Science of the Total Environment 580 (2017) 873–881

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Are we preventing flood damage eco-efficiently? An integrated method applied to post-disaster emergency actions

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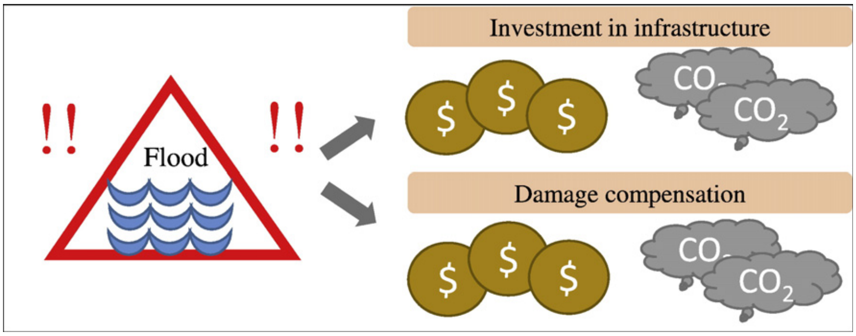
HIGHLIGHTS

- Mediterranean cities must manage floods eco-efficiently to adapt to climate change.
- We combined hydrology and eco-efficiency to assess post-disaster emergency actions.
- The net impact and payback period of the actions was estimated through avoided damage.
- The economic investment was recovered in 2 years; 25 years in environmental terms.
- Negative net impacts suggest that the actions provided benefits to the society.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 30 August 2016
Received in revised form 21 November 2016
Accepted 4 December 2016
Available online 13 December 2016

Editor: Simon Pollard

Keywords:
Risk management
Life cycle assessment
Life cycle costing
Damage prevention
Climate change

ABSTRACT

Flood damage results in economic and environmental losses in the society, but flood prevention also entails an initial investment in infrastructure. This study presents an integrated eco-efficiency approach for assessing flood prevention and avoided damage. We focused on ephemeral streams in the Maresme region (Catalonia, Spain), which is an urbanized area affected by damaging torrential events. Our goal was to determine the feasibility of post-disaster emergency actions implemented after a major event through an integrated hydrologic, environmental and economic approach. Life cycle assessment (LCA) and costing (LCC) were used to determine the eco-efficiency of these actions, and their net impact and payback were calculated by integrating avoided flood damage. Results showed that the actions effectively reduced damage generation when compared to the registered water flows and rainfall intensities. The eco-efficiency of the emergency actions resulted in 1.2 kg CO_2 eq. per invested euro. When integrating the avoided damage into the initial investment, negative net impacts were obtained (e.g., −5.2E + 05 € and −2.9E + 04 kg CO_2 eq. per event), which suggests that these interventions contributed with environmental and economic benefits to the society. The economic investment was recovered in two years, whereas the design could be improved to reduce their environmental footprint, which is recovered in 25 years. Our method and results highlight the effects of integrating the environmental and economic consequences of decisions at an urban scale and might help the administration and insurance companies in the design of prevention plans and climate change adaptation.

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http://dx.doi.org/10.1016/j.scitotenv.2016.12.034
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1. Introduction

Climate change and the increase in urban population pose a problem to flood risk management. By 2050 cities are expected to host 70% of the world's population (UN, 2012), resulting in more urban infrastructure and altering soil infiltration and natural watercourses. Floods are responsible for 34% of the global natural disasters (Guha-Sapir et al., 2009), and their management is especially complex in urban areas. The Spanish Mediterranean coast is an example. In this region, ephemeral streams are common hydrologic features that are typically dry except during torrential rainfall events that result in flooding. Some of the factors that increase the occurrence of these events are land use change, vegetation and soil removal and the construction of drainage networks. Therefore, prevention and mitigation strategies are essential for managing floods and reducing urban and natural damage (Barbosa et al., 2012). In the case of Spanish ephemeral streams, some engineering solutions include channeling or undergrounding the stream or regular maintenance activities. Still, flood damage amounts to 3E + 09 USD/year worldwide (around 2.6E + 09 euros - €) (Guha-Sapir et al., 2009). In Spain, the average insurance compensations for flood damage (e.g., lost properties, vehicles, etc.) reached 150 million euros/year from 1990 to 2014 (Insurance Compensation Consortium, 2015).

In the framework of sustainability, the consequences of flooding result in environmental and economic impacts at two different scales. On the one hand, damaged goods such as buildings or personal properties must be replaced or re-constructed, which requires materials, energy and money. On the other hand, prevention and mitigation strategies are often associated with investing physical and monetary resources for designing and constructing infrastructure. At this point, it is interesting to determine the environmental and economic balance of prevention and mitigation strategies with respect to the damage that they might prevent.

Existing articles proposed methods for integrating flood risk, prevention and damage. Most of the analyses simulated the hydrologic performance of different scenarios based on climate change predictions, control policies or alternative management systems and provided socio-economic results (Brouwer and van Ek, 2004; Haynes et al., 2008; Jonkman et al., 2008; Kubal et al., 2009; Zhou et al., 2012). These might include physical (e.g., building damage) and/or intangible costs (e.g., traffic delays or impacts on health). Cost-benefit analysis was usually the method applied to determine the economic feasibility of management alternatives (Jonkman et al., 2008; Zhou et al., 2012). The integration of environmental or ecological damage is more complex, but some studies attempted to include this dimension by estimating the potential damage to groundwater or biodiversity, for example (Brouwer and van Ek, 2004; Kubal et al., 2009). However, we still need to clearly define the environmental and economic impacts of flood prevention strategies in terms of investment and damage generation. In this context, post-disaster emergency actions are a field to explore, as the urgent need for urban restoration might lead to the application of economically and environmentally inefficient strategies.

To determine the environmental and economic investment in infrastructure, life cycle assessment (LCA) and life cycle costing (LCC) are commonly applied. Several studies on best management practices dealt with innovative systems, such as green roofs and retention systems (see for instance Flynn and Traver, 2013; Kosareo and Ries, 2007; Petit-Boix et al., 2015), but rehabilitation or post-disaster restoration strategies were not assessed, and neither were flood damage costs. However, this analysis is essential to provide an estimation of the eco-efficiency of the strategies, which is a measure of the environmental performance of a system in relation to its value (ISO 14045:2012) that helps to determine its feasibility through a bi-dimensional approach. When dealing with post-disaster emergency actions, this assessment should help reduce the economic investment while generating fewer environmental impacts. To our knowledge, the eco-efficiency approach was not applied to flood studies in the past.

This paper seeks to integrate post-disaster emergency actions and flood damage generation in hydrologic, environmental and economic terms with the aim of eco-efficiently planning prevention strategies in the future. We try to answer the following question: Are post-disaster emergency actions feasible when compared to the economic and environmental damage generated by floods? Our goal was to provide a method for estimating the environmental and economic balance and payback period of flood prevention from an eco-efficiency standpoint. This approach might facilitate and foster eco-innovation in the field of disaster management. We tested this method in the coast of Catalonia (Spain), where the combination of torrential rainfall and urbanized ephemeral streams poses a significant risk. This analysis was based on historical data and specific torrential events, as previous hydrologic analyses identified the need to focus on particular damaging events and their associated consequences instead of providing general inaccurate statistics (Olcina and Rico, 2000).

2. Methods

Fig. 1 illustrates the method applied for estimating the environmental and economic balance and payback period of implementing post-disaster emergency actions. The application of the method is detailed in the following sections.

2.1. Case study

The ephemeral streams under analysis are located in the Maresme region (Barcelona) (Table 1). The streams are called Vilassar, Cabrils and Cintet – hereinafter, streams A, B and C, respectively. Stream A rises from the city of Vilassar de Dalt, and streams B and C, from the city of Cabrils. All of them flow into the city of Vilassar de Mar and, finally, into the Mediterranean Sea. These streams are composed of granitic bedrock with a depth of fifteen meters, covered by an intermediate substrate of altered granites and sublevels of quaternary alluvial sands coming from the stream itself. The areas affected by streams A, B and C are 557, 569 and 445 ha, respectively (Junta d'Aigües, 1992).

Since the early 90s, these cities have experienced an intense urban growth (see Supporting information 1) and the population has doubled. In 2015, Vilassar de Dalt, Vilassar de Mar and Cabrils had a population of 8964, 20,447 and 7250, respectively (Idescat, 2016). Some consequences that resulted from this process include land use changes, construction of low-density neighborhoods, and a shift from agriculture to intensive greenhouse production and industries. As a result, between 1986 and 1996 the surface water flow increased by 4.5% and 54% in streams B and C, respectively (Lleonart and Tarruella, 2010).

In the last 20 years, flood prevention plans became more relevant, especially since the great torrential event that took place in September 1996, which resulted in almost 3 million euros of damage compensations and casualties (Insurance Compensation Consortium, 2015). In November/December 1996 a set of post-disaster emergency actions were implemented to improve the channels and complement previous interventions. These actions affected the three cities and mainly consisted of adapting the existing channels by (re)constructing concrete walls and ripraps in strategic areas (Table 1). In addition to these interventions, there were improvements at a smaller scale and certain areas of the streams were buried when located in urbanized areas.

2.2. Hydrologic characterization

Historical data were used to assess water flows and rainfall intensity. A total of 50 damaging events were considered for the period from 1996 to 2014. This information should be handled with care, as the flash floods that result from torrential events in this area do not perfectly fit in the methodologies developed for estimating water flows (Barrera et al., 2006). In the Mediterranean coast, floods are produced by torrential events, not by series of precipitations. These are sudden events that do