Aesthetic vs. functional restoration of urban and peri-urban rivers: the Manzanares River in Madrid (Spain)

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Abstract

The Manzanares River (Madrid, Spain) is living an ongoing process of transformation, essential if we understand the number and intensity of human pressures it has experienced during the last decades. It is also a paradigmatic case study of the current debate about the most suitable restoration approaches to urban and peri-urban rivers: aesthetic-based or functional-oriented alternatives have been proposed in different urban sites worldwide. This work analyses when and how those approaches can be used, which should be selected under the light of the present knowledge on urban rivers, and in what conditions they can coexist. All these questions have been addressed for the specific case of the Manzanares River, allowing some insights which can be transferred to other urban and peri-urban rivers, both in Mediterranean and non-Mediterranean areas. In this work, a multi-functional approach to urban rivers is proposed, considering the importance of providing self-sustaining actions, which can rehabilitate essential river processes inside the city, and which offer relevant ecosystem services to city dwellers. With that aim, some of the measures which are being taken in the Manzanares River to reach those goals are listed and presented. Among them, rehabilitation of relevant hydromorphologic processes, allowance of natural river forms to develop inside the riverbed, re-connection of the urban reach with upstream and downstream semi-natural and protected river reaches, improvement of riparian stands, and rehabilitation of the river corridor to allow the improvement of the ecological, landscape and recreational connectivity.

1. Introduction

After decades of relative forgetfulness and abandonment, urban rivers have been rediscovered over the last years as essential components of the cities. Their natural values and functions, and the large array of ecosystem services they provide, explain their importance for nature and people, and the legal, scientific and social recognition they have acquired during the last years (Gurnell *et al.*, 2007; Everard & Moggridge, 2012). Improvement of urban water environments may be of major significance for: i. reducing flood risk and optimizing flood risk planning; ii. allowing the city to better deal with water pollution and the degradation of its drainage network, by incorporating Sustainable Drainage Systems (SuDS) and natural water retention measures (Woods-Ballard *et al.*, 2007; Strosser *et al.*, 2015); iii. contributing to reduce the negative effects of the urban heat island; iv. enhancing recreational opportunities around natural and heavily modified channels; v. improving aquatic and riparian habitats (EEA, 2016).

In the legal sphere, some of the most relevant European Directives and policies refer to the necessary good status, integrity and resilience or urban rivers. The Water Framework Directive (2000/60/EC) and the Directive on the assessment and management of flood risks (2007/60/EC) define the main environmental objectives and managerial strategies of urban and non-urban water bodies, as integrated in urban and water planning. River Basin Management Plans and Flood Risk Management Plans contextualize, after the publication of the Directives, the efforts for the improvement of urban rivers. Both plans must be well coordinated, and incorporate public participation, something which may be especially relevant in urban environments (European Commission, 2014). The EU Urban Agenda coordinates efforts to deal with the urban aspects of EU and national legislation, and defines integrated sustainable urban development as one major milestone of the EU policies. The EU Urban Agenda and the Europe 2020 Strategy place sustainability in the urban areas in the centre of the socioeconomic and environmental discussion for the present and future of Europe. The ongoing preparation of an Urban Water Agenda 2030, focused on water and resource efficiency, water quality, sustainability of urban water infrastructures, flood prevention and nature based solutions, and citizens involvement too, shows the interest of the cities for their waterscapes, as well as their main concerns on this topic.

From a scientific perspective, different authors (Eden & Tunstall, 2006; May, 2006; Petts, 2006, 2007) have analysed the social and ecologic (sometime confronting) approaches to the restoration of urban rivers. Those works highlight the difficulties which arise from the commitment of the managerial

targets associated to the river biodiversity and habitats, to the minimization of flood risks, or to the need to respond to the expectations of different sectors of the society. Nowadays, urban rivers are being acknowledged as vertebral elements of the cities, capable of creating structural and functional connections with other components of the land matrix. For instance, Baschak & Brown (1995) discussed alternatives for the physical planning, design and management of urban river greenways. Walsh *et al.* (2005) presented methods to diagnose some major alterations of urban rivers and streams. Moreover, Martín-Vide (2001) and Findlay & Taylor (2006) offered clues for understanding the necessary rehabilitation of urban rivers, and some possible ways for designing those measures.

In social terms, the rediscovery and reconnection of people with rivers has only recently begun. In Europe, and particularly in Spain, social approaches to urban rivers have dramatically evolved during the last century. From near-natural channels where citizens fulfilled many of their daily routines (drinking, bathing, washing clothes, collection of natural resources or recreation) in the 30s, rivers became near-artificial canals for conveying wastewaters in the 60s, and almost fully degraded systems by the 80s (Chin, 2006). However, the last two decades have seen the social reborn of many rivers, thanks to the intense improvement of water quality, the rehabilitation of recreational activities and even the restoration of aquatic and riparian habitats, and their related landscape and ecosystem services (Paul & Meyer, 2001; Gómez-Baggethun & Barton, 2013).

Over the last years, an intense debate has confronted two very different ways to manage urban and peri-urban reaches. One, clearly focused on the aesthetic and landscape values of city rivers, which has emphasized the construction of design parks around them. And a second one which prioritizes the rehabilitation of critical river processes and aims at the recovery of their functionality, despite the many unsolvable constraints which cannot be mitigated.

A number of restoration or rehabilitation works recently developed, or under development, in the Manzanares River in Madrid has helped to reopen the aforementioned discussion in Spain, and to check what kind of measures are feasible in severely degraded urban and peri-urban reaches. This work tries to give insights into the discussion, by giving answer to the following questions:

1. Which measures were designed for the restoration or rehabilitation of the urban and peri-urban reaches of the Manzanares River?
2. Which are the goals of each measure in terms of functionality or aesthetics improvement?
3. How do the measures should be understood as part of the water legal framework in Spain and Europe?
4. Which would the best future managerial approaches for achieving the desired scenarios in the Manzanares River and in its drainage network, as a paradigm of other relevant urban river systems?

2. Materials and methods

2.1. Study area

The Manzanares River is one of the main river systems of the Madrid region, in Central Spain (Fig.1). It is considered an element of special interest because of its vertebral character of the territory, connecting the Guadarrama hillrange at the north of the region (at over 2000 m.a.s.l.) with the Lowland areas and the Countryside at the south (ca. 500 m.a.s.l.), along a rivercourse of 92 km. But also, because it is the most significant river that runs through the city of Madrid, in which it has historically been a social, cultural and environmental reference.

The river has suffered for centuries, and precisely because of its location and its characteristics, many human pressures, which have gradually changed its flow pattern, geomorphic features, ecologic processes, and the environmental services it provides. Those pressures have become especially relevant since the mid-twentieth century, transforming the landscapes of the Manzanares River in an intense but heterogeneous way, depending on the original conditions and the dynamics of each river reach.

One of the most outstanding sections of the river, according to its present values and social and ecological potential, is the peri-urban reach that runs upstream from the city of Madrid, in the surroundings of the historical site of El Pardo, and of the homonymous dam, which regulate the river flows in downtown Madrid, and which is nowadays the lower limit of the natural protected areas which were created to protect the environmental values of the river, in its upper and middle sectors (Guadarrama National Park, Manzanares River Reserve, and Regional Park of the Upper Manzanares Basin).

In this 15-km-long section, the geomorphological pattern of the Manzanares channel has evolved from multi-thread, braided and sediment-dominated to mono-thread, incised and narrow, due to: i. flow regulation by two large reservoirs: one constructed for domestic water supply (Santillana Reservoir) and a second one for flood risk management (El Pardo Reservoir), ii. progressive occupation of the river margins, and iii. modification of the hydromorphological characteristics of its drainage network (Fig.2).

In this peri-urban reach, several works have been carried out during the last decades:

- transversal works, such as gauging stations and weirs, which generate artificial backwaters, producing a dense de-

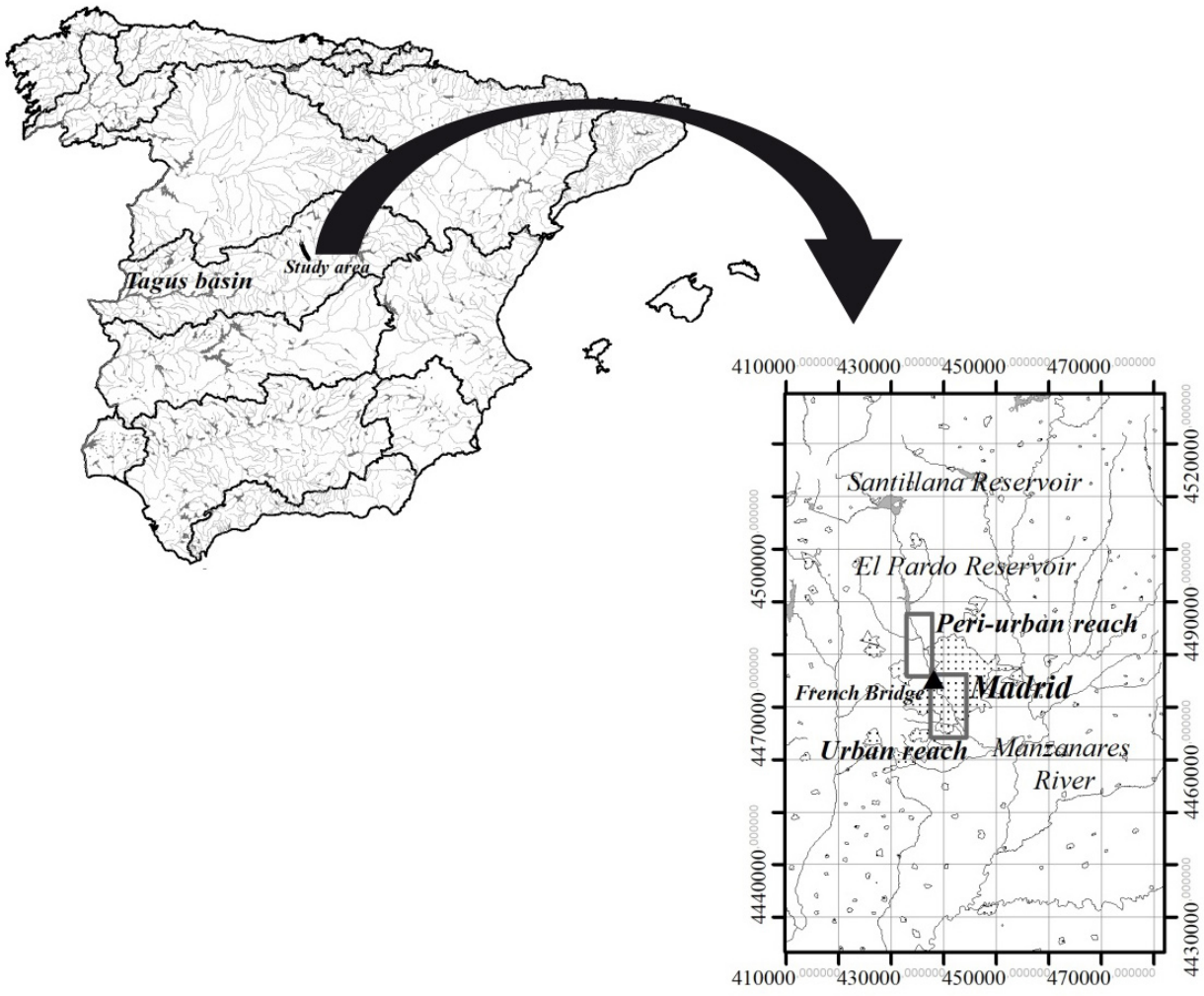


Figure 1 – Study area in the Manzanares River, Central Spain. Two reaches have been analysed: a peri-urban reach upstream and close to Madrid city, and a genuine urban reach which crosses the downtown area (Geographic coordinates system is ETRS89).

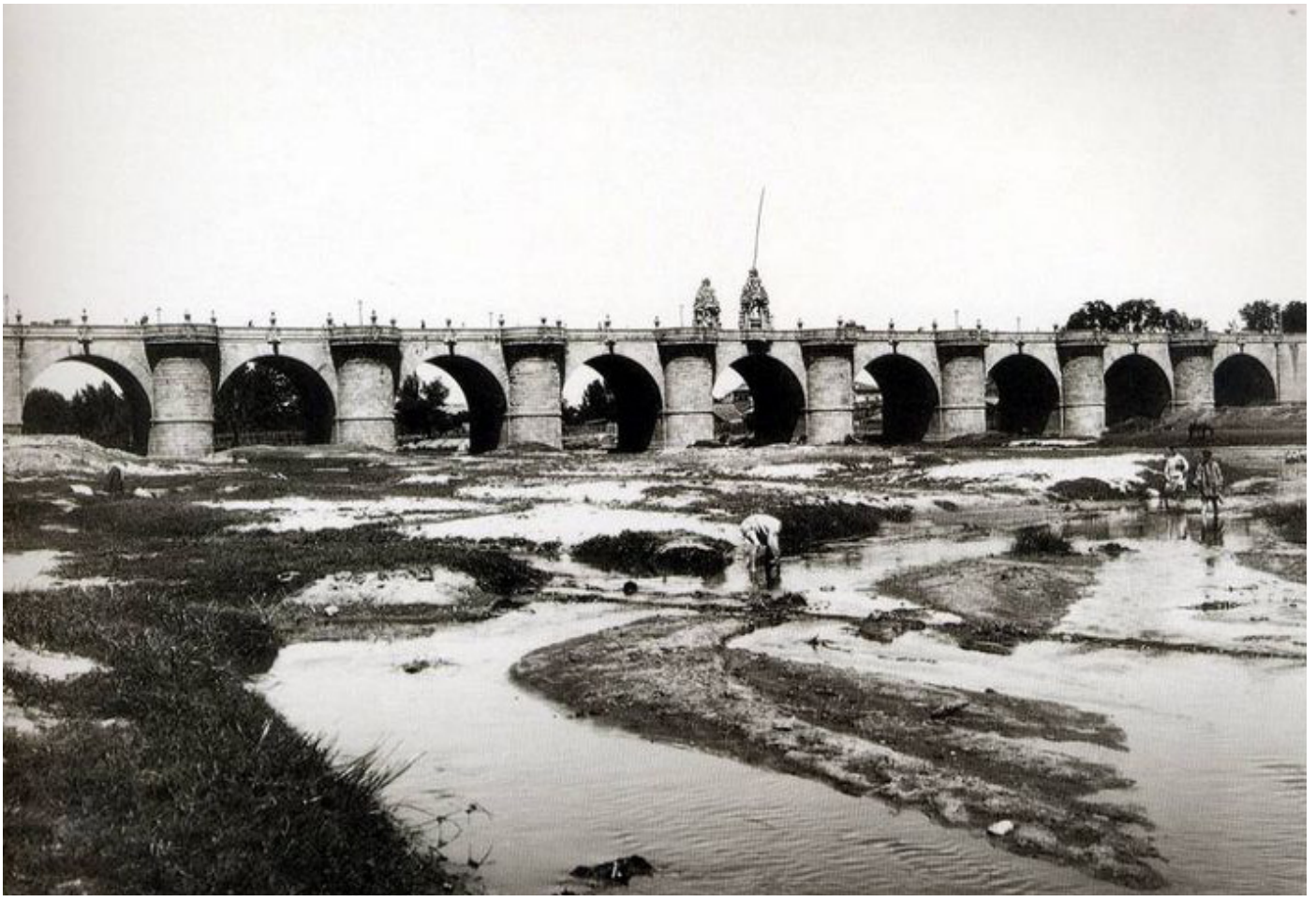
velopment of pioneer vegetation, in which the abundance of helophyte plant species stands out.

- longitudinal works, such as dredging and removal of sandy islands in the channel, or longitudinal levees to avoid overflowing and flooding, and to facilitate the urban occupation of the floodplain, which have resulted in loss of river space, simplification and impoverishment of aquatic and riparian biotopes, loss of transversal connectivity, loss of accessibility to the banks, loss of scenic values and reduced contact with the river (MAPAMA, 2015).

Downstream of the aforementioned reach, the river enters downtown Madrid, along a 10-km reach, which borders the historical city and some of its more renowned corners. This reach, which originally offered essential services to the city (water for domestic supply, bathing and washing clothes, sediments for construction, and many recreational values – as historically illustrated by famous painters), was canalized in the early 20th century (Fig.3). After the canalization, the river progressively suffered higher anthropic pressures. Among them, the construction of a large motorway on both margins, the total urbanization of its floodplain or the large decrease of its water quality (Valcárcel *et al.*, 2011).

Along with all the above pressures, the river flow pattern in both reaches also suffers additional alterations due to the homogenization of the flow features of its main tributaries. This being mainly caused by the regime of discharges of the sewer plants of the medium-sized municipalities that pour their purified wastewater into those tributary streams. The alteration of the flow patterns of the drainage network has also had effects on the genesis and transport of sediments throughout the whole system, enhancing unbalanced erosional and sedimentary processes in many different locations. Similar eco-hydromorphological processes have been described in other Mediterranean sites worldwide (e.g.,

Figure 2 – Aerial and detailed views of some segments of the Manzanares River peri-urban reach which is presently being restored: (a) occupation of the former river left floodplain, which has contributed to the present narrow structure of the river system; (b) weir which creates an artificial backwater, where a fish ramp will be created; (c) artificial backwater which has motivated the death of the riparian stands; the dead trees have already been eliminated and the backwater will soon be reduced by allowing a better sediment transport; (d) massive public use along the reach, but disconnected from many river values; the paths will be improved and reconnected with the river banks, and cycle and pedestrian differentiated paths will be created.



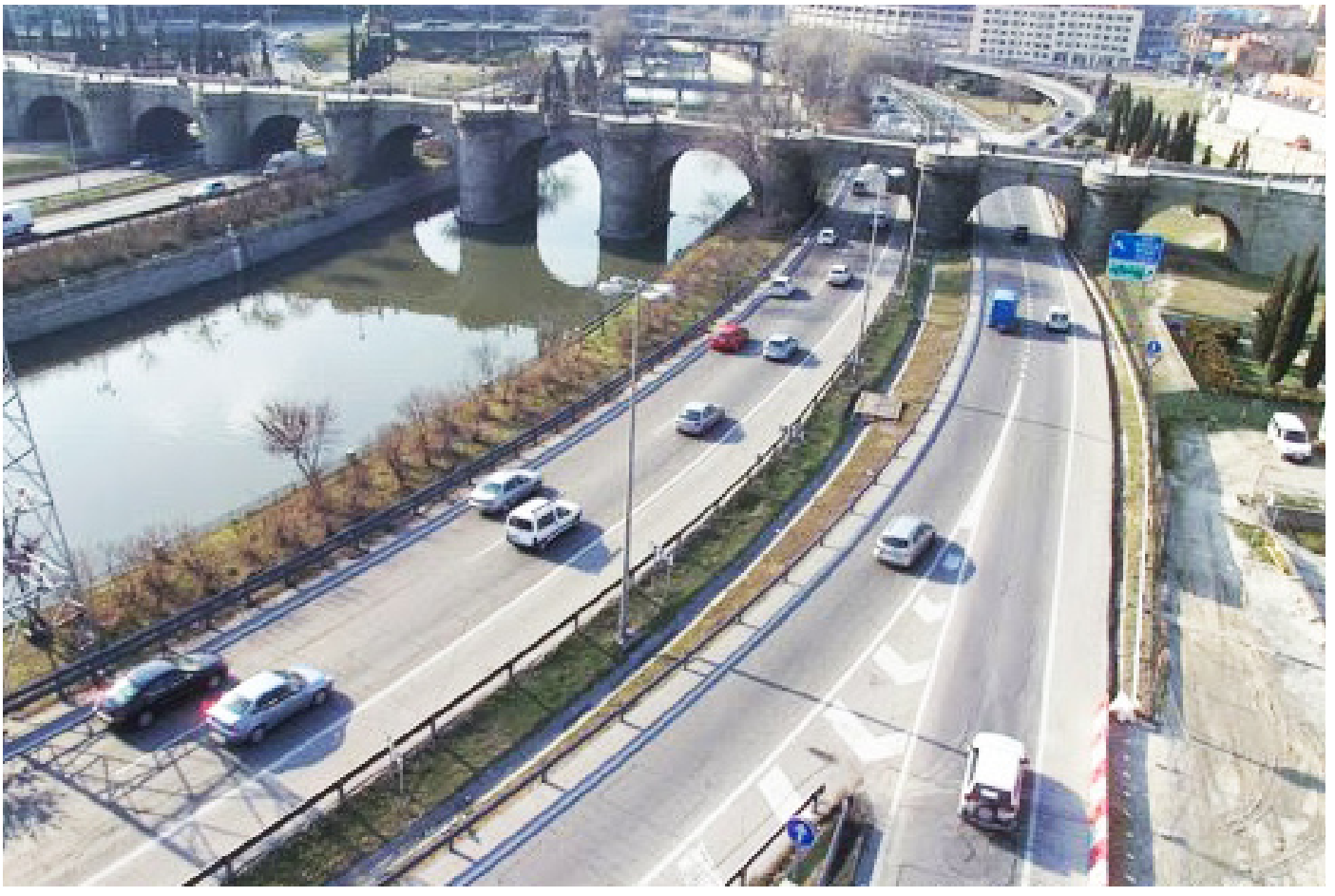


Figure 3 – Evolution of the urban reach of the Manzanares River near the historical Toledo Bridge: (a) by the early 20th century, showing the characteristic patterns of the near-natural multi-thread river channel; (b) in the 80s, after the canalization of the river and the construction of motorways along its banks; (c) in the early 21th century, after the motorways burial and the construction of a huge river park, but still with the weirs closed along the rivercourse; (d) after the full opening of the weirs and the allowance of a seminatural dynamics inside the limited space of the river (Photo sources: Madrid City Council and CEDEX).

Magdaleno *et al.*, 2017).

Regarding the ecological status of both reaches of the Manzanares River, it has also undergone significant changes over the last years. Because of the changes of the river flow and geomorphic pattern, the vegetation of banks and riparian areas has been modified in structure and composition, adapting to the new conditions. In the peri-urban reach, a more continuous presence of water, even in times of drought, has favoured the development of a greater vegetal biomass, and a linear structure in the riparian stands. Decades ago, vegetation was less likely to colonize the riverbed. The sandy substrate and the frequent occurrence of natural very-low flows during summer, naturally prevented the consolidation of a thick gallery forest. In the urban reach, a set of regulatory gates which enhance totally artificial hydraulic conditions has made unfeasible the colonization of the riverbed by any plant community.

From a socio-cultural perspective, the study reach constitutes an area of very high public use, due to its proximity to natural areas, its relevant landscape values, and its good accessibility from the city. Its recreational values ensure, daily, but especially during weekends and holidays, the arrival of thousands of visitors. In the network of paths which run parallel to the river, pedestrian and cycling uses coexist, not always easily due to the lack of separated infrastructures.

Finally, it should be mentioned the inherent difficulty of the management of the study area by different authorities, sometimes with concurrent competences: the Tagus Basin Authority, Madrid City Council, Regional Government of Madrid, the public water operator of the region (Canal de Isabel II), and the public entity National Heritage, which manages most of the riparian areas historically owned by the Spanish monarchy. Also, various departments of the Ministry of Agriculture and Fisheries, Food and Environment (such as Water, Environmental Assessment, or Climate Change, among others) participate in different legal or administrative procedures. Additionally, it is also necessary to refer to the municipalities which pour their purified wastewater into the river drainage network, affecting its hydromorphological and ecological dynamics. Finally, from the perspective of the social and environmental organizations which have participated in the river improvement, many were active during the process, such as WWF-Spain, *Ecologistas en Acción*, and different local groups.

Under the aforementioned scenario, and due to the problems presented by the Manzanares River in the study area, the competent authorities agreed, during the years 2015 and 2016, on the development of a comprehensive set of measures for: i. the improvement of the urban river reach which crosses downtown Madrid; ii. the restoration of the upstream peri-urban river reach between El Pardo reservoir and the urban segment.

2.2. Methods

A wide number of alternatives were assessed during the technical screening of the restoration projects. Hereinafter those alternatives are described and ordered, in accordance with the intensity of the projected actions. Once the best alternative was chosen, in terms of costs and benefits, a number of restoration actions were selected and designed. These are later explained.

- *Alternative 0 – Trend scenario*

  This alternative would involve developing no action in the river, neither in the urban nor in the peri-urban reach. Lack of any intervention in the river, according to the present dynamics and to the expected future functioning would probably lead to an accentuation of the unbalanced erosive and sedimentary processes which are causing a degradation of the aquatic and riparian habitats in the peri-urban reach, and an increase of the decay of ecologic processes and ecosystem services in that reach. This would probably contribute to a further deterioration of the reach, in social and environmental terms. In the urban reach, the trend scenario would involve the maintenance of the present ecohydraulic conditions, which involve very poor habitats and an almost total lack of ecologic connectivity and social connection with the river.

- *Alternative 1 – Holistic re-naturalization*

  The re-naturalization of the river´s processes and landscapes would require the restoration of the flow and geomorphic patterns: restoration actions should lead to a wide braided planform with many secondary channels, vegetated and non-vegetated bars and islands, associated to very variable flow levels. Considering the present constraints of the river in both reaches, this alternative is technically and economically unfeasible.

- *Alternative 2 – Rehabilitation of critically degraded areas*

  Along the river reaches under study, many sites can be found, where the hydrological, geomorphological and ecological degradation has been more intense, enhancing a clear decay from the desired environmental and landscape scenarios for the river. Under this alternative, the restoration actions would be focused on those especially degraded sites. Alternative 2 could fully shift the present degrading trends of those sites, but would not consider the overall processes which are contributing to the river´s degradation, and would not be based on the idea of generating a long and well-connected river corridor around the city, and along the own downtown areas.

- *Alternative 3 – Structural and functional restoration of the river corridor*

  This alternative was devised to restore some of the more important processes lost by the river, in terms of hydromorphology, ecology and ecosystem services. The restora-

tion actions would be linked to an objective-based approach, attempting to reach the best possible status under those anthropic pressures and constraints which are technically and economically impossible to eliminate or even mitigate. This approach would consider those sites which are more critically degraded, but to boost an overall improvement of the river, avoiding the maintenance of *black spots* in the watercourse. Thus, the restoration would be targeted to the whole river corridor, on the basis of the recovery of some essential processes and patterns, and the amelioration of the sub-reaches which may hamper the status of the entire river system.

After a thorough compared analysis of the assessed alternatives, number 3 was deemed to be the best in terms of cost-benefit and cost-efficiency. But even so, requiring a continuous monitoring of the restored reaches, which may lead to their adaptive management, and to the optimization of the efforts undertaken by authorities and stakeholders.

3. Results: restoration actions

3.1. Peri-urban reach

Along the peri-urban reach, many different actions have been included and designed in the restoration project of this reach. The execution of these works began in January 2017, and will develop along three years, with a total budget of around 2 M€. The restoration actions have been designed with the objective of providing an integral improvement of the study area, of being well coordinated and multi-functional, and of avoiding any disturbance to the native and protected habitats and species which use the reach during their biological cycles.

Figure 4 outlines the main restoration measures planned to reduce the hydrologic, geomorphic and ecologic alterations of the peri-urban reach, and to optimize ecosystem services in it. Some of those measures are the following:

- **Improvement of environmental flow regime:** The Basin Management Plan of the watershed already defines an environmental flow (e-flow) regime for this river reach. However, the hydromorphological diagnosis carried out has shown that the e-flow regime should be optimized to allow for a better river dynamics. Especially in its summer flows, and with the discharge of episodic controlled floods, capable of regenerating the riverbed and improving the solid transport (Magdaleno, 2017). The characteristics of these floods have been designed and proposed to the water authorities.
- **Rescue and transfer of native ichthyofauna**: various actions have been designed to reduce impacts to fish fauna, focusing on those river sections in which the need to permeate artificial barriers has been detected. The works will consist of carrying out rescue operations of ichthyofauna (capture and transfer) immediately prior to the improvement of the longitudinal continuity of the channel. In this way, specimens of barbel (*Luciobarbus bocagei*), Iberian nase (*Pseudochondrostoma polylepis*) and Iberian gudgeon (*Gobio lozanoi*) will be captured, as well as any other native species inhabiting the sections considered.
- **Increased complexity and hydraulic diversity:** The technique consists in increasing the complexity and hydraulic diversity of the reach by using materials of coarse granulometry at certain sections, favoring the generation of optimal erosion and sedimentation patterns. The action would be carried out considering the morphosedimentary and hydromorphological pattern of the river, the ecological requirements of the aquatic species, and the lack of proper mechanisms of the river for the improvement of aquatic habitats.
- **Forestry works and removal of exotic vegetation:** They would be based on the improvement of the structure and composition of the riparian vegetation of the Manzanares River according to the existing densities (low, medium or very high) along the entire left margin of the river. These works include the cutting of dry or dying vegetation, or the pruning of specimens that require an improvement in their structure or that have risks for the visitors. In addition, in different sites distributed along the corridor specimens in poor phytosanitary status and exotic species have been located (mainly ailanthus –*Ailanthus altissima*-, box elder –*Acer negundo*- and false acacias –*Robinia pseudoacacia*-). After a tree-by-tree analysis, the specimens will be selected and removed.
- **Restoration of riparian vegetation:** Four categories of revegetation have been established, according to the distance to the channel and the height above the water table:
  - river banks: located in areas where the slopes will be morphologically naturalized, using species such as *Salix alba, Salix salviifolia, Salix atrocinerea, Lonicera periclymenum subsp. hispanica, Clematis campaniflora* and *Rubus ulmifolius*.
  - margins: located in the upper range of the paths to be created, after the re-design of the slope, with *Populus alba, Populus nigra, Rosa canina, Ulmus minor, Crataegus monogyna, Pistacia terebinthus, Pyrus bourgaeana* and *Rubus ulmifolius*.
  - floodplain and distal areas: located in the upper part of the areas affected by the slope redesign and in the slope with scarce vegetation. They will be planted with species included or associated with the association *Junipero oxycedri-Quercetum rotundifoliae*.
- **Removal of excessive patches of helophytic species in**

the channel: Helophytic vegetation (reed -*Phragmites australis*- and narrowleaf cattail –*Typha angustifolia*-), which has boosted in the channel due to the existence of artificial backwater in the river will be extracted in those sections where their abundance is considered negative for the hydromorphological and ecological dynamics of the river reach.

• **Removal of obsolete transversal works and artificial barriers:** The progressive removal of obsolete works and artificial barriers has been designed. This includes the remains of an old gauging station, and some sedimentary heaps (with a total volume of 10,000 m^3) accumulated in the channel which are creating large backwaters, and which have been colonized by pioneer vegetation.

and to allow visitors to perceptually reconnect with the river. Therefore, land movements in will be carried out along the whole reach. Earthmoving on the banks will aim to achieve slopes 2(H):1(V), whenever possible. In all cases, the newly created surfaces will be re-vegetated, using plant propagules from the area.

• **Improvement of trails:** The project will include the adaptation of existing paths, in order to guarantee the safety of different users, by differentiating cycling and pedestrian trails, and relocating some narrow pedestrian paths along the river banks. A new pedestrian bridge will also be constructed, 20 m-long and whose hydraulic section is prepared

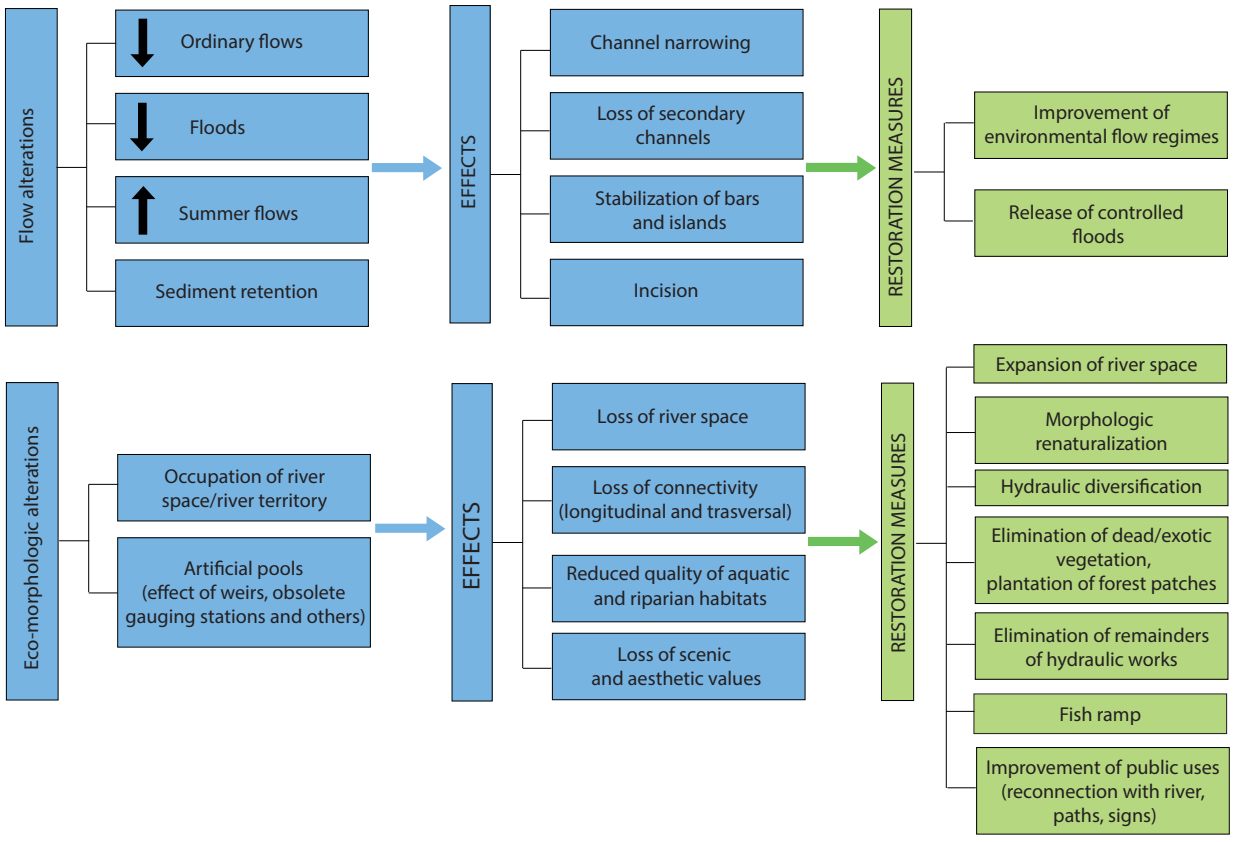


Figure 4 – Schematic diagram of the main flow and eco-geomorphic alterations which the Manzanares River peri-urban reach suffers today, their effects along the river, and the restoration measures under development (Source: J.A. Fernández Yuste, C. Martínez Santa-María, F. Magdaleno, pers. comm., 2015).

• **Construction of fish ramp:** The main constraint for the design of this fish pass is the migration ability of the species that inhabit this reach of the Manzanares River, without this reducing the supply of water from the weir to the legal users. The ramp will be constructed in rock, embedded in the water, and designed to allow an optimum permeability for fishes.

• **Removal of landfills in the riparian areas:** The main purpose of the earthmoving activities in the river margins is to recover a certain degree of naturalness in the transversal profiles of the channel, which are now very much incised,

for the 10 years return interval, to allow visitors to enjoy a circular route along both margins of the river. Different signs and educational materials will also be installed, to better allow them to know the natural and culture values, and environmental services provided by the restored river.

3.2. Urban reach

In 2016 and 2017, the Madrid City Council, echoing the requests of various conservationist and neighborhood associations, proceeded to the progressive opening of the regulatory gates of the Manzanares River. The first effect of this opening

was the reduction of the artificial depth of the dammed river (close to or greater than 2 m), the recovery, after decades of complete immobility, of sediment transport and the reappearance of a wide number of species of fauna and flora associated with the recently created fluvial forms. The creation of sandy islands and bars along the urban reach, and their rapid colonization by natural vegetation, has accelerated the change of the fluvial landscape, and the discussion on the optimal measures for its progressive re-naturalization. The city newspapers and many thousands of citizens are following the fast transformation of this river, which has been optimal considering the short time passed and the overall degradation of the river system in the early stages of the project. The re-colonization of the reach by many different species of aquatic and riparian birds is one of the effects which have been more impressive for managers and neighbours, creating an atmosphere of support to the project in most Madrid citizens.

The City Council plans, at this moment, the creation of bio-engineered slopes in the banks formerly covered by rip-raps, the planting of riparian species in the upper part of these slopes, and some other landscaping and environmental design project (such as the creation of a fish pass in one of the regulatory gates, the reintroduction of native ichthyofauna, or the creation of a fish breeding centre, among others). The budget for the first phase of the re-naturalization project is around 1.2 million euros, and its execution period is 9 months, for a first sub-reach of 1.3 km (French Bridge to Queen Victoria Bridge). New phases are being planned and will probably be executed during the following years.

4. Conclusions

i. The restoration projects under execution or recently implemented in the urban and peri-urban reaches of the Manzanares River in Madrid have shown the high capacity of historically degraded rivers to enjoy a fast recovery of many important functions and services, following a correctly designed hydromorphological and ecological restoration or rehabilitation.

ii. Even the more constrained urban reaches may sustain interesting aquatic and riparian habitats, and attract many different floral and faunal species. This is the case of the urban downtown reach of the river, which has bloomed in terms of bird and fish communities immediately after the restoration of some basic hydrogeomorphic patterns. In this case, the maintenance of a managerial approach strictly based on certain aesthetic values would have involved keeping the river in a very poor condition, with no natural processes attached and a total lack of relevant biotic communities.

iii. Restoration of a minimum functionality of urban reaches requires restoring, as far as possible, the dynamics of the peri-urban reaches both upstream and downstream. The urban reach must not be an isolated water shackle, unable to constitute part of a river corridor which offers a large diversity of functions and services to the city and to its citizens.

iv. The legal, scientific, technical and social advances recently developed in the approach to rivers must be reflected in their management. Strictly engineered solutions are frequently not cost-efficient, since they use to leave aside a wide number of the rivers´ functions and services. Self-maintenance or self-restoration of rivers is also not an appropriate solution in most cases, since the pressures and constraints around rivers require active managerial approaches. Green infrastructures and natural water retention measures, as presently considered in the literature and in the legal context, may guide the efforts to restore urban and peri-urban rivers, because they involve multi-functional solutions, and can create the necessary links between the many different laws and policies which nowadays rule urban and peri-urban rivers.

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