ISSN: 2230-9926

Available online at http://www.journalijdr.com

IJDR

International Journal of Development Research
Vol. 11, Issue, 05, pp. 46864-46868, May, 2021
https://doi.org/10.37118/ijdr.21776.05.2021

RESEARCH ARTICLE **OPEN ACCESS**

ECONOMIC VIABILITY OF STREAMBANK STABILIZATION WORK WITH NATURE-BASED SOLUTIONS APPLIED TO A PIPELINE STREAM CROSSING IN SOUTH AMERICA

Rita dos Santos Sousa*[1], Junior Joel Dewes[2], Charles Rodrigo Belmonte Maffra[3] and Fabrício Jaques Sutili[4]

[1]PhD in Forest Engineering, Postdoctoral Researcher, Soil Bioengineering Laboratory, Center of Rural Sciences, Federal University of Santa Maria, Brazil; [2]MS., PhD student in Forest Engineering, Soil Bioengineering Laboratory, Center of Rural Sciences, Federal University of Santa Maria, Brazil; [3]PhD in Forest Engineering, Soil Bioengineering Laboratory, Center of Rural Sciences, Federal University of Santa Maria, Brazil; [4]PhD. Prof., Department of Forest Sciences, Center of Rural Sciences, Federal University of Santa Maria, Brazil

ARTICLE INFO

Article History:
Received 20th February, 2021
Received in revised form
10th March, 2021
Accepted 27th April, 2021
Published online 22th May, 2021

Key Words:

Costs, Erosion control, Hydraulic stabilization, Infrastructure works, Soil bioengineering.

Corresponding author: Rita dos Santos Sousa

ABSTRACT

Pipelines are critically essential transportation infrastructures in most nations since they are essential to both standards of living, and economies. Traditional streambank stabilization in pipelines river crossings is carried out with civil engineering techniques. Environmental concerns have increased the demand for low environmental impact techniques that value the ecological characteristics and the hydraulic connectivity of fluvial systems. Soil bioengineering as a nature-based solution can be a suitable alternative to the civil engineering, which aside from being usually expensive, do not consider ecological issues. This work aimed to analyze the economic viability of a soil bioengineering work to stabilize a stream bed and banks with a pipeline stream crossing compared to a traditional engineering solution. Thus, to carry out the economic analysis, a comparison was made between the proposed budget for the civil engineering and the total cost of a soil bioengineering work performed. The financial analysis showed that the bioengineering intervention had a 49.06% lower cost than the solution foreseen by civil engineering, with the highest percentage of total value (39.97%) related to the materials acquisition. In conclusion, the soil bioengineering work presented economic viability to stabilize the streambed and banks when compared to the civil engineering solution.

Citation: Rita dos Santos Sousa, Junior Joel Dewes, Charles Rodrigo Belmonte Maffra and FabrícioJaques Sutili, 2021. "Economic viability of streambank stabilization work with nature-based solutions applied to a pipeline stream crossing in South America", *International Journal of Development Research*, 11, (05), 46864-46868.

INTRODUÇÃO

According to the American Society of Mechanical Engineers, the total length of transmission pipelines transporting gas and oil around the world has been estimated at 3.5 million km (64% carry natural gas, 19% carry petroleum products, and 17% carry crude oil). Additionally, 32,000 km of new onshore and 8,000 km offshore pipelines are constructed each year worldwide (Hopkins, 2007a; Sovacool and Dworkin, 2014). Brazil has a network of pipelines with 19,717 km of extension (5,959 km carry refined petroleum product, 11,696 km carry natural gas, 1,985 km crude oil, and 77 km carry ethanol/petrochemical) (CIA, 2020). Pipeline systems are critically essential transportation infrastructures in most nations since they are essential to both standards of living, and economies (Hopkins, 2007b). Although accidents on pipelines have low probability of occurrence (Zhou and Chen, 2015), when it happens has serious consequences in human health and safety, production, assets, and environmental losses (Norhamimi *et al.*, 2015), especially for transportation and distribution hazardous liquid pipelines. Pipelines may cross rivers, streams, and washes, and typically those pipelines are buried in the streambed, but may also be elevated aboveground on bridges (Day *et al.*, 1998). Pipelines in river crossings are more vulnerable to be exposed when heavy rain and floods occur. Exposed pipelines are submitted to tension stresses and are more susceptible to suffer from hydraulic–geotechnical risks, like support problems, vortex-induced vibration, debris flow, and other mass movements, and mechanical integrity issues, such as thermal variation and damage to cathodic protection (Maffra, Sousa and Sutili, 2017; Maffra and Sutili, 2020). Traditional streambank stabilization is carried out with conventional techniques of civil engineering such as gabion walls, concrete walls, and riprap. In pipelines river crossings are also employed techniques such as reinforced soil with woven polypropylene geotextiles, cellular confinement systems filled with soil-cement (Costa *et al.*, 2005), concrete revetment mattresses

(Witheridge, 2017), rock armoring, among other traditional techniques from civil engineering. However, these techniques, apart from expensive, may also cause severe impacts in the environment, adversely affecting the health and biodiversity of aquatic life, the hydraulic connectivity and the green corridor along the river. Environmental concerns have increased the demand for nature-based solutions with low environmental impact, that value the ecological characteristics and the hydraulic connectivity of fluvial systems, even in infrastructure works. In confronting this problem, nature-based solutions such as soil bioengineering can be a feasible alternative to the traditional techniques of civil engineering, which aside from being expensive, do not take into account ecological issues (Coppin and Richards, 2007; Sousa, Dewes and Sutili, 2018). Soil bioengineering pursues technological, ecological, and economic goals, as well as designs and seeks to achieve these primarily by using live materials (seeds, plants, parts of plants, and plant communities), which can be combined with inert materials (Schiechtl, 1980). Bioengineering techniques can be applied to structural problems for geotechnical and hydraulic stabilization, to control surface erosion processes, and simultaneously to design ecosystems in dynamic equilibrium (Sousa, 2015). The financial analysis and the cost-benefit ratio of bioengineering interventions are fundamental to specify the most appropriate solution that meets the technical and environmental conditions without neglecting economic conditions. Furthermore, benefit-cost analysis is a powerful tool to assist in decision making, since when benefits are quantified more efficient decisions can be made (Hagen *et al.*, 2001). As indicated by several authors, soil bioengineering presents more cost-efficient solutions than traditional civil engineering solutions (Donat, 1995; Schiechtl and Stern, 1996; Cornelini and Sauli, 2005; Coppin and Richards, 2007; Studer and Zeh, 2014; Bloemer *et al.*, 2015). However, evidence is needed to improve our understanding of the range of economic and environmental benefits provided by nature-based solutions like soil bioengineering techniques in infrastructure works such as pipelines. This work aimed to analyze the economic viability of a soil bioengineering work to stabilize a stream bed and banks with a pipeline stream crossing compared to a traditional civil engineering solution.

MATERIALS AND METHODS

Study area description: The study area is located in Cariacica, Espírito Santo state in Brazil. The area is in the rural zone, where the terrain conditions are very steepened, geotechnically characterized by the talus occurrence and the presence of solid blocks of variable dimensions. The vegetation cover is composed by forest areas, banana plantations, and pastures (Maffra, Sousa and Sutili, 2017). The region's climate is tropical Aw, where the rainy season is between October and January (Alvares *et al.*, 2013). In the summer of 2011/2012, there were intense rainfall events, especially in the week between 3rd and 10th January 2012, where there was an accumulated rainfall of 260 mm with a peak of 100 mm recorded on 06th January. The action of these rains exposed the gas pipeline and fiber optic cables due to the occurrence of an erosive process along 20 m of the stream bed and banks. As a consequence of the high velocity of water flow and the watershed characteristics, the pipeline was partially exposed and started to function as a dam and began to support additional tensions and whirling flow forces. In addition, the exposed pipeline has a higher risk of being damaged by third-party actions and greater susceptibility to geotechnical events typical of the region such as rock falls and debris flow. Furthermore, the technical standard of PETROBRAS N 464, specifies that pipelines must be protected with coverage with a thickness between 1.0 - 1.5 m, depending on their location (Petrobras, 2012). The characteristics of the stream stretch with the submerged gas pipeline crossing, after erosion processes, can be observed in Figure 1. In order to avoid erosion processes developing, as well as the loss of slope stability and likely damage to the pipeline, a civil engineering project was designed in October 2011. Afterward, the company that owns the pipeline requested another project that meets the technical conditions imposed by the erosion process typology but also presents an ecological feature to reduce the impact of the work on the environmental characteristics of the site. This project was mainly designed with soil bioengineering techniques and then submitted to the analysis and approval of the Brazilian Environmental Agency (*IBAMA*). The project was developed between September and December 2012, by the Soil Bioengineering Laboratory (LabEN) of the Federal University of Santa Maria (UFSM).

Figure 1. Stream after erosion processes with unstable bed and banks.a Landslide at the left side of the streambank; b Detail of exposed fiber the optical cables

Economic analysis: To carry out an economic analysis a comparison was performed between the proposed budget for the civil engineering work and the total cost of bioengineering work performed in 2014. The cost conversion was made from Brazilian Reais to Euros considering the exchange value in September 2019. The costs, considering all the expenses involved in executing the work, namely labor, materials, and equipment, as well as all the necessary infrastructure for execution (construction site, local administration, mobilization, and demobilization) were then analyzed for the two constructive solutions.

Description of intervention techniques: The civil engineering design was composed by gabion walls for stabilizing the streambanks and gabion mattress for stabilizing the streambed (Figure 2). The gabion was designed as being 2.5 m high, 24.0 m in length and 2.0 m deep at the base and 1.0 m deep at the top of the structure, filled with 210 m^3 of rock. The mattress was designed having 200 m^2 of area and 0.23 m thickness, filled with 60 m^3 of rock. The application of non-woven geotextile with a density of 200 g/m^2 in a quantity of 460 m^2 was also considered.

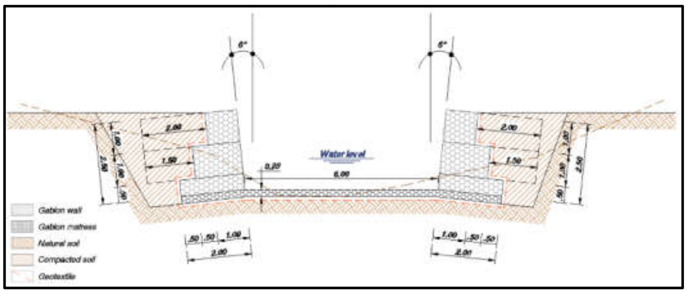

Figure 2. Site type section with Civil Engineering interventions

The soil bioengineering project was composed by the left bank stabilization with vegetated log cribwall having 2.6 m height, 7.5 m length, and 2.25 m depth. The structure was filled with 45 m^3 of soil, 675 autochthonous shrubs, and live cuttings, and 18 straw wattles of 0.3 m in diameter. The constructive details of the live cribwall can be observed in Figure 3. The right bank was protected with straw wattles of 0.3 m in diameter, straw geotextile, planting of autochthonous seedlings, and seeding. Streambed stabilization was performed with a small dam executed with 16 m^3 of concrete. A drainage system was also designed on the top of the cribwall to redirect rainwater surplus from the slope. The drainage consisted of 25 m of channels with dimensions of 30 x 30 cm executed in cement grouted rocks and reinforced concrete.

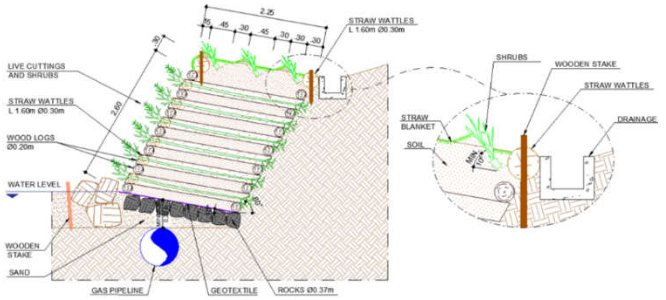

Figure 3. Left streambank type section with vegetated log cribwall

In the design phase, were performed hydrological and hydraulic analyzes, and geotechnical calculations for all structures. The solutions adopted were sized for a recurrence interval of 25 years, exceeding the lifetime considered for the pipeline by 5 years.

RESULTS AND DISCUSSION

The civil engineering solution budget was € 93,997.60, and the total cost of the soil bioengineering execution was € 47,885.10. The financial analysis showed that the bioengineering intervention had a 49.06% lower cost than the solution foreseen by civil engineering. This percentage is within the values reported by Venti et al. (Venti *et al.*, 2003), who state that biotechniques are 40% to 90% less expensive than traditional interventions. Sousa et al. (Sousa, Dewes and Sutili, 2018) found a 50% lower value for bioengineering in a comparative study carried out in Brazil. Lewis et al. (Lewis, Salisbury and Hagen, 2001) found that bioengineering was 42,93% less expensive than traditional methods considering the evaluation of three sites with soil bioengineering works. Hagen et al. (Hagen *et al.*, 2001) also found that soil bioengineering techniques can also be considered a viable solution with a higher benefit-cost ratio than the traditional interventions for roadside management problems. It is important to note that since the civil engineering solution has not been implemented, it is not possible to make a real analysis of its final execution cost. Usually, the costs are higher in the execution phase than projected. This occurs because the conditions during work execution cannot be fully predicted at the design stage, such as rainy days, delays with suppliers, smaller or less efficient working teams than those considered in the project, among others. Therefore, the bioengineering work could potentially be even more economical. Besides that, soil bioengineering solutions have a longer life cycle and less maintenance than traditional methods (Hagen *et al.*, 2001).

The comparative cost for the two interventions based on the total cost of each work phase is shown in Figure 4. The costs of the initial services, temporary work, and final services are the same for the two solutions. The cost difference for earthworks is related to the need for greater soil movement to execute the gabion wall and the mattress. Building the transversal structures cost € 4,984.50. This phase does not exist in the civil engineering solution, since building structures that act transversally to the water flow was not foreseen. The longitudinal structures in the civil engineering project would cost € 63,179.20, and in the bioengineering project cost € 11,863.20. This means that the longitudinal structures in the biotechnical intervention had an 81.22% lower cost than those predicted for the traditional solution. This difference of values is because the impacted area for biotechniques execution is smaller than the area required for gabion walls. The materials are also more economical than the gabion mesh and rocks. The execution time of the biotechnical structures (5 days) is also shorter than expected for the execution of the gabions (25 days). These differences explain the large difference between the final values. Only the execution value for the gabion walls represents a total of 24.21% higher cost than all the soil bioengineering work. A comparative percentage of manpower, materials, and machines can be performed for each solution in relation to the total costs, as observed in Figure 5. The civil engineering design had a total budget of € 93,997.60, of which 47.61% refers to materials acquisition, 29.70% corresponds to manpower, 22.30% to the use of machines, and 0.39% for the topography services, as shown in Figure 5 (to the right). The total cost for soil bioengineering work was €47,885.10, for which 39.97% refers to materials, 30.12% to machines, 29.15% to manpower, and 0.76% to topography services, as shown in Figure 5 (to the left).

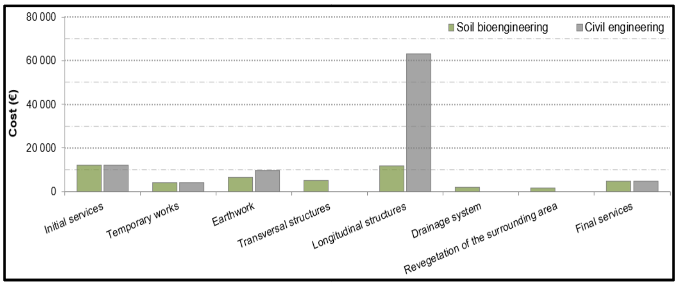

Figure 4. Comparative cost of civil engineering and soil bioengineering works based on the total costs of each phase

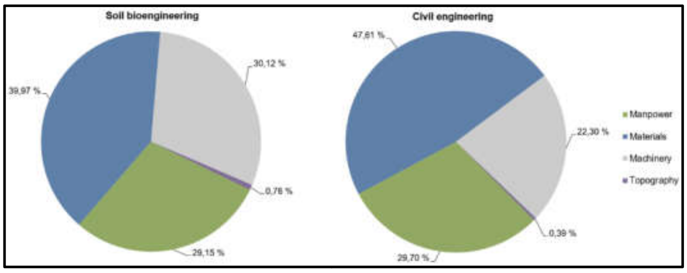

Figure 5. Percentage of costs regarding the use of manpower, materials, machinery, and topography for civil engineering and soil bioengineering works

Figure 6. Evolution of soil bioengineering work. a Work immediately after execution in August 2014; b Intervention after 16 months.

The highest costs in the soil bioengineering intervention are related to materials acquisition. In this type of work, preference is usually given to using existing materials on site (wood, rocks, and plants) (Fernandes and Freitas, 2011), which means that acquisition costs are low, and the higher costs are usually assigned to manpower, as verified in works performed in Europe (Italy) and Central America (Ecuador, Guatemala, and Nicaragua) (Petrone and Preti, 2005). Labor costs in Italy are higher due to higher employee salaries, while these costs in Ecuador, Guatemala, and Nicaragua are high because of the use of local manpower instead of technologies (more sophisticated materials and machines), as a way of supporting the creation of jobs. In this case, the workforce presented lower percentage costs than materials, since there were no materials at the intervention site likely to be used, except for live cuttings. In addition, manpower in Brazil, mainly in the construction industry, has lower salaries when compared with European or North American countries. However, for works where all materials are available at the intervention place, there will be no costs related to their acquisition (Sotir and Gray, 1992; Watson, Abt and Thornton, 1994), which could make these interventions even cheaper. In addition to presenting economic viability, the performed soil bioengineering work met the criteria for which it was designed. The execution of the live cribwall on the left bank provided the consolidation of the slope, while the drainage system allowed the redirection of rain surpluses to the stream.

The techniques of the right bank prevented the progression of the erosive process and the enlargement of the watercourse. The construction of the small dam promoted the formation of a new longitudinal profile and therefore soil and rocks deposition and retention above the pipeline. Furthermore, to the technical benefits, the intervention provided ecological and aesthetic gains. The use of autochthonous plants promoted the establishment of a more developed plant community in the frame of the natural vegetation succession and increased biodiversity and habitat functionality. Figure 6 shows the work after the execution and the results after 16 months of evolution.

CONCLUSION

The civil engineering solution budget was € 93,997.60, and the total cost for executing the soil bioengineering project was € 47,885.10. The financial analysis showed that the soil bioengineering intervention had a 49.06% lower cost than the solution foreseen by civil engineering. The highest percentage of the total value of the soil bioengineering work was related to the materials acquisition (39.97%), while machinery, manpower, and topography represented 30.12%, 29.15%, and 0.76%, respectively. In conclusion, the soil bioengineering work presented economic viability to stabilize the stream bed and banks when compared with a traditional civil engineering solution. Besides, the bioengineering work proved to be technically and ecologically feasible. The reduction of environmental impacts plays a fundamental role in ecological restoration and conservation actions, and therefore it can be assumed that soil bioengineering techniques have a higher intrinsic value due to their ecological and aesthetic functions. Furthermore, in emerging markets such as Brazil and other South American countries, where transportation infrastructures like pipelines have such economic importance, the use of nature-based solutions should be encouraged since they have low environmental impacts, are technical and ecological suited, and besides these are cost-competitive.

Acknowledgments: The authors acknowledge the support of the National Petroleum, Natural Gas and Biofuels Agency (ANP), the Leopoldo Américo Miguez de Mello Research and Development Center (CENPES/PETROBRAS) and Coordination for the Improvement of Higher Education Personnel (CAPES).

REFERENCES

Alvares, C. A. *et al.* (2013) 'Köppen's climate classification map for Brazil', *Meteorologische Zeitschrift*, 22(6), pp. 711–728. doi: 10.1127/0941-2948/2013/0507.

Bloemer, S. *et al.* (2015) *European Guidelines for Soil and Water bioengineering*. Europäische Föderation für Ingenieurbiologie. Available at: http://www.rdpc.uevora.pt/handle/10174/14589 (Accessed: 21 October 2018).

CIA (2020) *The World Factbook - Field Listing: Pipelines*, *Central Intelligence Agency*. Available at: https://www.cia.gov/library/publications/resources/the-world-factbook/fields/383.html (Accessed: 26 February 2020).

Coppin, N. J. and Richards, I. G. (eds) (2007) *Use of Vegetation in Civil Engineering*. 2ª. London, UK: Construction Industry Research and Information Association (CIRIA).

Cornelini, P. and Sauli, G. (2005) *Manuale di Indirizzo delle Scelte Progettuali per Interventi di Ingegneria Naturalistica*. Roma, Itália: Ministero dell'Ambiente e della Tutela del Territorio, Direzione Generale per la Difesa del Suolo, Progetto Operativo Difesa Suolo (PODIS).

Costa, C. A. *et al.* (2005) 'The repair of ground cover of Bolivia-Brazil gas pipeline near Paraguay River crossing, in a swamp soft soil region, using geo synthetics reinforced backfilling (IBP1286-05)', in *Proceedings of Rio Pipeline 2015 Conference & Exposition*. *Rio Pipeline Conference & Exposition 2005*, Rio de Janeiro, Brasil: Instituto Brasileiro de Petróleo Gás e Biocombustíveis, p. 8. Available at: https://www.osti.gov/etdeweb/biblio/20890463 (Accessed: 25 February 2020).

Day, N. B. *et al.* (1998) *Pipeline Route Selection for Rural and Cross Country Pipelines*. Reston, Virginia, USA: ASCE Publications (ASCE Manuals and Reports on Engineering Practice, 46).

Donat, M. (1995) *Bioengineering Techniques for Streambank Restoration - A Review of Central European Practices*. 2. Canada: British Columbia, Watershed Restoration Program, Ministry of Environment, Lands and Parks and Ministry of Forests, p. 92.

Fernandes, J. and Freitas, A. (2011) *Introdução à Engenharia Natural*. Portugal: EPAL - Empresa Portuguesa das Águas Livres, S.A.

Hagen, S. *et al.* (2001) 'Soil Bioengineering as an Alternative for Roadside Management: Benefit-Cost Analysis Case Study', *Transportation Research Record: Journal of the Transportation Research Board*, 1794(1), pp. 97–104. doi: 10.3141/1794-12.

Hopkins, P. (2007a) 'Oil and Gas Pipelines: Yesterday and Today. Pipeline Systems Division, International Petroleum Technology Institute, American Society of Mechanical Engineers. USA'. Pipeline Systems Division, International Petroleum Technology Institute, American Society of Mechanical Engineers.

Hopkins, P. (2007b) 'Pipelines: Past, Present, and Future', in *Proceedings 5th Asia Pacific IIW International Congress*. *5th Asia Pacific IIW International Congress*, Sydney, Australia: International Institute of Welding, p. 27.

Lewis, L., Salisbury, S. and Hagen, S. (2001) *Soil Bioengineering for Upland Slope Stabilization*. Seattle, Washington: Washington State Transportation Center (TRAC) (Research Project, WA-RD 491.1).

Maffra, C. R. B., Sousa, R. S. and Sutili, F. J. (2017) 'Engenharia Natural para estabilização de travessia dutoviária - Caso 2', *Ciência & Ambiente*, 46/47, pp. 153–176.

Maffra, C. R. B. and Sutili, F. J. (2020) 'The use of soil bioengineering to overcome erosion problems in a pipeline river crossing in South America', *Innovative Infrastructure Solutions*, 5(1), p. 24. doi: 10.1007/s41062-020-0273-5.

Norhamimi, M. H. *et al.* (2015) 'Environmental Loss Assessment for Gas Pipeline Failure by Considering Localize Factors Using Fuzzy Based Approach', *Applied Mechanics and Materials*, 735, pp. 163–167. doi: https://doi.org/10.4028/www.scientific.net/AMM.735.163.

Petrobras (2012) 'Norma Técnica Petrobras N-464 - Construção, montagem, e condicionamento de duto terrestre'. Rio de Janeiro.

Petrone, A. and Preti, F. (2005) *Ingegniería naturalística en Centroamérica*. Istituto Agronomico per L'Oltremare. Firenze: Società Editrice Fiorentina.

Schiechtl, H. (1980) *Bioengineering for land reclamation and conservation*. Edmonton, Canada: Department of the Environment, Government of Alberta. University of Alberta Press.

Schiechtl, H. and Stern, R. (1996) *Ground bioengineering techniques for slope protection and erosion control*. Oxford, UK: Blackwell Science Ltd.

Sotir, R. and Gray, D. H. (1992) *Soil Bioengineering for Upland Slope Protection and Erosion Reduction*. United States Department of Agriculture-Natural Resources Conservation Service. Washington, D.C.: Soil Conservation Service, USDA/NRCS (Engineering field handbook).

Sousa, R. S. (2015) *Metodologia para especificação de plantas com potencial biotécnico em Engenharia Natural*. Dissertação de Mestrado. Universidade Federal de Santa Maria.

Sousa, R. S., Dewes, J. J. and Sutili, F. J. (2018) 'Viabilidade econômica de uma obra de estabilização fluvial realizada com técnicas de Engenharia Natural', in *Anais do XIII Congresso Florestal Estadual do Rio Grande do Sul*. *XIII Congresso Florestal Estadual do Rio Grande do Sul*, Nova Prata.

Sovacool, B. K. and Dworkin, M. H. (2014) *Global Energy Justice - Problems, Principles, and Practices*. Cambridge, UK: Cambridge University Press.

Studer, R. and Zeh, H. (2014) *Soil Bioengineering: Construction Type Manual*. 2ª. Zurich: vdf Hochschulverlag an der ETH.

Venti, D. *et al.* (2003) *Manuale Tecnico di Ingegneria Naturalistica della Provincia di Terni. Applicabilità delle tecniche, limiti e soluzioni*. Itália: Provincia di Terni, Servizio Assetto del Territorio.

Watson, C. C., Abt, S. R. and Thornton, C. I. (1994) *Recommendations for Bioengineering Stabilization of Five Sites on Harland Creek, Mississippi*. Commander U.S. Army Corps of Engineers Waterways Experiment Station. Colorado: Civil Engineering Department Colorado State University. Available at: http://www.usbr.gov/tsc/techreferences/hydraulics_lab/pubs/PAP/PAP-0777.pdf (Accessed: 4 September 2016).

Witheridge, G. (2017) *Erosion & Sediment Control Field Guide for Pipeline Projects – Part 1*. Brisbane, Queensland: Catchments and Creeks Pty Ltd.

Zhou, Z. H. and Chen, G. H. (2015) ‘Challenges to Risk Management of Underground Transmission Hazardous Material Pipelines in China’, *Procedia Engineering*, 130, pp. 1503–1513. doi: 10.1016/j.proeng.2015.12.319.

****