Research, Society and Development, v. 9, n. 11, e109119444, 2020
(CC BY 4.0) | ISSN 2525-3409 | DOI: http://dx.doi.org/10.33448/rsd-v9i11.9444

Water reuse at the pulp and paper industry using water source diagram

Reuso de água na indústria de celulose e papel usando diagrama de fontes de água

Reutilización del agua en la industria de pulpa y papel usando el diagrama de fuente de agua

Received: 10/19/2020 | Reviewed: 10/24/2020 | Accept: 10/28/2020 | Published: 10/30/2020

Marianna Oliveira Moura
ORCID: https://orcid.org/0000-0001-8107-6661
Universidade Federal de Pernambuco, Brasil
E-mail: marianna.omoura@gmail.com
José Jailton Marques
ORCID: https://orcid.org/0000-0001-6927-6089
Universidade Federal de Sergipe, Brasil
E-mail: jjailton@academico.ufs.br
Inaura Carolina Carneiro da Rocha
ORCID: https://orcid.org/0000-0002-5654-0714
Universidade Federal de Sergipe, Brasil
E-mail: inaura.rocha@academico.ufs.br

Abstract

One of the main issues in the present and upcoming decades is the improvement of natural resource use efficiencies. The industrial use of water is preferred as a target for the implementation of sustainable models of water management with the purpose of reducing the use of this resource and generates less waste. This study aims the application of the Water Source Diagram (WSD) method in paper industry, typology associated to high wastewater generation, as a potential strategy to achieve sustainable industrial processes through wastewater reuse. Operational data from paper industry were provided by previous works. Two scenarios of freshwater consumption were generated to model the system. Both cases showed that the freshwater consumption may be reduced over 30.22%, in relation to the baseline of no reuse. The efficiency of the WSD was also compared to other results reported in the literature. Although economic evaluation has not been addressed in this work, the method could be considered as a strategic tool for decision making.

Keywords: Water; Reuse; WSD; Operation; Paper.

Resumo

Um dos principais problemas nas décadas atuais e nas próximas é a melhoria da eficiência do uso dos recursos naturais. O uso industrial da água é preferido como alvo para a implantação de modelos sustentáveis de gestão da água com o objetivo de reduzir o uso desse recurso e gerar menos resíduos. Este estudo visa à aplicação do método Diagrama de Fontes de Água (DFA) na indústria de papel, tipologia associada à alta geração de efluentes, como uma estratégia potencial para alcançar processos industriais sustentáveis por meio do reuso de efluentes. Os dados operacionais da indústria de papel foram fornecidos por trabalhos anteriores. Dois cenários de consumo de água doce foram gerados para modelar o sistema. Ambos os casos mostraram que o consumo de água doce pode ser reduzido em mais de 30,22%, em relação à linha de base de não reutilização. A eficiência do DFA também foi comparada com outros resultados relatados na literatura. Embora a avaliação econômica não tenha sido abordada neste trabalho, o método pode ser considerado uma ferramenta estratégica para a tomada de decisões.

Palavras-chave: Água; Reuso; DFA; Operação; Papel.

Resumen

Uno de los principales problemas de la presente y las próximas décadas es la mejora de la eficiencia en el uso de los recursos naturales. Se prefiere el uso industrial del agua como objetivo para la implementación de modelos sostenibles de gestión del agua con el propósito de reducir el uso de este recurso y generar menos residuos. Este estudio tiene como objetivo la aplicación del método Diagrama de fuente de agua (DFA) en la industria papelera, tipología asociada a alta generación de aguas residuales, como una estrategia potencial para lograr procesos industriales sostenibles a través de la reutilización de aguas residuales. Los datos operativos de la industria del papel fueron proporcionados por trabajos anteriores. Se generaron dos escenarios de consumo de agua dulce para modelar el sistema. Ambos casos mostraron que el consumo de agua dulce puede reducirse más del 30,22%, en relación con la línea de base de no reutilización. La eficiencia del DFA también se comparó con otros resultados reportados en la literatura. Si bien la evaluación económica no se ha abordado en este trabajo, el método podría considerarse como una herramienta estratégica para la toma de decisiones.

Palabras clave: Agua; Reutilizar; DFA; Operación; Papel.

1. Introduction

The 2030 Agenda consists of a Declaration with 17 objectives and 169 goals, which make up an action plan created to guide nations on the most sustainable path, by the year 2030. The reuse and recycling of water in industry are strictly related to objective 12 (responsible consumption and production) and 9 (industry, innovation and infrastructure), demanding a change in the way we produce and consume goods and resources (United Nations Development Programme [UNDP], 2020).

One of the main issues to achieve these objectives is the improvement of resource use efficiencies by integrating various life supporting systems, in a such way that the wastes of one mankind activity can be used as inputs to others being beneficial to the system at all (Urbaniec, 2016). In this context, industries must be highlighted since they are great consumers of water for use as raw material or auxiliary input of production (Mierzwa & Hespanhol, 2005). The high costs related for water capture and wastewater discharge have encouraged reuse within the industrial environment (Mancuso & Santos, 2009) by reducing the volume of fresh water and generating fewer effluents. However, an ecologically correct operation reduces the water capture costs, but increases the investment in technology and the value of the necessary inputs, which leads to an increase in the cost of the aqueous stream treatment (Souza et al., 2009).

Thus, the WSD consists of a method of process integration, conceptually related to the IE and Cleaner Production (CP) models, that provides support for decision making in the field of sustainable industrial management, by enabling the setup of optimized water networks in different reuse and regeneration situations, rationalizing water consumption within the industry (Mirre, 2012). It is a theoretical method based on heuristic rules and mass transfer brought together in an algorithm, where a contaminant load added to the process during an operation is transferred at a given rate to the extractive agent, hypothetically taken as water in this case (Souza et al., 2010). It meets criteria of simplicity, industrial applicability, efficiency and economy, being one of the main tools in the management of industrial waters (Calixto et al., 2020). WSD can be viewed as an improvement of other procedures (Castro et al., 1999; Gómes et al., 2001). Further description of how the WSD works is available in literature (Gomes et al., 2007; Calixto et al., 2015).

WSD encompasses a variety of situations, such as (i) reuse; (ii) multiple water sources; (iii) water losses along the process; (iv) flow rate constraints; (v) regeneration and reuse; and (vi) regeneration and recycling. Moreover, it is beneficial to point out that this procedure, like the graphical one proposed (Wang & Smith, 1994) considers all types of process possibilities, but in an easier way than the others that have been used (Gomes et al., 2007).

Some studies on WSD have been conducted in recent years by expanding and improving the procedure. One of them (Gomes et al., 2013) used data from different studies previously published to develop a WSD extension for multi-contaminant processes with a focus on maximum reuse, applying concepts to choose the reference contaminant. On the other hand, another study (Calixto et al., 2015) presented a new approach to WSD downgrading the significance of choosing the reference contaminant in multicomponent cases by adopting a decomposition strategy. Other approach (Francisco et al., 2015) seen as an extension of the method for water networks involving processes with flow fixation and contaminant loads, either individually or simultaneously (hybrid systems), as well as considering water losses. They applied the method in four case studies: 1) Production plant of a chemical specialty; 2) Aluminum oxide plant; 3) Case 2 plus regeneration process operating as a centralized treatment; 4) Brazilian pulp mill.

The paper industry is one of the branches where the potential for implementing the method can be demonstrated, since this category figures in the world ranking of water consumption. In the final stage of paper production, there is water input due to the wet pulp from previous stages and for use in cleaning, lubricating and cooling the machine. Water is used and discarded in most operations of this industry, from the formation of the pulp to the final product, a fact that still drives the search for new water reuse approaches (Hamaguchi, 2007).

In this sense, the aim of this study is the application of WSD as a strategy both for the reduction of water consumption and wastewater generation in paper industry, through water networks with minimum input of freshwater to the paper processing, focusing on the efficiency of WSD compared to other methodologies.

2. Materials and Methods

The methodology used in this research fits the quantitative and descriptive type, (Pereira et al., 2018), based on a case study from literature. Specific data were collected from previous works and used to design new water source diagrams. The procedure presented in this work for processes in batches followed the approach of Immich et al. (2007).

2.1 Industrial process overview

Pulp and paper mill production is growing every year worldwide. As a consequence, the volume of generated waste is increasing, along with increasing concern of this topic (Simão et al., 2018). Since 2013 the USA, China, Canada, Brazil, Sweden, Finland, Japan, Russia, Indonesia and Chile have been the top ten pulp producers (Swedish Forest Industries Federation [SFIF], 2019). In 2018, Brazil solidified its position as the world's second largest producer of cellulose pulp, behind only the USA. A total of 21.1 million tons of highyield pulp was produced, including both short fiber (eucalyptus) and long fiber (pine) cellulose, via the chemical process. Besides, Brazil ranks eighth among global paper producers, with 10.4 million tons (Indústria Brasileira de Árvores [Ibá], 2019).

Thus, the proposal of applying WSD procedure in the paper industry was drived by the large quantity of process water and its consequent great wastewater generation. The overall water consumption is of about 0.076 to 0.227 m3/kg of product and approximately the same ratio of high strength wastewater in terms of biochemical oxygen demand (BOD), chemical oxygen demand (COD), suspended solids (SS), toxicity and color (Pokhrel & Viraraghavan, 2004).

Wastewater details and further description about the chain of papermaking industry are available elsewhere (Alexandersson, 2003; Monte et al., 2009; Khodaparas & Kamali, 2015). In the branch of cellulosic biomass, all transformation from the extraction of the raw material to the final product can be divided into two main processes: pulp production (pulping) and paper production (papermaking). In general, the main stages of pulping are the removal of soil, impurities and shells from the raw material, the breaking of the fibers into small pieces and the separation of the lignin and hemicellulose fibers from the cellulose fibers, which are used in the formation of paper. All this process results in a pulp with selected and well distributed fibers. Regarding to the paper production, it occurs in the paper machine (or papermaking process) and is the moment in which the pulp is dewatered and dried by means of pressing and drying mechanisms (Khodaparas & Kamali, 2015). Altogether, there are operations such as cleaning, lubricating and cooling that also demand great quantities of water.

Papermaking can be divided generally into three stages: wet or forming section, press section and dry section. In the first section, the aqueous fiber suspension is spread on a porous belt, where water removal and retention of fibers and additives occur. The pressing section, composed of rolls and presses, is responsible for increasing the dry content to 35-50%, which is raised again to 90-95% after passing through the dry section, which has the function of removing the additional water. After this last section, the sheet is stored in the form of reels, for further cutting, packaging and transport (Alexandersson, 2003).

2.2 Case study

The case study was carried out on the operational data presented in two reports (Yang et al., 2000; Koppol et al., 2003) that provided optimized water networks for different operations of a papermaking, using mathematical programming methods, focusing on the removal of total suspended solids (TSS). These studies gave support to configuration of the system submitted to the WSD, as shown in Table 1 where the all the operation/currents are fully characterized by their respective mass loads and maximum output and input TSS concentrations.

Table 1. Operational data of the case study total suspended solids.

Operation	Description	$m^{(1)}$(kg/s).10^3	$C_{in, max}{}^{(2)}$(ppm)	$C_{out, max}{}^{(3)}$(ppm)	$f_L{}^{(4)}$(kg/s)
OP1	Head box	1.94	0	200	9.72
OP2	Breast roll	6.22	100	500	15.56
OP3	Knockoff	17.38	200	650	38.61
OP4	Trim squirt	0.56	0	200	2.78
OP5	Wire pit	2.43	50	300	9.72
OP6	Cooling water	0.29	50	200	1.94
OP7	Vaccum pumps	3.67	50	300	14.67
OP8	Cylinder showers	10.42	300	600	34.72
OP9	Felt showers	0.92	20	100	11.56

(1) m is the quantity of contaminant transferred over time in a given operation;
(2) $C_{in, max}$ is the maximum contaminant concentration permitted at the inlet;
(3) $C_{out, max}$ the contaminant concentration at the outlet of the operation
(4) f_L is the operation flow rate
Source: Yang et al. (2000) and Koppol et al. (2003).

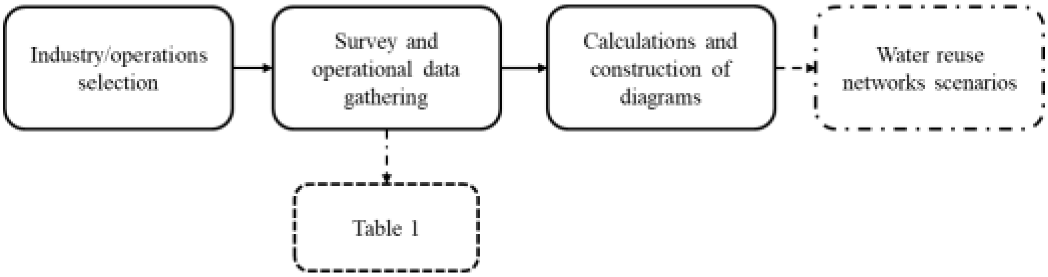
The construction of mass transfer networks followed three main heuristic rules foreseen by the WSD - which must be observed always when reuse can be applied: (i) external sources of water are used only when internal sources are unavailable; (ii) the maximum amount of contaminant must be transferred within the established concentration range; (iii) when an operation splits over more than one interval, the stream must follow to the end, so that the division of operations is avoided (Souza et al., 2009; Mirre, 2012; Gomes et al., 2007).

The application of WSD procedure aiming for the maximum reuse followed the steps

(CC BY 4.0) | ISSN 2525-3409 | DOI: http://dx.doi.org/10.33448/rsd-v9i11.9444

exhibited in Figure 1.

Figure 1. Step-by-step of WSD procedure.



Source: Authors.

The procedure requires two calculation sequences: the first one to obtain water consumption without reuse application (A); the second to obtain the fresh water consumption for maximum reuse, through the WSD (B). In this way, it becomes possible to verify the efficiency of WSD to minimize water use by comparing the obtained values. Both sequences were based on Table 1, by using equations to calculate the maximum load of contaminant to be transferred in each interval for each operation (Equation 1) and to calculate the necessary flow to remove the contaminant in each interval of each operation (Equation 2).

$$\Delta m_{kj} = f_{Lk} . (C_{fj} - C_{ij}) \quad (1)$$

$$f_{pkj} = \Delta m_{kj} / (C_{fj} - C_P) \quad (2)$$

where:

Δm_{kj}: load of contaminant transferred in operation k, in the interval j.

f_{pkj}: flow from the external or internal source p required for the removal of the contaminant in operation k, in the interval j.

f_{Lk}: operating limit flow k.

C_{fj}: final concentration of the interval j.

C_{ij}: initial concentration of the interval j.

C_P: concentration of external or internal source. Afterwards, the diagrams referring to the sequences (A) and (B), representing the situation without reuse and the two scenarios proposed for consumption with reuse, are carried out.

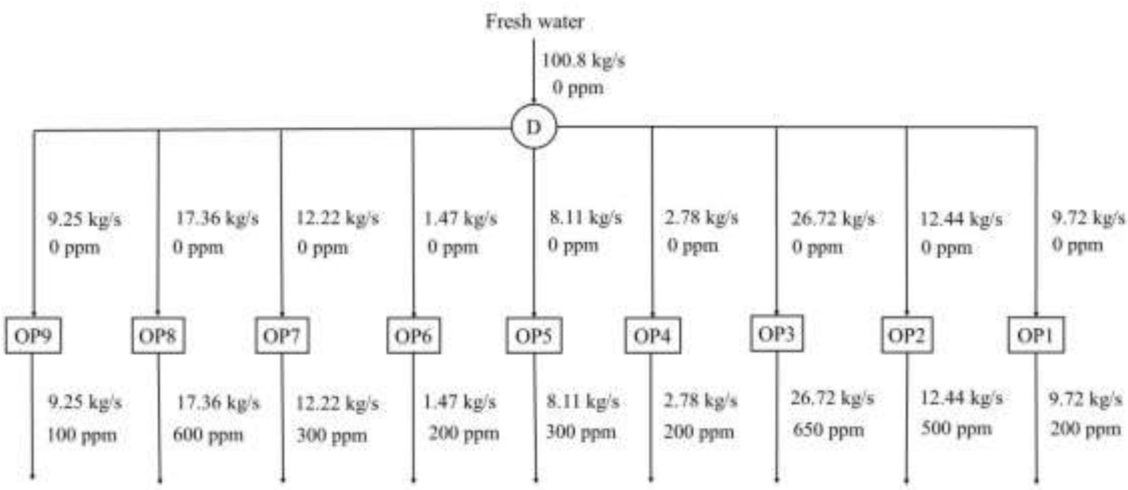
3. Results and Discussion

Water networks were designed to illustrate two situations: (A) without reuse and (B) by considering reuse.

3.1 Water network without reuse (A)

The diagram of water consumption without reuse considering TSS contaminant as the reference showed that the flow rate requirement for the papermaking is 100.8 kg/s for the TSS concentrations (ppm). The values depicted in Figure 2 correspond to the final network obtained through the use of equations (1) and (2), as exemplified below.

Figure 2. Water network for a paper machine without water reuse where there is a division of currents represented by D.



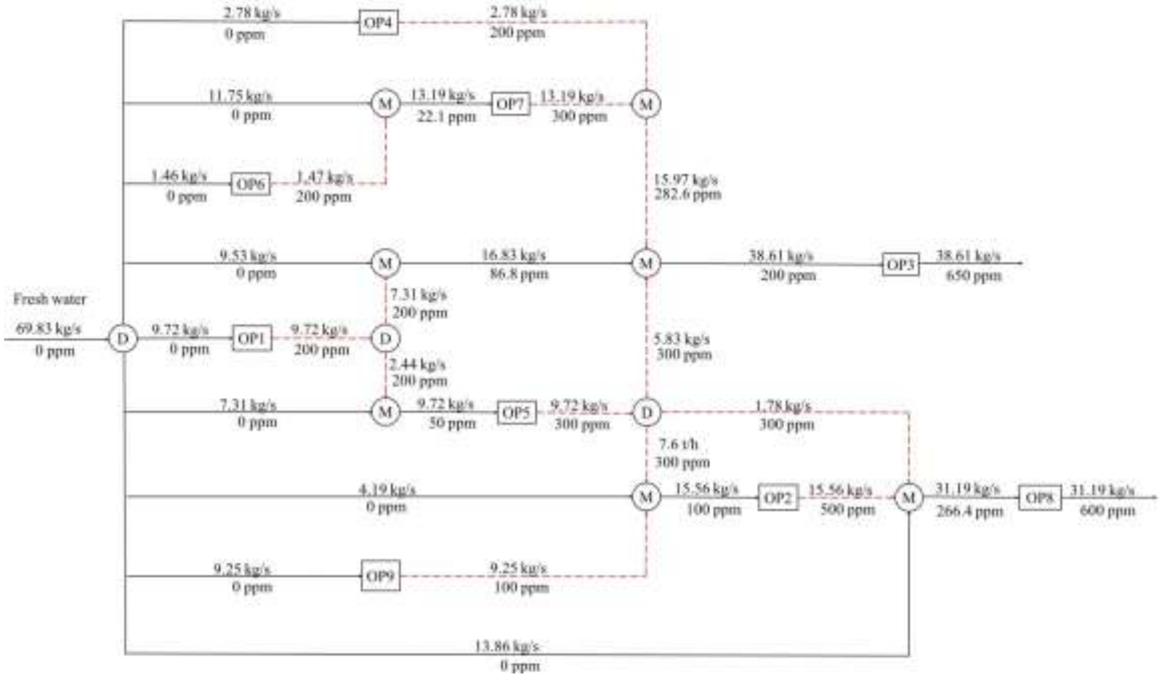
Source: Authors.

3.2 Water networks with reuse (B)

Two water distribution networks were obtained based on the WSD procedure for maximum reuse scenario. Both cases showed that the freshwater consumption may be reduced to 69.83 kg/s (Figure 3 and Figure 4), which represents a minimization of 30.25 kg/s (30.22%), in relation to the baseline of no reuse. A full comparison between the cases is summarized in Table 2, showing the freshwater consumption before and after optimization for each operation in each proposed scenario.

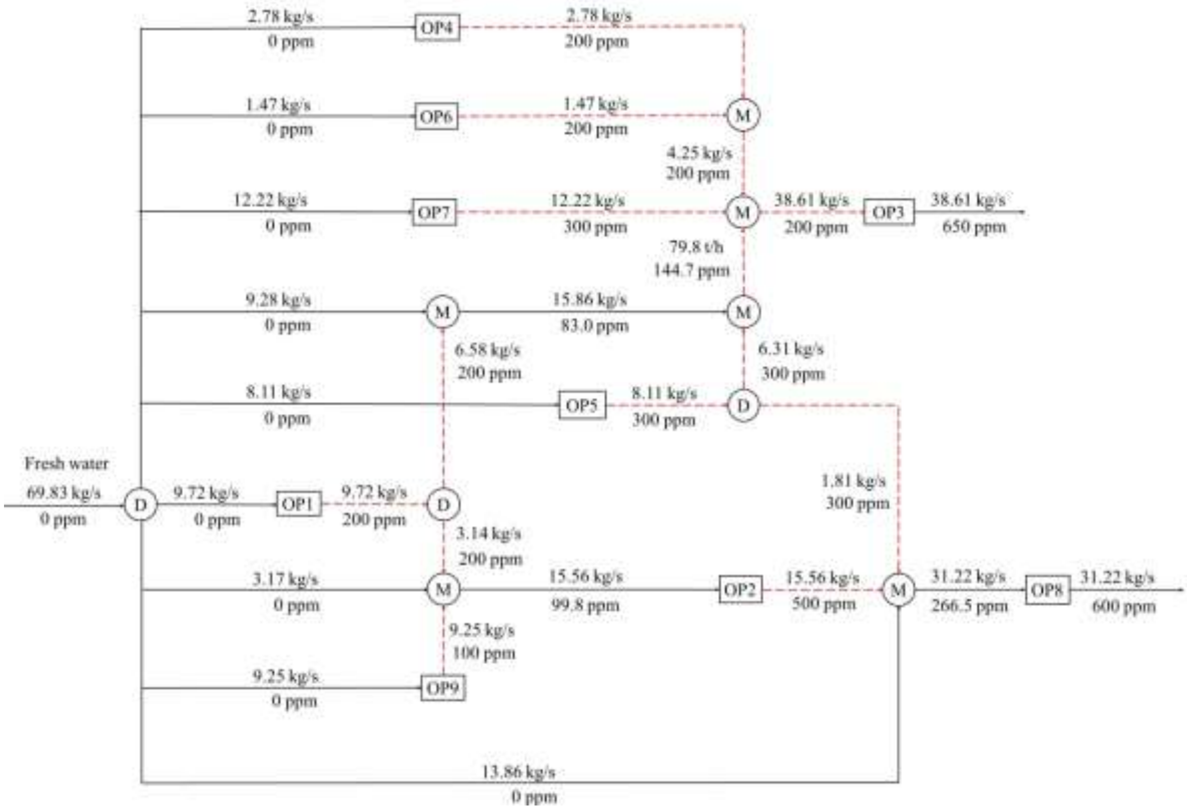
(CC BY 4.0) | ISSN 2525-3409 | DOI: http://dx.doi.org/10.33448/rsd-v9i11.9444

Figure 3. Optimized water network 1 for maximum reuse, where M and D represent stream mixers and splitters, respectively.



Source: Authors.

Figure 4. Optimized water network 2 for maximum reuse, where M and D represent stream mixers and splitters, respectively.



Source: Authors.

Table 2. Comparison of freshwater consumption in papermaking with and without reuse.

Operation	Description	$C_{in,\ max}$ (ppm)	No water reuse (kg/s)	Reuse	
				Network 1 (kg/s)	Network 2 (kg/s)
OP1	Head box	0	9.72	9.72	9.72
OP2	Breast roll	100	12.44	4.19	3.17
OP3	Knockoff	200	26.72	9.53	9.28
OP4	Trim squirt	0	2.78	2.78	2.78
OP5	Wire pit	50	8.11	7.31	8.11
OP6	Cooling water	50	1.47	1.47	1.47
OP7	Vaccum pumps	50	12.22	11.75	12.22
OP8	Cylinder showers	300	17.36	13.86	13.86
OP9	Felt showers	20	9.25	9.25	9.25
	Total freshwater (kg/s)		100.08	69.83	69.83
	Water reduction (%)		-	30.22	30.22

Source: Authors.

In both networks, there was a significant extension of reuse, once most of water streams could be entirely reused. Only the effluents from operations OP3 (knockoff) and OP8 (cylinder showers) were not suitable for reuse, since they exceeded the maximum allowed input concentrations of other operations.

It is important to note that the streams need to be mixed or divided inside along the wastewater reuse networks, which are represented by the symbols M and D, respectively, requiring the implementation of storage tanks, current splitters, and pumping systems. Figure 3 shows that 7 stream mixers and 3 streams splitters are needed in network 1, whereas 6 mixers and 3 streams splitters are required in network 2. This difference may be one of the aspects considered during the economic and technical feasibility assessment, once more investment is demanded if a relevant number of storage and pumping systems must be installed (Moreira, 2009). Thus, network 2 would be more advantageous than network 1 for the WSD implementation.

As can be observed in Table 2, the operations whose inlet stream concentrations are more restricted (OP1, OP4, OP6, OP 7 and OP9) are least affected by changes in the water flow rates, in comparison with the "no reuse" scenario. In contrast, streams that allow higher TSS input concentrations (OP2, OP3 and OP8) have their water consumption sharply reduced due to reuse. Hence, in this context, it is important to highlight that the presence of many operations with restrictions in their input quality conditions reduces the number of reuse possibilities in the WSD.

The wastewater consumption per operation has also been evaluated (see Table 3). It can be observed that OP3 was the one that most consumed previously used streams, once 29.11 and 29.36 kg/s of effluent from other operations entered it in networks 1 and 2, respectively. These amounts represent about 75% of reused water, considering that 38.61 kg/s leave the paper machine from this operation. The OP2 (73%) and OP8 (55%) were other operations to which relevant amounts of effluent were allocated.

Other studies have also achieved similar efficiencies like (Yang et al., 2000) that first applied mathematical programming to four operations (head box, breast roll, knockoff and trim squirt), supposing the removal of only TSS. A further approach added other three operations (wire pit, cooling water and vacuum pumps), targeting the removal of TSS and dissolved chemicals (DC). Freshwater reductions of 21.4 and 33.4% were reached, respectively. In the present study, WSD was applied to those seven operations, plus cylinder showers and felt showers. The results were very close to the aforementioned results reported by (Yang et al., 2000) showing an excellent agreement between numerical simulation and WSD method whose predicted efficiencies were 30.22% for both networks.

Table 3. Wastewater reused by operation in each network.

Operation	Network 1 (kg/s)	Network 2 (kg/s)
OP1	-	-
OP2	11.36	12.39
OP3	29.11	29.36
OP4	-	-
OP5	2.44	-
OP6	-	-
OP7	1.47	-
OP8	17.33	17.36
OP9	-	-
Total	61.72	59.11

Source: Authors.

Researchers confirmed the WSD potential (Marques, 2008) achieving 34% of freshwater reduction by applying the procedure to the same set of operations chosen (Yang et al., 2000) in order to remove TSS and DC. Additionally, the efficiency attained 21.4% in a system composed by four out of those seven operations focusing only on TSS removal (Mirre, 2012). Table 4 presents a summary of the results obtained by some studies involving paper processing.

Besides, the use of WSD for maximum reuse in other industry typologies reinforce that this method may reduce water consumption in at least 15%. Studies related to petroleum refining showed reductions from 30 to 40% in some networks, for the removal of one contaminant (Mirre, 2012), similarly to other studies where the efficiencies were close to 20% (Peixoto, 2011). Moreover, water minimization applied to citric juice, textile and petrochemical industries have achieved optimization rates of 25%, 18% and 16%, respectively (Marques, 2008).

Table 4. Freshwater reductions predicted by WSD and mathematical programming for paper processing operations.

Operation	Contaminant	Reference	Method	Freshwater reduction
OP1; OP2; OP3; OP4	TSS	[23]	Mathematical Programming	21.4%
		[9]	WSD	21.4%
OP1; OP2; OP3; OP4; OP5; OP6; OP7	TSS and CD	[23]	Mathematical Programming	33.4%
		[2]	WSD	34%
OP1; OP2; OP3; OP4; OP5; OP6; OP7; OP8; OP9	TSS	Present study	WSD	30.22% (network 1) 30.22% (network 2)

Source: Authors.

4. Conclusion

This paper corroborates the Water Source Diagram as a tool that helps the construction and suggestion of optimized water networks, with lower wastewater generation. Therefore, this procedure can be taken as an initial step in a decision-making process to achieve more sustainable productive systems. The application of this method for a hypothetic paper process, by considering direct reuse without any current regeneration, confirmed its efficiency to reduce freshwater consumption in about 30%. Furthermore, it showed that the minimization can be carried out under different network configurations.

The WSD design approach was applied by taking several operational simplifications and neglecting either cost-effectiveness or technical assessment. Nevertheless, enhanced approaches to meet these other requirements can be tailored based on the networks here proposed. To evaluate the proposed configurations and to choose the most feasible one, it is important to consider other aspects, such as: water losses, multiple external water sources, flow rate constraints, changes of limiting operation data according to the employed equipment, and the presence of other contaminants inherent to the papermaking process. As a helpful solution, the implementation of regeneration processes can avoid possible operational troubles caused by reuse, thus assuring the effectiveness of the minimization strategy.

Therefore, with a view to study improvement, are suggested for future work: (i) application of DFA for maximum reuse with regeneration of the SST contaminant by physical separation processes. This technique would allow even greater reductions than consumption of fresh water, as it reduces the concentration of pollutants before reuse of chains; (ii) application of DFA for maximum reuse and removal of multi-components. Like this, the presence of contaminants other than SST would be considered, working with the reality of the paper mill; (iii) economic and technical assessment to analyze possible consequences due to the reuse of chains for the production process.

References

Alexandersson, T. (2003). *Water reuse in paper mills: measurement and control problems in biological treatment* (Licentiate Thesis). Lund University, Lund, Sweden. Retrieved from https://portal.research.lu.se/portal/en/publications/water-reuse-in-paper-mills--measurements-and-control-problems-in-biological-treatment(95ff1208-61a4-4ce7-8526-aa745ab2d209).html

Calixto, E. E. S., Quaresma, A. C. L., Queiroz, E. M., & Pessoa, F. L. P. (2015). Water sources diagram in multiple contaminant industrial case studies: Adoption of a decomposition approach. *Industrial and Engineering Chemical Research*, 54 (41), 10040-10053. doi:10.1021/acs.iecr.5b01749

Calixto, E. E. S., Pessoa, F. L. P., Mirre, R. C., Francisco, F. S., & Queiroz, E. M. (2020). Water sources diagram and its applications. *Processes*, 8 (313), 1-10. doi:10.3390/pr8030313www.mdpi.com/journal/processes

Castro, P., Matos, H., Fernandes, M. C., & Nunes, C. P. (1999). Improvements for mass-exchange networks design. *Chemical Engineering Science*, 54, 1649-1665. doi:10.1016/S0009-2509(98)00526-0

Francisco, F. S., Bagajewicz, M. J., Pessoa, F. L. P., & Queiroz, E. M. (2015). Extension of the water sources diagram method to systems with simultaneous fixed flowrate and fixed load processes. *Chemical Engineering Research and Design*, 104, 752-772. doi:10.1016/j.cherd.2015.10.024

Gomes, J. F. S., Mirre, R. C., Delgado, B. E. P. C., Queiroz, E. M., & Pessoa, F. L. P. (2013). Water sources diagram in multiple contaminant processes: Maximum reuse. *Industrial and Engineering Chemical Research*, 52 (4), 1667-1677. doi:10.1021/ie301537c

Gomes, J. F. S., Queiroz, E. M., & Pessoa, F. L. P. (2007). Design procedure for water/wastewater minimization: Single contaminant. *Journal of Cleaner Production*, 15, 474-485. doi:10.1016/j.jclepro.2005.11.018

Gómes, J., Savelski, M. J., & Bagajewicz, M. J. (2001). On a systematic design procedure for water utilization systems in refineries and process plant. *Chemical Engineering Communications*, 186, 183-203. doi:10.1080/00986440108912873

Guelli Ulson de Souza, S. M. A., Xavier, M. F. S., & Ulson de Souza, A. A. (2011). Water reuse and wastewater minimization in chemical industries using differentiated regeneration of contaminants. *Industrial and Engineering Chemical Research*, 50, 7428-7436. doi:10.1021/ie200305z

Hamaguchi, M. (2008). *Análise do circuito de água em processo de fabricação de papel imprensa integrada com produção de pastas termomecânicas* (Dissertação de mestrado). Universidade de São Paulo, São Paulo, Brasil. Retrieved from https://teses.usp.br/teses/disponiveis/3/3137/tde-09012008-175600/pt-br.php

Indústria Brasileira de Árvores. (2019). *Relatório Ibá 2019*. Retrieved from https://iba.org/datafiles/publicacoes/relatorios/iba-relatorioanual2019.pdf

Immich, A. P. S., Gusatti, M., Mello, J. M. M., Guelli U. Souza, S. M. A. & Pessoa, F. L. P. (2007). Application of the water source diagram (WSD) procedure to water use minimization in a batch process. In European Congress of Chemical Engineering, *Proceedings*

Copenhagen: EFCE, Copenhagen: Immich, A. P. S., Gusatti, M., Mello, J. M. M., Guelli U. Souza, S. M. A., Pessoa, F.L.P.

Khodaparas, Z., & Kamali, M. (2015). Review on recent developments on pulp and paper mill wastewater treatment. *Ecotoxicology and Environmental Safety*, 114, 326-342. doi:10.1016/j.ecoenv.2014.05.005

Koppol, A. P. R., Bagajewicz, M., & Dericks, B. (2003). On zero water discharge solutions in the process industry. *Advances in Environmental Research*, 8, 151-171. doi:10.1016/S1093-0191(02)00130-2

Mancuso, P. C. S, & Santos, M. F. (2003). *Reuso de água* (1st ed). São Paulo: Manole.

Marques, S. V. (2008). *Minimização do consumo de água e da geração de efluentes aquosos: Estudos de casos* (Dissertação de mestrado). Universidade Federal do Rio de Janeiro, Rio de Janeiro, RJ, Brasil.

Mierzwa, J. C., & Hespanhol, I. (2005). *Água na indústria: Uso racional e reuso*. São Paulo: Oficina dos textos.

Mirre, R. C. (2012). *Metodologia para o gerenciamento sustentável do reuso de águas e efluentes industriais por meio da integração de processos* (Tese de doutorado). Universidade Federal do Rio de Janeiro, Rio de Janeiro, RJ, Brasil. Retrieved from http://186.202.79.107/download/gerenciamento-sustentavel-do-reuso-de-aguas.pdf

Monte, M. C., Fuente, E., Blanco, A., & Negro, C. (2009). Waste management from pulp and paper production in the european union. *Waste Management*, 29, 293-308. doi:10.1016/j.wasman.2008.02.002

Moreira, R. C. (2009). *Minimização de efluentes em uma unidade de tratamento de água industrial* (Dissertação de mestrado). Universidade Federal da Bahia, Salvador, BA, Brasil.

Peixoto, T. C. L. C. (2011). *Reuso de água: comparação entre os métodos DFA, programação linear e programação não linear* (Dissertação de mestrado). Universidade

Federal do Rio de Janeiro, Rio de Janeiro, RJ, Brasil. Retrieved from http://tpqb.eq.ufrj.br/download/reuso-de-agua-dfa-programacao-linear-e-nao-linear.pdf

Pereira, A. S., Shitsuka, D. M., Parreira; F. J., & Shitsuka, R. (2018). *Metodologia da pesquisa científica*. Santa Maria, RS: UFSM, NTE. Retrieved from https://repositorio.ufsm.br/bitstream/handle/1/15824/Lic_Computacao_Metodologia-Pesquisa-Cientifica.pdf?sequence=1

Pokhrel, D., & Viraraghavan, T. (2004). Treatment of pulp and paper mill wastewater: A review. *Science of the total environment*, 333, 37-58. doi:10.1016/j.scitotenv.2004.05.017

Simão, L., Hotza, D., Raupp-Pereira, F., Labrincha, J. A., & Montedo, O. R. K. (2018). Wastes from pulp and paper mills: A review of generation and recycling alternatives. *Cerâmica*, 64 (371), 443-453. doi:10.1590/0366-69132018643712414

Swedish Forest Industries Federation. (2019). *Statistics*. Retrieved from https://www.forestindustries.se/forest-industry/statistics/

Ulson de Souza, A. A., Forgiarini, E., Brandão, H. L., Xavier, M. F., Pessoa, F. L. P., & Guelli Ulson de Souza, S. M. A. (2009). Application of water source diagram (wsd) method for the reduction of water in petroleum refineries. *Resources, Conservation and Recycling*, 53, 149-154. doi:10.1016/j.resconrec.2008.11.002

Urbaniec, K., Mikulčić, H., Duić, N., & Lozano, R. (2016). SDEWES 2014 - Sustainable development of energy, water and environment systems. *Journal of Cleaner Production*, 130, 1-11. doi:10.1016/j.rser.2017.10.057

United Nations Development Programme. (2020). *Sustainable development goals*. Retrieved from https://www.undp.org/content/undp/en/home/sustainable-development-goals.html.

Wang, Y. P., & Smith, R. (1994). Wastewater minimization. *Chemical Engineering Science*, 49 (7), 981-1006. doi:10.1016/0009-2509(94)80006-5

Yang, Y. H., Lou, H. H., & Huang, Y. L. (2000). Synthesis of an optimal wastewater reuse network. *Waste Management, 20,* 311-319. doi:10.1016/S0956-053X(99)00298-6

Percentage of contribution of each author in the manuscript

Marianna Oliveira Moura –50%

José Jailton Marques –10%

Inaura Carolina Carneiro da Rocha–40%