes)		
	RT = 10	RT = 20	RT = 50
Ayres	10		
Kirpis	64		
Chow	197		
Giandotti	212		
Soil Conservation Service (SCS)	18	22	29

Based on the lacks of the previous methods, a hydrological model was built in order to understand the precipitation/runoff phenomena in the river Couros basin. The Hydrologic Engineer Center's - Hydrologic Modeling System (HEC-HMS) model was chosen due to the user-friendly interface and worldwide usage

(Feldman, 2000; Ford *et al*., 2008; Scharffenberg & Fleming, 2009). This model user-interface and the definition of this hydrological watershed are depicted in Figure 4.

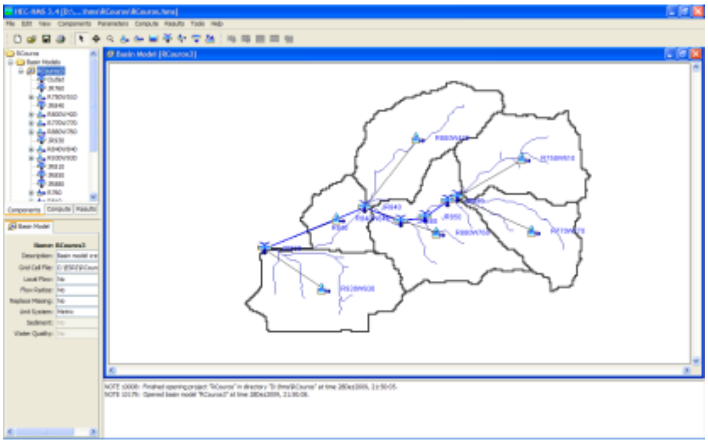

Figure 4 – HEC-HMS hydrological model: Couros creek sub-basins definition

The outcomes from this methodology application were several predictive hydrograms (Fig. 5) for the studied sub-basins that represent the flood flow over time, considering the same simulated conditions (recurrence period of 10 years).

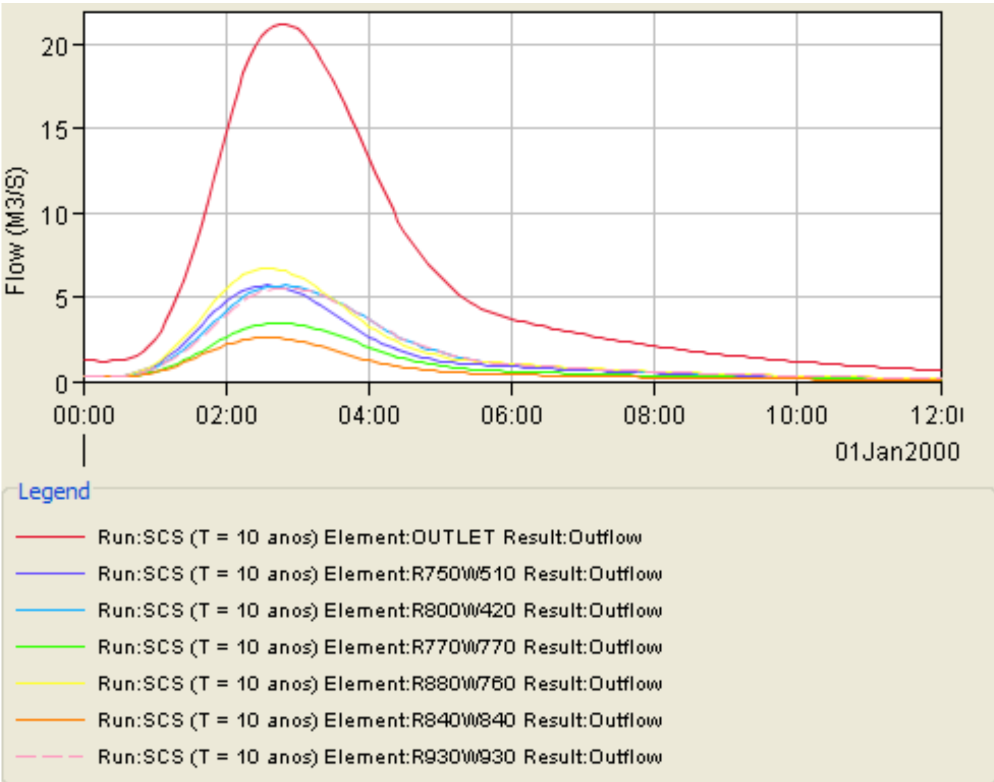

Figure 5 – Resulting hidrograma in HEC-RAS (RT=10 years)

3.2 Hydrodynamic model

The different methods of estimating flood flows allow, through simplified methodologies, to predict the flood flows associated with large rainfall intensities, and their probability of occurrence. Some methods also allow estimating the duration of these phenomena, helping the design of structural measures to reduce the economic impacts and the loss of human lives.

The predictive nature of these methods originates uncertainties in their actual occurrence, especially with the change of the conditions on what those methods where based, as climate change or the permanent change in the occupation of the soil in urban areas.

Moreover, the effects of flood flows along the water stream are closely linked to the geomorphology, which can vary significantly along the streamline. It is therefore important to assess the hydrodynamic conditions of the different river sections, under different flow rates.
In the last decade significant advances have been achieved on the modelling of natural phenomena, which can be a valuable contribution for the prediction of their effects, especially in situations of uncertainty.
For the simulation of the present case study, the Hydrologic Engineering Centers – River Analysis System (HEC-RAS), was selected. This model has been extensively tested for the simulation of river hydrodynamics. However, the use of models requires the physical characterization of the simulated environment. River cross-sections where defines, with a 20 meters longitudinal distance, from which resulted about 310 cross-sections. The Figure 6 depicts the interventions area and the definition of these sections.

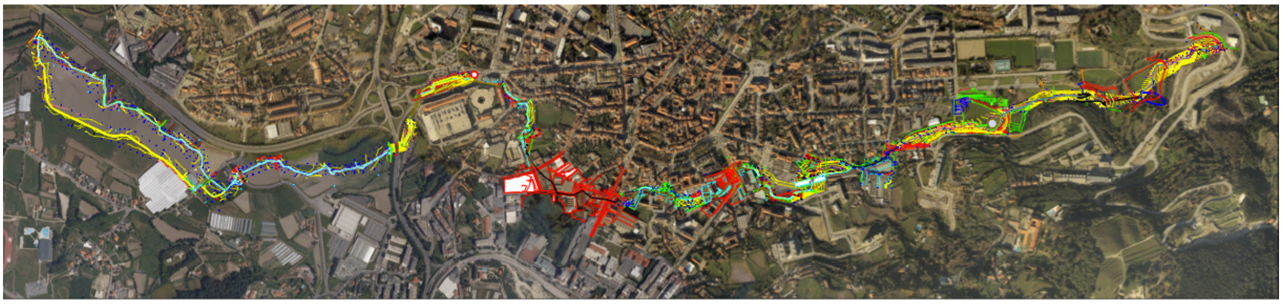

Figure 6 – Definition of the river cross-sections

An extensive field survey was the next step, in order to define the physical and geometric characterization of these river cross-sections. These values were chosen based on in-situ observations and their identification with the values proposed by different authors. Figure 7 shows the defined river sections that resulted from the field survey, and a 3D representation of the river.

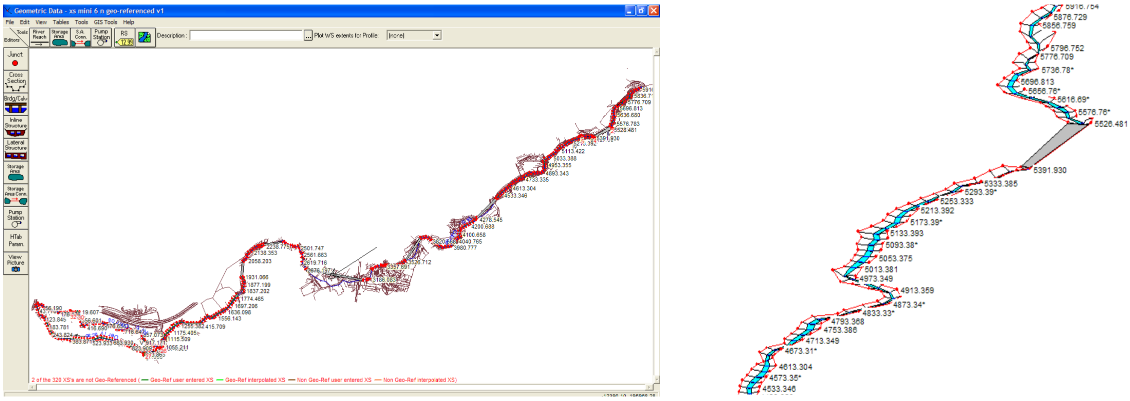

Figure 7 – Hydrodynamic model and 3D representation of the river.

After the characterization of the water system, different scenarios where chosen to assess the effects associated with different probabilities of occurrence of intense rainfall. These scenarios were representatives of recurrence times of 10, 20 and 50 years.
The distribution of flood flows along the river was done based on the existing tributaries, and the accumulated caching area. This analysis allowed defining, for each cross-section and scenario, the flows to compute.
Based on the collected data, a hydrodynamic model of the Couros creek systems was developed, allowing us to predict the river hydraulic behaviour at each cross-section, for different flow scenarios.
Figures 8, 9, 10 and 11 present the results of the performed computations, for four representative hydraulic zones of the studied river.
These graphical outputs, based on a simple representation of the computational results, allowed identifying the water level predicted for each cross-section, for the different scenarios, and to estimate the related hydraulic conditions and resulting hazards.

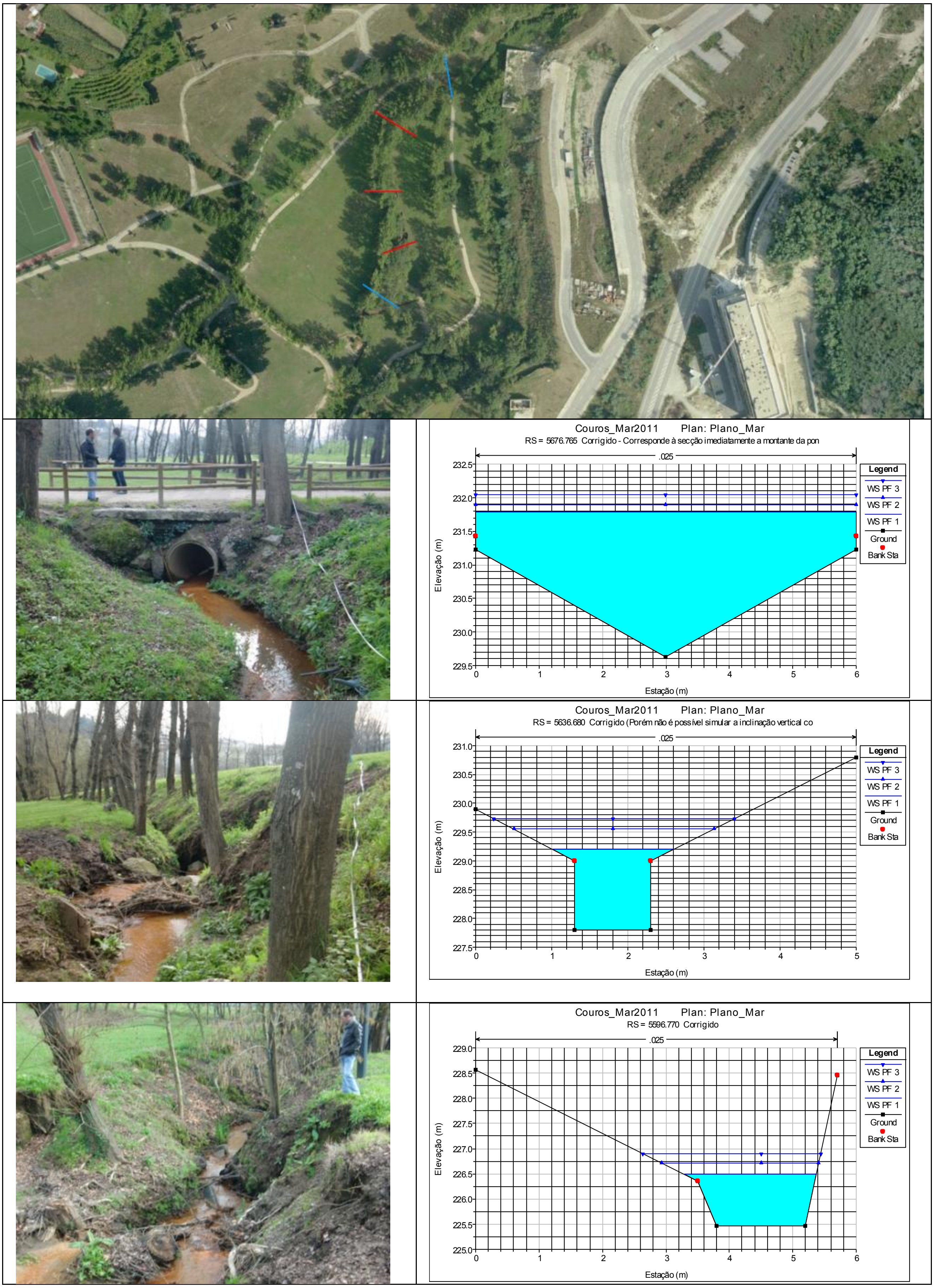

Figure 8 – Estimated river hydrodynamic conditions, for different recurrence time – Zone 1

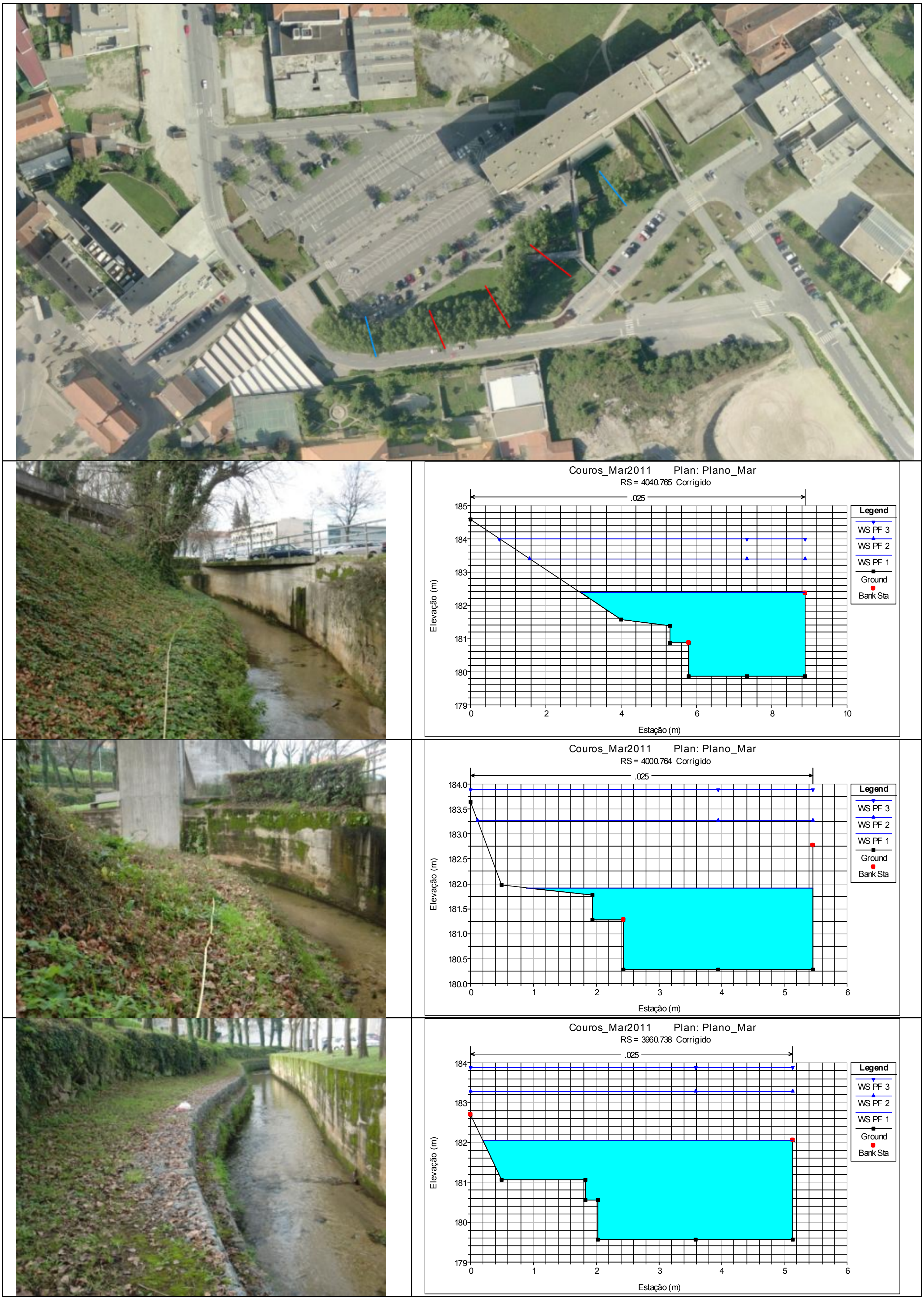

Figure 9 – Estimated river hydrodynamic conditions, for different recurrence time – Zone 2

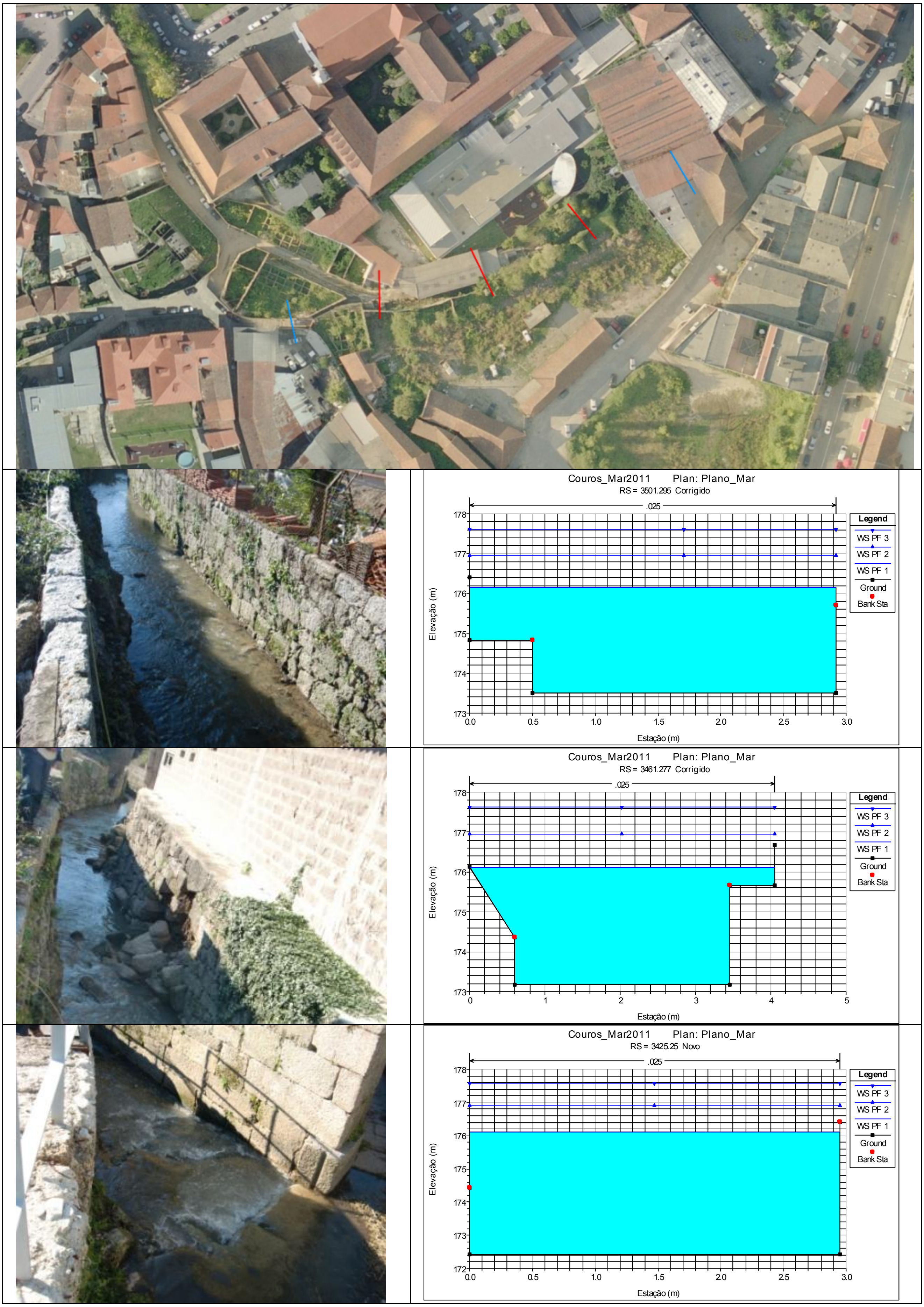

Figure 10 – Estimated river hydrodynamic conditions, for different recurrence time – Zone 3

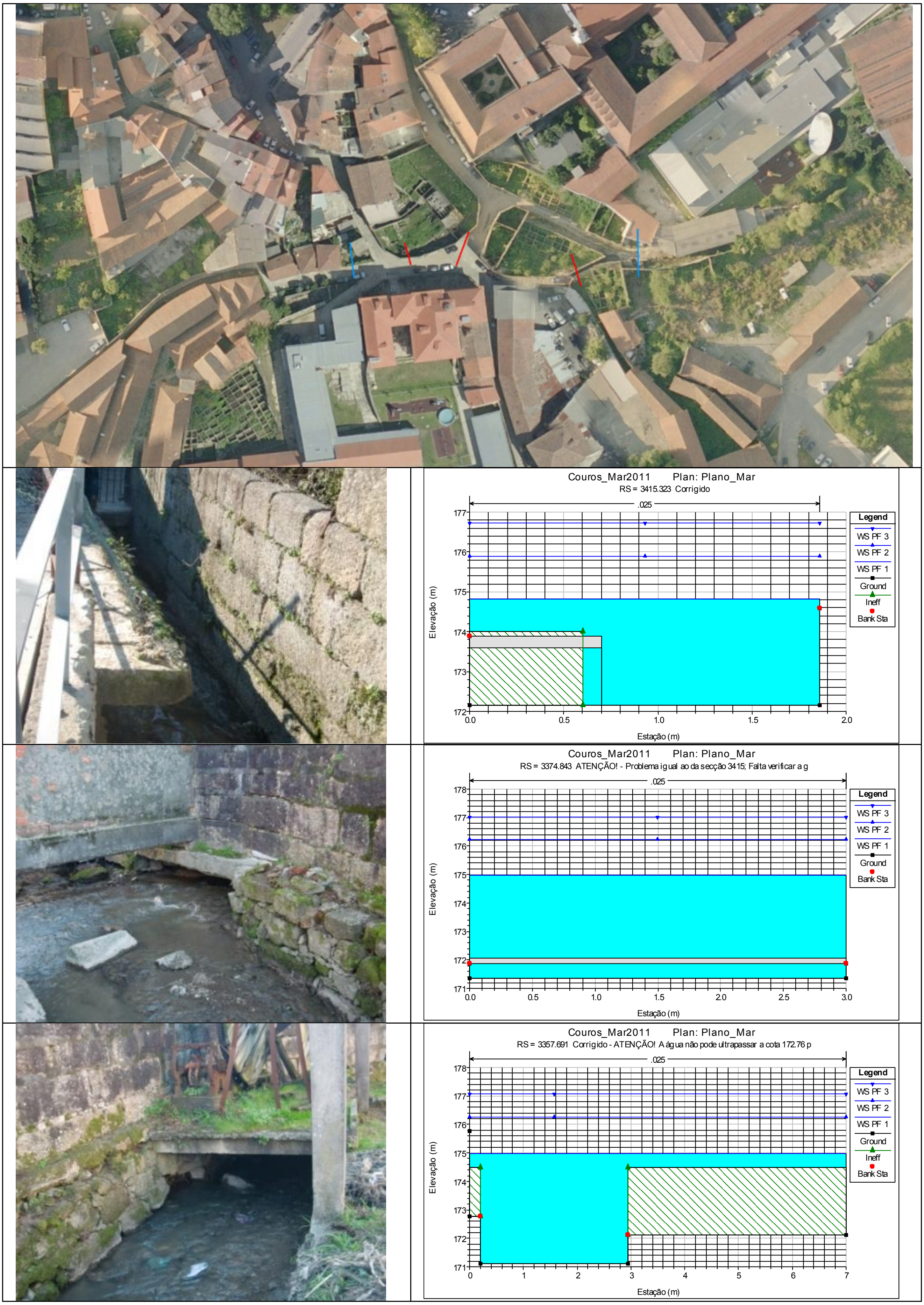

Figure 11 – Estimated river hydrodynamic conditions, for different recurrence time – Zone 4

3.3. Typification of management measures

The analytical and graphical outputs from the hydrodynamic model where analysed in order to identify the cross-sections that represented a limitations to the river hydrodynamics or high hazards.
After this analysis, in order to define the most adequate intervention measures, specific studies where done for the most important cases, simulating different solutions.
Figure 12 represents the comparison of the water level with the proposed corrective measure and the original conditions.

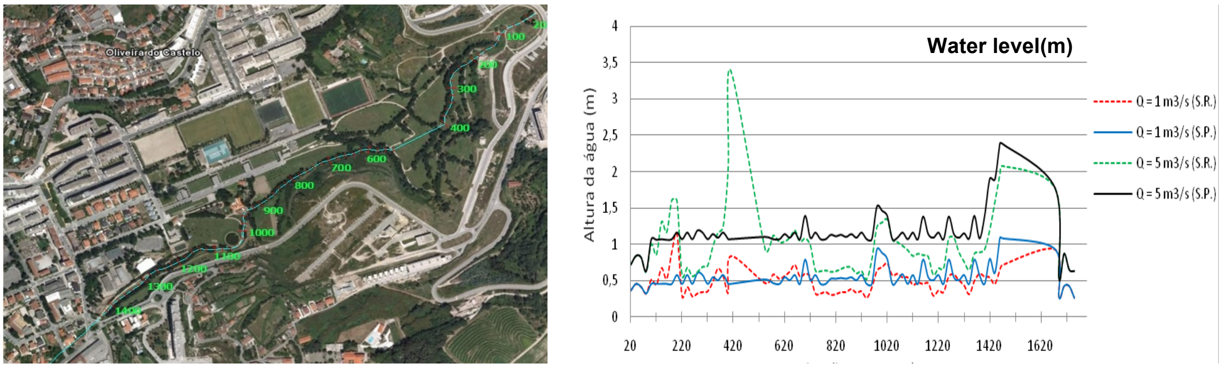

Figure 12 – Hydrodynamic simulation – existing conditions *vs*. proposed intervention measures.

Table 3 resumes the major proposed interventions that resulted from this integrated study, categorized on non-structural measures, structural measures and measures aiming to mitigate the negative flood effects.

Table 3 – Synthesis of the proposed intervention measures

Measures	Proposed interventions
Non-structural	• Cleaning of specific sites • Rehabilitation of degraded drainage elements • Creation of environmental education centres
Structural	• Correction of the longitudinal slope • Redefinition of existing cross-sections • By-pass • Erosion protection • Containment barriers
Mitigation of flood effects	• Waterproofing of existing walls • Structural enforcement of existing structures • Creation of urban and natural embodiment for regularization of peak flows

Figures 13, 14 and 15 depict some elucidative examples of some proposed physical interventions for each kind of measures.

Figure 13 – Example of non-structural

Figure 14 – Example of structural measures

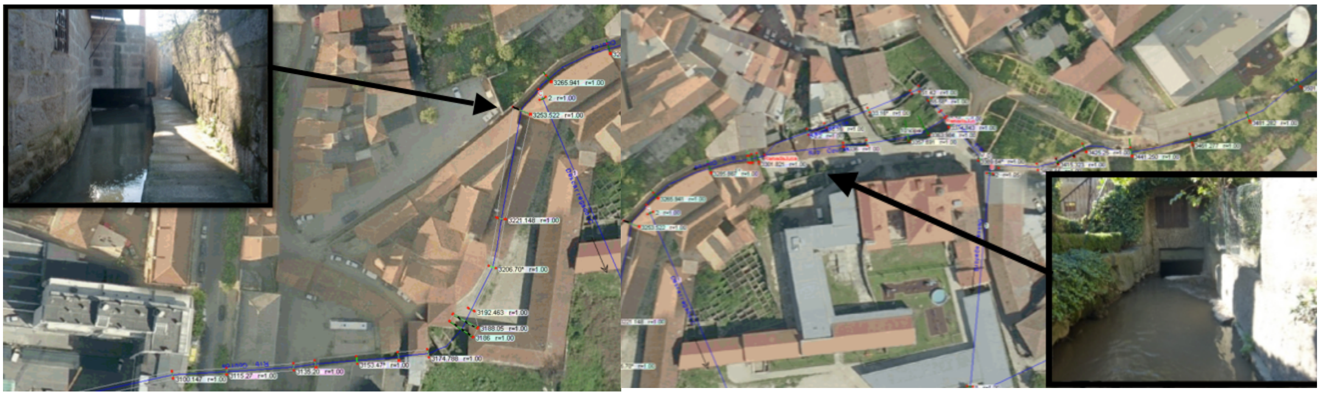

Figure 15 – Example of measures to mitigate the effect of floods

4. CONCLUSIONS

The rediscover of the rivers ecosystem importance to the life quality, especially in the urban environment, motivates the implementation of rehabilitation programs to mitigate the errors accumulated from many decades of unsustainable water resources management (Ramisio, 2010).

This rehabilitation, especially in the urban environment, presents itself as a demanding and complex mission due to the technical, political and economic issues involved.

This paper presents the results from the Couros creek case study, based on the use of hydrological and hydrodynamic models, in order to predict the runoff associated with high intensity precipitation and the estimation of related river hydrodynamics.

The flood flows where estimated, with different methodologies and for different recurrence times, and the hydrodynamic conditions at each cross-sections where computed.
Based on the hydrodynamic results, and the related risk, intervention measures where proposed and typified, allowing surgical interventions, from which can result a minimum investment and a global overall improvement in the hydraulic performance.
The implementation of this methodology in the management of urban watersheds can contribute for the establishment of effective measures for flood management in urban environment, changing the traditional reactive approach that neglected for decades the importance of this subject for the sustainability of cities.
Finally, due to the high cost of interventions in the urban environment, the use of these predictive models was proven to be and effective approach to provide an easy and feasible way to evaluate the existing conditions, identify associated risks, and to test intervention measures and estimate their effectiveness.
Furthermore, the developed models can also be used in the future, as a support tool for the management of this urban watershed, evaluating the effects of different precipitation patterns, or the impact of different urban occupations, allowing also to provide data to support different management measures for summer and winter conditions, and by this way contributing for a integrated flood management in the urban environment.

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REFERENCES

Correia, F.N., Saraiva, M.G., Silva, F.N., Ramos, I. (1999). Floodplain management in urban developing areas. Part I: Urban growth scenarios and land-use controls*. Water Resources Management*, **13** (1), pp. 1-21.

Feldman A (2000). HEC-HMS Hydrologic Modeling System - Technical Reference Manual. U.S. Army Corps of Engineers - Hydrologic Engineering Center. USA

Fleming M (2009). HEC-HMS Hydrologic Modeling System - Quick Start Guide (Version 3.4). U.S. Army Corps of Engineers - Hydrologic Engineering Center. USA

Ford D, Pingel N, DeVries J (2008). HEC-HMS Hydrologic Modeling System - Applications Guide. U.S. Army Corps of Engineers - Hydrologic Engineering Center. USA

Price, R.K., Vojinovic, Z. (2008). Urban flood disaster management. *Urban Water Journal,* **5** (3), pp. 259-276.

Ramisio, P.J. (2010). *An urban watershed regeneration project: The Costa/Couros river case study*.

Scharffenberg W, Fleming M (2009). HEC-HMS Hydrologic Modeling System - User's Manual (Version 3.4). U.S. Army Corps of Engineers - Hydrologic Engineering Center. USA.

Stalenberg, B., Han Vrijling, I. (2005). *Urban flood control in the Netherlands*. Proceedings of the Urban River Rehabilitation Conference, Dresden, Germany, pp. 1-6.