INTEGRATED METHODOLOGY FOR URBAN FLOOD RISK MITIGATION IN CITTANOVA, ITALY

Integrated Methodology for Urban Flood Risk Mitigation in Cittanova, Italy

Fabio Scionti, Ph.D.; Marcelo Gomes Miguez, D.Sc.; Giuseppe Barbaro, Ph.D.; Matheus Martins De Sousa, D.Sc.; Giandomenico Foti, Ph.D.; and Caterina Canale, Dr.Eng.

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Corresponding Author:	Giuseppe Barbaro Universita degli Studi Mediterranea di Reggio Calabria Reggio Calabria, ITALY
Corresponding Author E-Mail:	giuseppe.barbaro@unirc.it
Order of Authors:	Fabio Scionti
	Marcelo Gomes Miguez
	Giuseppe Barbaro
	Matheus Martins De Sousa
	Giandomenico Foti
	Caterina Canale
Suggested Reviewers:	Francesco Laio francesco.laio@polito.it Expert in in hydrology, water resources assessment, environmental modelling, and statistics
	Dragan Savic D.Savic@exeter.ac.uk Expert in development and application of decision-support systems, simulation and optimization models to improve understanding and provide solutions to water engineering problems, and management of urban water systems.
	Kevin E. Lansey lansey@email.arizona.edu Expert in water resources problems with emphasis on water distribution and systems analysis.

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An Integrated Methodology for urban flood risk mitigation: the case study of Cittanova (Italy)

Fabio Scionti[1]; Marcelo Gomes Miguez[2]; Giuseppe Barbaro[3]; Matheus Martins De Sousa[4]; Giandomenico Foti[5]; Caterina Canale[6]

[1] Ph.D., Mediterranea University, DICEAM Department, Via Graziella località Feo di Vito, 89122 Reggio Calabria (Italy). E-mail: fascipama@tiscali.it

[2] Associate Professor, Universidade Federal do Rio de Janeiro-UFRJ, Escola Politécnica-POLI & Civil Engeneering Program-PEC/COPPE Av. Athos da Silveira Ramos, 149, CT, I-206 Cidade Universitária Rio de Janeiro - RJ - Brasil. E-mail: marcelomiguez@poli.ufrj.br

[3] Associate Professor, Mediterranea University, DICEAM Department, Via Graziella località Feo di Vito, 89122 Reggio Calabria, Italy (corresponding author). E-mail: giuseppe.barbaro@unirc.it

[4] D.Sc.., AquaFluxus-Consultoria Ambiental em Recursos Hídricos Rua Paulo Emídio Barbosa, 485, 1A, CE-TIC, 106 Cidade Universitária - Parque Tecnológico da UFRJ Rio de Janeiro - RJ – Brasil. E-mail: matheus@aquafluxos.com.br

[5] Ph.D., Mediterranea University, DICEAM Department, Via Graziella località Feo di Vito, 89122 Reggio Calabria (Italy). E-mail: giandomenico.foti@unirc.it

[6] Dr.Eng., Mediterranea University, DICEAM Department, Via Graziella località Feo di Vito, 89122 Reggio Calabria (Italy). E-mail: kcanale@libero.it

Abstract

Urban growth usually aggravates flooding problems, disrupting city life and requiring engineering works to ensure safety conditions to lower lying city areas. Traditionally, canalisation works were the preferred choice for flood mitigation. However, increased city growth limits the effectiveness of this approach due to the lack of free spaces and local canalisation practices tend to transfer flooding downstream in a non-sustainable way. In the last eighty years, the town of Cittanova, in the province of Reggio Calabria (Italy), has been subjected to several flooding events related to river overflows or storm drain failures causing significant damages to mobility, households and even to public safety. This paper focuses on the Forio Creek, which is a tributary of the Vacale River and runs through the city. The study was carried out using mathematical tools within a conceptual framework with the aim of mapping floods to prevent damage to the city and avoid future losses, thus reducing risks. MODCEL was the hydrodynamic model used to map urban floods and to support the use of the Flood Risk Index (FRI), which is a quantitative multi-criteria tool relating flood levels to socio-economic losses. Both the MODCEL and the FRI were previously available, but their combined use and the final integrated analyses carried in this paper introduce a simple and quantifiable flood risk procedure to identify the present flood risks and to foresee future scenarios whilst supporting alternative design and prioritizing flood control choices. This framework was applied to Cittanova and validated by practical observations.

Keywords: Urban floods; Flood risk management; Planning and design; MODCEL; Multi-criteria index; Cittanova.

Introduction

A city's interaction with its natural watershed leads to typical urban structures acting hydraulically, complementing the drainage system functions, when this system fails in its primary task of safely conveying rainwaters. In this situation, for example, streets may act as channels, squares and buildings may act as undesired reservoirs, walls may play the role of weirs, and so on. The land shapes and varied structures of the built environment thus interact to diversify possible flow patterns (Miguez *et al*., 2011), increasing the complexity of the phenomenon Therefore, the inherent difficulties in predicting the dynamics of water flowing in complex urban environment systems lead to the use of mathematical models.

The development of models describing the rainfall-runoff relation over a catchment area has been the prime focus of hydrological research for many decades. Hydrodynamic models are also commonly used to route floods in watersheds. The answers provided by these models, however, are just the first step in the task of risk analysis.

Risk assessment involves two distinct components: the probability of an event; and the magnitude of consequences produced by that event (Mcanally *et al*., 2013). It is necessary to know what vulnerabilities arise from the urban system and what damages and losses may occur when the socio-economic elements of the system are exposed to hazard. These expected losses can be explained by:

(1) the exposure of the system elements,

(2) the susceptibility to suffer damage related to these exposed elements, and

(3) their ability to react and return to their reference state, which is associated with the concept of resilience (see for instance Andersson, 2006; Godschalk, 2003; Jha *et al.*, 2012; Prasad *et al*., 2009; Vale & Campanella, 2005; Wang & Blackmore, 2009; Miguez & Veról, 2016; Connelly *et al.*, 2016; Hossain *et al.*, 2017).

Rainfall is the natural source event that triggers a flood hazard. However, the flood characteristics and severity depend on how the watershed converts rainfall into runoff, and the consequent peak discharges conveyed. Flood control measures are therefore required to enhance the resilience of the urban environment to adapt to extreme rainfall events. In this context, the opportunities offered by the open spaces system and landscaping to re-interpret and update urban water systems are considered (Blackmore and Plant, 2008). Reducing flood risk is a task that may be accomplished by minimising the results of the rainfall-runoff transformation with on-source control measures, and redistributing the flood flows in space and time by using storage and infiltration structures to fulfil this aim (Burian and Edwards, 2002).Drainage design procedures are evolving from a single focus on the primary services that ensure public health, such as flood mitigation, towards a more integrated use of urban waters within the city itself (Walsh *et al*., 2016). These new trends in urban drainage design point to systemic solutions for flood control. Distributed measures are used to restore flow patterns in the watershed, simulating hydrologic conditions that happened prior to urbanisation.

The related literature shows the development of a set of concepts that stress the evolution of a more holistic approach (Fletcher *et al*., 2015). It is possible to mention some examples that highlight this conceptual evolution as follows: Low Impact Development-LID (US EPA, 2000; Ahiablame *et al*, 2012; Carlson *et al*., 2014; Ahiablame, 2016; Giacomoni & Joseph, 2017); Sustainable Urban Drainage Systems-SUDS (Woods-Ballard *et al*. 2007, Chocat *et al*., 2007, Barbosa *et al*., 2012; Miguez *et al*, 2012; Mguni *et al*., 2016); and Water Sensitive Cities (Argue, J.R., ed., 2004; Wong and Brown, 2008; Johnstone, 2011, Brown *et al*., 2016). In general, these approaches integrate urban water management needs with city infrastructure functions, and try to accommodate the urban waters within the urban landscape in a positive way, by increasing biodiversity, providing recreational uses and revitalizing both the built environment and the river corridors.

Rainwaters can additionally be harvested and offered as a valuable resource. Kim and Han (2007) for example, proposed the Rainfall-Storage-Drain (RSD) model to support the design of rainwater harvesting reservoirs integrated with the drainage system demands. These relatively small reservoirs distributed in the urban tissue and acting to lower the impact development on hydrology, were able to reduce peak discharges from 25% to 75% when compared to the original discharge values (Avila *et al*., 2016).

However, when investment capacity is limited, it is necessary to identify which are the most fragile areas in terms of negative flooding results, and where the protection offered will be more effective against socio-economic losses. This consideration points to system vulnerabilities. The association of multi-objective tools with hydrodynamic models can provide useful support to decision makers in choosing among feasible alternatives, with optimal cost-quality ratios (Barreto *et al*., 2010). Although different academic studies were already developed following this new trend, daily practices in urban water management show that most cities are still focused only on mitigating inundation.

In this work, a hydrodynamic model is combined with a quantitative multi-criteria flood risk assessment. The model of choice was MODCEL (Mascarenhas and Miguez., 2002; Mascarenhas *et al*., 2005; Miguez *et al*., 2011). This is a *quasi*-2D model, which is capable to represent city patterns and a complex flow net, using simple topographic data. On the other hand, the Flood Risk Index (FRI) uses a multi-criteria approach to target complex socioeconomic variables, also in a simple way, using the available information, which is easily gathered from census databases or from local interviews. The proposed framework tries to keep the flood and risk modelling simple and representative to allow for and favour a wide practical application. This approach was applied in a case study in the city of Cittanova, in the province of Reggio Calabria (Italy). This city is located in the Petrace river basin, near its tributaries Serra and Vacale. The city has been flooded several times in the recent past, and its main problem is related to the urban storm water management. Therefore, superficial flows play an important role in the city flooding. More specifically, the objectives drawn for this study may be summarised as follows:

- Draw hazard maps for the urban centre of Cittanova, identifying areas of high, medium and low probability of flooding.
- Track potential vulnerability maps, considering the possible damages to each flooded area (depending on number of inhabitants, strategic facilities, environmental goods, etc.).
- Propose and test innovative solutions to restore natural water cycle functions that were lost due to the urbanisation process. This approach also seeks to support a sustainable urban storm water management, integrated with land use control, and ultimately seeking recommendations for a safer future development.

The novelty of this approach does not fall in the individual tools used, but rather on the composite framework that is proposed. The joint combination of a hydrodynamic model, with a quantitative flood risk index to support flood control design and land use planning, involving the participation of the local population and public managers, provided a useful procedure to assess different risk scenarios, to evaluate alternative choices for flood control, and to properly define the landscape planning and land use control guidelines for Cittanova.

Mathematical Hydrodynamic Modelling

Many mathematical models tend to reduce the time-space interaction to a single result in a specific section (see, for instance, HEC-HMS - Scharffengerg and Fleming, 2010). Other models tend to concentrate on water systems management or on the behaviour of hydraulic structures, for example, SWMM (Rossman, 2015). Some approaches use one-dimensional (1D) relations focusing on the drainage network, others represent two-dimensional (2D) flood plain flows. However, the modelling of urban floods should be carried out with a mixed approach considering runoff generation, consequent superficial flows, storm drains and river flows. Flows in flood plains may occur in various directions and may be influenced by local structures. Therefore, a model capable of fulfilling the requisites for urban floods simulation should preferentially be able to perform rainfall-runoff transformation and to represent the watershed flow patterns in a distributed way, integrating surface flows with the storm drains network.

When the superficial flow is governed by urban patterns (interaction with buildings, walls and other structural obstacles), it is difficult to represent the flooding surface with traditional 2D models, because there are in fact several discontinuities in the resulting water surface. On the other hand, 1D models focusing on the drainage system behaviour tend to misrepresent the important superficial processes.

Abily *et al*. (2013) modelled a dense and complex industrial site, with above ground structures affecting drainage paths (similar to what happens in the urban landscape) and stressed that models based on 2D equations can face several problems, such as rapid changes in flow regime, small water depths and high gradients, vertical effects in runoff hydrodynamics, and free/ surcharged flow in drainage pipes, among others. On the other hand, Leandro *et al*. (2009) discussed the use of 1D/1D and 1D/2D models, observing that 2D models are computationally much more expensive than 1D models, resulting in much greater times of computation.

An alternative that combines the simplicity of 1D models and their low computational costs with the details of 2D representation of superficial flows, and also recognises the presence of above ground obstacles, refers to quasi-2D models. This paper uses a mathematical quasi-2D model to simulate urban floods. MODCEL (Mascarenhas and Miguez, 2002; Miguez *et al*., 2011) is based on the concept of flow cells (Zanobetti *et al*., 1970) integrating urban land surface and drainage net features. It represents the watershed through a set of homogeneous compartments which interact with each other creating a complex flow net connected by several different and relatively simple hydraulic laws. Although its conception is old, it remains quite useful when physical interpretation is required and an extensive and continuous 2D water surface is not observed in practice (see, for instance, Barbedo *et al*., 2015; Nardini *et al*., 2016). The choice of MODCEL to simulate floods in Cittanova is mainly supported by the following case characteristics:

- The main problem refers to storm drain overflows (and not to river overflows), and the observed flooded areas do not define a continuous flow surface–local obstacles are important and flows are driven by urban structures.
- It is important to model flood control alternatives using landscape features, not only focusing on the drainage net – there is little space for storm drain enlargements and a sustainable approach is required, with on-source control measures and multifunctional landscapes capable of storing part of the floods.

The MODCEL Model

MODCEL was built to model the urban surface using a set of homogeneous compartments called flow cells, integrating the catchment area. The compartments interact through cell links representing different hydraulic laws. Each cell also transforms rainfall into run-off using the rational method in a distributed way, due to the spatial coverage provided by the interconnected cells. The mesh of cells composes a hydrodynamic looped model that links surface flow, channel flow and storm drain flow. A vertical link communicates the superficial layer, corresponding to free surface channels and flooded areas, with the underground layer, related to free surface or surcharged flow in storm drains. Figure 1 illustrates the MODCEL schematic representation. A pre-defined set of cell types is available as follows:

- River/channel cells: represent river reaches or open channel reaches, with simple or compound rectangular cross sections. Note that it is a reasonable approach when considering urban drainage.
- Storm drain cells: act as complements to the drainage net, representing underground pipes.
- Urbanized superficial cells: represent free surface flow over urban floodplains – the flow itself occurs through the streets, while open spaces, squares and even buildings work as storage areas. This cell present compound bottom levels, as shown in figure 2.

- Natural superficial cells: they preserve a natural pattern, without buildings. They may have a storage area minor than that of total superficial area (where rainfall occurs), excluding natural elevations from the mass balance.
- Reservoir cells: used to simulate water storage in a temporary pond or reservoir, using a curve for the elevation versus surface area.

The hydrodynamic model uses the conservation law and a set of hydraulic relations. A detailed deduction of the original flow equations may be found on Cunge et.al (1980). The latest version of MODCEL may be found in Miguez *et al*. (2011). The hydraulic links used in this study are listed below:

- River/Channel link – represented by the Saint-Venant dynamic equation.
- Surface flow link – represented by the Saint-Venant dynamic equation without inertia terms.
- Storm drain link – open channel flow represented either by the Saint Venant equation, if free flow occurs, or by the Bernoulli equation, if surcharged flow occurs. The model manages transitions between these two states, checking at each time step.
- Gutter inlet link – This link promotes the interface between surface flow and storm drain cells. When not drowned, this link acts as a weir; otherwise, it acts as an orifice.
- Broad crested weir link.
- Orifice link.
- Reservoir link – This link combines an orifice, as the outlet discharge of a reservoir, with a weir, which can be activated depending on reservoir water levels.

Flood Risk Index (FRI)

The concept of flood risk mitigation (Balica *et al*., 2009; Woodward *et al*., 2013) has gained importance in recent decades. However, flood risk assessments face some difficulties due to the subjective nature of its evaluation and due to the large number of factors that interfere with risk. Zonensein (2008) proposed a quantitative multi-criteria index, named Flood Risk Index (FRI), to address these difficulties. This index is able to conjugate sub-indices related both to flood characteristics and to flood consequences over the city's socioeconomic system. FRI was spatialized and conjugated with MODCEL representation, so that each cell was associated with a FRI normalized value ranging from 0 to 100. The indicators selected to represent flood properties include:

- the maximum water depth, which directly accounts for losses in the buildings, related to both structure and contents,
- the velocity factor, resulting from the product of the water depth by the flow velocity and accounting for the dragging forces that can carry people, vehicles or even buildings, and
- the duration factor, associated with the permanence of the water level above pre-defined thresholds, representing water levels affecting people, traffic and buildings. The time of contact with inundation waters may aggravate losses and affect public health.

In addition, indicators for household density, income per capita, traffic hierarchy and inadequate sanitation represent, respectively, the estimated flood consequences over people, structures and their contents, mobility, and public health. A weighted product of two weighted summations, as seen in Equation 1, comprises the formulation of FRI. In order to have the FRI scale ranging from 0 to 100, all of the indicators were normalised. For example, water depths were divided by a reference value which was considered to lead to a total loss for the building contents. The household density was also divided by a reference density, considering the maximum effect in the watershed. In general, a percent reasoning was used.

$$FRI = FP^{q_{FP}} \cdot C^{q_C} \quad (1)$$

Where:

- FRI: Flood Risk Index, ranging from 0 (lowest risk) to 100 (highest risk).
- FP: sub-index representing a weighted summation of the flood properties for a design rainfall with a certain return period.

- C: sub-index representing a weighted summation of the consequences of flood.
- q_{FP}, q_C: weights corresponding to flood properties and consequences, respectively.

Note that if either sub-index is null or negligible, there must be no risk. On the other hand, the presence of at least one non-zero indicator in each sub-index results in non-negligible risk. Bringing together the views of the institutions and of the managerial class that is responsible for flood risk management in Cittanova, has guided the weights definition. The public managers and the municipality staff also helped in the discussion that defined the classes of risk, as briefly defined below:

- FRI value between 0 and 25: tolerable risk;
- FRI value between 25 and 50; manageable risk;
- FRI value between 50 and 75: medium to high risk – demands intervention;
- FRI value between 75 and 100: high to very high risk – high priority; demands intervention.

Methodology

Using the tools described above and organizing a set of procedures to join flood control and risk management, the following methodology was proposed and used in this work:

- The watershed was considered as the basic unit for planning and design purposes.
- A detailed conceptual diagnosis for the main watershed flooding problems was produced.
- A spatial analysis provided a broad view of conflicts and potentialities in the considered territory – it is important to highlight from the beginning what you intend to preserve, recover or allow.
- Flood hazard maps were produced with MODCEL.
- Natural limits were recognised from the modelling results and the previous analysis.
- The main socioeconomic variables were mapped.
- Risk maps were produced combining FRI with MODCEL.

- Design alternatives for reducing risks were tested to better shape urban needs according to the natural limits imposed.

Case study

Study Area and river basin characteristics

The study area consists mainly of the urban area of Cittanova, in the province of Reggio Calabria – Italy (Figure 3). The city is 400 m above mean sea level and 65% of its land is flat. It is located on the plain of Gioia Tauro, in the foot of the Aspromonte Mountains. The Vacale and Serra rivers are the major watercourses in the city area. Both rivers belong to Petrace river basin. However, Forio Creek, which is a tributary of Vacale, is the main river responsible for the Cittanova flooding. Its drainage area covers the centre of the city (2 km^2), and the hill east of the city (1.2 km^2), to reach 3.2 km^2. Forio Creek has torrential characteristics, with high bottom slopes and a short time of concentration. A concentration time of 26 minutes was calculated according to the route taken by Forio from its upstream stretches until it reaches the local railway, exiting the city centre. Concrete walls or stone works appear in great parts of the riverbanks, except for the centre of Cittanova, where there are no dykes. The increasing urbanisation process and the consequent canalisation of the watercourse forced the creek to run underground, through 300m of storm drains, in a situation that favours drainage failure and the likelihood of flood hazards (Barbaro *et al*., 2015).

In 1936, an extraordinary rainfall event of 260 mm devastated the city causing landslides and flooding. City services collapsed. Another great flood occurred in October 1951, producing one death and the collapse of the railway bridge that connects Cittanova and San Mauro. In the following decades the city was hit by several other flood events, but the worst rainfall occurred in November 2011. During that event, 366.4 mm of rainfall disrupted the city. The main roads and the connection with rural areas were unusable. Rainwaters invaded schools, shops and public offices. It was a great disaster, including loss of life. Today, people remember the tragic event with fear and a great feeling of insecurity.

A detailed survey of urban area of Cittanova, aiming to identify the characteristics of the territory and the geometry of the storm drains system (manholes, inlet grates etc.), was carried out before starting the mathematical modelling. In parallel to this field activity, a questionnaire prepared by the authors was distributed to a sample of inhabitants. It was structured in three parts, namely: the description of the territory, the description of the buildings and the description of the goods owned by the inhabitants residing there. This questionnaire was used to reliably estimate the economic losses due to the floods.

Hydrological analysis

The watershed physical characteristics, such as topography, urbanisation patterns and land use, as well as the storm drain system characteristics, were used in the hydrologic studies.

The hydrological input data was produced using rainfall intensity-duration-frequency curves for different return periods (50, 200 and 500 years). The return period of 50 years was taken as reference for the current studies and the rainfall intensity for this return period may be obtained by Equation 2.

$$h_t = 77.088.t^{0.4025} \tag{2}$$

Where:

- h_t: total precipitation in mm.
- t: rainfall duration in hours.

The design rainfall was built considering incremental rainfall blocks of ten minutes each. The duration of ten minutes was considered as the minimal critical time step to evaluate minor drainage behaviour. That is, when considering blocks of ten minutes, the maximum intensity obtained for this duration is the critical rainfall to curbs and inlets in the local scale. On the other hand, completing the total design hyetograph until reaching the concentration time of 30 minutes, the watershed is also subjected to its critical rainfall event in terms of total volume. Therefore, the total rainfall and the intensity were calculated every 10 minutes, up to 30 minutes, as presented in Table 1. Note that the second block is the result of the total rainfall for 20 minutes minus the total rainfall for the first 10 minutes. Similarly, the third block refers to the total rainfall of 30 minutes minus the total rainfall of 20 minutes. This approach allowed to simulate the critical rainfall intensity in the watershed scale (represented by the average value of the three blocks), as well as the critical rainfall intensity in the local scale (given by the rainfall intensity of the first block). It is important to remind that the resulting hydraulic effects on the watershed responses depend not only on the volume of the hydrograph, but also on its shape. This complementary aspect, however, was not explored in this research.

Hydrodynamic analysis

MODCEL was used to model the urban centre of the city as well as the eastern hills, which directly contribute to the city main channel of the Forio Creek. The final model has 9 open or covered channel cells, representing the main stream crossing the city. There are 36 other cells representing minor drainage storm drains and, in addition to these, the model has 132 surface cells. The final division of the basin into cells has been written as a topological scheme, which defines the relative positions between each two cells and defines the hydraulic relations linking these cells. Figure 4 shows the watershed subdivision into cells. The model calibration was held in a non-conventional way. There were no formal measures for the observed flooding over streets and consequent superficial flows. Therefore, considering the rainfall design as the critical reference event to proceed with the calibration process, the model was adjusted to represent the flooded areas and the relative severity of the flooding in these areas, accordingly to the information given by the municipality staff and population memory of flood records. This support was important to raise the model reliability.

Simulation scenarios

We proposed a set of simulation scenarios in the design phase, in order to assess the different possibilities and to check which measures could enhance the final solution in terms of risk reduction:

- ALT.0 – BASELINE: represents the reference alternative to be compared with all the others. The "ALT.0" simulation considered the current situation of Cittanova, without carrying out any works. This may be a possible choice when protection works are too expensive and the socioeconomic losses do not justify the investment.
- ALT.1 – DETENTION PONDS: in this alternative, five squares and green areas of Cittanova were converted into detention basins, in a multifunctional landscape approach (that is, the flood storage function was added to original functions). The location of these areas is shown in Figure 5.
- ALT.2 – ON-SITE DETENTION TANKS: this alternative considers the construction of on-site detention tanks with 3.6 m^3 per each 100 m^2 of rooftops
- ALT.3 - ON-SITE DETENTION TANKS: this alternative considers the construction of on-site detention tanks with 4.5 m^3 per each 100 m^2 of rooftops.
- ALT.4 – This alternative joins ALT.1+ALT.2.
- ALT.5 – OPENING OF FORIO CREEK: this alternative opens a reach of 300 m of the underground watercourse running through Cittanova.
- ALT.6 – This alternative assumes ALT.1 + ALT.2 + ALT.5.
- ALT.7 – DAM CONSTRUCTION IN MONTE FOSSO: this alternative simulates a dam in the Forio Creek, upstream of the town of Cittanova, with the objective of damping its floods.
- ALT.8 – This alternative assumes ALT.1 + ALT.3 + ALT.5.

Appendix 1 shows the results obtained in the format of flood maps.

Mapping flood risk

The main stakeholders involved in this case study set the final FRI indicators and their weights. Therefore, regarding the flood properties only, the values of water depth and velocity factor have been used and normalised, while regarding the consequences, the population, importance of roads, economic activities and structures of particular interest, including cultural or archaeological heritage and environmental assets, have been considered. Thus, the following risk maps (Figure 6) were obtained for the following selected alternatives: ALT.0; ALT.2; ALT.7 and ALT.8.

This study allowed us to identify the most fragile and risky areas of the city of Cittanova and to understand how the main physical processes act, as well as their relative importance. In addition, the different alternatives allowed the evaluation of different possibilities of reducing flood risks at different levels. This study is able to support the decision-making regarding social and economic drivers.

Indeed, in this case, important points are highlighted as follows:

- The current situation shows the inefficiency of the drainage system to deal with floods.
- By observing the results obtained with the single alternatives (using just one type of measure at a time) acting in a distributed way over the watershed (ALT.1, ALT.2 and ALT.3) and that obtained with the laminating dam (ALT.7), it was possible to say that urban runoff plays a central role in the city’s flooding. The dam controlled water levels in the river, but the flood map still showed significant areas under water. On the other side, when using larger on-site detention tanks (4.5 m^3 per each 100 m^2 of rooftops - ALT.3), there was a significant improvement in the results, with lower water levels in fewer restricted areas.
- Comparing ALT.7 (dam) with ALT.5 (opening of 300 m of Forio Creek, which is currently closed underground), we perceive that both actions work by mainly reducing floods in the river.
- The best result in terms of flood control comes from a combined set of actions, using green areas and public squares as detention ponds and detentions tanks (ALT.4), on source control,

and a partial urban river restoration approach, by re-opening a reach of 300m of Forio Creek (ALT.8).

- In terms of reducing risks, however, ALT.2, ALT.4 and ALT.8 had similar results.

In the end, there was a strong correlation between the problems highlighted in the hydraulic modelling and the ones identified by the city population through the questionnaires previously described. This result showed how the involvement of the population is valuable in improving the model reliability in the calibration phase.

Conclusions

The process of urbanisation has changed the natural landscape and increased flooding problems in the city of Cittanova, in Reggio Calabria (Italy). In fact, due to the urbanisation process of the past recent years and the consequent soil sealing, it has become more difficult to manage floods and more valuable assets are now exposed to risks.

Using the support of mathematical models, and by combining a hydrodynamic model and a quantitative multi-criteria risk index (MODCEL + FRI), it was possible to assess flood hazards and urban vulnerabilities, and produce a huge amount of results which highlighted various options for urban risk mitigation. This framework produced a decision support tool that allowed the evaluation, identification and comparison of critical areas in terms of flood risks and flood levels. Subsequent to this, it was possible to evaluate flood risk scenarios associated with different flood control alternatives, and to support the strategic planning for flood risk mitigation for the city of Cittanova, which led to a combined perspective which considered both the hazard and its associated consequences.

This combined methodology can be used as a decision supporting tool to allow a quantitative comparison and ranking of critical areas. It is also useful in defining the hierarchy of different possible interventions and in the justification of public investment. It is interesting to note that it is also possible to compare quantitatively different scenarios for the same region, estimating the impacts of future urban development, and thus providing planning recommendations, considering the population safety as a primary objective.

In the case examined, the current drainage system is inefficient in managing flooding in the city of Cittanova. The alternative solution concerning the construction of storage ponds in green areas is very useful to achieve the objective of safeguarding the buildings, roads, railways and especially public safety, with relatively low associated costs. This alternative solution can be further complemented by two other actions that improve flood risk control:

(1) the opening of Forio Creek, bringing it back into the urban landscape, and offering it more space to avoid the backwater effects on the storm drains; and

(2) the individual adaptation of the existing buildings by adding a detention tank to control the runoff generated by rooftops.

This second action also shows the positive aspect of actively involving the population in the proposed solution, which is a key element in upholding any solution over time. On the other hand, these complementary actions imply a greater public investment in re-opening Forio Creek and greater private investments in adapting the city housing. A strategy to implement this alternative should be developed, matching municipal and private investment capacity. This is the proposed next step to complement the research – to develop and introduce this framework – it will be important to provide a quantitative measure to hierarchise investments, comparing the costs and benefits of each proposition, and verifying if the chosen alternative is feasible.

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Captions

Figure 1: schematic representation of a portion of a watershed divided into cells, showing different interactions and flow patterns modelled by MODCEL.

Figure 2: pre-defined urban pattern introduced in a MODCEL simulation.

Figure 3: the town of Cittanova and its urban tissue appear on the left; Vacale watershed, with Forio passing through the centre of the city, appears on the right.

Figure 4: aerial view and plan cell division.

Figure 5: location of the detention ponds.

Figure 6: Flood risk maps for alternatives ALT.0, ALT.2, ALT.7 and ALT.8.

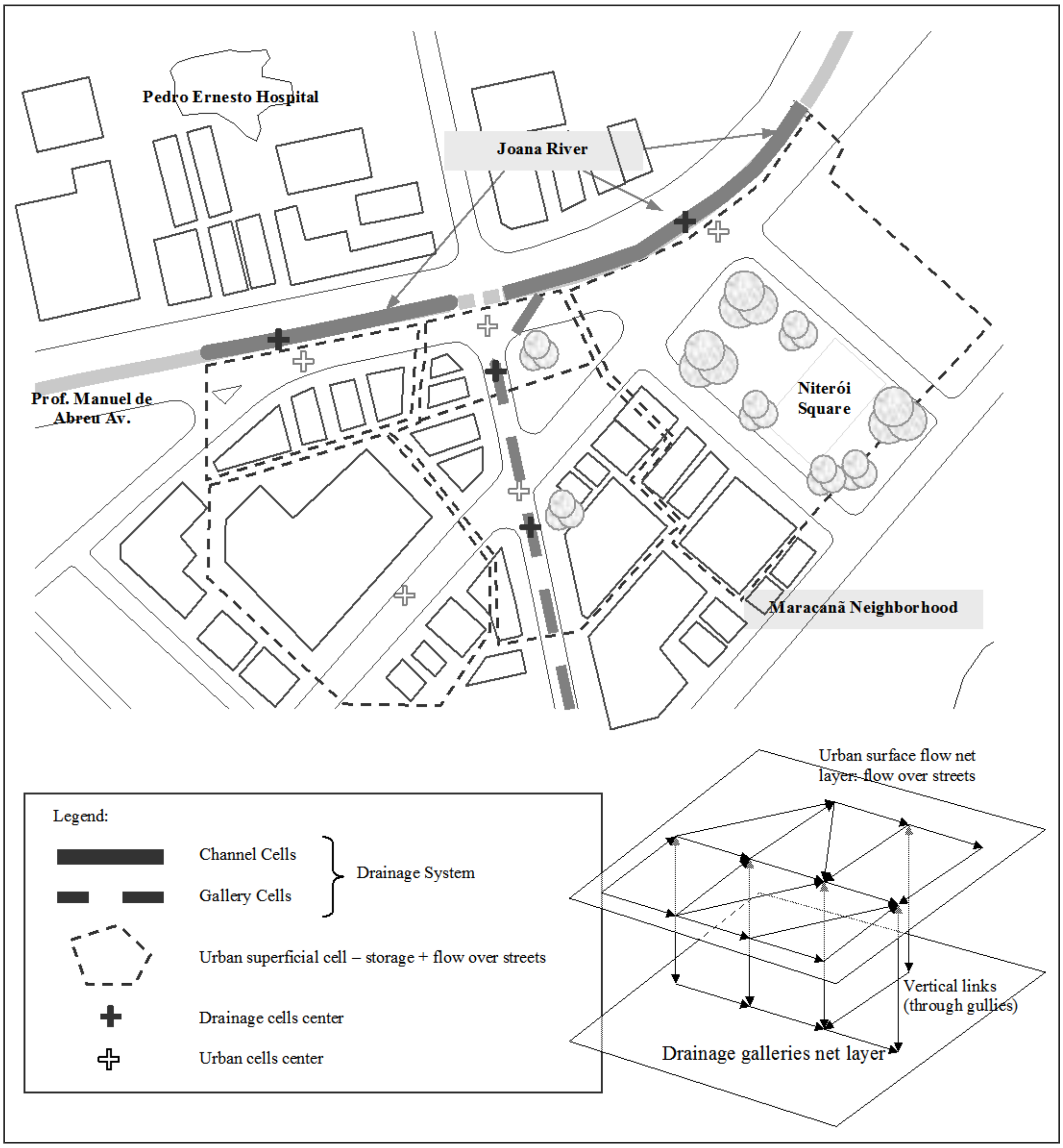
Table 1: design rainfall.

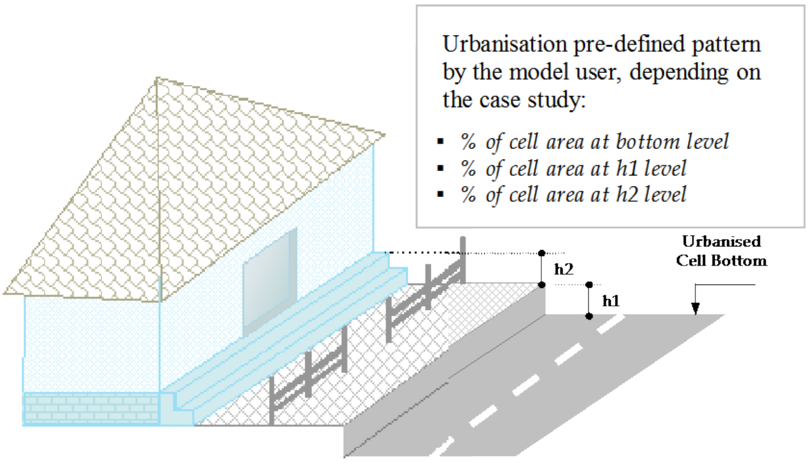
Appendix 1: flood maps results for the simulated alternatives using a return period of 50 years.

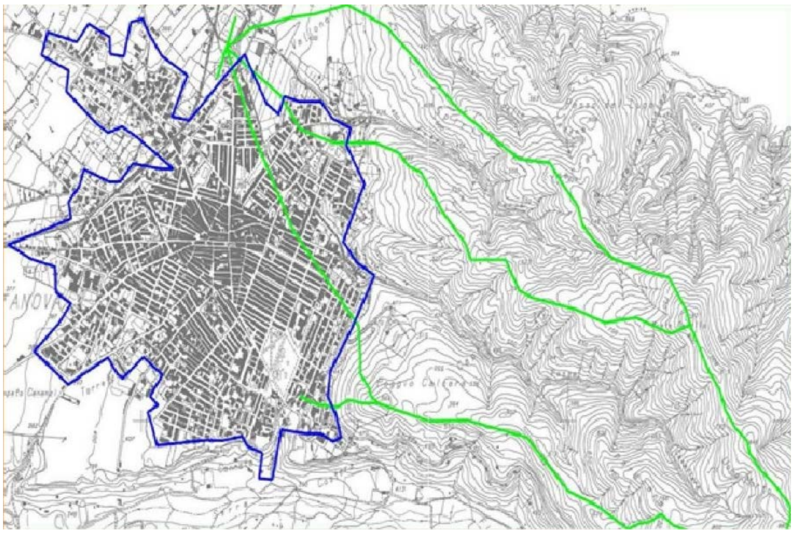
Tables

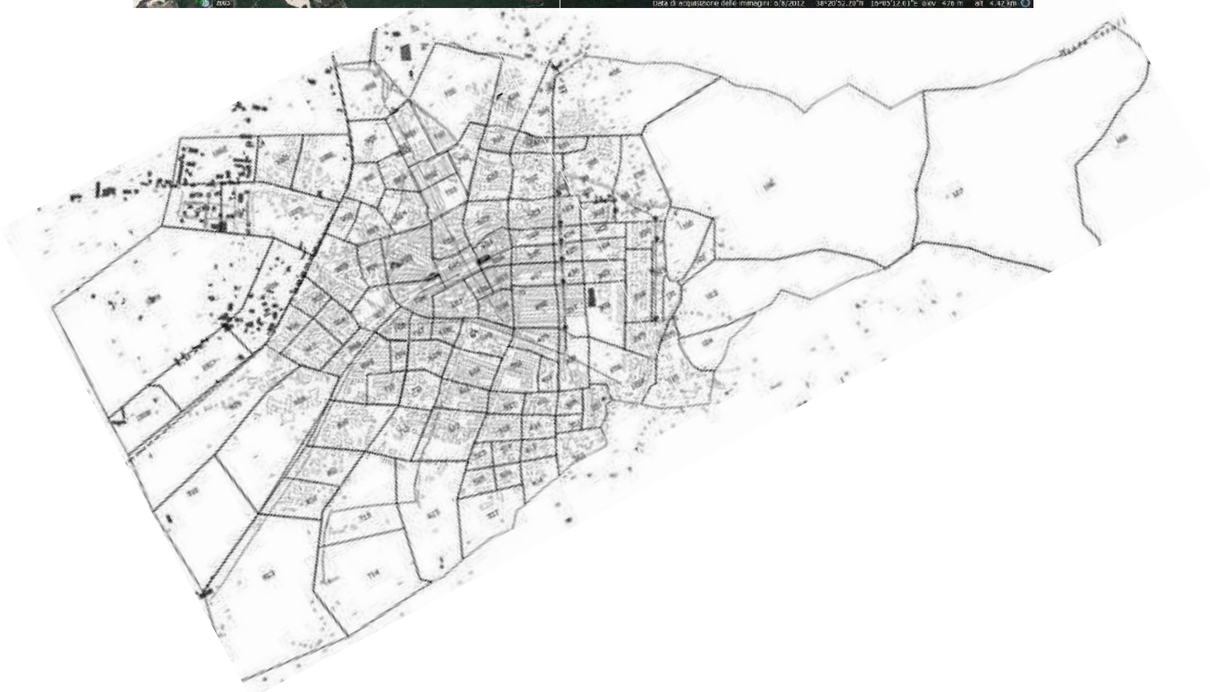
Table 1: design rainfall.

Time [minutes]	Total rainfall [mm]	Average intensity [mm/h]	Incremental rainfall in 10 minute time step [mm]
10	37.8	226.8	37.8
20	49.9	149.7	12.1
30	58.8	117.6	8.9

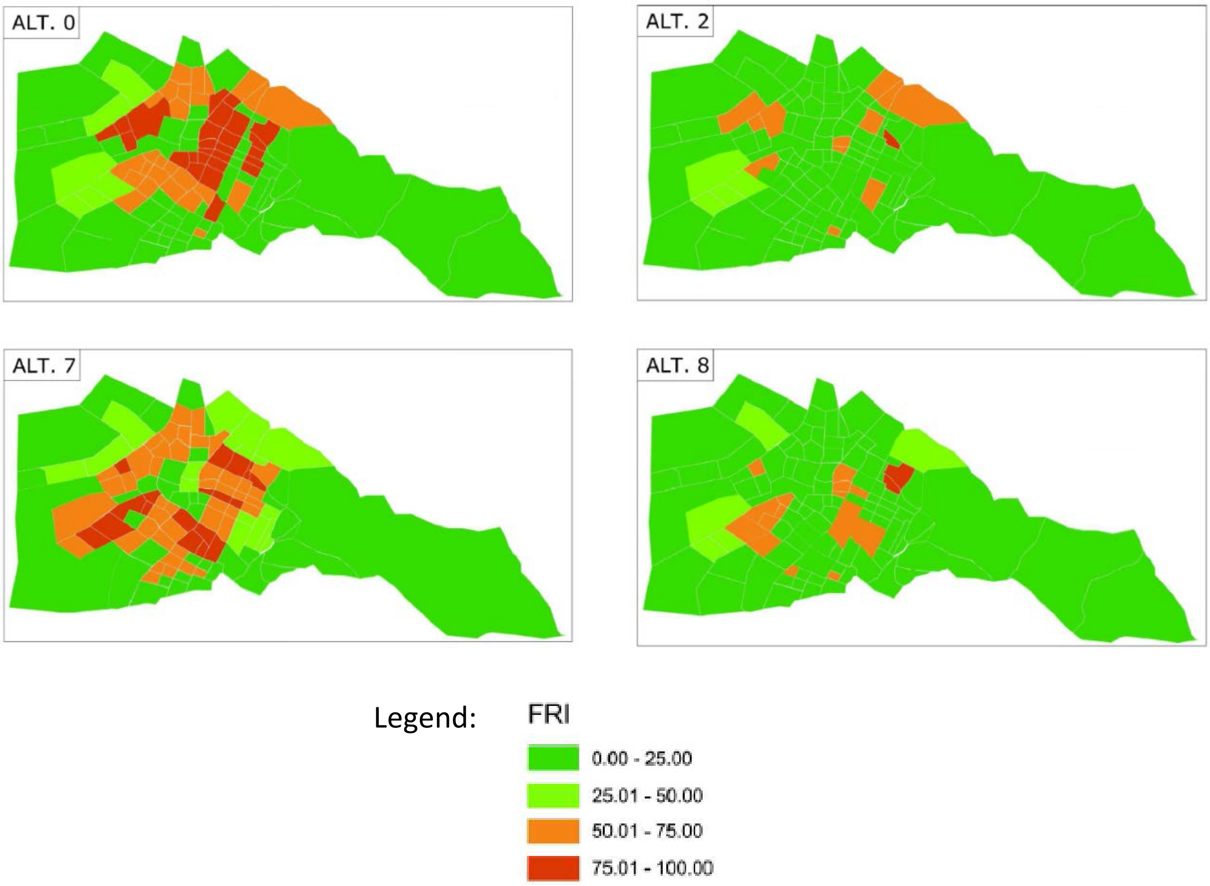

Pedro Ernesto Hospital
Joana River
Prof. Manuel de Abreu Av.
Niterói Square
Maracanã Neighborhood
Legend:
Channel Cells
Gallery Cells
Drainage System
Urban superficial cell – storage + flow over streets
Drainage cells center
Urban cells center
Urban surface flow net layer: flow over streets
Vertical links (through gullies)
Drainage galleries net layer


Urbanisation pre-defined pattern by the model user, depending on the case study:
% of cell area at bottom level
% of cell area at h1 level
% of cell area at h2 level
Urbanised Cell Bottom
h2
h1





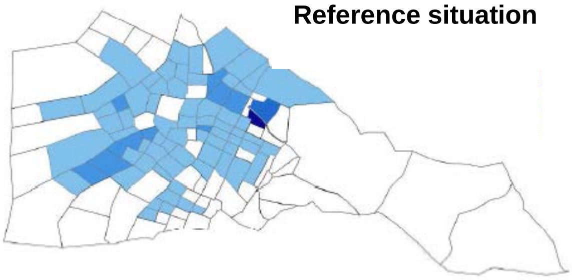

Detail of a detention pond in a square
© 2014 Google
Image © 2014 DigitalGlobe
Google earth
Data das imagens: 6/7/2012 lat 38.355492° lon 16.079758° elev 404 m altitude do ponto de visão 2.70 km


ALT. 0
ALT. 2
ALT. 7
ALT. 8
Legend:
FRI
0.00 - 25.00
25.01 - 50.00
50.01 - 75.00
75.01 - 100.00

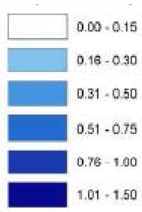
Cittanova:

Reference situation

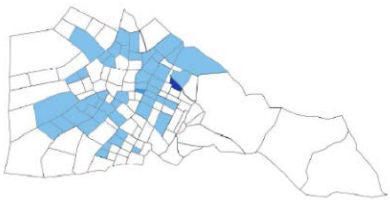
ALT.0



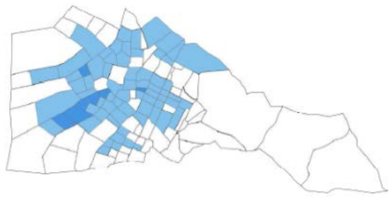
Water depths:



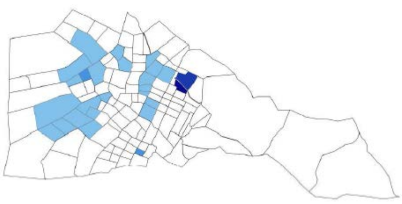
ALT.1



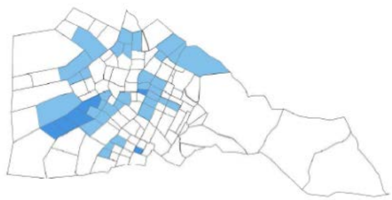
ALT.5



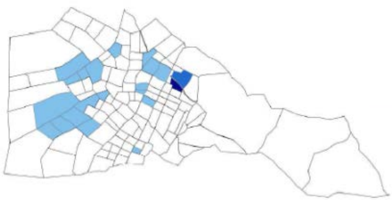
ALT.2



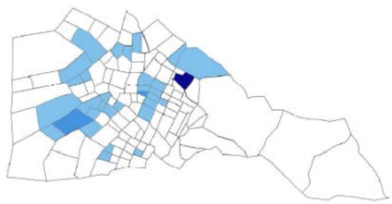
ALT.6



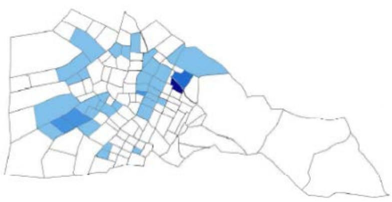
ALT.3



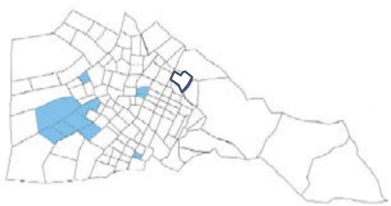
ALT.7



ALT.4



ALT.8



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Author(s) – **Names, postal addresses, and e-mail addresses of all authors**

Fabio Scionti. Via Graziella località Feo di Vito, 89122 Reggio Calabria (Italy). fascipama@tiscali.it

Marcelo Gomes Miguez. Av. Athos da Silveira Ramos, 149, CT, I-206 Cidade Universitária Rio de Janeiro (Brasil). marcelomiguez@poli.ufrj.br

Giuseppe Barbaro. Via Graziella località Feo di Vito, 89122 Reggio Calabria (Italy). giuseppe.barbaro@unirc.it

Matheus Martins De Sousa. Rua Paulo Emidio Barbosa, 485, 1A, CE TIC, 106 Cidade Universitária - Parque Tecnologico da UFRJ Rio de Janeiro (Brasil). matheus@aquafluxus.com.br

Giandomenico Foti. Via Graziella località Feo di Vito, 89122 Reggio Calabria (Italy). giandomenico.fo

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"An Integrated Methodology for urban flood risk mitigation: the case study of Cittanova (Italy)"

Authors: Fabio Scionti; Marcelo Gomes Miguez; Giuseppe Barbaro; Matheus Martins De Sousa; Giandomenico Foti; Caterina Canale

Author's Responses to EDITOR:

Editor Comments:

Editor: Based on the reviews, it is recommended that the author should revise and resubmit the manuscript. The author is encouraged to review the past JWRM publications on this subject and to take the reviewer comments into consideration in improving the paper

Author`s response: We revised the past JWRM publications and we found it very useful, improving our literature review. Four (4) new references from the JWRM were added to the references list, in a total of eight (8) citations, as seen below:

Avila H., Avila L. and Sisa A. (2016) "Dispersed Storage as Stormwater Runoff Control in Consolidated Urban Watersheds with Flash Flood Risk" **Journal of Water Resources Planning and Management**, 142 (12)

Barreto W., Vojinovic Z., Price R. and Solomatine D. (2010). "Multiobjective Evolutionary Approach to Rehabilitation of Urban Drainage Systems" **Journal of Water Resources Planning and Management**, 136 (5).

Blackmore J. and Plant R. (2008). "Risk and Resilience to Enhance Sustainability with Application to Urban Water Systems ", Journal of Water Resources Planning and Management, 134 (3).

Carlson, C., Barreteau, O., Kirshen, P., & Foltz, K. (2014). Storm water management as a public good provision problem: survey to understand perspectives of low-impact development for urban storm water management practices under climate change. **Journal of Water Resources Planning and Management**, 141(6), 04014080.

Giacomoni, M. H., & Joseph, J. (2017). Multi-Objective Evolutionary Optimization and Monte Carlo Simulation for Placement of Low Impact Development in the Catchment Scale. **Journal of Water Resources Planning and Management**, 143(9), 04017053.

Mcanally, W.H., Wallen C.M., Sanborn, S.C. and Maak E.C. (2013).Composite risk assessment for the Sacramento–San Joaquin delta levee system. **Journal of Water Resources Planning and Management**, v. 140, n. 5, p. 734-743.

Wang, C. H., & Blackmore, J. M. (2009). Resilience concepts for water resource systems. **Journal of Water Resources Planning and Management**, 135(6), 528-536.

Woodward, M., Gouldby, B., Kapelan, Z., & Hames, D. (2013). Multiobjective optimization for improved management of flood risk. **Journal of Water Resources Planning and Management**, 140(2), 201-215.

Reviewers' comments:

Editor: I apologize for the delay with this review. A number of reviewers were either unresponsive or unable to complete their reviews. However, I have checked authors' responses to previous review comments and have found them to be satisfactory, with the possible exception of one remaining concern, noted by Reviewer #1 below.

Author`s response: Reviewer #1 concern will be answered in the sequence.

I also note that the paper is over-length. Technical papers should be 10,000 word-equivalents or less, including the word-equivalent space of tables and figures For example, a printed journal page is about 1,200 words, and thus a large figure or table using 1/2 page would be 600 word-equivalents. Alternatively, double-spaced manuscripts meeting this requirement are usually about 30-35 pages (including tables and figures), and this manuscript exceeds 40 pages, including figures and tables. Authors are asked to consider omitting some detailed results, or else including them as Supplemental Information (especially figures that have been designated as part of an Appendix). Also, Figures 7-10 might be combined as one or two multi-panel figures.

Author`s response: the text as a whole was thoroughly revised and reduced in almost 10%. We apologize by the length of the final paper, but it is important to note that we started with a manuscript matching the rules, but its size increased to fulfil the Reviewers comments along the revision process. We also eliminated Figure 4 and we combined figures 7, 8, 9 and 10 in only one figure. All the main figures (except for the appendix) are now occupying about 3 pages. The text from the introduction to the conclusion has now 4948 words, even considering that we introduced 4 new references. The total manuscript length, also considering title, author’s names, abstract and references has 7008 words. In terms of number of pages, the manuscript presents about 30 pages, double-spaced, including all figures and tables.

Reviewer #1: The authors answered satisfactorily to two of the three points addressed in the previous reviews.

About the third point, the one about the need of performing several hydraulic analysis in order to predict the hydraulic risk for fixed time return periods in all the basin area, we must observe the following:

The criterion used by the authors to design the input hydrograph guarantees that the most dangerous event, corresponding to a time period of 10 minutes, is attained only for the smaller sub-basins with smaller concentration time. For the closure sections of larger sub-basins and of the entire basin, it is well-known that hydraulic effect of the input hydrograph depends not only by the volume of the hydrograph, but also by its shape. According to the proposed procedure the shape of the input hydrograph (assuming very small time intervals with constant rain intensity) has an initial discontinuity and then asymptotically decreases. Is this a dangerous shape? There is some reference in literature? The authors should address this point before publication.

Author`s response: We understood the Reviewer #1 concerns. Our text was revised to address his comment and it now reads as:

"The design rainfall was built considering incremental rainfall blocks of ten minutes each. The duration of ten minutes was considered as the minimal critical time step to evaluate minor drainage behaviour. That is, when considering blocks of ten minutes, the maximum intensity obtained for this duration is the critical rainfall to curbs and inlets in the local scale. On the other hand, completing the total design hyetograph until reaching the concentration time of 30 minutes, the watershed is also subjected to its critical rainfall event in terms of total volume. Therefore, the total rainfall and the intensity were calculated every 10 minutes, up to 30 minutes, as presented in Table 1. Note that the second block is the result of the total rainfall for 20 minutes minus the total rainfall for the first 10 minutes. Similarly, the third block refers to the total rainfall of 30 minutes minus the total rainfall of 20 minutes. This approach allowed to simulate the critical rainfall intensity in the watershed scale (represented by the average value of the three blocks), as well as the critical rainfall intensity in the local scale (given by the rainfall intensity of the first block). It is important to remind that the resulting hydraulic effects on the watershed responses depend not only on the volume of the hydrograph, but also on its shape. This complementary aspect, however, was not explored in this research.