Urban water resources. Management for renaturation and Ecosystem services. Case study.

Miguel Torroaes Valente Bochechas

Civil Engineering Department, Instituto Superior Técnico, Universidade de Lisboa

October 2019

Abstract

Urban watercourses and the green areas surrounding them have a very important role in today's way in which cities operate. These areas perform different roles such as regulating climate factors, preservation and conservation of biodiversity and ecosystems, as well as approaching the natural environment to the population.

The main purpose of this dissertation was to study the major problems associated with urban watercourses and how to overcome them to restore the natural conditions of these places. Several case studies regarding interventions on watercourses were analysed, identifying the different methodologies used and the associated problems. Classification and valuation methods were also analysed in order to use the concept of the ecosystems services and theirs associated benefits to evaluate the interventions in watercourses.

The last part of this dissertation was the implementation of the studied methods and techniques in a proposal for the renaturalization of the Alcântara valley, in Lisbon. Three main areas were identified, in a first phase, where it will be possible to apply the necessary renaturalization measures to the Alcântara stream. The tangible and some of the intangible benefits that the proposed changes could return to the Lisbon city were quantified. These valuation methods contribute to a better acceptance by the local population of the projected interventions thus allowing to achieve all the objectives of the ranaturalization project.

Keywords: watercourse, renaturalization, ecosystem services, benefits valuation

Introduction

Fresh water is nowadays a natural resource that needs to be protected from human bad uses and discharge of contaminants (Conselho Nacional da Água, n.d.). In the urban environment an enormous number of watercourses were physical altered to allow water to quickly drain from city centres. At the same time, the increase of impermeable surfaces increases the amount of water flow draining during intense precipitation. These modifications on urban watercourses give a false sense of safety, and at the same time produce various problems to the natural water flow.

Physical alterations of a riverbed result in several problems to the ecosystems surrounding it such as less infiltration, destruction of habitats, deterioration of water quality and alterations of the river flows affecting both the natural environment and humans.

Water quality is mostly affected by human interaction due to the heavy domestic and industrial discharges on rivers but also due to the high amount of fertilizers and pesticides used in agriculture.

In the present dissertation all these problems were tackled by reviewing different studies of watercourses intervened in different places. Different methods of analyse and classification were considered as well as the different ways of mitigating these problems. The last part of this work was the implementation of the studied methods and techniques in a proposal for the renaturalization of the Alcântara valley, in Lisbon.

Renaturalization of water resources, ecosystem services – Review

In the past, urban watercourses had a different role in ancient societies, from water supply sources for agriculture or domestic use, to an important traffic route to transport all the goods for and from cities. Riverbeds and banks were amended in order to serve the needs and interest of the local populations leaving aside any concern about the surrounding ecosystems.

The amount of pollutants discharged in rivers increase significantly since the industrial revolution. City centres and their suburbs suffered an immense pressure resulting in an enormous damage to the water quality and to rivers in general.

With the end of the industrial revolution and the beginning of the Modern Age started the first interest in solving the problems associated with rivers discharges and their negative impact on humans. However, until the second part of the twentieth century almost nothing was done to stop pollution and destruction of habitats and ecosystems.

During the 1970's and 1980's, although several urban areas had already water treatment systems to treat and control pollutant discharges (Joshi, Tortajada, & Biswas, 2012). Physical alterations on rivers were still not controlled and continue to be implemented in many places (Zhao, Liu, Lin, Lv, & Wang, 2013).

Nowadays with the extreme increase of cities' population, the pressure on urban watercourses is even higher than before (Ritchie & Roser, 2018). In several cases, watercourses are seen as an obstacle to the development of cities and as a result are destroyed or altered drastically. Another problem associated with the increase of urban population is the increase of impermeable surfaces, disrupting the natural flow of water.

Urban watercourses have different types of benefits associated with them as environmental, social and economic benefits. Through the restoration of the natural characteristics of urban watercourses and the green areas around them several functions of these areas could be restored benefiting directly or indirectly the local populations. Environmental benefits embrace the increase of carbon sequestration, the water purification and the restoration of ecosystems and habitats (Schirmer et al., 2014). Social benefits are the ones which produce a direct benefit to the populations like the reduction of the local temperature, the increase of human wellbeing or due to the calm areas allowing the local inhabitants to practice exercise or decreasing the stress (Lee, Park, Tsunetsugu, Kagawa, & Miyazaki, 2009).

On the other hand, economic benefits are in several ways related to the environmental and social benefits. The increase of carbon sequestration produces an economic benefit related to the carbon value in international markets. The purification of water, besides the social benefit, reduces the costs of water treatment in case of an existing water supply. The reducing of air temperature reduces the needs with cooling and its associated costs (Chen, 2017).

Regarding the implementation of a renaturalization project there are several constraints that need to be considered. The location of the interventions is the first possible constrain, due not only by the local conditions such as the soil, climate and topography, but also considering the different laws applied. The laws vary even in the same country, where each city might have its own regulations. The political forces in power will have an important role defining the course of projects and their objectives which might vary even considering the same law.

Another important factor regarding the localization of a project is the cultural aspect and the local traditions. The attachment that the local communities have with the watercourses and the green areas surrounding it will affect the final result of the projects and for that reason they should be involved in the project from the begining. On the other hand, with a large number of entities involved in the decision making the final outcome of the projects will produce less satisfactory results in all areas of action considering that they have to please every entity.

One important method to define the benefits extracted from the renaturalization projects is the use of ecosystem services concept. Ecosystem services are generated when an ecosystem produces a benefit that contributes for the needs of human being. The *UN Millennium Ecosystem Assessment* (MEA) defined four different categories for the services: provisioning services related to the resources extracted from the ecosystem; regulating services related to the benefits of processes that regulate the natural environment; cultural services; and supportive services, that gathered the essential processed that sustain the integrity, resilience and the functionality of ecosystems (Alcamo et al., 2003).

The ecosystem services method is used to give an economic valuation to the different benefits extracted from the ecosystem. There are different types of analyses to the ecosystem services such as the PES (Payment for Ecosystem Services), the PWS (Payment for Water Ecosystem Services) or the IPA (Importance Performance Analysis). The PES and the PWS are very similar and define a monetary value to the different ecosystem services that produce tangible benefits, allowing a more efficient financial approach as well as preserving and valuing the ecosystems. The social services of an ecosystem that produce intangible benefits cannot be defined using these methods because they were not developed considering it.

The IPA analysis considers the satisfaction of the different social groups with each ecosystem services. This type of analysis is usually used to compare the importance given by the community and the performance of ecosystem services, allowing a more realistic view to where the problems are, and to solve them (Hua & Chen, 2019).

Intervention methodologies

The first step of an intervention is the definition of the location where an intervention is necessary. Defining a project that pleases every entity involved and the public in general is the next step. The number of players involved will affect the final result of the positive environmental impact. In general, the larger the number of players, the less positive impacts will have the interventions.

Connecting all the different points of views and ideas for the different parts of a renaturalization project can be done through the use of ecosystem services. Gathering all the information regarding the ecosystem services coupled with a monetary valuation allow a more complete and precise analysis. The ecosystems services with intangible benefits might be valued with the WTP method (Willing to Pay) and the WTA (Willing to Accept). These methods are based in surveys to the population inquiring if they are willing to pay for a change or if they are willing to accept a compensation for an unchanged situation (Zhao et al., 2013).

Several areas of actuation in urban watercourses were define according to the references analysed. The first area defined is the natural flow of water and the ability of creating natural meanderings. The natural formation of meanderings allows the formation of fast and slow areas promoting the establishment of several species of fauna and flora.

Controlling the erosion effect in watercourses is very important to maintain their natural conditions. Without control the riverbed and the riverbanks can be negatively affect as well as the fauna present. The destruction of the riverbanks could create problems for agriculture or urban areas in the surroundings of the river. The control of the erosion could be executed creating fast and slow zones, with the shape of the river or with natural obstacles placed in strategic spots. Protecting the riverbanks with plants or natural engineered riverbanks is another option.

The flow velocity and the infiltration are another important aspects that must be covered. During a renaturalization project the flow velocity must be controlled ensuring that the velocity is neither

to fast, increasing the erosion, neither to slow, creating stationary water, reducing the amount of dissolved oxygen and increasing the proliferation of diseases and plagues.

The natural infiltration is affected by different factors such as the amount of impermeable areas or the velocity of the flow. Promoting the natural balance in the watercourses would have a positive impact on the infiltration. During the renaturalization of water lines the soil used has an important role, considering that clayed soils have a less capacity of infiltration then sandy soils.

Water quality control is the first step into a more natural water line. For this, replacing the natural characteristics of the riverbed and riverbanks is crucial as well as avoiding the pollutant discharges from domestic and industrial facilities. The removal of several industries from the riverbanks if applicable, such as port facilities is also very important (Joshi et al., 2012).

Dredging has both positive and negative impacts on watercourses. For one hand, dredging must be avoid due to the destruction of habitats and ecosystems, except for the removal of polluted soils. Several projects of renaturalization are associated with some dredging in order to remove contaminants or even soil that have deposited due to human action, creating an artificial ecosystem (Joshi et al., 2012).

Profound changes in the surroundings of a watercourse not only can destroy the ecosystems but also creates difficulties to a more ambitious intervention. Riverbanks extremely altered must be intervened considering the resettlement of people or industries. Roads and streets sometimes must be removed in order to complete the intervention needed. In the river Cheonggyecheon, Seoul, South Korea, the area was completely altered in order to achieve a more natural watercourse (Island Press, n.d.).

Requalification of riverbanks is important to achieve a natural watercourse as well as to control the erosion. There are several methods to secure the riverbanks that will vary with the different characteristics of the river flow and riverbanks. The water flow velocity and the function need for each area will characterise the methods that could be used in the different sections. The slope allowed in the riverbanks will affect the type of protection used as well.

Considering the slope, the construction methods can include: walls of gabions for higher slopes with controlled water velocities; rockfill interleaved with plants for high slopes associated with strong currents; and live retaining walls, or cribwall, constructed with wood interleaved with plants to ensure a correct protection and the proliferation of vegetation. For lower slopes one of the methods used is the *faxinas*, the Portuguese name given to a long roll of tree branches mixed with live branches that avoids the destruction of the riverbanks (FEUP & ARHcentro, 2013).

The methods used have to be adapted to every location, and in several cases, they should be mixed. In areas with high flow speeds combined with others with lower speeds, the methods must change and be adapted in the best possible way.

Case study – *Alcântara* valley

In the past, the *Alcântara* valley was seen as a source of diseases and plagues, due to the amount of uncontrolled discharges conducted to the water line. In 1887 the first stretch of the watercourse was covered in order to build the train station of *Alcântara-Terra*. Between the 1940's and the 1960's the all extension of the water line was covered allowing the construction of the *Avenida de Ceuta*. The covered watercourse was then used to drain large areas of Lisbon and also as a collector for domestic sewage. After the construction of the water treatment plant in Alcântara, all the water was treated and then drained to the Tagus River.

Nowadays, the entire extension of the water line is covered. In this dissertation three different areas were analysed and some modifications were proposed. The first modification needed in the entire watershed of the water line is the replacement of almost all of the sewage systems in place, changings the combined system by a separative system. This substitution will split the sewage from the rainwater, allowing that with the renaturalization the water draining into the riverbed has no longer sewage.

The first area analysed for interventions was in the intersection of Avenida de Ceuta with Avenida Calouste Gulbenkian. Considering that with heavy rain the area usually floods, it is proposed to build a drainage basin. The surrounding area will be covered with several plants and trees increasing the green area and promoting biodiversity.

The next area where some interventions were proposed is the *Quinta do Zé Pinto*. In this sector, the water line is renaturalized by transforming the covered riverbed into a watercourse with a new geometry. The riverbanks of the new geometry are proposed to be protected using a cribwall. In areas with higher flow speeds, as in the border between the new geometry and the cover watercourse, rockfill interleaved with plants should be used. This modification and the modification on the next area can only be implemented after splitting the sewage from the rainwater.

The surrounding area will be a new urban park, with wooded zones as well as grasslands. The rehabilitation of this area of the city would establish the previous ecosystems and habitats and encourage local population to use and benefit from it.

Downstream of *Quinta do Zé Pinto* in *Avenida de Ceuta*, it is proposed that the water line must be uncovered, replacing the current tunnel with a new renaturalized geometry. In order to achieve this geometry one lane of traffic in each way of the *Avenida de Ceuta* needs to be eliminated. To protect the riverbanks the same type of constructions is proposed, cribwall and rockfill interleaved with plants insections with higher speeds. To reduce the number of lanes without creating a traffic chaos it is necessary to increase the public transport offer, implementing new tram lines, more buses and the opening of *Alvito* train station. The access from *Alcântara* to A2 (highway number 2) should be altered allowing cars to access all directions from *Alcântara*, as well as the opposite.

Combining all the modification proposed for the *Alcântara* valley, a valuation of the different ecosystem services was done. The valuation considered different parameters from different

authors: Costanza et al. (1997), J. S. Pereira et al. (2007), Mangi (2012) and Wu & Li (2019). The final result is presented in table 1.

Results discussion

An ecosystem services analysis and a monetary valuation are very important to promote renaturalization interventions. Disseminate the information regarding the earnings of the intervention changes the public view of the project, allowing them to see the interventions as an investment instead of a charge.

The ecosystem services method is still difficult to fully implement due to the intangible benefits. Another difficulty associated with the benefits is the generalization of the values linked with the services, which vary significantly from place to place. In some locations people give more relevance environmental aspects, while in other places they give more relevance to social benefits. The tangible benefits need to adapt to the different location using new data, producing more realistic valuations.

Considering the case study, the first approach to the Avenida de Ceuta was to uneven one traffic lane in each way, allowing the watercourse to overflow and cover those lanes. This suggestion was rapidly excluded due to safety reasons, and because it was not the perfect solution in terms of environmental solutions.

The solutions proposed for the traffic diversion from the Avenida de Ceuta to A2 has to be complemented with an increase of public transport systems, because it is not sufficient to accommodate all the traffic from the Avenida de Ceuta. An economic review as to be made before the implementation.

The public transportation system needs a strong reinforcement, both in tram lines and buses. The opening of a train station in Alvito is also proposed in order to reduce the chaos of traffic in Alcântara.

In the begging, this type of project usually has a large number of criticisms only referring to the problems that it will create in traffic, without considering the benefits. Ecosystem services have an important role in order to change this negative view.

The geometries proposed for the two areas might change due to deep studies. With different flow conditions the geometry has to adapt, allowing new protection methods to be implement in the riverbanks.

The benefits regarding the reduction of air temperature will have some delay considering that only big trees have the capacity to reduce the temperature. Predicting how long does it take to start production positive results is very difficult, considering that it will vary with the amount of water, nutrients and light that trees will need.

The biggest limitation regarding the implementation of the proposals is the fact that most of the sewage systems is still combined. The full change will be very expensive and it will take a huge amount of time.

Conclusion

Through this dissertation several interventions on watercourses were analysed, and the benefits extracted from the interventions are environmental, social and economic. The constraints usually associated with this type of projects are: physical, climatic, cultural, political and legal. The importance given to each one of them varies from the location of the intervention.

Within the ecosystem's services the ones that have the biggest importance for watercourses are: Water Supply, Food Production, Primary Production, Air quality regulation and carbon sequestration, Climate regulation, Water quality regulation, Natural Disaster Regulation, Erosion prevention, Soil formation, Cultural heritage, education, aesthetic value, Tourism and Recreation, Maintenance of populations and habitats.

The principal areas of actuation on watercourses are: controlling riverbeds, erosion, flow velocity and infiltration, water quality, dredging and profound alterations on the envelope.

For controlling and protecting the riverbanks several methods were analysed. For urban watercourses the ones defined as the most suitable were: wall of gabions, rockfill interleaved with plants, cribwall, or the use of *faxinas.*

Tree locations on the Alcântara valley were selected. In the Avenida de Ceuta and in Quinta do Zé Pinto, the proposed protections were the cribwall, and in the areas were the flow speed was higher it should be used rockfill interleaved with plants. In Quinta do Zé Pinto an urban park was also propose. For the third location, the intersection of Avenida de Ceuta with Avenida Calouste Gulbenkian, it was only proposed an drainage basin, presenting the downstream areas to flood during heavy rain.

Future studies need to address intangible benefits more effectively, so it would be possible to produce more realistic values to the renaturalization projects. Implementing a balance between social and environmental measures if also very important in order to increase the connection between the population ant the intervened areas.

Tabela 1 – Valuation of ecosystem services in the three studied areas

Ecosystem Services		Initial Situation	Situation with the Proposal	Annual Appreciation (€)
Provisioning Services	Water Supply	Residual	Increased water seepage, aquifer recharge, increased amount of recycled water (WWTP) used	31.7
	Food Production	Non-existent	Urban vegetable garden, enhancement of wooded areas	564.0
	Primary Production	Negligible/ Non-existent	Biomass / fibber production in wooded areas	1 456.3
Regulatory and Supportive Services	Air quality regulation and carbon sequestration	Negligible/ Non-existent	Wooded areas, air quality improvements, increased carbon sequestration	1 114.4
	Climate regulation	Negligible/ Non-existent	Local temperature reduction	1 488.0
	Water quality regulation	Non-existent	Elimination of combined sewerage systems, increasing efficiency of domestic wastewater treatment, increased water filtration	5 174.4
	Natural Disaster Regulation	Covered watercourse - rapid outflow of large volumes of water	Creation of flood buffer zones, increased infiltration area with reduced runoff	28 152.1
	Erosion prevention	Negligible/ Non-existent	Increased wooded area with consequent reduction of runoff	1 090.9
	Soil formation	Negligible/ Non-existent	Increase due to wooded areas	108.2
Cultural / Social Services	Cultural heritage, education, aesthetic value	Non-existent	Promotion of renaturalization techniques and valorisation of ecological resources, promoting good environmental practices	6 863.0
	Tourism and Recreation	Non-existent	Creation of recreational areas	1 767.2
	Maintenance of populations and habitats	Negligible/ Non-existent	Resettlement of species and habitats	107 752.3

References

Alcamo, J., Ash, N. J., Butler, C. D., Callicott, J. B., Capistrano, D., Carpenter, S. R., … Hamilton, K. (2003). Ecossistemas e o Bem-estar humano: Estrutura para uma avaliação. *Avaliação Do Milênio Dos Ecossistemas*, 32. Retrieved from http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Ecossistemas+e+o+Bem-estar+Humano:+Estrutura+para+uma+Avalia��o#0

Chen, W. Y. (2017). Environmental externalities of urban river pollution and restoration: A hedonic analysis in Guangzhou (China). *Landscape and Urban Planning*, *157*, 170–179. https://doi.org/10.1016/j.landurbplan.2016.06.010

Conselho Nacional da Água. (n.d.). Água no Planeta Terra. Retrieved May 8, 2019, from conselhonacionaldaagua.weebly.com website: https://conselhonacionaldaagua.weebly.com/aacutegua-no-planeta-terra.html

Costanza, R., Arge, R., Groot, R. De, Farber, S., Hannon, B., Limburg, K., … Groot, D. (1997). The Value of the World ' s Ecosystem Services and Natural Capital. *Nature*, *387*(6630), 253–260.

FEUP, & ARHcentro. (2013). *ESTUDO ESTRATÉGICO PARA INTERVENÇÕES DE REABILITAÇÃO NA REDE HIDROGRÁFICA DA ARH DO CENTRO*. Retrieved from https://apambiente.pt/_zdata/Divulgacao/Projectos/agua/EstudoEstrategico/GuiaIntervencaoLinhasAguaARHC.pdf

Hua, J., & Chen, W. Y. (2019). Prioritizing urban rivers' ecosystem services: An importance-performance analysis. *Cities*, *94*(August 2018), 11–23. https://doi.org/10.1016/j.cities.2019.05.014

Island Press. (n.d.). Case Study: Cheonggyecheon; Seoul, Korea. Retrieved September 9, 2019, from Global Designing Cities Initiative website: https://globaldesigningcities.org/publication/global-street-design-guide/streets/special-conditions/elevated-structure-removal/case-study-cheonggyecheon-seoul-korea/

Joshi, Y. K., Tortajada, C., & Biswas, A. K. (2012). Cleaning of the Singapore River and Kallang Basin in Singapore: Economic, Social, and Environmental Dimensions. *International Journal of Water Resources Development*, *28*(4), 647–658. https://doi.org/10.1080/07900627.2012.669034

Lee, J., Park, B. J., Tsunetsugu, Y., Kagawa, T., & Miyazaki, Y. (2009). Restorative effects of viewing real forest landscapes, based on a comparison with urban landscapes. *Scandinavian Journal of Forest Research*, *24*(3), 227–234. https://doi.org/10.1080/02827580902903341

Mangi, B. (2012). Assessment of the changes of ecosystem services as a result of the tide management in the River Elbe. *Agric-Econ.Uni-Kiel.De*. Retrieved from http://www.agric-econ.uni-kiel.de/arbeiten_PDFs/2012/MA2012HalimaLB.pdf

Pereira, J. S., Mateus, J. A., Aires, L. M., Pita, G., Pio, C., David, J. S., … Rodrigues, A. (2007). Net ecosystem carbon exchange in three contrasting Mediterranean ecosystems - The effect of drought. *Biogeosciences*, *4*(5), 791–802. https://doi.org/10.5194/bg-4-791-2007

Ritchie, H., & Roser, M. (2018). Urbanization. Retrieved June 10, 2019, from https://ourworldindata.org/urbanization

Schirmer, M., Luster, J., Linde, N., Perona, P., Mitchell, E. A. D., Barry, D. A., … Durisch-Kaiser, E. (2014). Morphological, hydrological, biogeochemical and ecological changes and challenges in river restoration the Thur River case study. *Hydrology and Earth System Sciences*, *18*(6), 2449–2462. https://doi.org/10.5194/hess-18-2449-2014

Wu, S., & Li, S. (2019). Ecosystem service relationships: Formation and recommended approaches from a systematic review. *Ecological Indicators*, *99*(5), 1–11. https://doi.org/10.1016/j.ecolind.2018.11.068

Zhao, J., Liu, Q., Lin, L., Lv, H., & Wang, Y. (2013). Assessing the comprehensive restoration of an urban river: An integrated application of contingent valuation in Shanghai, China. *Science of the Total Environment*, *458–460*, 517–526. https://doi.org/10.1016/j.scitotenv.2013.04.042