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Nature based solutions as a promising alternative for river restoration and flood reduction

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Nature based solutions (NBS), have been used mainly in European countries, in the United States, and more recently in China. In this paper are identified international studies (2015-2018) which presented environmental solutions aiming at river requalification and reducing the effects of floods in municipalities. Based on the method of bibliographical revision, 12 (twelve) articles were selected. The results revealed that these nature based solutions of which uses tools from Natural Engineering and Biotechniques proved themselves to be efficient to promote the restoration of the hydromorphological conditions of the rivers, and its use in estuarine municipalities is suggested.

Keywords: Natural Engineering. Flood Mitigation. Manning Coefficient.

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Soluções baseadas na natureza como uma alternativa promissora para a restauração fluvial e a redução de inundações

Soluções baseadas na natureza (SBN), têm sido usadas principalmente em países europeus, nos Estados Unidos e, mais recentemente, na China. Neste trabalho são identificados estudos internacionais (2015-2018) que apresentaram soluções ambientais visando a requalificação dos rios e a redução dos efeitos das inundações nos municípios. Com base no método de revisão bibliográfica, foram selecionados 12 (doze) artigos. Os resultados revelaram que as soluções baseadas na natureza, que utilizam ferramentas da Engenharia Natural e Biotécnicas, mostraram-se eficientes para promover a restauração das condições hidromorfológicas dos rios, sendo sugerido seu uso em municípios estuarinos.

Palavras-chave: Bioengenharia. Mitigação de Alagamento. Coeficiente de Manning.

Soluciones basadas en la naturaleza como una alternativa prometedora para la restauración fluvial y la reducción de inundaciones

Las soluciones basadas en la naturaleza (NBS) se han utilizado principalmente en países europeos, en los Estados Unidos y más recientemente en China. En este artículo se identificaron estudios internacionales (2015-2018) que presentaron soluciones ambientales para la recalificación de los ríos y la reducción de los efectos de las inundaciones en los municipios. Basado en el método de revisión documental, se seleccionaron 12 (doce) artículos. Los resultados revelaron que estas soluciones basadas en la naturaleza, que utilizan herramientas de ingeniería natural y biotecnología, demostraron ser eficientes para promover la restauración de las condiciones hidromorfológicas de los ríos y se sugiere su uso en municipios estuarinos.

Palabras clave: Ingeniería natural. Mitigación de inundaciones. Coeficiente de Manning.

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Nature based solutions as a promising alternative for river restoration and flood reduction

Clarissa Rosa Vieira Della Justina et al.

1 Introduction

First mentions to the expression "nature based solutions (NBS)" were found in literature in the late 2000's (COHEN-SHACHAN *et al.*, 2016; POTSCHIN *et al.*, 2016). Despite of recent and still in debate (NESSHÖVER *et al.*, 2017) NBS conceptual formulation usually encompasses previously technological processes described literature and is often employed to mediate relations and interventions in the environment. Ecosystem based management researchers are giving attention to build a framework for the assessment of NBS co-benefits. Academic debates turn around the maintenance or restoration of ecosystem goods, functions and services, involving the design of practical alternatives able to cope simultaneously with environmental hazards, sustainable utilization of natural resources and human well-being promotion (NESSHÖVER *et al.*, 2017; RAYMOND *et al.*, 2017; KEESSTRA *et al.*, 2018).

Defined by the European Union as "actions inspired by, supported by or copied from nature; both using and enhancing existing solutions to challenges, as well as exploring more novel solutions" (NESSHÖVER *et al.*, 2017, p. 1217), NBS can be classified into three main categories: (i) better use of natural/protected ecosystems, with no or minimal intervention in ecosystems; (ii) management approaches for sustainability and multifunctionality of ecosystems and landscapes, commonly related to sustainable forestry, natural systems agriculture or agroecology; and (iii) design and management of new ecosystems, such as building green and blue infrastructures, including the restoration of heavily degraded or polluted areas to mitigate anthropogenic impacts, mainly in urban or in highly human-altered territories (COHEN-SHACHAN *et al.*, 2016; KEESSTRA *et al.*, 2018).

NBS are recommended as important tools for achieving the UN 2030 Agenda's Sustainable Development Goals (SDG) (UN, 2015), and are specially connected to SDG 6: "clean water and sanitation for all in the world", which will not be achieved through business-as-usual approaches (UNESCO, 2018). Managing water sustainably is challenged by water scarcity, poor water quality and inadequate sanitation in many poor places all around the world. Thus, upscaling and adopting NBS is considered central to face extreme events, ecosystems degradation and increasing water demand due to population and economic activities growth. NBS implementation usually involves low costs when compared to traditional engineering, structural interventions (grey structures) requires relatively few additional financial resources and has been indicated as the key for policy strategic actions aimed at dealing with water-related risks, enhancing water security, and managing water quality and availability (ECD, 2018; UNESCO, 2018).

Among integrated water resources management (IWRM) related NBS: natural wetlands, improvements in soil moisture and more efficient recharge of groundwater are the indicated solutions for drought mitigation and also for water availability, once they aim to improve water storage capacity in landscapes, preventing problems for scarcity periods. In urban and peri-urban environment, green infrastructure (including green buildings, green walls, roof gardens and vegetated infiltration or drainage basins) is increasingly being used to manage and reduce pollution from urban or storm water runoffs and also to support wastewater treatment, employing natural and artificial wetlands. According to UNESCO (2018), NBS for flood management is based on enhancing both the hydrological connectivity and the conveyance between hydric bodies' component, and can involve water retention by managing infiltration and overland flow.

Flooding is a natural process in which rivers and streams overflow and occupy the floodplain, but can also result from water accumulation in urbanized areas caused by poor drainage systems. This phenomenon represents a kind of hydrological hazard, eventually linked to occupation and anthropic use of riparian areas, and can contribute to increase in the state of human population's vulnerability in relation to risks and in danger (MIGUEZ *et al.*, 2018). Furthermore, the modification of river channels is responsible for changes on the dynamics of rivers and their river basins. Rectilinear stretches cause increases in channel slope and flow velocity (ASSUMPÇÃO; MARÇAL, 2012).

Flood risk management arises as a counterpart to hydrological disasters, their consequences and impacts. Managing risks involves socioeconomic and environmental issues, which encompass several actions at different points in the cycle of a disaster, activities such as: prevention, mitigation, preparedness, response, and recovery ones. Mitigation activities occur when the prevention one has failed, and a portion of the city is exposed to the risk of a hydrologic disaster occurring in a given flood event (MIGUEZ *et al.*, 2018). According to Canholi (2014) it is possible to classify mitigation activities as structural measures (characterized by the execution of works) and non-structural measures (characterized by laws, programs that govern awareness, environmental education, and control of the use and occupation within the municipalities).

Some authors advocate that public awareness of flood risk and sensitivity to environmental issues is a societal need that involves economic, technological and political aspects. The employment of an "Integrated Full Risk Management" model with focus on risk reduction, which could be applied on regional scale through the implementation of structural and non-structural measures is a challenge, in which risk identification and risk areas, mapping and risk assessment for the elaboration of management plans should all be considered (BARENDRECHT *et al.*, 2015). Academic literature in IWRM commonly states that the adaptive posture rather than the reactive approach would be indicated to deal with system uncertainties (CLARK; SEMMAHASAK, 2013). Adaptive management is postulated to be the ideal approach to deal with the risks associated with extreme events. In urban centers, it is usual to invest in structural measures to contain floods. Although costly or energy intensive, many engineering solutions are available, such as piping, flow retardation using detention or retention areas), soil erosion contention and drainage structures (bypass tunnels and channels) (CANHOLI, 2014), soil erosion contention structures, block barriers, docks, locks and dams, among others (CHADWICK *et al.*, 2017).

However, there are countries, such as the United States, Canada, England, Germany and Denmark, which have sought alternatives that aim to slow the flow of the river in the channel, generically named river requalification. This concept was inspired by the concepts of conservation and restoration, whose priority is the search for the original natural conditions of the rivers and streams, or by conditions closer to them (ASSUMPÇÃO; MARÇAL, 2012), and by the use of techniques that work together with nature (CHADWICK *et al.*, 2017). In this sense, many authors have turned their research towards sustainable solutions, with less artificial intervention, and using the materials disposed in nature.

Therefore, the present study aims to identify the main studies on the use of Natural Engineering and Biotechnology techniques as tools and mitigation activities that can contribute to the process of re-qualification of rivers and streams and thus reduce the effects of floods in municipalities, in view of the NBS proposal applicable to the low course of the estuarine municipalities.

2 Method

The present descriptive research followed the concepts of bibliometrics, as a method of bibliographical revision. It was based on the following bibliographic sources:

- The Brazilian scientific databases available from the Coordination of Improvement of Higher Education Personnel (CAPES) was used to identify experiences abroad, with focus on flood incident reduction, and likewise, experiments of restoration of the fluvial bed in the most natural way possible;

- Direct search of technical literature in hardcopy books, guides and/or digital manuals, contact with the author(s): the search was carried out by thematic area related to concepts of hydraulic, environmental and civil engineering, allied to the risk management of hydrological disasters and flood control works.

2.1 Database search details

The CAPES Portal includes the following databases: Scopus, Science Citation Index, Expanded (Web of Science), One File (Gale), Materials Science, Engineering Database, Technology Research, Database, ASFA (Aquatic Sciences and Fisheries Abstracts), and Science Direct Journals.

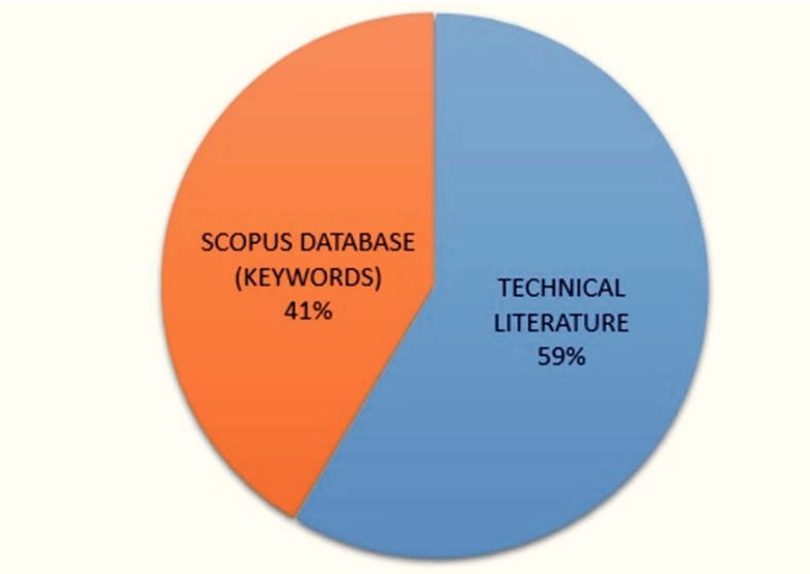
In the Homepage of CAPES portal, available at: www.periodicos.capes.gov.br, in the remote access area via "federated academic community (cafe)" the option of "Advanced search" was used ranging the limits of publications from Jan-2015 to May-2018 and filtered results in English. There were three (3) sets of researches, using different combinations of keywords: (1) roughness, manning, flood reduction, runoff and "restoration river"; (2) gabion, roughness and river; (3) "river hydraulic model" and "technique bioengineering".

3 Results and Discussion

3.1 Bibliometric Research Results

The bibliometry was based on 27 (twenty-seven) bibliographic data sources according to the distribution shown in Figure 1:

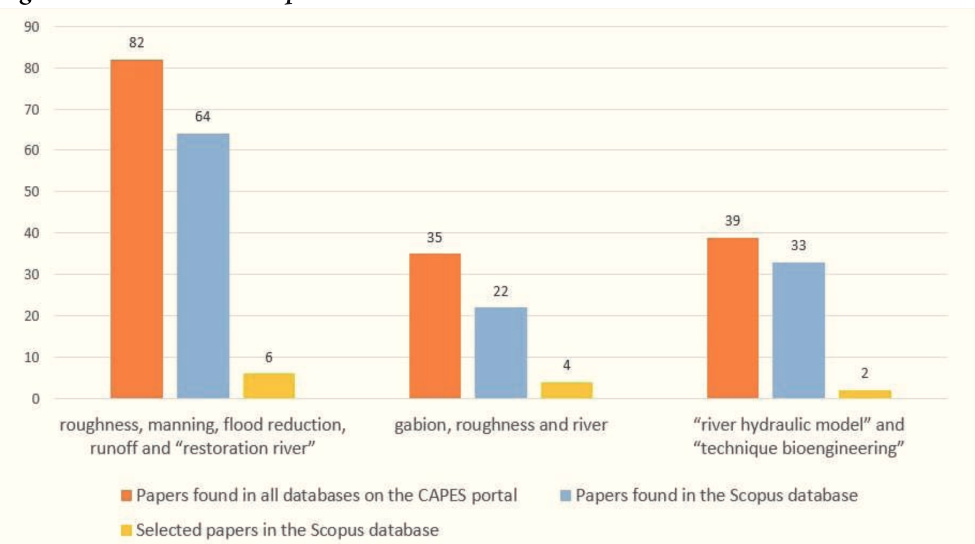
Figure 1. Distribution Chart of Bibliographic Sources



Source: Authors (2018)

The search for keywords in the CAPES portal found 156 (one hundred and fifty-six) articles located in several databases, such as Scopus, Science Citation Index, Expanded (Web of Science), One File (Gale), Materials Science, Engineering Database, Technology Research, Database, ASFA (Aquatic Sciences and Fisheries Abstracts), and Science Direct Journals. From the total articles found, 119 (one hundred and nineteen) are located in the Scopus database. The Figure 2 below shows the results obtained:

Figure 2. Search Result Graph in the CAPES Portal and SCOPUS Database



Source: Authors (2018)

Given the scope of the Scopus database, the 41% share shown in Figure 1 above (Distribution Chart of Bibliographic Sources), corresponds to the 12 (twelve) articles that were selected according to the proximity to the thematic area of the present research and then analyzed individually, after that grouped into three subgroups: (1) journal classification; (2) countries of origin of the article / countries under study; (3) thematic area. Table 1, 2 and 3 below discriminate each of the subgroups and list the identified articles:

Table 1. Bibliographic Review - Research in the Scopus Scientific Database (Journal Classification)

Journal Classification	Identified References
Ecological Economics	(DAIGNEAULT *et al.*, 2016)
Geomorphology	(WANG *et al.*, 2017), (NORMAN *et al.*, 2017), (MA *et al.*, 2016), (WOHL, 2017)
Enviromental Earth Sciences	(MONDAL *et al.*, 2018)
Water Enginnering/Hidrodynamics	(CHEN *et al.*, 2016), (CHAO *et al.*,2015)
Sediment Research	(PAN *et al.*, 2016)
Science of the Total Environment	(KEESSTRA *et al.*, 2018)

Source: Authors (2018)

Table 2. Bibliographic Review - Research in the Scopus Scientific Database (Countries of origin of the article/countries under study)

Countries of origin of the article / countries under study	Identified References
Fiji – Oceania	(DAIGNEAULT *et al.*, 2016)
United States of America	(MIROSLAW-SWIATEK; AMATYA, 2017), (WOHL, 2017), (NORMAN *et al.*, 2017)
China	(WANG *et al.*, 2017), (CHEN *et al.*, 2016), (PAN *et al.*, 2016), (CHAO *et al.*, 2015), (MA *et al.*, 2016)
India	(MONDAL *et al.*, 2018),
European countries	(KEESTRA *et al.*, 2018), (KIEDRZYN´SKA *et al.*, 2015)
Ethiopia	(KEESTRA *et al.*, 2018)

Source: Authors (2018)

Table 3. Bibliographic Review - Research in the Scopus Scientific Database (Thematic area)

Thematic Area	Identified References
Flow resistance analysis / use of vegetative matter / roughness	(MIROSLAW-SWIATEK; AMATYA, 2017), (WANG *et al.*, 2017), (CHAO *et al.*, 2015), (MA *et al.*, 2016), (WOHL, 2017)
Ecological management measures / flood risk management	(MONDAL *et al.*, 2018), DAIGNEAULT *et al.*, 2016), (KIEDRZYN´SKA *et al.*, 2015)
Use of Biotechniques (inert materials, gabions, woods)	(NORMAN *et al.*, 2017), DAIGNEAULT *et al.*, 2016), (WOHL, 2017)
Computational modelling / numerical simulation	(NORMAN *et al.*, 2017), DAIGNEAULT *et al.*, 2016), (WOHL, 2017), (MA *et al.*, 2016), (CHAO *et al.*, 2015)
Evaluation of the ecological restoration capacity of the coating / use of bioengineering/ solutions based on nature / ecological restoration techniques	(CHEN *et al.*, 2016), (PAN *et al.*,2016), (KEESSTRA *et al.*, 2018)

Source: Authors (2018)

3.2 Technical content result

Of the 27 (twenty-seven) bibliographic data sources that supported this research, some references were highlighted in which the methodology and materials used are presented below:

Liu *et al.* (2004) proposed a distributed model at WetSpa to study the rehabilitation of the Steinsel tributary of the Alzette river basin, Grand Duchy of Luxembourg. In the simulation, the proposal was based on the reconstitution of the riparian vegetation and the re-meandering of the river in the canal stretches.

The use of computational tools, such as hydrological simulation tools as WetSpa, Mohid Land, Hec-Ras and ArcHydro are collaborating in decision-making process in the design and execution of intervention projects to mitigate the occurrence of floods. The results of this study are presented in Table 1 and Table 2 (SANTOS *et al.*, 2016; NORMAN *et al.*, 2017).

Using computational modeling tools, Tavares *et al.* (2017) and Tavares *et al.* (2018) have identified that punctual solutions such as the construction of a dam on Macaé River, in the city of Macaé, Southeast of Brazil, respond positively at the site of implementation with 50% of the flood wave attenuation, but in downstream stretches such as the urban center of Macaé, it is restricted to only 10-15%.

In this context, it is important to mention the work of Chow (1959), who presented limit values to compose the roughness coefficient in natural and artificial waterways, obtained through practical experience acquired by the participation of project elaboration and execution of hydraulic works in the U.S.

In the literature review on Nordic experiences, Nilsson *et al.* (2018) pointed to ecological restoration measures in rivers to contain large floods. The proposal is to increase the roughness coefficient of the canal and evapotranspiration upstream from the propitious to full area by introducing retentive vegetation, lateral channel openings in a septic system, the introduction of representative timber and stones in the streams.

Arcement and Schneider (1989) studied the relationship of canal forms, their margin and bottom coatings, and the existence of obstructions such as tree trunks, boulders, bridge pillars. The study is performed by dividing the channel into section and cross-section in order to obtain an equivalent roughness coefficient.

Santos *et al.* (2016) developed an estimation of the infiltration potential of the Caçula basin of Ilha Solteira through the ArcHydro computational tool associated to land use and occupation data, geomorphology, geology, pedology, coverage analysis and regional precipitation. The interaction allowed to locate areas of accumulation of flow, greater potential of degradation, mass movements and erosion under the effects of floods.

Tavares *et al.* (2017) and Tavares *et al.* (2018) constructed a hydrological simulation model of Macaé river basin using Mohid Land software. Data such as topographic characteristics of the river basin, precipitation record and Manning roughness coefficient were used in the construction of the model. In the opportunity, the hypothetical reservoir implantation in Macaé river, located in the intermediate region of Macaé city, was analyzed to mitigate the effects of urban floods. The simulations analyzed periods of recurrence of 20 and 50 years.

Norman *et al.* (2017) presented a comparative study of geomorphological characteristics analysis in ephemeral canals in southeastern Arizona, USA. The monitoring lasted 3 (three) years in two sections of the channels: the first with a rock containment intervention built over 30 years; the second, a recent intervention with the use of gabion structure. The analysis combined field observations and computational modeling.

Miroslaw-Swiatek and Amatya (2017) studied the effects of the roughness provided by the introduction of cypress logs, (diameter and height), as resistance factors of the vegetation in the calculation of the flow of the river basin of the Turkey Creek located in South Carolina (USA). The hydraulic characteristics of the cypress trunks were determined by the inventory along the main stream channel. The Pasche method was used to calculate the Darcy-Weisbach total friction factor and in the calculation of discharge capacity of the studied watershed.

Muhtar and Abayati (2016) verified that, for open channel conditions, the roughness coefficient is more adaptable and precise in the Manning coefficient than in the Chezy's. It was verified in the experiment that, as the value of the roughness coefficient increases for Manning, the value of the flow decreases.

Fracassi (2017) analyzed roughness coefficient values obtained through practical experiments in reduced models. The materials used were gabions and gabion mattresses. After being tested in American laboratories, they were checked in the laboratories of the Hydraulic

Technological Center Foundation (FCTH in São Paulo) and confirmed at the National Water Institute (INA in Buenos Aires - Argentina). The results obtained in the tests showed a variation of 0.025 to 0.030 depending on the flow conditions.

It is observed that the values of the roughness coefficient obtained by Fracassi (2017) correspond only to the contribution part referring to materials, in this case, inert coatings, stones of varied diameter and wire mesh frame.

The Manning equation (1) below is used to determine the velocity from a known normal depth (Dn):

$$v = \frac{1}{n} R^{2/3} So^{1/2} \quad (1)$$

where: v = velocity [m/s]; So = channel declivity [m/m]; R = hydraulic radius [m]; n = roughness coefficient [$m^{-1/3}s$].

Using a combination with the continuity equation, we can obtain the flow Q (2) as a function of the value of the roughness coefficient n:

$$Q = \frac{a}{n} R^{2/3} So^{1/2} \quad (2)$$

where: *a* is the transversal area [m^2].

The hydraulic radius corresponds to the hydraulic efficiency of a channel because the higher the value of R, the greater the flow through the cross section (GRIBBIN, 2017). While the roughness coefficient, n, parameterizes the resistance of the coating to the flow. It can be calculated by means of the flow and the free surface dimension, from the knowledge of the cross section and slope. They are data that can be based on values calculated in similar channels (CHOW, 1959).

The surface roughness is characterized by the size and shape of the grains of the materials that form the wet perimeter and produce a retarding effect on the flow. Fine grains (sand, clay and silt) found in alluvial rivers provide a low value of n and are not affected by the change in channel flow, while grains with larger grain size, such as gravel and gravel, accumulate at the bottom of the channel and produce a value height of n at the lowest depth (CHOW, 1959).

The vegetation is also considered a type of surface roughness. Its characteristics (height, plant density, distribution and vegetation species) cause effects that considerably reduce the channel's ability (CHOW, 1959) to transport sediments of varying sizes and shapes (FRACASSI, 2017). The lower velocity of the flow corresponds to the smaller size of the material transported, and also the smaller carrying capacity of the materials (DURLO; SUTILI, 2014).

The cross sections of the channels are composed of subsections at points where there is greater inequality or change of geometry (forest junction or floodplain and main channel). As data, the velocity, the total force of resistance to the flow and the total discharge of the flow influence the determination of the coefficients of roughness for each subsection, and to obtain an equivalent n. (ARCEMENT; SCHNEIDER, 1989).

Chow (1959) explains that for the determination of the roughness coefficient it is necessary to understand the factors that affect the value of n; consult typical values of n presented in tables for conditions already studied in similar works; perform research on typical channels, whose roughness coefficients are known; determine the value of n by an analytical procedure based on the theoretical velocity distribution in the cross section of the channel and the speed or roughness measurement data.

According to Miguez *et al.* (2016), the existence of obstructions along the path of the flow also contributes to the increase of the roughness coefficient of Manning. Toothed Ramps, Impact Blocks, and Step Creation create mechanisms that assist in the dissipation of flow energy (PMSP, 1999).

The lower reaches of the rivers generally consist of a large flood plain. It is a temporary natural storage system for floods (CHADWICK *et al.*, 2017). Floodplains have a high contribution potential for water and air quality, local landscape, ecosystem preservation, and the distribution and maintenance of an efficient natural drainage network (PMSP, 1999).

The search for delaying the flow in the gutter and the floodplains, encompasses concepts of conservation and restoration. It is a process of river requalification, which seeks to restore rivers in a more natural way (MIGUEZ *et al.*, 2018). The solutions studied need to guarantee the maintenance of the greater bed (floodplain) of the streams. Preserve the windings (meanders), promote the restoration of ciliary vegetation, and other measures that seek to clean up the bottoms of valleys (CANHOLI, 2014).

New constructive methods and the use of diverse materials have been evaluated so that the dynamics of the rivers and streams and the hydromorphological characteristics are reestablished (FRACASSI, 2017).

Table 4 below describes some of the biotechniques used that may be associated with Bioengineering:

Table 4: Practices of Biotechniques and Natural Engineering (Bioengineering) ***(continues)***

Techniques	Intervention method	Function
Beams	Longitudinal hydraulic work	stabilization of the slope and revegetation of the banks
Layer of shrubs	branches cut into layers between layers of soil	Bank reinforcement
Stakeout	use of living material in the form of stakes (near the site)	by means of rooting facilitating the development of a new plant
Planting	woody species and shrubs of native species	River flow riverside protection
Rolo estruturado	cylindrical structure made of coconut fiber between shrubs	increase consolidation between the rollers and the ground, and guarantee the re-vegetation of the river banks
Biomanta and geomanta	lattice structure of organic or inorganic composition	soil protection against surface erosion; seed revegetation

Table 4: Practices of Biotechniques and Natural Engineering (Bioengineering) *(conclusion)*

Techniques	Intervention method	Function
Systems of reinforced soil with vegetation	soil use and double twist wire mesh/polymeric material with high tensile strength	containment structure (reinforcement) installed with cut branches and /or plants with roots on the front face
Blanket vegetated initially	coconut fiber mat or geosynthetic blanket	vegetated with emerging aquatic plants /roots already developed
Gabions with soil	wire mesh box, double twist and vegetable soil	Stabilization and erosion control
Reinforced floor structure	compacted soil block and double twist wire mesh.	Contention structure that promotes the growth of vegetation
Inert elements	loosen stones	prevent the erosion of the river bank
Gabion box and gabion mattress	Double twist wire mesh boxes filled and bonded together with stones.	continuous protection works, contribute to a natural drainage of the slope and protection against erosion.

Source: adapted from Fracassi (2017)

4 Conclusion

It was observed that China has been highlighting with research related to bioengineering techniques, its performance and influence in sediment load and river flow. Meanwhile, European and American researchers have turned their research into managing flood mitigation measures and river requalification techniques.

It was evidenced that the techniques of Natural Engineering, using living natural matter as the vegetation, have been more explored as research object than the Biotechniques, with the use of inert material such as gabions, rockfills, metallic screens, and tree trunks, among others. When they are used together, they are important tools for the elaboration of the river requalification project in stretches of rivers and streams that have undergone a straightening of the route.

These techniques contribute to the increase in the Manning roughness coefficient, and can still significantly attenuate the peak flood and provide reduction of the flow velocity of the channel in the downstream stretch. They should be studied for each section and subsection of a channel, where there is a change in the physical conditions of the site. Studies on NBS for river requalification are still incipient in Brazil.

That the final result as a mitigation proposal for the reduction of flood effects will depend on the state of recovery and requalification which the river was classified/categorised. After the restoration of the hydro-morphological characteristics of the river, it can contribute in a positive way in response to the floods.

The studies carried out in this research contribute to the elaboration of a model of risk management that attends the particularities of the retilinized stretches of the rivers. It is also important to study the geomorphological characteristics of the respective sections that compose an intervention proposal, using computational simulation to analyze and predict the hydrological effects.

River engineering needs to develop a more holistic view and to propose specific techniques able to "work along with the nature". Best practices should be previously studied trough ecosystem based management lens prior to the evaluation of local projects, and have an interface with hydrology, hydraulics, sediment transport, river morphology, geomorphology, wildlife, landscape, recreation, fishing areas, navigation water quality, groundwater, archeology, aquatic biology and fluvial maintenance, as recently stated by Chadwick and coworkers. Otherwise, the achievement of SGD 6´s targets will not be feasible neither in local nor in regional or global scales.

References

ARCEMENT, G. J.; SCHNEIDER, V. R. *Guide for Selecting Manning´s Roughness Coefficients for Natural Channels and Flood Plains*. U.S.: Geological Survey, 1989. DOI: 10.3133/wsp2339

ASSUMPÇÃO, A. P.; MARÇAL, M. S. Retificação dos canais fluviais e mudanças geomorfológicas na planície do rio Macaé, RJ. *Revista de Geografia (UFPE)*, v. 29, n. 3, 2012.

BARENDRECHT, M. H.; VIGLIONE, A.; BLÖSCH, G. A dynamic framework for flood risk. *Water Security*, n. 1, p. 3-11, 2017. http://dx.doi.org/10.1016/j.wasec.2017.02.001.

CANHOLI, A. P. *Drenagem urbana e controle de enchentes.* 2. ed. São Paulo: Oficina de Textos, 2014.

CHADWICK, A.; MORFETT, J.; BORTHWICK, M. *Hidráulica para engenharia civil e ambiental.* Tradução de Tibério Júlio Couto Novais. Revisão técnica William Bonino Rauen. 5. ed. Rio de Janeiro: Elsevier, 2017.

CHAO, W. *et al*. Interactions between vegetation, water flow and sediment transport: A review. *J. Hydrodyn*, v. 27, n. 1, p. 24-31, 2015. DOI: http://dx.doi.org/10.1016/S1001-6058(15)60453-X.

CHEN, Y.; XU, S.; JIN, Y. Evaluation on Ecological Restoration Capability of Revetment in Inland Restricted channel. *KSCE Journal of Civil Engineering*, v. 20, n. 6, p. 2548-2558, 2015. DOI: http://dx.doi.org/10.1007/s12205-015-0291-6.

CHOW, V. *Open Channel Hydraulics*. Tóquio: McGraw-Hill, 1959.

CLARK, J. R. A.; SEMMAHASAK, C. Evaluating Adaptive Governance Approaches to Sustainable Water Management in North-West Thailand. *Environmental Management*, v. 51, p. 882-896, 2013. http://dx.doi.org/10.1007/s00267-012-9993-4.

DAIGNEAULT, A.; BROWN, P.; GAWITH, D. Dredging versus hedging: Comparing hard infrastructure to ecosystem-based adaptation to flooding. *Ecological Economics*, n. 122, p. 25-35, 2016. DOI: http://dx.doi.org/10.1016/j.ecolecon.2015.11.023.

DURLO, M. A.; SUTILI, F. J. *Bioengenharia*: manejo biotécnico de cursos de água. 3. ed. Santa Maria: O autor, 2014.

ECD. European Commission Decision. *EN Horizon 2020*: Work Programme 2018-2020, 12: Climate action, environment, resource efficiency and raw materials. 2018.

FRACASSI, G. *Proteção de rios com soluções Maccaferri*. São Paulo: Oficina de Textos, 2017.

GRIBBIN, J. E. *Introdução a hidráulica, hidrologia e gestão de águas pluviais*. Tradução A. P. S. Aguiar; Revisão técnica M Libâneo. 4. ed. São Paulo: Cengage Learning, 2017.

KEESSTRA, S. *et al*. The superior effect of nature based solutions in land management for enhancing ecosystem services. *Science of the Total Environment*, n. 610/611, p. 997-1009, 2018. DOI: http://dx.doi.org/10.1016/j.scitotenv.2017.08.077.

KIEDRZYN´SKA, E.; KYEDRZYN´SKI, M.; ZALEWSKI, M. Sustainable floodplain management for flood prevention and water quality improvement. *Nat Hazards*, n. 76, p. 955-977, 2015. DOI: http://dx.doi.org/10.1007/s11069-014-1529-1.

LIU, Y.B. *et al*. Simulation of flood reduction by natural river rehabilitation using a distributed hydrological model. *Hydrology and Earth System Sciences*, v. 8, n. 6, p. 1129-1140, 2004.

MA, Y.; QING HUANG, H. Controls of channel morphology and sediment concentration on flow resistance in a large sand-bed river: A case study of the lower Yellow River. *Geomorphology*, n. 264, p. 132–146, 2016. DOI: http://dx.doi.org/10.1016/j.geomorph.2016.03.035.

MIGUEZ, M. G.; GREGORIO, L. T. di; VERÓL, A. P. *Gestão de riscos e desastres hidrológicos*. 1. ed. Rio de Janeiro: Elsevier, 2018.

MIGUEZ, M. G.; VERÓI, A. P.; REZENDE, O. M. *Drenagem urbana:* do projeto tradicional à sustentabilidade. 1. ed. Rio de Janeiro: Elsevier, 2016.

MIROSLAW-SWIATEK, D.; AMATYA, D. M. Effects of cypress knee roughness on flow resistance and discharge estimates of the Turkey Creek watershed. *Annals of Warsaw University of Life Sciences SGGW*, n. 49, p. 179-199, 2017.

MONDAL, S.; PATEL, P. P. Examining the utility of river restoration approaches for flood mitigation and channel stability enhancement: a recent review. *Environmental Earth Sciences*, n. 77, p. 195-220, 2018. DOI: https://doi.org/10.1007/s12665-018-7381-y.

MUHTAR, B.; ABAYATI, M. A. Determination Of Chezy´s And Manning´s Coefficient For Different Aggregate Bed Using Different Notches In Hydraulic Bench. *International Journal of Scientific & Technology Research,* v. 5, n. 3, p. 167–175, 2016.

NESSHÖVER, C. *et al*. The science, policy and practice of nature-based solutions: An interdisciplinary perspective. *Science of the Total Environment*, n. 579, p. 1215–1227, 2017. DOI: http://dx.doi.org/10.1016/j.scitotenv.2016.11.106.

NILSSON, C. *et al*. Ecological Restoration as a Means of Managing Inland Flood Hazards. *BioScience*, v. 68, n. 2, p. 89-99, 2018. DOI: http://dx.doi.org/10.1093/biosci/bix148.

NORMAN, L. M. *et al*. Quantifying geomorphic change at ephemeral stream restoration sites using a coupled-model approach. *Geomorphology*, n. 283, p.1-16, 2017. DOI: http://dx.doi.org/10.1016/j.geomorph.2017.01.017.

PAN, B. P. *et al*. A review of ecological restoration techniques in fluvial rivers. *International Journal of Sediment Research*, n. 31, p. 110–119, 2016. DOI: http://dx.doi.org/10.1016/j.ijsrc.2016.03.001.

POTSCHIN, M. *et al*. Nature-Based Solutions. *OpenNESS,* 2016. Available in: http://www.biomimicry.org. Access in: 7 out. 2018.

RAYMOND, C. M. *et al*. A framework for assessing and implementing the co-benefits of nature-based solutions in urban areas. *Environmental Science and Policy*, n. 77, p. 15–24, 2017. DOI: http://dx.doi.org/10.1016/j.envsci.2017.07.008.

SANTOS, F. M.; LOLLO, J. A. Low cost potential infiltration estimation for wet tropical watersheds for territorial planning support. *Journal of Urban and Environmental Engineering (JUEE),* v. 10, n. 2, p.233-241, 2016. DOI: http://dx.doi.org/10.4090/juee.2016.v10n2.233241.

SÃO PAULO (cidade). Prefeitura Municipal de São Paulo. *Diretrizes básicas para projetos de drenagem urbana no município de São Paulo.* São Paulo: FCTH, 1999.

SHACHAM, E. C. *et al. Nature-based Solutions to address global societal challenges*. Gland (Switzerland): IUCN, 2016. DOI: http://dx.doi.org/10.2305/IUCN.CH.2016.13.en.

TAVARES, L. P. da S. *et al*. Modelagem hidrológica da bacia hidrográfica do Rio Macaé utilizando o MOHID Land. *Boletim do Observatório Ambiental Alberto Ribeiro Lamego*, Campos dos Goytacazes, Essentia Editora, v. 11, n. 1, p. 169-181, jan./jun. 2017. Disponível em: http://www.essentiaeditora.iff.edu.br/index.php/boletim/article/view/9916/7596. Access in: 16 jul. 2018.

TAVARES, L. P. S. *et al*. Water management and urban flood mitigation: studies and proposals for the Macaé river basin in Brazil. *Journal of Urban and Environmental Engineering (JUEE)*, v. 12, n. 8, 2018.

UN. United Nations. *Transforming our world*: the 2030 Agenda for Sustainable Development, 2015.

UNESCO. United Nations Educational, Scientific and Cultural Organization. *The United Nations World Water Development Report 2018:* Nature-based solution for water nature. France: UNESCO, 2018. Available in: http://www.unesco.org/new/en/natural-sciences/environment/water/wwap/. Access in: 7 out. 2018.

WANG, S. *et al*. Effects of vegetation on debris flow mitigation: A case study from Gansu province, China. *Geomorphology*, n. 282, p. 64–73, 2017. DOI: http://dx.doi.org/10.1016/j.geomorph.2016.12.024.

WOHL, E. Bridging the gaps: An overview of wood across time and space in diverse rivers. *Geomorphology*, n. 279, p. 3–26, 2017. http://dx.doi.org/10.1016/j.geomorph.2016.04.014.