Environmental flow mechanism and management for river–lake-marsh systems

Xinan Yin Peng Hu Jiangguo Zhou

Abstract

Sustaining environmental flows (e-flows) is a basic requirement for river, lake and marsh management. Rivers, lakes and marshes have close hydrological and ecological connections in a river basin, and form river–lake-marsh systems. Any measure that is designed to address problems related to only one of these water bodies in isolation of the others may lead to unexpected, undesired and sub-optimal consequences for one or all of the water bodies. Papers were selected for this special issue 'Environ-mental Flow Mechanism and Management for River-Lake-Marsh Systems' to illus-trate recent advances in revealing new mechanisms connecting hydrological and environmental/ecological processes, developing new methods for e-flow calculation, and establishing new measures for e-flow management.

KEYWORDS

environmental flow, management, restoration, river–lake-marsh system

1 | INTRODUCTION

A majority of river, lake and marsh ecosystems around the world have been degraded under the increasing influences of human activities and climate change. Researchers and managers are confronting the challenges to balance the needs of human beings and freshwater ecosystems. Sustaining environmental flows (e-flows, the volume of water that should remain in a freshwater ecosystem and its variation over time to sustain specified ecosystem conditions) is a basic requirement for freshwater ecosystem protection and restoration. Lots of e-flow research has been performed for rivers, lakes and marshes.

For rivers, the hydrological methods (purely based on hydrological data) were first established for e-flow calculation (Chen et al., 2016; Jain, 2012; Tharme, 2003; Yang & Zhang, 2003). The hydrological methods are the simplest and commonly used methods for e-flow calculation. The Tennant method (Tennant, 1976), 7Q10 method (Boner & Furland, 1982) and the flow duration curve method (Cigizoglu & Bayazit, 2000) are representative hydrological methods. However, these hydrological methods do not consider the interaction between aquatic species and environmental factors, and thus cannot clearly reflect the requirements of aquatic species and ecological functions. Recently, the e-flow research mainly seeks to incorporate the detailed requirements of aquatic species protection and ecological function maintenance. For example, Boavida et al. (2018) chose water depth, flow velocity and substrate as fish habitat indicators and determined the weighted usable area for *barbel spawner*. Abebe et al. (2021) linked the ecological conditions (fish, macro-invertebrate, riparian vegetation and physicochemical) with hydrological components to assess the holistic e-flows of the Gumara River in Ethiopia. Akter and Tanim (2018) presented an approach comprising of hydrological, hydrodynamic and habitat simulation to determine e-flow of ungauged semidiurnal tidal river.

For lakes, the e-flow calculation methods are established from the hydrological or ecological perspectives (Gleick, 1998; Liu & Yang, 2002). Based on the hydrological perspectives, Guo et al. (2021) combined water balance method and linear regression method and calculate the e-flow delivery volume to maintain current water surface area of Qingtu Lake. In the absence of specific river-bio data, Yasi and Ashori (2017) used multiple hydrological methods to calculate the e-flows of rivers around the Urmia Lake, and took the results as the e-flow requirement of the lake. Gan et al. (2015) presented an ecological water level index system based on the annual guarantee certainty method, and recommended the timing and duration of the low and high water level, and water level rise rate and so forth. Differently, methods from an ecological perspective take into account more information about life stages of aquatic organism and its mutual effect on environmental indicators. Chen et al. (2019) studied the influence of water depth on waterfowl feeding in wintering period, and suggested the optimal water level for wintering waterfowls in the Poyang Lake. Haghighi et al. (2018) considered both the farmers' water use behaviour and the natural flow regime, and designed an optimized monthly e-flow release strategy for reservoirs, which could effectively restore the lake to an acceptable ecological level. He et al. (2020) adopted the grey correlation method to analyse the relationship between the water level and ecological indicators (reed yield, fishery yield, phytoplankton species, benthic animal species, waterfowl species), calculated the annual degrees of certainty for the e-flow, and pointed out the months from August to March needed water delivery.

Marshes play an irreplaceable role in biodiversity conservation (Drexler et al., 2008; Li et al., 2009; Li & JianJian, 2011). The e-flow calculation for marshes involves multidisciplinary knowledge, and the methods used can be generally divided into statistical analysis and model simulations. Li, Gong, et al. (2019) classified land cover to calculate the ecological water storage of the marsh in the beginning, middle and late stage of plant growth. Campbell et al. (2021) surveyed the floodplain vegetation condition over 1 year to determine the e-flows, and demonstrated the value of increased flow frequency in recovering vegetation health. Gong et al. (2021) assessed the area change of reed marshes and the instantaneous evapotranspiration of the wetland, and found that the distribution of evapotranspiration within a year presented single-peak curve and the water replenishment should be changed according to seasons. Karim et al. (2014) modelled the hydrological connectivity in a tropical marsh, and identified the time when water depths fell below critical thresholds for fish movement, which is critical for setting environmentally acceptable flows. Li, Guo, et al. (2019) established the hydrological dynamic relationship model of lake storage capacity-elevation-area-salinity to restore the plateau salt marsh. They found that under the optimum balance condition between water quantity and salt concentration, simulating the water transfer mode in precipitation replenishment is an effective means during breeding season. These previous e-flow studies were performed for rivers, lakes and marshes, respectively, and have effectively promoted the advance of e-flows. However, rivers, lakes and marshes have close hydrological and ecological connections within landscapes, and form river–lake-marsh systems. Much research has revealed the interactions among rivers, lakes and marshes, and proved the importance of river, lake and marsh protection and restoration from a system perspective. Yu et al. (2020) monitored the water surface rate of river–lake-marsh systems in China from 1990 to 2010. The results presented that grassland, arable and forest have strong correlation with the mutual transformation of river and lake systems. Al-Quraishi and Kaplan (2021) studied the effect of river flow variability on Al-Hammar marsh area and indicated that river-marsh connection was critical for restoration of unique social-ecological system. Mayo et al. (2018) established a model for nitrogen transformation in typical wetlands connecting the lake and river. The results showed that total nitrogen can be removed by the wetland system largely through sedimentation, plant uptake and denitrification, which will benefit the lake ecosystem. Su et al. (2021) analysed the effects of urbanization on regionals climate in lake-marsh area. The results suggested that urbanization has formed the 'Rain Island Effect' due to the existence of lake-marsh system, which increases the potential risk of urban flood control warning.

To advance e-flow research from isolating rivers, lakes and marshes to connecting them, a special issue 'Environmental Flow Mechanism and Management for River-Lake-Marsh Systems' has been organized. Papers in this special issue are presented covering three themes (1) e-flow mechanism; (2) e-flow calculation and (3) e-flow management.

2 | ENVIRONMENTAL FLOW MECHANISM

The mechanisms connecting hydrological and environmental/ecological processes are the basis for e-flow calculation and management. For a river–lake-marsh system, e-flow research should consider the maintenance of both its structure and function. The hydrological connectivity is an important indicator for the structure of a river–lake-marsh system, while aquatic organism provision is an important function for a river–lake-marsh system. The main functions of hydrological connectivity of river–lake-marsh system include five categories: source function, sink function, lag function, transformation function and refuge function (Leibowitz et al., 2018; USEPA, 2015). When the overflow connects one water-body to other water-bodies, the source function occurs (Lane et al., 2018), and can provide water, organic matter, heat energy to other water-bodies. River–lake-marsh systems have huge water capacity and could sink water through deep percolation and evapotranspiration; this feature allows connective wetlands to sink flood, sediment and pollutants in the upstream water-bodies and prevent their transport to the downstream water-bodies (Battin et al., 2008; Weng et al., 2003). The lag function is often reflected in the hydrological process of reducing flood peak and maintaining base flows in drought periods (Lane et al., 2018). The mechanism of transformation function is similar to that of sink function; but the sink function prevents the movement to downstream, while the transformation function continues the transportation by transforming the energy and material in the river–lake-marsh system (Fritz et al., 2018). High degree of connectivity in river–lake-marsh system forms interconnected corridors, and can provide refuge for migrant species under threated (Leibowitz et al., 2008; Wohl et al., 2021). Meanwhile, these functions show the application potential of hydrological connectivity for flow maintenance, water quality improvement, endanger species protection and water resource regulation at the basin scale.

In this special issue, for the research on hydrological connectivity, Liu, Cui, et al. (2020) evaluated the longitudinal connectivity based on fluxes of materials (water, sediment and chemicals) in a typical river–lake-marsh system. The results indicated that landscape patterns could significantly affect fluxes in the system and should be taken into account. Liu, Wang, et al. (2020) explored the potential application of an interferometric synthetic aperture radar (InSAR)-based methodology to determine hydrological connectivity and barriers in fragmented wetlands, and mapped different types of barriers affecting connectivity.

Besides hydrological connectivity, the relationship between aquatic organisms and hydrological processes is also an important mechanism for e-flow assessment. In this special issue, Liu et al. (2021) conducted laboratory experiments to explore the influence of hydrological processes on reproductive migration quality, and found that low flow velocity and water temperature could affect the swimming behaviour and gonad development of Chinese grass carps. Li, Sun, et al. (2021) studied the connection between water level regimes and macrophyte communities, and found that water level regimes influenced diversity through the concentration of total nitrogen and chemical oxygen demand.

3 | ENVIRONMENTAL FLOW CALCULATION

E-flow calculation for a river–lake-marsh system should also consider the maintenance of both the structure and function. Accordingly, the hydrological connectivity and aquatic organisms are considered in this special issue. The aquatic organisms could be fishes, plants, waterbirds and so forth.

In terms of hydrological connectivity, Yang et al. (2021) applied a new method to evaluate the stereoscopic spatial connectivity of river–lake-marsh systems, and established a relationship between this connectivity and the requirements of animal habitat and migration. This framework is useful for e-flow calculation at the watershed scale. The vertical connectivity between surface water and groundwater is also an important factor for e-flow assessment. Guo et al. (2020) proposed a method to analyse the driving factors for groundwater resource changes in arid irrigated areas, and determined the effects of three factors (land use, climate and groundwater extraction) on the interactions between surface water and groundwater.

For aquatic organism protection in river–lake-marsh systems, three papers are selected. Hu et al. (2021) built a two-dimensional model to obtain the fitting curves between fish's Weighted Usable Area (WUA) and water levels, and then identified suitable water levels in different periods. To control algal bloom in the middle and lower reaches of Han River, Li, Yin, et al. (2021) established a hydrological management framework and determined the threshold flow velocities. The results indicated that differences in river morphology and background nutrient levels could cause significant differences in the critical threshold flow velocities for algal bloom outbreaks. Waterbird habitat provision is also an important aim for e-flow assessment. The reverse seasonal hydrological patterns in lake-marsh systems will lead to the degradation of waterbird habitat. Based on the habitat requirements of waterbirds, the sheltering and forageable areas for waterbirds under different water-depth and aquatic plant distribution scenarios, Qin et al. (2021) established a new method for e-flow assessment in lake-marsh systems with reverse seasonal hydrological patterns.

4 | ENVIRONMENTAL FLOW MANAGEMENT

The water that can be used for e-flow supply is very limited, especially under the ever-increasing water resource demands for human supplies and irrigation. Due to the stress of water supply, e-flow requirement usually cannot be achieved by hydrological management alone. It is necessary to consider the balance between human and ecosystem needs, and propose new e-flow management methods (such as plant or topography management) in addition to the traditional hydrological management measures.

The balance between human and ecosystem needs is an important task for e-flow management. Xing et al. (2021) pointed out that previous e-flow studies mainly focused on determining e-flow requirements, while much less attention was paid to a more important problem—how such e-flows could be reached under changed watershed hydrological processes. They further proposed to conduct a basin water balance analysis based on a hydrological process analysis of the watershed.

Four new e-flow management methods were proposed to mitigate the pressure of e-flow provision. Xu et al. (2021) combined e-flow and macrophyte management in the restoration of a large eutrophic lake-marsh system, accounting for interactions between hydrological and nutrient removal processes, and developed an optimization model to guide upstream water release. Qiu et al. (2021) proposed to combine hydrological management and artificial planting for waterbird habitat provision in wetlands. The results indicated that artificial planting could effectively mitigate the pressure of hydrological management. Bi et al. (2020) proposed an optimal lake-marsh pattern determination method, associated with eco-hydrological management, to relieve the competitions between land use and water use. They found that the possible optimal patterns could be obtained, with the area ratio of lake and marsh in a certain range. In water-deficient rivers, e-flows are usually sustained via interbasin water transfer projects from water-sufficient rivers, but these projects incur tremendous costs. Gao et al. (2021) proposed to transfer hydropower instead of water from water sufficient rivers, and established a framework to determine the hydropower amount required for e-flow supply.

ACKNOWLEDGEMENTS

This research was supported by the National Natural Science Foundation of China (52079007), and the National Key R&D Program of China (2017YFC0404500).

REFERENCES

Abebe, W. B., Tilahun, S. A., Moges, M. M., Wondie, A., Dersseh, M. G., Assefa, W. W., & McClain, M. E. (2021). Ecological status as the basis for the holistic environmental flow assessment of a tropical Highland River in Ethiopia. *Water*, *13*(14), 1913. https://doi.org/10.3390/w13141913

Akter, A., & Tanim, A. H. (2018). A modeling approach to establish environmental flow threshold in ungauged semidiurnal tidal river. *Journal of Hydrology*, *558*, 442–459. https://doi.org/10.1016/j.jhydrol.2018.01.061

Al-Quraishi, A. K., & Kaplan, D. A. (2021). Connecting changes in Euphrates River flow to hydropattern of the Western Mesopotamian marshes. *Science of the Total Environment*, *768*, 144445. https://doi.org/10.1016/j.scitotenv.2020.144445

Battin, T. J., Kaplan, L. A., Findlay, S., Hopkinson, C. S., Marti, E., Packman, A. I., Newbold, D., & Sabater, F. (2008). Biophysical controls on organic carbon fluxes in fluvial networks. *Nature Geoscience*, *1*(2), 95–100. https://doi.org/10.1038/ngeo101

Bi, W. X., Weng, B. S., Yan, D. H., Li, M., Yu, Z. L., Wang, L., & Wang, H. (2020). Optimal lake-marsh pattern determination in lake-marsh systems based on the eco-hydrological processes management. *Hydrological Processes*, *34*(26), 5260–5277. https://doi.org/10.1002/hyp.13941

Boavida, I., Jesus, J. B., Pereira, V., Santos, C., Lopes, M., & Cortes, R. M. V. (2018). Fulfilling spawning flowrequirements for potamodromous cyprinids in a restored river segment. *Science of the Total Environment*, *635*, 567–575. https://doi.org/10.1016/j.scitotenv.2018.04.167

Boner, M. C., & Furland, L. P. (1982). Seasonal treatment and variable effluent quality based on assimilative-capacity. *Journal Water Pollution Control Federation*, *54*(10), 1408–1416.

Campbell, C. J., Freestone, F. L., Duncan, R. P., Higgisson, W., & Healy, S. J. (2021). The more the merrier: Using environmental flows to improve floodplain vegetation condition. *Marine and Freshwater Research*, *72*(8), 1185–1195. https://doi.org/10.1071/mf20303

Chen, A., Sui, X., Liao, W. G., & Chen, K. L. (2016). Review study on instream ecological base flow in China. *Journal of China Institute of Water Resources and Hydropower Research*, *14*(06), 401–411. https://doi.org/10.13244/j.cnki.jiwhr.2016.06.001

Chen, L., Chen, L., Jia, J., Xu, Y., Luan, Z., & Shi, Y. (2019). Quantitative effects of water level variation on the habitat area of wintering waterfowl in dry season of the Poyang Lake. *Journal of Hydraulic Engineering*, *50*(12), 1502–1509. https://doi.org/10.13243/j.cnki.slxb.20190647

Cigizoglu, H. K., & Bayazit, M. (2000). A generalized seasonal model for flow duration curve. *Hydrological Processes*, *14*(6), 1053–1067. https://doi.org/10.1002/(sici)1099-1085(20000430)14:6<1053::Aid-hyp996>3.0.Co;2-b

Drexler, J. Z., Anderson, F. E., & Snyder, R. L. (2008). Evapotranspiration rates and crop coefficients for a restored marsh in the Sacramento-san Joaquin Delta, California, USA. *Hydrological Processes*, *22*(6), 725–735. https://doi.org/10.1002/hyp.6650

Fritz, K. M., Schofield, K. A., Alexander, L. C., McManus, M. G., Golden, H. E., Lane, C. R., Kepner, W. G., LeDuc, S. D., DeMeester, J. E., & Pollard, A. I. (2018). Physical and chemical connectivity of streams and riparian wetlands to downstream waters: A synthesis. *Journal of the American Water Resources Association*, *54*(2), 323–345. https://doi.org/10.1111/1752-1688.12632

Gan, F., Tang, L., Guo, H., & Gao, W. (2015). New method and application of estimating ecological water level of the Lake Poyang. *Journal of Lake Science*, *27*(5), 783–790.

Gao, T., Liu, H. R., Sun, Y. Y., & Zhang, E. Z. (2021). Sustaining environmental flows in water-deficient rivers via inter-basin hydropower transfer. *Hydrological Processes*, *35*(2), e14027. https://doi.org/10.1002/hyp.14027

Gleick, P. H. (1998). Water in crisis: Paths to sustainable water use. *Ecological Applications*, *8*(3), 571–579. https://doi.org/10.1890/1051-0761(1998)008[0571:Wicpts]2.0.Co;2

Gong, Z., Lu, L., Jin, D., Qiu, H., Zhang, Q., & Guan, H. (2021). Remote sensing estimation of evapotranspiration and ecological water demand in Zhalong wetland under land use /cover change. *Acta Ecologica Sinica*, *41*(9), 3572–3587.

Guo, C. Y., Liu, T., Niu, Y. X., Liu, Z. B., Pan, X. H., & De, M. P. (2020). Quantitative analysis of the driving factors for groundwater resource changes in arid irrigated areas. *Hydrological Processes*, *35*(1), e13967. https://doi.org/10.1002/hyp.13967

Guo, Y. T., Shao, J. L., Zhang, Q. L., & Cui, Y. L. (2021). Relationship between water surface area of Qingtu Lake and ecological water delivery: A case study in Northwest China. *Sustainability*, *13*(9), 4684. https://doi.org/10.3390/su13094684

Haghighi, A. T., Fazel, N., Hekmatzadeh, A. A., & Klove, B. (2018). Analysis of effective environmental flow release strategies for Lake Urmia restoration. *Water Resources Management*, *32*(11), 3595–3609. https://doi.org/10.1007/s11269-018-2008-3

He, S., Yin, X., Li, H., & Zhang, E. (2020). Estimating the ecological water demand in lakes and the degree of certainty based on the Markov process. *Journal of Hydroecology*, *41*(5), 13–20. https://doi.org/10.15928/j.16743075.2020.05.002

Hu, P., Yang, Z. F., Zhu, Q. D., Wang, W. Z., & Yang, Q. (2021). Quantifying suitable dynamic water levels in marsh wetlands based on hydrodynamic modelling. *Hydrological Processes*, *35*(2), e14054. https://doi.org/10.1002/hyp.14054

Jain, S. K. (2012). Assessment of environmental flow requirements. *Hydrological Processes*, *26*(22), 3472–3476. https://doi.org/10.1002/hyp.9455

Karim, F., Kinsey-Henderson, A., Wallace, J., Godfrey, P., Arthington, A. H., & Pearson, R. G. (2014). Modelling hydrological connectivity of tropical floodplain wetlands via a combined natural and artificial stream network. *Hydrological Processes*, *28*(23), 5696–5710. https://doi.org/10.1002/hyp.10065

Lane, C. R., Leibowitz, S. G., Autrey, B. C., LeDuc, S. D., & Alexander, L. C. (2018). Hydrological, physical, and chemical functions and connectivity of non-floodplain wetlands to downstream waters: A review. *Journal of the American Water Resources Association*, *54*(2), 346–371. https://doi.org/10.1111/1752-1688.12633

Leibowitz, S. G., Wigington, P. J., Rains, M. C., & Downing, D. M. (2008). Non-navigable streams and adjacent wetlands: Addressing science needs following the Supreme Court's Rapanos decision. *Frontiers in Ecology and the Environment*, *6*(7), 366–373. https://doi.org/10.1890/070068

Leibowitz, S. G., Wigington, P. J., Schofield, K. A., Alexander, L. C., Vanderhoof, M. K., & Golden, H. E. (2018). Connectivity of streams and wetlands to downstream waters: An integrated systems framework. *Journal of the American Water Resources Association*, *54*(2), 298–322. https://doi.org/10.1111/1752-1688.12631

Li, H., Gong, Z., Bu, F., & Zhou, D. (2019). Estimation of ecological water storage of marsh wetlands in Honghe National Nature Reserve. *Wetland Science*, *17*(2), 210–214. https://doi.org/10.13248/j.cnki.wetlandsci.2019.02.012

Li, J., Yin, W., Jia, H. Y., & Xin, X. K. (2021). Hydrological management strategies for the control of algal blooms in regulated lowland rivers. *Hydrological Processes*, *35*(6), e14171. https://doi.org/10.1002/hyp.14171

Li, J. I. A., & JianJian, L. U. (2011). The meaning of water storage in wetlands and analysis of cases. *Wetland Science*, *9*(2), 116–119.

Li, L. J., Li, J. Y., Liang, L. Q., & Liu, Y. M. (2009). Method for calculating ecological water storage and ecological water requirement of marsh. *Journal of Geographical Sciences*, *19*(4), 427–436. https://doi.org/10.1007/s11442-009-0427-z

Li, S. H., Sun, T., Yang, W., Cui, B. S., & Yin, X. N. (2021). A biodiversity evaluation framework for restoration of aquatic macrophyte communities in shallow lakes driven by hydrological process management. *Hydrological Processes*, *35*(1), e13983. https://doi.org/10.1002/hyp.13983

Li, T. X., Guo, S. B., An, D. F., & Nametso, M. (2019). Study on water and salt balance of plateau salt marsh wetland based on time-space watershed analysis. *Ecological Engineering*, *138*, 160–170. https://doi.org/10.1016/j.ecoleng.2019.07.027

Liu, D., Wang, X., Aminjafari, S., Yang, W., Cui, B. S., Yan, S. J., & Jaramillo, F. (2020). UsingInSARto identify hydrological connectivity and barriers in a highly fragmented wetland. *Hydrological Processes*, *34*(23), 4417–4430. https://doi.org/10.1002/hyp.13899

Liu, H. R., Yin, X. A., Qiu, X. T., Qin, J. L., Yang, W., & Zhang, J. (2021). Coupled influence of flow velocity and water temperature on grass carp swimming behaviour and gonad development. *Hydrological Processes*, *35*(4), e14052. https://doi.org/10.1002/hyp.14052

Liu, J., & Yang, Z. (2002). A study on the calculation methods of the minimum eco-environmental water demand for lakes. *Journal of Natural Resources*, *17*(5), 604–609.

Liu, Y. L., Cui, B. S., Du, J. Z., Wang, Q., Yu, S. L., & Yang, W. (2020). A method for evaluating the longitudinal functional connectivity of a river–lake–marsh system and its application in China. *Hydrological Processes*, *34*(26), 5278–5297. https://doi.org/10.1002/hyp.13946

Mayo, A. W., Muraza, M., & Norbert, J. (2018). Modelling nitrogen transformation and removal in mara river basin wetlands upstream of Lake Victoria. *Physics and Chemistry of the Earth*, *105*, 136–146. https://doi.org/10.1016/j.pce.2018.03.005

Qin, J. L., Yin, X. A., Qiu, X. T., Liu, H. R., Zhang, E. Z., & Sun, Y. Y. (2021). Environmental flow assessment in a lake-marsh system with reverse seasonal hydrological patterns. *Hydrological Processes*, *35*(5), e14224. https://doi.org/10.1002/hyp.14224

Qiu, X. T., Liu, H. R., Yin, X. A., & Qin, J. L. (2021). Combining the management of water level regimes and plant structures for waterbird habitat provision in wetlands. *Hydrological Processes*, *35*(5), e14122. https://doi.org/10.1002/hyp.14122

Su, H. D., Wang, W., Jia, Y. W., Han, S. C., Gao, H., Niu, C. W., & Ni, G. H. (2021). Impact of urbanization on precipitation and temperature over a lake-marsh wetland: A case study in Xiong'an new area, China. *Agricultural Water Management*, *243*, 106503. https://doi.org/10.1016/j.agwat.2020.106503

Tennant, D. L. (1976). Instream flow regimens for fish, wildlife, recreation and related environmental resources. *Fisheries*, *1*(4), 6–10. https://doi.org/10.1577/1548-8446(1976)001<0006:IFRFFW>2.0.CO;2

Tharme, R. E. (2003). A global perspective on environmental flow assessment: Emerging trends in the development and application of environmental flow methodologies for rivers. *River Research and Applications*, *19*(5–6), 397–441.

USEPA. (2015). Connectivity of Streams and Wetlands to Downstream Waters: A Review and Synthesis of the Scientific Evidence. Washington. Retrieved from https://cfpub.epa.gov/si/si_public_record_report.cfm?Lab=NCEA&dirEntryId=296414

Weng, P., Sanchez-Perez, J. M., Sauvage, S., Vervier, P., & Giraud, F. (2003). Assessment of the quantitative and qualitative buffer function of an alluvial wetland: Hydrological modelling of a large floodplain (Garonne River, France). *Hydrological Processes*, *17*(12), 2375–2392. https://doi.org/10.1002/hyp.1248

Wohl, E., Castro, J., Cluer, B., Merritts, D., Powers, P., Staab, B., & Thorne, C. (2021). Rediscovering, reevaluating, and restoring lost river-wetland corridors. *Frontiers in Earth Science*, *9*, 653623. https://doi.org/10.3389/feart.2021.653623

Xing, Z. Q., Huang, H. J., Li, Y. Y., Liu, S. S., Wang, D., Yuan, Y., Zhao, Z., & Bu, L. S. (2021). Management of sustainable ecological water levels of endorheic salt lakes in the inner Mongolian plateau of China based on eco-hydrological processes. *Hydrological Processes*, *35*(5), e14192. https://doi.org/10.1002/hyp.14192

Xu, Z. H., Yang, Y., Yu, C. X., & Yang, Z. F. (2021). Optimizing environmental flow and macrophyte management for restoring a large eutrophic lake-marsh system. *Hydrological Processes*, *35*(1), e13965. https://doi.org/10.1002/hyp.13965

Yang, Q., Hu, P., Wang, J. H., Zeng, Q. H., Yang, Z. F., Liu, H., & Dong, Y. Y. (2021). The stereoscopic spatial connectivity of wetland ecosystems: Evaluation method and regulation measures. *Hydrological Processes*, *35*(5), e141074. https://doi.org/10.1002/hyp.14074

Yang, Z., & Zhang, Y. (2003). Comparison of methods for ecological and environmental flow in river channels. *Journal of Hydrodynamics*, *18*(3), 294–301.

Yasi, M., & Ashori, M. (2017). Environmental flow contributions from In-Basin Rivers and dams for saving Urmia Lake. *Iranian Journal of Science and Technology-Transactions of Civil Engineering*, *41*(1), 55–64. https://doi.org/10.1007/s40996-016-0040-1

Yu, C., Liu, Q. B., He, Z. Z., Gao, X. D., Wu, E. X., Guo, J. C., Zhou, C., & Feng, Z. H. (2020). Epitaxial graphene gas sensors on SiC substrate with high sensitivity. *Journal of Semiconductors*, *41*(3), 032101. https://doi.org/10.1088/1674-4926/41/3/032101