water

MDPI

Editorial

Leverage Points Used in a Systems Approach of River and River Basin Restoration

Theodore A. Endreny

Department of Environmental Resources Engineering, SUNY ESF, Syracuse, NY 13210, USA; te@esf.edu

Received: 10 September 2020; Accepted: 11 September 2020; Published: 18 September 2020

check for updates

Abstract: River basins are complex spatiotemporal systems, and too often, restoration efforts are ineffective due to a lack of understanding of the purpose of the system, defined by the system structure and function. The river basin system structure includes stocks (e.g., water volume or quality), inflows (e.g., precipitation or fertilization), outflows (e.g., evaporation or runoff), and positive and negative feedback loops with delays in responsiveness, that all function to change or stabilize the state of the system (e.g., the stock of interest, such as water level or quality). External drivers on this structure, together with goals and rules, contribute to how a river basin functions. This article reviews several new research projects to identify and rank the twelve most effective leverage points to address discrepancies between the desired and actual state of the river basin system. This article demonstrates river basin restoration is most likely to succeed when we change paradigms rather than trying to change the system elements, as the paradigm will establish the system goals, structure, rules, delays, and parameters.

Keywords: watershed; systems; restoration

---

1. Introduction

River and river basin restoration faces significant technical challenges as well as challenges to our conception or paradigm for the purpose of the river basin. This article defines the term restoration as reestablishing structure and function of an ecosystem, yet invites readers to substitute in the terms rehabilitation, defined as making an ecosystem useful after disturbance, or reclamation, defined as changing the biophysical capacity of an ecosystem. The major technical challenges include: (a) the restoration target is often unknown, is not likely an initial or completely natural state, and remains poorly understood; (b) restoration structures should provide multiple functions across seasonal flow regime to benefit humans and biodiversity; (c) restoration spatial scale and complexity should consider local to basin-level issues; and (d) restoration resiliency should handle uncertain future drivers related to urbanization and climatic disruption [1].

Human systems and ecosystems are separated to show their interaction in the United Nations model of the river basin system (Figure 1), recognizing the agency of humans to affect change, i.e., the Anthropocene epoch [1]. In this model, humans depend on the services from the same ecosystems we diminish by polluting, harvesting, and other pressures (e.g., climate disruption). Furthermore, humans can assess the actual state of the ecosystem (e.g., water volume or quality) and compare it with our desires for the state of the ecosystem (e.g., below target). New to this model is what comes next, that we use this comparison of the actual and desired state of the system to formulate the paradigm rather than the policy for our river basin restoration, which may be active or passive. It is the purpose of this paper to show the task of formulating our paradigm for the purpose of a river basin is equally if not more important than the list of major technical challenges for river basin restoration.

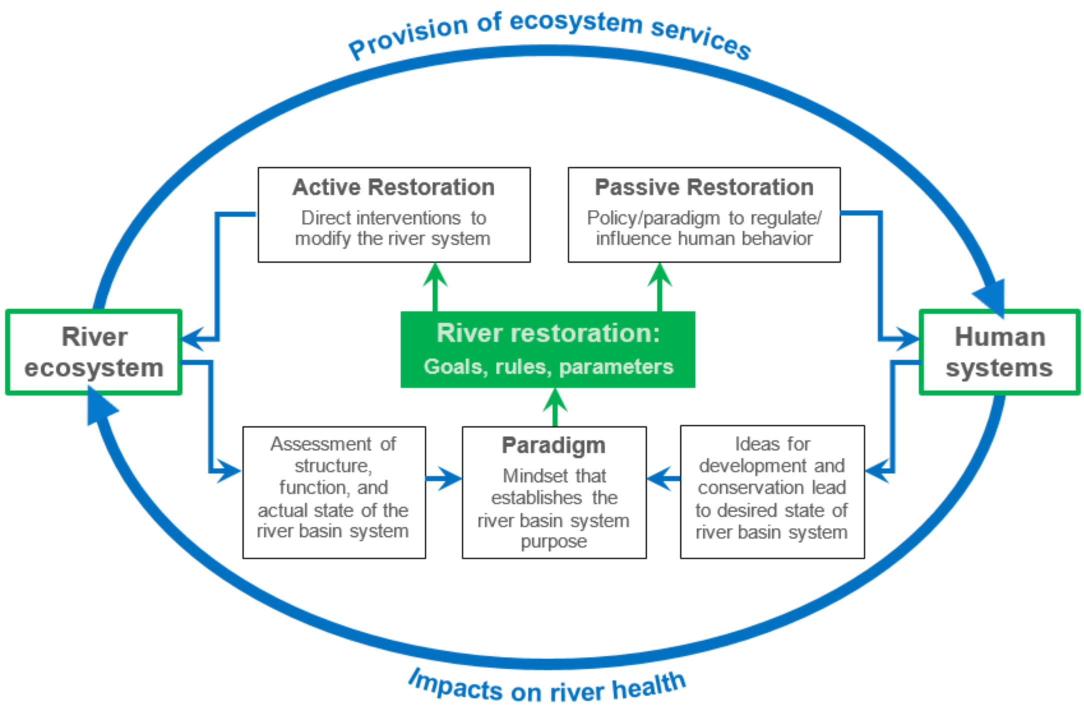

Figure 1. Conceptual model of a river basin system with human systems benefiting from and affecting the ecosystems, and the formulation of a paradigm for river basin restoration based on comparing actual vs. the desired state of the system. Adapted from Speed et al. [1].

2. Evolution of a Systems Approach to River Basins

River basin scientists and engineers have made important progress in recognizing that these challenges are all part of a single complex system [2], noting that tinkering with elements in one location or time tends to impact the state or function of elements in other parts of the system [3,4]. Actually managing the complexity of the river basin system is yet another challenge and progress in this area requires better understanding of systems and their leverage points.

Systems are generally defined as a set of spatially and temporally interconnected parts that respond to internal and external signals, such as those from the surrounding environment. Systems, including those of river basins, typically have a structure that includes stocks (e.g., water levels or quality in basin), inflows (e.g., precipitation or fertilization), outflows (e.g., evaporation or runoff), and positive and negative feedback loops with delays in responsiveness, that all function to change or stabilize the state of the system (e.g., the stock of interest, such as water level or quality). When there are discrepancies between the desired and actual state of the system, managers want to intervene. Too often, a lack of understanding of system structure and functions results in interventions not achieving the desired outcome. Systems theorist and practitioner Meadows [5], who led the Limits to Growth study for the Club of Rome, sought to improve outcomes by identifying twelve strategic leverage points for intervening in any system.

3. Strategic Leverage Points to Advance Restoration of the River Basin System

To arrive at the most strategic leverage points for intervening in systems, Meadows [5] began by observing how we need to look beyond system outcomes (e.g., events such as excessive flooding or pollution) to consider the system structure by which parts are related and the system functions which respond to the rules, opportunities for change, and goals of the system. Together, the structure and function create the state of the system and can be defined as the actual purpose of the system, whether or not if that purpose aligns with our desire. In the end the state of the system, i.e., the outcomes such as water level or quality, tell us the purpose of the system, and if we do not like the outcomes, we either have to change our paradigm or the system's purpose. From this insight emerged the twelve most strategic leverage points for intervening in systems, ranked from least to most effective, and adapted for river basins (see Table 1).

Table 1. Strategic leverage points for intervening in systems, such as river basin restoration, ranked from least to most effective. Adapted from Meadows [5].

Reverse Rank	Leverage Points for Intervening in River Basin Systems
Lever 12	Constants, parameters, numbers (such as subsidies, water rates, standards).
Lever 11	The sizes of buffers and other stabilizing stocks, relative to their flows.
Lever 10	The structure of material stocks and flows (such as transport networks, population age structures).
Lever 9	The lengths of delays, relative to the rate of system change.
Lever 8	The strength of negative feedback loops, relative to the impacts they are trying to correct against.
Lever 7	The gain around driving positive feedback loops.
Lever 6	The structure of information flows (who does and does not have access to information).
Lever 5	The rules of the system (such as incentives, punishments, constraints).
Lever 4	The power to add, change, evolve, or self-organize system structure.
Lever 3	The goals of the system.
Lever 2	The mindset or paradigm that establishes the system goals, structure, rules, delays, parameters.
Lever 1	The power to transcend paradigms.

4. Illustrations of Leverage Points and Their Relative Effectiveness in River Basin Restoration

A systems approach to river basin restoration then involves addressing the grandest and most intractable challenges by transcending paradigms and our mindset, and then, changing the goals of the system. This Special Issue takes us further along the path in understanding the river basin as a complex system, while probing the effectiveness of several important leverage points to affect change.

Rampinelli et al. [6] examined the leverage point #12 of constants, parameters, and numbers related to flooding from the framework of uncertainty analysis, which then provides a framework for updating the leverage point #5 of rules of the system for setting flood policy and managing risk. Rampinelli et al. [6] found that variance in flow data records can be analyzed with a Bayesian approach to separately represent the flood level uncertainty due to uncertainties in flow rate associated with return interval (frequency analysis) and river stage (rating curves). Their method can lead to a more accurate range of expected flood level outcomes to inform restoration and management. Golpira et al. [7] examined leverage points #7 (positive feedback loops) and #11 (sizes of buffers and other stabilizing stocks) as they relate to in-channel boulder placement and subsequent channel bed shear and erosion. Golpira et al., showed that information about this system (leverage point #6) was constrained by the type of instrumentation available to collect data and the subsequent calculation of shear stress (they compared four calculations—reach-average, Reynolds, turbulent kinetic energy (TKE), and modified TKE). Working with different boulder spacing densities and flow levels, which ranged from unsubmerged to fully submerged boulders, it was found that for unsubmerged conditions, the four shear stress equations generated different information, and for submerged conditions, the feedback between boulders and sediment erosion could be controlled by reducing boulder density.

Abebe et al. [8] explored the impact of new rules for the system (leverage point #5) and the length of delays (leverage point #9) to establish a holistic basis for setting flow regimes in Ethiopia's Gumara

River basin, which feeds Lake Tana and is the source of the Blue Nile. The current flow regime, set by an existing set of rules and flow delays that prioritize irrigation, dams, and river regulation, has contributed to dry channels, interrupted fish migration and spawning, and the loss of fishing. The research demonstrates that proposed rules to allocate 10 to 25% of flows to the environment will not achieve ecological health targets without considering the coupling between flow timing (i.e., delays) and flow to achieve naturalization of the flow regime that supports key ecological processes [8]. Liu et al. [9] examined how power to add, change, evolve, or self-organize system structure (leverage point #4) could lead to changes in the rules (leverage point #5) that are fairer and achieve water quality targets. The research used a multi-scale and multi-pollutant waste-load allocation model to explore changes in pollution quotas across 1350 areas within the Xian-jiang river basin of China, finding an allocation that reduced inequality (based on Gini coefficients) yet was more economical and met pollutant thresholds for chemical oxygen demand, ammonia nitrogen, and total phosphorus [9].

Doehring et al. [10] examined the leverage points #11 (the sizes of buffers) and #9 (the length of delays) as they relate to establishing vegetation in riparian buffers across 5 to 34 years, and the emergence of indicators of restoration, such as healthy aquatic microbial communities. The research used paired river reaches in the Waikato region of the central North Island, New Zealand, each pair containing a treatment with exclusion fencing and a control with grazing. Doehring et al. [10] showed that reaches with livestock exclusion led to greater measured riparian shade and greater cotton tensile-strength loss, which is an indicator of better established microbial communities and ecosystem functioning, yet delay in recovery or insufficient buffer size (e.g., only 2% of river basin) led to many missing indicators and makes restoration questionable. Abdi and Endreny [11] created a new river temperature model to identify thermal pollution causes and solutions, which can simulate leverage points #7 to 12 and their impact on outcomes. The i-Tree Cool River model can simulate the shading of riparian vegetation, groundwater and surface water exchange, and the thermal effects of stormwater runoff and green infrastructure treatments, and was written in freely accessible software and with a relatively small number of inputs in order to increase the number of people with access to the information (leverage point #6).

Saulys et al. [12] created an elegant study that monitored the system output signal of nitrate and phosphate concentrations along six rivers of the Nemunas and Venta basins in Lithuania, contrasting reaches straightened for flood drainage with natural unstraightened reaches. By finding the natural unstraightened reaches had statistically higher self-purification rates, defined as reductions in nitrate and phosphate from upstream to downstream, they validated at a national scale the functional importance of curvature in rivers, and to contribute to the change in mindset (leverage point #2) across Europe that self-purification is more important than straight rivers [13]. Zhou and Endreny [14] utilize leverage point #4 (the power to self-organize) to show how restored curvature in bedform topography, without awaiting full channel bank meander restoration, will reorganize the water column flows and restore hydraulic complexity, important for fish, and connectivity with the hyporheic zone, which is beneath the riverbed. Kruegler et al. [15] use leverage points #7 to 12 in a river corridor groundwater model to explore how the hyporheic zone, and its interaction with the river, can be changed and organized (leverage point #4) by riparian drawdown induced by evapotranspiration from riverside plantings. The research provides guidance on how to create opportunities for self-purification of pollutants, using natural resources powered by renewable energies.

5. New Paradigms in River Basin Restoration Include Honoring Water

Incrementally, the research on river basin restoration is bringing about the power to transcend paradigms, which is leverage point #1. This can be seen in the new approach to flood control announced by the US Department of Homeland Security and their Federal Emergency Management Agency, where they use language of "larger-scale migration or relocation" [16] rather than the older paradigm of "rebuild and flood-proof". This new paradigm of yielding to water rather than expecting water to yield to humans approaches the paradigm of honoring water, practiced by the Haudenosaunee

Confederacy of North America, who predate European settlement. The Haudenosaunee make it their duty to protect the water so that water can perform her duties. The Onondaga Nation, a member of the Haudenosaunee Confederacy, lived on the hills surrounding their Sacred Lake rather than settling within the floodplain. By contrast, Europeans who subsequently settled along Onondaga Lake, New York, undertook massive flood control and development projects that have led to the degradation of river basin fisheries and water quality [17]. This Haudenosaunee paradigm of gratitude for water, and its leverage on informing their mindset, is expressed in their Thanksgiving Address, "We give thanks to all the Waters of the world for quenching our thirst and providing us with strength. Water is life. We know its power in many forms, waterfalls and rain, mists and streams, rivers and oceans. With one mind, we send greetings and thanks to the spirit of Water. Now our minds are one." [18].

This Special Issue encourages our readers to utilize these new findings and the leverage points to restore river basin systems. The most effective leverage point is transcending paradigms and developing new mindsets for working with the complexity of river basin systems. Of course, developing the paradigm is part of the system. So the systems path scientists and engineers might follow in restoration (Figure 1), as adapted from the UN [1], is: (1) identifying, understanding, and working with the physical, chemical, and biological processes comprising river basin and river health and delivering ecosystem services; (2) identifying, incorporating, and involving socio-economic values and broader planning and development activities linked to river basin and river health; (3) addressing structure and function relationships at the appropriate scales to address limiting factors to river health; (4) setting clear, achievable, and measurable goals, framed in terms of changes to ecosystem structure and function, the provisioning of ecosystem services, and, where feasible, socioeconomic factors; (5) planning, implementing, and managing to provide resilience to a range of scenarios over time, including changes to climate, land use, hydrology, pollutant loads, and population, so restoration outcomes are sustained over the long term; (6) involving all relevant stakeholders in an integrated approach, addressing land and water issues, and involving interagency and community collaboration, to achieve the greatest benefits; and (7) monitoring, evaluating, adapting, and reporting the actual state of river basin health relative to the desired state, and formulating our paradigm to guide restoration and adaptive management. Together on this journey we can improve social and ecological systems within our river basins.

Funding: This research received no external funding.

Acknowledgments: The author is grateful for the insights provided by the 2016 UN report on river basin restoration [1] and for the development of system leverage points by Meadows [5].

Conflicts of Interest: The author declares no conflict of interest.

References

1. Speed, R.; Li, Y.; Tickner, D.; Huang, H.; Naiman, R.; Cao, J.; Gang, L.; Yu, L.; Sayers, P.; Zhao, Z.; et al. *River Restoration: A Strategic Approach to Planning and Management*; UNESCO: Paris, France, 2016.
2. Cai, X.; Ranjithan, R. Special Issue on the Role of Systems Analysis in Watershed Management. *J. Water Resour. Plan. Manag.* **2013**, *139*, 461–463. [CrossRef]
3. USDA-NRCS. *National Engineering Handbook—Part 654 Stream Restoration Design*; United States Department of Agriculture, Natural Resources Conservation Service: Washington, DC, USA, 2007; pp. 6–36.
4. Mitsch, W.J.; Jorgensen, S.E. *Ecological Engineering and Ecosystem Restoration*; John Wiley & Sons: New York, NY, USA, 2004.
5. Meadows, D. *Thinking in Systems: A Primer*; Chelsea Green Publishing: White River Junction, VT, USA, 2008.
6. Rampinelli, C.G.; Knack, I.; Smith, T. Flood Mapping Uncertainty from a Restoration Perspective: A Practical Case Study. *Water* **2020**, *12*, 1948. [CrossRef]
7. Golpira, A.; Huang, F.; Baki, A.B.M. The Effect of Habitat Structure Boulder Spacing on Near-Bed Shear Stress and Turbulent Events in a Gravel Bed Channel. *Water* **2020**, *12*, 1423. [CrossRef]

8. Abebe, W.B.; Tilahun, S.A.; Moges, M.M.; Wondie, A.; Derseh, M.G.; Nigatu, T.A.; Mhiret, D.A.; Steenhuis, T.S.; Camp, M.V.; Walraevens, K.; et al. Hydrological Foundation as a Basis for a Holistic Environmental Flow Assessment of Tropical Highland Rivers in Ethiopia. *Water* **2020**, *12*, 547. [CrossRef]
9. Liu, Q.; Jiang, J.; Jing, C.; Liu, Z.; Qi, J. A New Water Environmental Load and Allocation Modeling Framework at the Medium–Large Basin Scale. *Water* **2019**, *11*, 2398. [CrossRef]
10. Doehring, K.; Clapcott, J.E.; Young, R.G. Assessing the Functional Response to Streamside Fencing of Pastoral Waikato Streams, New Zealand. *Water* **2019**, *11*, 1347. [CrossRef]
11. Abdi, R.; Endreny, T. A River Temperature Model to Assist Managers in Identifying Thermal Pollution Causes and Solutions. *Water* **2019**, *11*, 1060. [CrossRef]
12. Šaulys, V.; Survilė, O.; Stankevičienė, R. An Assessment of Self-Purification in Streams. *Water* **2020**, *12*, 87. [CrossRef]
13. Anonymous. Re-Engineering Britain's Rivers: Why the Wiggles are Being Put Back into Watercourses, 6 March 2020. Available online: https://www.latestnigeriannews.com/news/8279579/reengineering-britains-rivers.html (accessed on 17 September 2020).
14. Zhou, T.; Endreny, T. The Straightening of a River Meander Leads to Extensive Losses in Flow Complexity and Ecosystem Services. *Water* **2020**, *12*, 1680. [CrossRef]
15. Kruegler, J.; Gomez-Velez, J.; Lautz, L.K.; Endreny, T.A. Dynamic Evapotranspiration Alters Hyporheic Flow and Residence Times in the Intrameander Zone. *Water* **2020**, *12*, 424. [CrossRef]
16. DHS. *Notice of Funding Opportunity Fiscal Year 2020 Building Resilient Infrastructure and Communities*; Department of Homeland Security (DHS): Washington, DC, USA, 2020; p. 37.
17. Effler, S.W. *Limnological and Engineering Analysis of a Polluted Urban Lake: Prelude to Environmental Management of Onondaga Lake*; Springer: New York, NY, USA, 1996; p. 832.
18. King, J.T. The Value of Water and the Meaning of Water Law for the Native Americans Known as the Haudenosaunee Cornell. *J. Law Public Policy* **2007**, *16*, 449–472.