water

MDPI

Editorial

Sustainability of Lakes and Reservoirs: Multiple Perspectives Based on Ecosystem Services

Long Ho * and Peter Goethals

Department of Animal Sciences and Aquatic Ecology, Ghent University, 9000 Ghent, Belgium; Peter.Goethals@UGent.be
* Correspondence: long.tuanho@UGent.be; Tel.: +32-926-438-95

Citation: Ho, L.; Goethals, P. Sustainability of Lakes and Reservoirs: Multiple Perspectives Based on Ecosystem Services. *Water* **2021**, *13*, 2763. https://doi.org/10.3390/w13192763

Received: 22 August 2021
Accepted: 24 September 2021
Published: 6 October 2021

This special issue consists of fourteen selected articles, that cover a wide spectrum of Ecosystem Services (ES) of lakes and reservoirs, including: (1) water purification [1,2]; (2) hydropower [3–5]; (3) sediment cycling [6]; (4) water storage and supply [7–9]; (5) climate change [10]; (6) flood control [5]; (7) fisheries [11] and (8) tourism [12]. Together with a description of these ES, a brief summary of these papers is provided below.

Waste stabilization ponds (WSPs) have been globally applied for municipal wastewater treatment worldwide as they offer natural, low-cost, and simple water purification [13]. In the US, more than half of wastewater treatment plants (WWTPs) are WSPs (ca. 8000 facilities) which are also the first choice for nearly all remote communities in northern Canada [14]. Similarly, in Europe, WSPs account for 20% of the total number of WWTPs in France and 33% of the WWTPs in Germany [15]. The most known and broadly used WSP layout is composed of a sequence of anaerobic (AP), facultative (FP), and (a series of) maturation ponds (MP). Anaerobic ponds are normally located at the primary treatment stage to remove organic matter, due to their robustness against a high loading rate [16,17]. Subsequently, taking advantage of photosynthetic oxygenation, FPs are applied for further organic matter and nutrient removal with minimal operational costs [18]. Lastly, MPs are designed with shallow depths to remove pathogens and excessive nutrients [19].

Despite the many abovementioned advantages, WSPs have several drawbacks, such as long retention time, odor nuisance, low nutrient removal efficiency, and fluctuating performance [20,21], which are addressed and investigated in two articles in this Special Issue. Particularly, dos Santos and van Haandel [2] propose an alternative for typical APs and preliminary FPs by a combination of an upflow anaerobic sludge blanket (UASB) reactor and sequential batch polishing ponds (SBPP) for pre and post-treatment, respectively. The results of pilot-scale experiments showed that this configuration produced higher quality effluents with low concentrations of organic matter, nutrient and pathogens with a much smaller treatment area. Moreover, due to the absence of odor nuisance, pond engineers can construct this configuration near or within urban areas.

Optimizing the operation of WSPs, Pham [1] applied a data-driven model to investigate the key driving factors of dissolved oxygen (DO) in FPs and MPs. The results showed that the concentration of algae had a strong impact on DO level near the water surface, while organic matter was the most influential factor on DO variability at the bottom of the pond. This provided a large amount of useful information on pond performance and insightful recommendations on DO monitoring and regulations in WSPs.

To investigate the hydrological alternation of a small HR, Braun-Cruz [3] applied 17 indicators based on daily data series of the Itiquira Hydroelectric Plant (Brazil). The results showed that the river ecosystem was more susceptible to hydroelectric operations during the dry season than during the rainy season. Specifically, 88% of the proposed indicators were significantly altered during the dry season compared to 71% during the rainy season. This finding is the first piece of evidence in the basin that illustrates how a small run-of-the-river reservoir can cause significant hydrological changes over the subdaily regime of the river, which should be taken into account in energy planning of the region.

To assess the roles of constructed wetlands in mitigating the impact of the Doan Dam (South Korea) on water quality, Lee [4] applied a water system model that integrates watershed conditions (HSPF), reservoirs (CE-QUAL-W2), and streams (EFDC). Based on the results from this modeling research, the constructed wetlands in the Kangnung Namdae Stream reduced the suspended solids (SS) concentration by approximately 30%. Furthermore, other current management practices, such as artificial floating islands and sedimentation basins, further decreased the SS concentration by around 7%. These findings illustrate that an appropriate modeling tool is useful to investigate the quantitative effects of stream interventions to support water management with reliable evidence.

To investigate sediment deposition and predict future trends in the Shimen Reservoir (Taiwan), Huang [6] applied a two-stage approach that combined a numerical-based model and an empirical-based equation to simulate the physical mechanism of the density current flow. After comparing with field measurements, the prediction value of this two-stage approach showed high accuracy and efficiency compared to the results obtained from the numerical simulation alone. Moreover, the approach is also user-friendly and quickly accessible, which can facilitate its future application in early-warning systems for control of natural disasters via model-based reservoir operation.

Dealing with one of the major issues of water reservoirs, Largo [8] investigated the potential risk of heavy metal contamination in agricultural irrigation systems as a threat to water security and product safety downstream. Specifically, the research assessed the use of an artificial floating island with *Vetiver* (AFIV) for arsenic removal in a reservoir in Ecuador. Pilot-scale experiments showed a high remediation efficiency of 97% in water and 84% in sediment for arsenic, while this number was 87% for iron. These heavy metals were found to accumulate in the roots of macrophytes whose survival rate was 92% in the experiments. These findings highlighted the potential application of an AFIV system for the rehabilitation of arsenic-contaminated reservoirs in adverse climatic conditions.

Aiming for sustainable water use in agriculture, Shadkam [9] proposed a Water-Saving Strategies Assessment (WSSA) Framework that estimates five key components of water balance: (1) demand; (2) availability; (3) withdrawal; (4) depletion and (5) outflow. This framework was applied in a restoration program in Urmia Lake (Iran) whose water surface area diminished by 90% from 1998 to 2016. By disclosing the potential impacts of planned activities, and accounting for future changes regarding climate and socioeconomics, WSSA proved itself a useful communication tool that can raise the awareness of decision makers on mistakes in water-saving strategies.

By applying an integrated approach, Jiang [7] investigated the interaction between surface water and groundwater to quantify water availability and determine appropriate integrated water resources management policies. Particularly, a coupled SWAT-MOFLOW modeling approach was applied in the Yanqi Basin (China) with a focus on its lake wetland systems. The models indicated that agricultural extraction activities can have a severe impact on water quantity of the lake wetland as the amount of water discharge from the waterbodies to underground aquifer has increased from 37% to 463% while the escalation in groundwater extraction was from 15% to 150%. These findings indicate the importance of considering the interaction between surface water and groundwater in integrated water management, for which integrated modeling approaches are effective tools.

The impacts of climate change were also found in the case study of Li [10] in the saline-alkali area of the Songnen Plain, Northeast China, where more than 25% of the lakes and reservoirs disappeared from 1985 to 2015. Using Landsat satellite imagery, the research found that the average temperature of the ~700 remaining lakes has been rising while their annual precipitation and evaporation have been declining. Li [10] concluded that the degradation and disappearance of small lakes (<10 km^2) in this area are mainly caused by drying and warming of the climate and the shortage of replenishment resources. On the other hand, it appeared that the driving factors affecting the changes in large lakes (>10 km^2) are anthropogenic. These findings can contribute to current replenishment projects in the area as a scientific basis by which a long-term strategy for sustainable management of lakes and regional economic development can be integrated.

Wan [5] proposed a new concept of dynamic flood-limited water level (FLWL) that aims to balance the risk of downstream flooding, environmental impacts, and economic benefits. Based on the forecast flood and reservoir dynamic design-flood probability, the concept was applied to a case study in the Three Gorges Reservoir (China). The results indicated that the new approach allowed for more effective and economic daily operation of the reservoir without increasing flood risks. This finding highlighted the application of dynamic water level control in improving the flood forecast accuracy during the flood season.

Fisheries and aquaculture have become a research hotspot in lake and reservoir studies as the amount of research has tripled from 20 to 60 publications per year during the last decade [22]. In practice, while the natural fish resources in lakes have declined due to overfishing, rapid growth of fish culture in manmade ponds and reservoirs has accelerated since the 1960s [23]. From the 1970s to the 2010s, global aquaculture production has increased 40-fold and is expected to quintuple in the coming 50 years [24]. The unprecedented expansion of fisheries and aquaculture has led to negative impacts on the ecosystems of lakes and reservoirs, such as loss of biodiversity, increasing invasive species, and degraded mangrove forests [25,26].

Lake Tana in Ethiopia is not only the largest lake of the country, but the associated basin is moreover home to more than 90,000 inhabitants and plays a crucial rule in local economic activities [11]. Unfortunately, the ecosystem of Lake Tana has undergone a very severe pressure resulting from the diverse exploitations and human development, mainly because the conservation management of natural resources has often been neglected in this waterbody. Gebremedhin [11] indicated the issues of overfishing and illegal fishing which have strongly affected the population of the endemic *Labeobarbus* species in Lake Tana. Specifically, the monthly catch of this species has decreased by 76% since 2001 as the catch per unit effort (CPUE) declined from 63 kg $trip^{-1}$ to only 2 kg $trip^{-1}$ from 1991 to 2017.

Sanchez-Rivero [12] provided a mini-review of inland water tourism which highlights the importance for this type of tourism on a global scale. The review focuses on a case study in Extremadura (Spain) where tourism plays a substantial role in the local economic development. A total of 4625 surveys was given to the tourists of this region during 2017 and used for developing a logit model to analyze the application of inland water tourism with regard to the characteristics of the tourists. The results revealed the higher interest by domestic visitors and young tourists traveling in a group or with friends in choosing inland waters in Extremadura as their destinations. These findings are useful for tourism management of the area to establish a suitable development strategy for sustainable tourism in Extremadura.

Given the tremendous benefits of lakes and reservoirs offered to human society, environmental well-being, and economic welfare, their sustainability needs to be more explicitly related to the diverse SDGs [27]. This approach is highlighted in the review paper of Ho [28] in this Special Issue. This paper discloses both synergistic and antagonistic interlinkages between the sustainability of lakes and reservoirs and the SDGs. The analysis shows that the sustainable development of lakes and reservoirs strongly connects with nine SDGs divided into 3Ps: (1) People (SDGs 1, 2, and 3); (2) Planet (SDGs 6, 13, 14, and 15) and (3) Prosperity (SDGs 7 and 8). The authors indicated that despite the abundance of the synergies, potential conflicts can occur among the SDGs via the antagonistic relations between some of the SDGs, and therefore a smart balance needs to be found and implemented to achieve sustainable development [29].

To solve water use conflicts, Chilima, et al. [30] highlighted that a wide participatory approach to understand the starting conditions is pivotal to ensuring success in collaborative planning and water governance. Specifically, the authors advised to gather and use information on the prehistory of conflicts and the incoherence of regulatory instruments, the diverse perceptions of stakeholders to multi-perspective decisions, and the most contentious areas of water use. It is also emphasized that a meaningful inclusion of stakeholders throughout the planning process is key to address water system challenges in a context of sustainable development.

Author Contributions: Conceptualization, writing—original draft preparation, L.H.; writing—review and editing, L.H., P.G. All authors have read and agreed to the published version of the manuscript.

Funding: Long Ho is a postdoctoral fellow of the FWO (project number 1253921N).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The editors would like to thank all the authors that contributed their works to this Special Issue.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Pham, D.T.; Ho, L.; Espinoza-Palacios, J.; Arevalo-Durazno, M.; Van Echelpoel, W.; Goethals, P. Generalised Linear Models for Prediction of Dissolved Oxygen in a Waste Stabilisation Pond. *Water* **2020**, *12*, 1930. [CrossRef]
2. Dos Santos, S.L.; van Haandel, A. Transformation of Waste Stabilization Ponds: Reengineering of an Obsolete Sewage Treatment System. *Water* **2021**, *13*, 1193. [CrossRef]
3. Braun-Cruz, C.C.; Tritico, H.M.; Beregula, R.L.; Girard, P.; Zeilhofer, P.; Ribeiro, L.D.S.; Fantin-Cruz, I. Evaluation of Hydrological Alterations at the Sub-Daily Scale Caused by a Small Hydroelectric Facility. *Water* **2021**, *13*, 206. [CrossRef]
4. Lee, H.W.; Yeom, B.-M.; Choi, J.H. Modelling Water Quality Improvements in a South Korean Inter-Basin Water Transfer System. *Water* **2020**, *12*, 3173. [CrossRef]
5. Wan, W.; Lei, X.; Zhao, J.; Wang, M.; Khu, S.-T.; Wang, C. A Forecast-Skill-Based Dynamic Pre-Storm Level Control for Reservoir Flood-Control Operation. *Water* **2021**, *13*, 556. [CrossRef]
6. Huang, C.-C.; Lin, W.-C.; Ho, H.-C.; Tan, Y.-C. Estimation of Reservoir Sediment Flux through Bottom Outlet with Combination of Numerical and Empirical Methods. *Water* **2019**, *11*, 1353. [CrossRef]
7. Jiang, M.; Xie, S.; Wang, S. Water Use Conflict and Coordination between Agricultural and Wetlands—A Case Study of Yanqi Basin. *Water* **2020**, *12*, 3225. [CrossRef]
8. Largo, K.F.; Depablos, J.R.; Espitia-Sarmiento, E.; Moreta, N.L. Artificial Floating Island with *Vetiver* for Treatment of Arsenic-Contaminated Water: A Real Scale Study in High-Andean Reservoir. *Water* **2020**, *12*, 3086. [CrossRef]
9. Shadkam, S.; Van Oel, P.; Kabat, P.; Roozbahani, A.; Ludwig, F. The Water-Saving Strategies Assessment (WSSA) Framework: An Application for the Urmia Lake Restoration Program. *Water* **2020**, *12*, 2789. [CrossRef]
10. Li, Z.; Cao, Y.; Tang, J.; Wang, Y.; Duan, Y.; Jiang, Z.; Qu, Y. Relationships between Temporal and Spatial Changes in Lakes and Climate Change in the Saline-Alkali Concentrated Distribution Area in the Southwest of Songnen Plain, Northeast China, from 1985 to 2015. *Water* **2020**, *12*, 3557. [CrossRef]
11. Gebremedhin, S.; Bruneel, S.; Getahun, A.; Anteneh, W.; Goethals, P. The Endemic Species Flock of *Labeobarbus* spp. in L. Tana (Ethiopia) Threatened by Extinction: Implications for Conservation Management. *Water* **2019**, *11*, 2560. [CrossRef]
12. Sánchez-Rivero, M.; Rodríguez-Rangel, M.C.; Fernández-Torres, Y. The Identification of Factors Determining the Probability of Practicing Inland Water Tourism through Logistic Regression Models: The Case of Extremadura, Spain. *Water* **2020**, *12*, 1664. [CrossRef]
13. Ho, L.; Jerves-Cobo, R.; Morales, O.; Larriva, J.; Arevalo-Durazno, M.; Barthel, M.; Six, J.; Bode, S.; Boeckx, P.; Goethals, P. Spatial and temporal variations of greenhouse gas emissions from a waste stabilization pond: Effects of sludge distribution and accumulation. *Water Res.* **2021**, *193*, 116858. [CrossRef]
14. Ho, L.; Goethals, P.L. Municipal wastewater treatment with pond technology: Historical review and future outlook. *Ecol. Eng.* **2020**, *148*, 105791. [CrossRef]
15. Ho, L.T.; Alvarado, A.; Larriva, J.; Pompeu, C.; Goethals, P. An integrated mechanistic modeling of a facultative pond: Parameter estimation and uncertainty analysis. *Water Res.* **2019**, *151*, 170–182. [CrossRef]
16. Ho, L.; Pompeu, C.; Van Echelpoel, W.; Thas, O.; Goethals, P. Model-Based Analysis of Increased Loads on the Performance of Activated Sludge and Waste Stabilization Ponds. *Water* **2018**, *10*, 1410. [CrossRef]

17. Ho, L.T.; Pham, D.T.; Van Echelpoel, W.; Alvarado, A.; Espinoza-Palacios, J.E.; Arevalo-Durazno, M.B.; Goethals, P.L.M. Exploring the influence of meteorological conditions on the performance of a waste stabilization pond at high altitude with structural equation modeling. *Water Sci. Technol.* **2018**, *78*, 37–48. [CrossRef] [PubMed]
18. Ho, L.; Pham, D.T.; Van Echelpoel, W.; Muchene, L.; Shkedy, Z.; Alvarado, A.; Espinoza-Palacios, J.; Arevalo-Durazno, M.; Thas, O.; Goethals, P. A Closer Look on Spatiotemporal Variations of Dissolved Oxygen in Waste Stabilization Ponds Using Mixed Models. *Water* **2018**, *10*, 201. [CrossRef]
19. Ho, L.T.; Van Echelpoel, W.; Goethals, P.L. Design of waste stabilization pond systems: A review. *Water Res.* **2017**, *123*, 236–248. [CrossRef] [PubMed]
20. Ho, L.; Van Echelpoel, W.; Charalambous, P.; Gordillo, A.P.; Thas, O.; Goethals, P. Statistically-Based Comparison of the Removal Efficiencies and Resilience Capacities between Conventional and Natural Wastewater Treatment Systems: A Peak Load Scenario. *Water* **2018**, *10*, 328. [CrossRef]
21. Ho, L.; Jerves-Cobo, R.; Forio, M.A.E.; Mouton, A.; Nopens, I.; Goethals, P. Integrated mechanistic and data-driven modeling for risk assessment of greenhouse gas production in an urbanized river system. *J. Environ. Manag.* **2021**, *294*, 112999. [CrossRef]
22. Ho, L.; Goethals, P. Research hotspots and current challenges of lakes and reservoirs: A bibliometric analysis. *Scientometrics* **2020**, *124*, 603–631. [CrossRef]
23. Jia, P.; Zhang, W.; Liu, Q. Lake fisheries in China: Challenges and opportunities. *Fish. Res.* **2013**, *140*, 66–72. [CrossRef]
24. Avnimelech, Y.; Verdegem, M.; Kurup, M.; Keshavanath, P. Sustainable Land-based Aquaculture: Rational Utilization of Water, Land and Feed Resources. *Mediterr. Aquac. J.* **2008**, *1*, 45–54. [CrossRef]
25. Sampantamit, T.; Ho, L.; Van Echelpoel, W.; Lachat, C.; Goethals, P. Links and Trade-Offs between Fisheries and Environmen-tal Protection in Relation to the Sustainable Development Goals in Thailand. *Water* **2020**, *12*, 399. [CrossRef]
26. Sampantamit, T.; Ho, L.; Lachat, C.; Sutummawong, N.; Sorgeloos, P.; Goethals, P. Aquaculture Production and Its Environmental Sustainability in Thailand: Challenges and Potential Solutions. *Sustainability* **2020**, *12*, 2010. [CrossRef]
27. Flörke, M.; Bärlund, I.; van Vliet, M.T.; Bouwman, A.F.; Wada, Y. Analysing trade-offs between SDGs related to water quality using salinity as a marker. *Curr. Opin. Environ. Sustain.* **2019**, *36*, 96–104. [CrossRef]
28. Ho, L.G. Peter Opportunities and Challenges for the Sustainability of Lakes and Reservoirs in Relation to the Sustainable Development Goals (SDGs). *Water* **2019**, *11*, 1462. [CrossRef]
29. Ho, L.; Goethals, P. Imperiled Lake Ecosystems. In *Reference Module in Earth Systems and Environmental Sciences*; Elsevier: Amsterdam, The Netherlands, 2021. [CrossRef]
30. Chilima, J.; Blakley, J.; Diaz, H.; Bharadwaj, L. Understanding Water Use Conflicts to Advance Collaborative Planning: Lessons Learned from Lake Diefenbaker, Canada. *Water* **2021**, *13*, 1756. [CrossRef]