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Water Meta-cycle model and indicators for industrial processes- the pulp & paper case in China

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ABSTRACT

To address the increasingly grim water environmental crisis and achieve the sustainable development goal in 2030, a fresh water Meta-cycle model and corresponding indicators are proposed to optimize the water resources utilization within a local industrial area. The out-of-date single-track and linear water utilization mode is improved in the Meta-cycle model in which it possesses the characteristics of closed-loop, multiple order and high efficiency. The efficient and ecological utilization, conservation, regeneration as well as recycling of water resources are highly emphasized in the model. The water Meta-cycle model comprises 5 levels: the natural metabolic level (Level 0), the ecological treatment level (Level 1), the wastewater treatment in industrial park level (Level 2), the wastewater pretreatment within enterprise level (Level 3), and the production related water within enterprise level (Level 4). Based on this conceptual model, a series of indicators is presented in the paper, including recycling rate and recycle time, water source diversity index, greenhouse gas (GHG) emission, direct water footprint of the model and adaptive evaluation of water treatment. A case of a typical pulp and papermaking enterprise is used to illustrate the proposed model. The results demonstrate the key role of ecological regeneration cycle. It is expected that the Meta-cycle model will be an effective mode for the safe and sustainable management of regional water resources.

1. Introduction

Currently, the world is experiencing an increasingly serious water crisis. The increasing population and urbanization result in a huge increase in demand for fresh water. The quantity of available fresh water resources is shrinking due to water pollution and destruction of water ecological system (Xue et al., 2015). It is estimated that the water demand will increase by more than 40% by 2050. By 2025, two-thirds of the global population will be threaten by clean water (Eliasson, 2015; Prouty and Zhang, 2016). Thus, higher requirements are imposed on the current water management systems as a result of the serious water crisis. To this end, in 2015, 17 Sustainable Development Goals (SDGs) were adopted by all member states of the United Nations, in the hope that these objectives could be achieved by 2030 (United Nations, 2015). Among the 17 goals, clean water and sanitation is ranked as the 6th goal.

However, there are some limitations to the traditional, linear and single-track water management system (Hu et al., 2015) that prevent it from fulfilling the objective of clean water and sanitation in SDGs (Brown and Farrelly, 2009). First, water utilization efficiency is quite low in the single-track water management system. As the whole water management model is linear, the entire water flow leaves the sub-model and enters the next sub-model directly without a water recycling scheme. Second, a simple water supply network and unitary water quality cannot meet the different water quality requirements of water consumers. Third, industrial wastewater and domestic wastewater are mixed before being treated in the current sewer system, which increases the difficulty of waste water treatment plants. Moreover, it also restricts the possibility of water reuse and the utilization of sludge. Therefore, it is urgent to improve the current theory of water management to form a sustainable water management model.

At the same time, in China, because of the rapid expansion of urbanization and industrialization, China is also facing severe problems with environmental water pollution and water ecosystem deterioration

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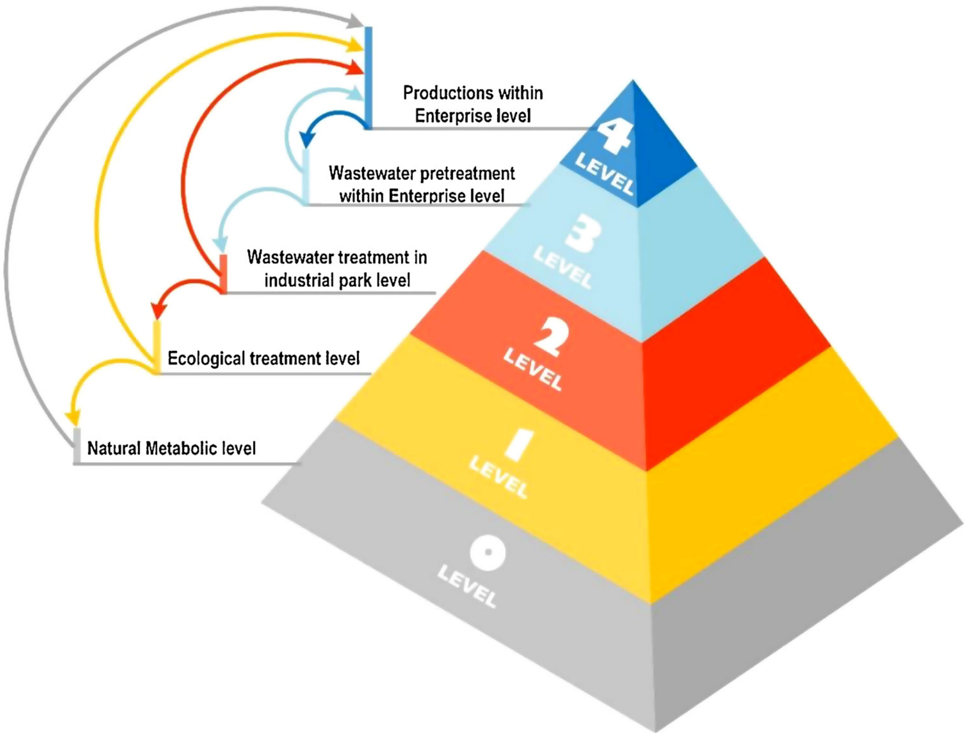

Fig. 1. The Meta-cycle model for enterprise.

(Dong, 2011). To alleviate the existing problems, governments and enterprises have taken some intensive actions in recent years (Chen et al., 2017). In addition to technology exploitation and constructing a sound water infrastructure, the outdated water management system is also required to be improved.

To address these issues above, plenty of scientific papers related to water utilization model, water management or water evaluation have been published. At first, the obstacles that obstructed the improvement of water management system were dicussed. Brown et al. (2009) reviewed the institutional barriers that impeded the establishment of sustainable water management. A typology of barriers was systematically identified, which might be beneficial to overcome the barriers for water policy strategists (Brown and Farrelly, 2009). Secondly, related water utilization models that help to overcome the barriers were introduced by researchers. The concept of sustainable urban water management (SUWM) was proposed to respond to the challenges associated with environmental degradation, rapidly growing urban populations and impacts of climate change (Brown et al., 2009; Zhang et al., 2007). Donofrio et al. (2009) discussed a newly emerging model of a water-sensitive city in the sustainable urban planning. The key point of the WSUD (Water-Sensitive Urban Design) model is to reduce the impact of other disturbances on the natural water cycle as much as possible by integrating different types of water sources (wastewater or storm water) into the WSUD. Thirdly, the importances of wastewater or unconventional water resource were further emphasized by reserchers. Wastewater or unconventional water resource recycling are essential to fill up the gap between traditional water supply and the increasing demands aroused by the rapid expansion of urbanization and industrialization (Jing et al., 2017; Shevah, 2014). Rahmana et al. (2012) investigated the feasibility of rainwater harvesting in Sydney, Australia and assessed the water savings potential, reliability and economic benefits of rainwater harvesting. Andrews et al. (2011) investigated the recycling of industrial wastewater in Europe, and discussed the mechanisms driving enterprises to conduct wastewater recycling. Furthermore, the reuse of wastewater not only reduces the fresh water consumption, but it also can recovers the potential resources in wastewater, such as thermal energy, organic compounds and nutrients (Hering et al., 2013; Mitchell et al., 2001). As shown in the aforementioned literature, more attention should be paid to water reuse in water management system. This is because it plays a key role in establishing a new water management system. However, it should be noted that these explorative and successful practices to improve water management are mainly focused on urban water management (Listowski et al., 2013; Marteleira et al., 2014).

Detailed and thorough research or discussion related to the water cycle and/or wastewater reuse in industrial production is very limited. The construction of water cycle systems in industry is also an important part of sustainable water management system (Sapkota et al., 2018). Compared with the urban water cycle system, water cycles of industrial processes are much more complex and diverse. In the industrial water cycles, there are various effluents with complicated contaminants, and diverse water treatment techniques exist, e.g., ecological, biochemical, chemical and physical techniques. Furthermore, effluents have different water reuse forms, e.g., cascaded utilization within manufacturing facility, reuse through ecological regeneration and reuse through industrial regeneration. Therefore, on the basis of these water cycle theories, the water Meta-cycle model for industrial sustainable water management was proposed by Hu et al. (2015).

The concept, system structure, advantages and goals of the water Meta-cycle were discussed (Hu et al., 2015). More details of how to define, distinguish and evaluate these techniques and water reuse forms have not been thoroughly studied in the integrated framework. The novelties of this work are highlighted as follows: 1) the concept of the Meta-cycle model is more specified and defined. It is divided into 5 detailed levels to make it applicable in industrial processes. 2) Some indicators are proposed to distinguish and evaluate these techniques and water reuse forms of the Meta-cycle model. 3) A typical case is chosen to demonstrate the applicability of the proposed model.

The remainder of this paper is divided into 5 sections. Section 2 introduces the Meta-cycle model. Some indicators are proposed to evaluate the model in Section 3. The case of the Tranlin Paper Company is analyzed with the Meta-cycle model in Section 4, and the model indicators with Tranlin are calculated in Section 5. Finally, the conclusion and perspectives of the paper are summarized in Section 6.