Engineering With Nature®

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Engineering With Nature® in Fluvial Systems

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PURPOSE: The purpose of this technical note is to underline the growing need for Engineering With Nature® (EWN) guidance for inland fluvial systems. In comparison to the EWN coastal initiatives, guidance, and technical publications, emphasis on inland fluvial systems has been primarily focused on larger river systems, rather than smaller and intermediate-sized tributary systems. As EWN continues to expand its offerings and support inland systems, there is a strong need to fill data gaps and offer case study examples from underrepresented issues across different hydro-physiographic regions and ecosystems. Accordingly, this technical note offers background on the growing need for riverine EWN guidance as well recommendations moving forward to help address those needs.

BACKGROUND AND PROBLEM STATEMENT: As coined by the US Army Corps of Engineers (USACE) in 2010, the EWN initiative supports more sustainable practices, projects, and outcomes through the alignment of natural and traditional engineering processes to sustainably deliver economic, environmental, and social benefits through multi-disciplinary integration. As such, EWN is designed to efficiently and sustainably deliver economic, environmental, and social benefits through the use of natural systems in infrastructure projects. By using a combination of natural and conventional processes and materials, natural infrastructure can assist in the protection of people, homes, and habitats. Nature-based solutions (NBS) can take many forms and scales. This includes wave attenuating structures engineered to reduce storm surge and waves in coastal settings, re-connection of floodplains along rivers that allow the rivers to ebb and flow while reducing flood risks to communities, and protection or restoration of wetlands to filter pollution and sediments while providing ecological habitat improvement. Since the inception of EWN, significant progress has been made in the development and application of practical methods that demonstrate the benefits of a systems approach to infrastructure development and operations. As the EWN initiative celebrated its 10 years of practice and collaboration in 2020, it has continued to refine its vision and strategy by looking ahead at what remains to be accomplished in the EWN Strategic Plan 2018 – 2023. One area identified as a high-priority initiative is expanding upon the knowledge base of EWN principles and practices within inland fluvial systems.

Figure 1 shows the life-cycle relationship between EWN, climate adaptation, and resiliency, representing graphically the inter-relationship between sound integration of NBS with (1) climate risk assessment, (2) planning and design, (3) blue/green infrastructure, (4) watershed management, (5) water resources, (6) ecology and restoration, and (7) operations, maintenance, and monitoring.

Figure 1. Life-cycle illustration for EWN climate adaptation, and resiliency.

Throughout the integration of each of these life-cycle relationships, EWN becomes a sound means of increasing climate adaptation and resiliency through the incorporation of innovative, cost-effective, and importantly sustainable solutions. Through such an approach, EWN offers a mechanism to protect and enhance nature-based infrastructure while offering an improved response to perturbation, natural and anthropogenic stressors, and long-term and more effective resource management.

Inland fluvial systems are dominated by freshwater rivers, streams, floodplains, wetlands, and geomorphic features, such as natural levees, oxbows, streambanks, point bars, and terraces. EWN principles and practices focused upon smaller-order inland fluvial systems have seen less attention in comparison to coastal systems and larger riverine systems, resulting in a gap of knowledge necessary to support inland EWN practitioners. Riverine systems vary from first-order through twelfth-order systems with first- , second-, and third-order systems consisting of smaller headwater streams that flow into and feed larger systems. Streams that are classified as fourth- through sixth-order are medium-sized systems whereas anything classified from a seventh- to the twelfth-level system is classified as a large river (Horton 1945).

Upon review of EWN Geographic Project Mapping Tool Project (EWN ProMap) (*https://ewn.el.erdc.dren.mil/ProMap/index.html*) the disparity can be noted in regard to a higher emphasis having been placed upon coastal versus inland EWN featured projects and therefore the need for additional case study examples and guidance, particularly across the Rocky Mountain, Intermountain West, Southwest, and Great Plains Regions. As stated in the 2015 ProMap US Army Engineer Research and Development Center (ERDC) technical note, one of the key hindrances to implementation of the EWN concepts is comprehensive documentation of project type, description of practices and monitoring, and documentation of success (Fredette et al. 2011; Fredette et al. 2015; Bridges 2012). Accordingly, this technical note formally identifies the growing need for fluvial EWN guidance that aligns with Emergency Watershed Protection guiding principles and offers recommendations to advance EWN guidance among inland fluvial systems.

EWN FLUVIAL OVERVIEW: Functioning riverine system can provide a cascade of ecological functions and services. Stream *functions* were defined into five categories by Fischenich (2006) to serve as a basis for assessment, design and management and later expanded upon by others (Figure 2). The Stream Functions Pyramid (Figure 2) is a five-level hierarchical framework that helps to categorize stream function and parameters. Each level builds on the previous one to show the interconnection of stream functions. For example, the biological system cannot fully function without lower-level functions such as hydrology and hydraulics.

Stream functions described by Fischenich (2006)

System Dynamics	Geomorphology	Biology
Maintain stream evolution processes	Sediment continuity	Support biological communities and processes
Energy management processes	Maintain substrates and structural processes	Provide necessary aquatic and riparian habitats
Provide for riparian succession	Quality and quantity of sediments	Maintain trophic structure and processes

Hydrology	Physiochemical
Surface water storage processes	Maintain water and soil quality
Maintain surface/subsurface connections and processes	Maintain chemical processes and nutrient cycles
General hydrodynamic balance	Maintain landscape pathways

Stream functions pyramid from Harman et al. (2012)

Figure 2. Comparison of stream functions and organization of the stream functions pyramid (Fischenich 2006; Harman et al. 2012).

There is an intrinsic connection between the abiotic parameters of hydrology, hydraulics, geomorphology, and physiochemistry with the biology and functional ecology inherent within a given system (Figure 3). If a river system is not functioning properly, the reduction of services cascades downstream and has the ability to negatively impact coastal systems. For example, look to river diversions into interdistributary basins along the Louisiana coast. Nutrients carried by the Mississippi River (among other variables) are important for the function of the coastal marshes. Certain nutrient concentrations may be too high (or low) for the ecosystem to function *naturally*. While this seems like a coastal problem, the nutrient loads are being supplied to the river upstream from smaller-order streams carrying nutrients from irrigation or urban runoff. Through incorporating the entirety of these considerations through regulatory, cultural, planning, design, implementation, and iterative management, there is holistic integration of traditional and EWN parameters in such a way that improves the resiliency of a given system while enhancing its ecological functions and services in a manner that benefits its inherent organisms and increases its overall resiliency.

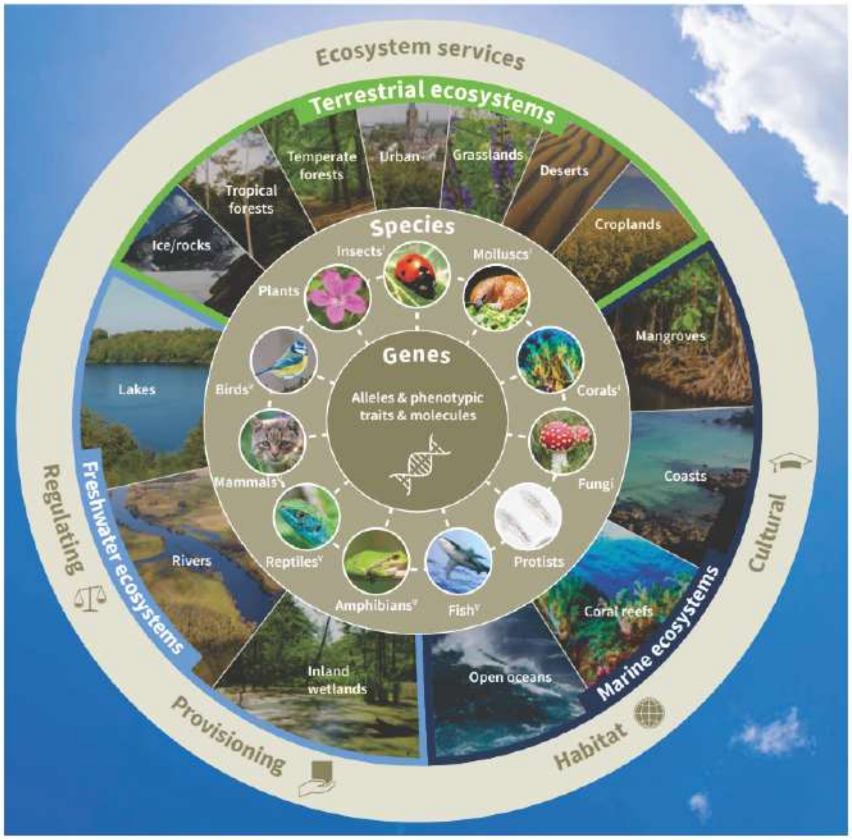

Figure 3. Nature-positive illustration showing the relationship between nature-based planning, design, and implementation with organism-specific habitat requirements (NABU BCG 2020).

Restoration efforts that incorporate EWN principles have been occurring within the inland fluvial systems across the United States for many decades. A synthesis of US River Restoration Efforts was published by Bernhardt et al. (2005), which reviewed over 37,099 projects throughout the United States. Bernhardt and his colleagues found that the most commonly stated goals for river restoration are water quality enhancement, riparian management, in-stream habitat improvement, fish passage, and bank stabilization. Restoration efforts are expected to become more frequent in response to an increase in natural and anthropogenic triggered catastrophic events as well as other factors such as (1) an ever-increasing awareness of the diverse benefits to local communities from river restoration; (2) an increase of resiliency planning and response to address catastrophic disasters such as flooding and fires, (3) decreasing resource availability and increasing population growth compounded by potential climatic shifts; and (4) and increasing requirement for corporations and governments to align with international goals and programs. For example, the United Nations has declared 2021–2030 as the Decade of Ecosystem Restoration and has called for the protection and revival of ecosystems around the world. Additionally, the United Nations has established Sustainable Development Goals (SDGs) to act as a blueprint to address global challenges such as climate change and environmental degradation to achieve a more sustainable future. SDG #11, titled sustainable cities and communities, seeks greater efficiencies in urban planning and management practices that address aging infrastructure and ongoing air, water, and soil pollution. SDG #11 calls for innovative ecological techniques to increase the long-term sustainability and resiliency of nature-based solutions (NBS), which in turn allow for greater efficiencies in urban planning and management practices. As such, in response to the ever-increasing role of river restoration in environmental management and policy decisions, it is beneficial for the EWN program to increase guidance for fluvial systems throughout the United States.

AN EWN ROADMAP FOR FLUVIAL SYSTEMS: To advance EWN guidance among fluvial systems, USACE ERDC offers a prioritized roadmap focused on four main pillars essential for designing EWN projects within fluvial systems: Watershed Science, River Science, Biological and Ecological, and Socio-Economic (Figure 4). These prioritizations encompass the spectrum of fluvial EWN approaches and topics to benefit practitioners and communities across the United States as well as internationally.

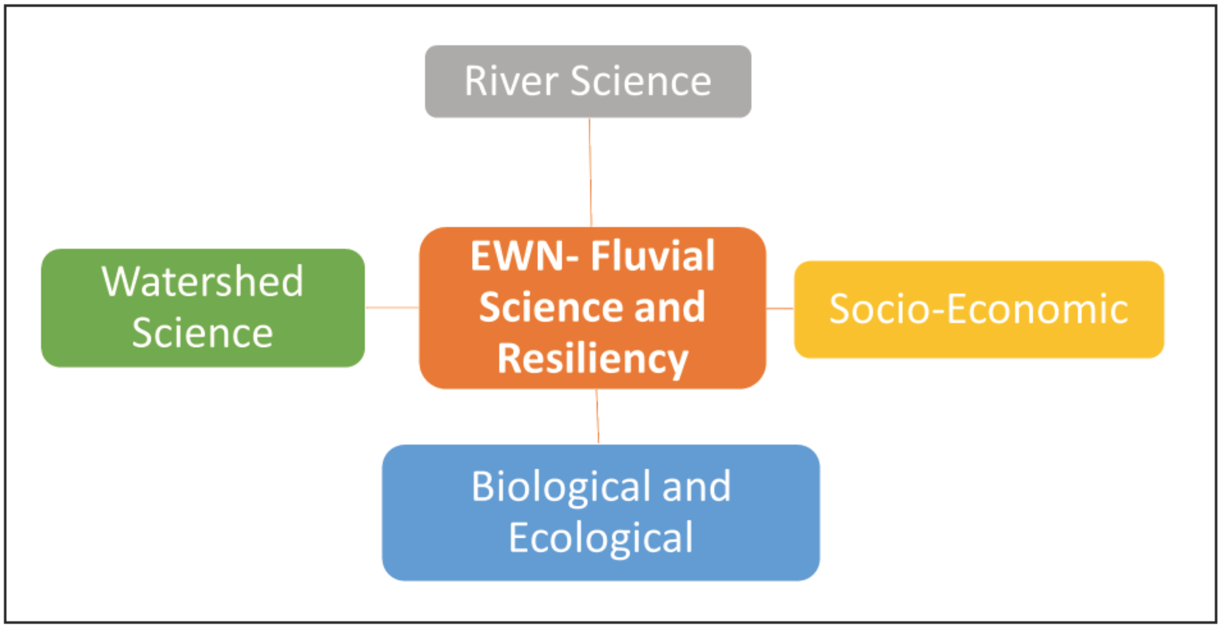

Figure 4. Four main pillars crucial to obtain and disseminate EWN fluvial science and resiliency data.

River Science (RS), otherwise referred to as the study of processes that affect river systems, while widely understood, there are numerous topics in RS that are not widely understood and require further investigation. In addition, information on RS could be better disseminated in a way that is most useful, understandable, and accessible to engineers, planners, designers, and the public at large. As catastrophic flood events are increasing in frequency and severity, it is of utmost importance that the most resilient design options based in RS are thoughtfully and effectively incorporated into USACE designs.

For the RS pillar, it is recommended that the primary focus be placed on increased training workshops and further development of interactive tools such as project mappers and geomorphic assessment tools that assist with the understanding and integration of bioengineering, fluvial geomorphology, hydrology, and hydraulic considerations and how these factors can be incorporated within designs to increase resiliency within the river systems (Figure 5).

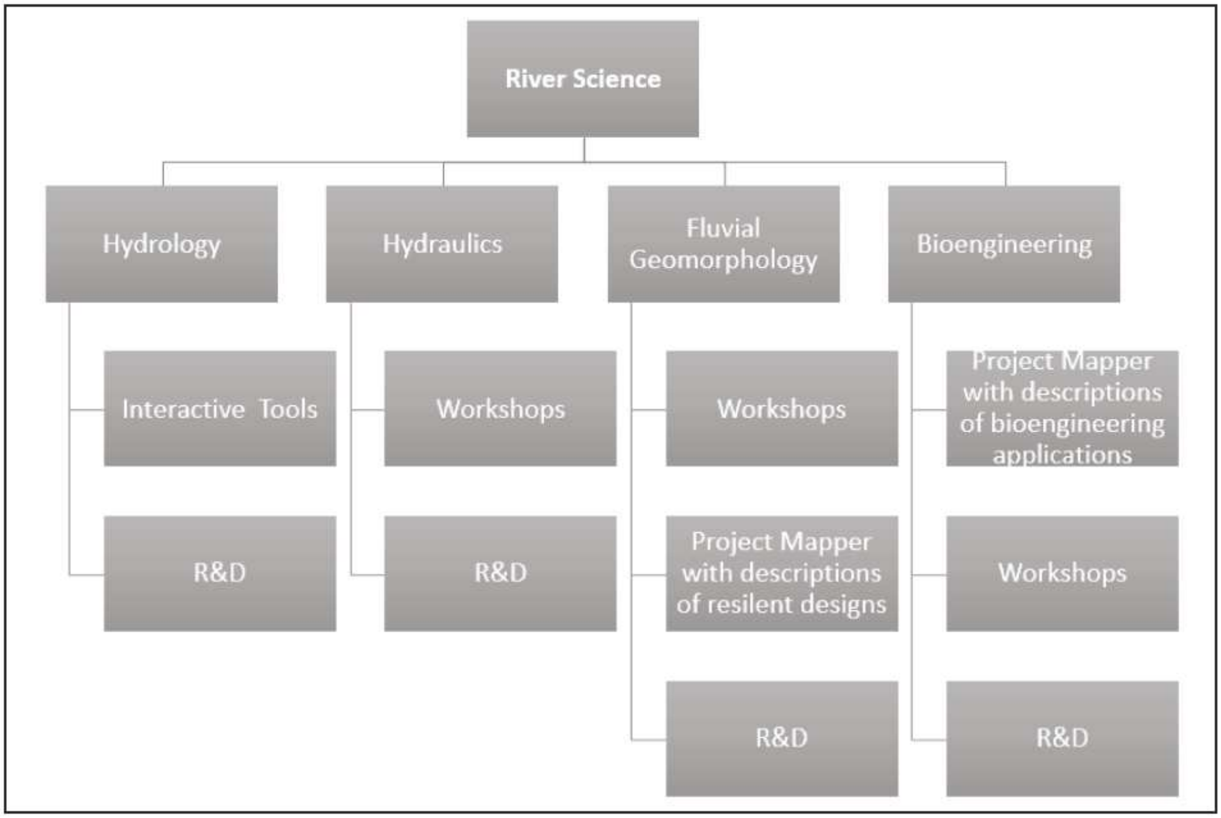

Figure 5. RS pillar.

Socio-Economic considerations are currently often overlooked within river design; however, it is arguably one of the most important considerations for EWN projects. For the Socio-economic pillar, it is recommended that there is an increased incorporation of research and development, educational renderings, interactive storytelling, guidance documents, social media engagement, and performance measures framework (Figure 6). The performance measure framework should be incorporated into each of the socio-economic avenues in a manner that helps to ensure that projects are adequately incorporating this essential pillar into EWN approaches.

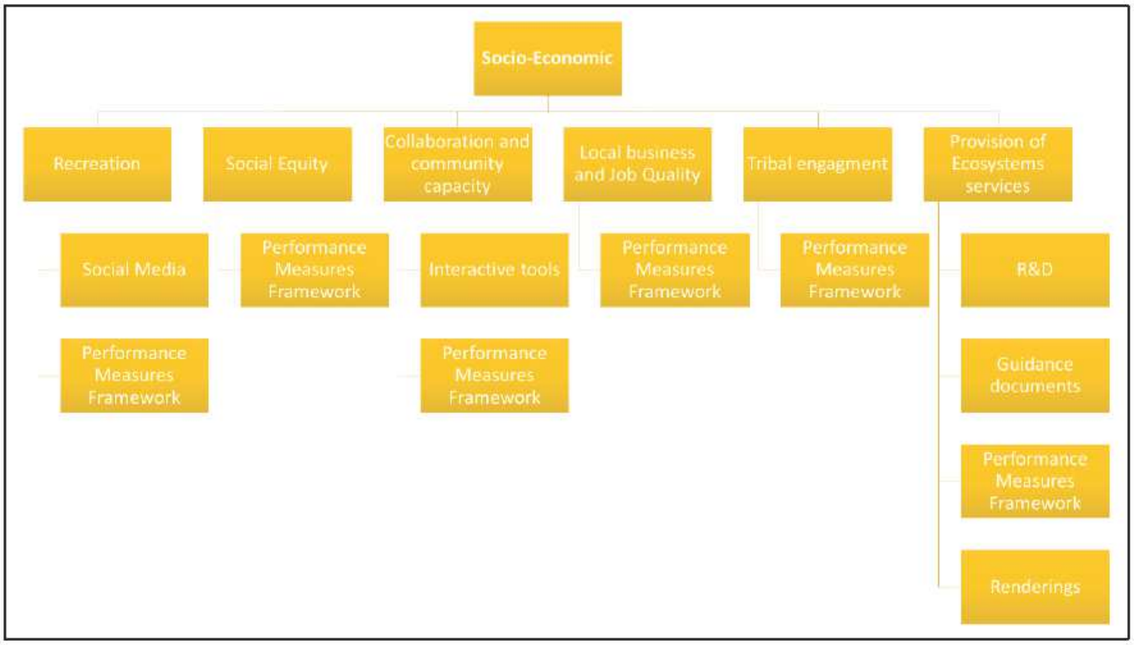

Figure 6. Socio-economic pillar.

Biological and Ecological aspects of EWN approaches are generally well understood by practitioners, but there is still a need for more ecological modeling development for better implementation, monitoring, and iteratively management throughout river design projects. The biological and ecological components of a river can help guide designers to better understand the quality, health, and functionality of a river system pre- and post-implementation. A performance measures framework that is focused on biological and ecological functions could assist with improving results-based management. Improved research and development focused on EWN approaches could be used more effectively to further understand ecosystem services and how each design impacts the ecosystem function of a river (Figure 7).

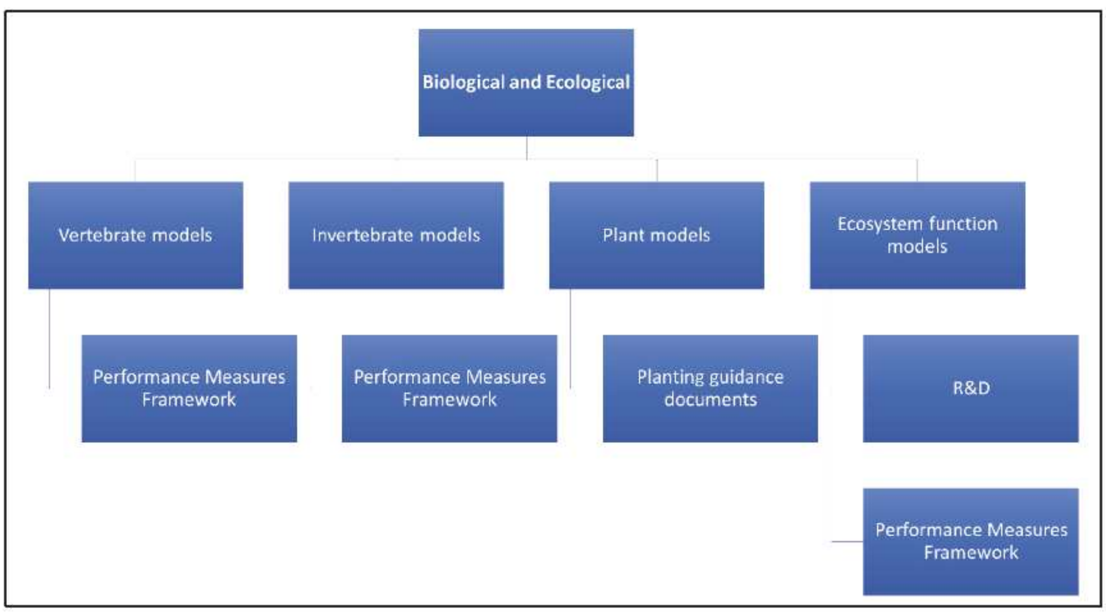

Figure 7. Biological and Ecological pillars.

Watershed Science is an essential component of the EWN approach as it allows engineers, designers, and managers to better incorporate a holistic view of watershed management considerations into their designs. Watershed science integrates concepts such as sediment transport, habitat connectivity, land use hydrology, geomorphology, ecological function, water quality, and additional considerations into the EWN approach. For the EWN program, research and development, sediment and disturbance regime risk mappers, performance measures frameworks, guidance documents, and interactive storytelling can be used to progress watershed science within the program (Figure 8).

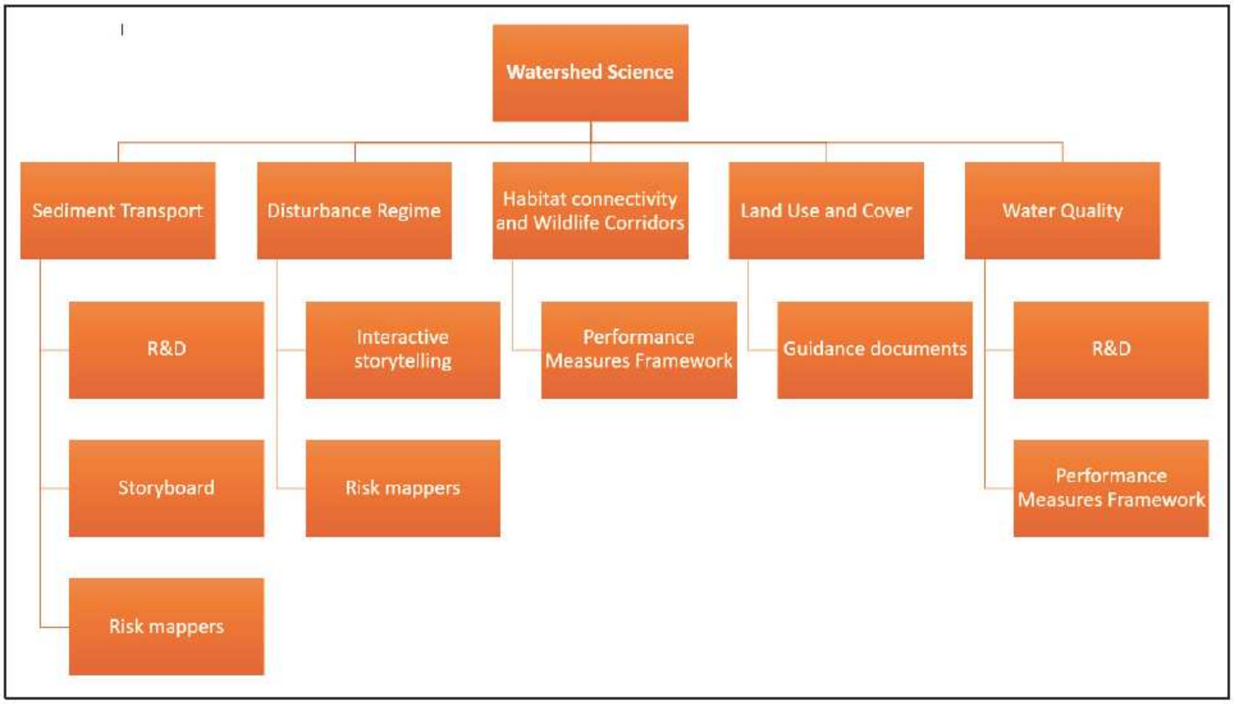

Figure 8. Watershed Science pillars.

Case Example. A systematic approach for disaster recovery applied in a Colorado Disaster recovery program (Figure 9) incorporated the following steps:

1. Involve all vested stakeholders in an integrative manner that addresses land and water issues, including federal, state, municipal, and community collaboration to ensure buy-in.
2. Identity, understand, and work with the hydrologic, hydraulic, geomorphologic, physiochemical, and ecological processes that compositely comprise riverine health and deliver ecosystem services.
3. Identify, incorporate, and integrate socio-economic values, master planning, and development activities linked to riverine health and functionality.
4. Address structural and functional relationships in an appropriate manner to address the limiting factors to riverine health.
5. Develop clear, actionable, and measurable goals and objectives, based upon changes in ecosystem function and structure, through the provision of ecosystem services and socio-economic benefits.
6. Plan, design, implement, and manage the riverine system in a manner that provides resilience over time to such stressors as climate change, land use, altering hydrology, pollutant loads, population growth, etc.

7. Monitor, evaluate, and adaptively manage the riverine system to align health and function to the desired state considering evolving stressors and conditions (Endreny 2020).

A holistic representation of a systems-based approach to river restoration in response to disaster response to address the 2013 Colorado Floods is shown in Figure 9 (CWCB 2020).

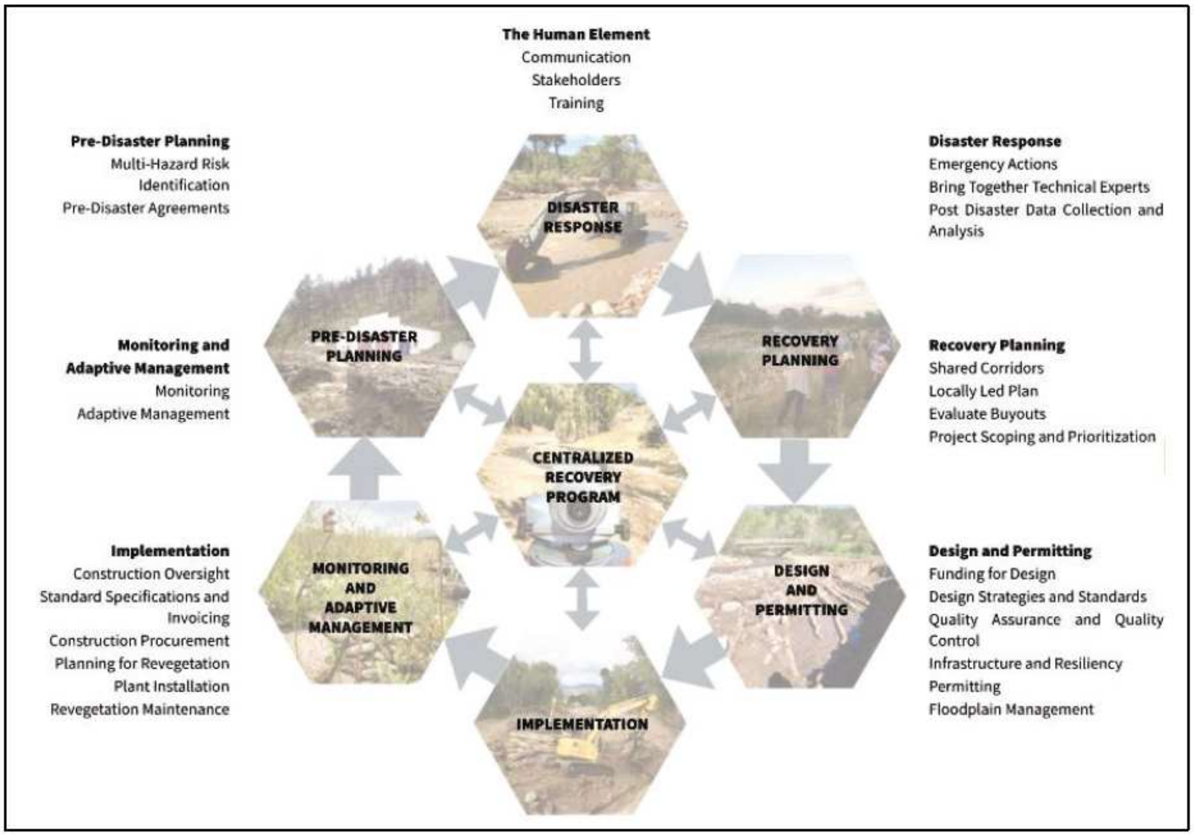

Figure 9. Illustration of a systems-based approach to river restoration to facilitate disaster recovery (CWCB 2020).

A crucial step for a systems approach to river restoration is the proactive identification of associated potential risks and stressors, such as flood potential, restricted floodplain access, excessive sediment infilling channels and floodplains. The understanding and avoidance of hazard represents the soundest strategy. Using tools such as Federal Emergency Management Administration floodplain maps in concert with identification of fluvial hazards, such as erosion potential and sediment deposition patterns, past site history, and proactive sizing, alignment, and location of culverts, bridges, roadways, building corridors, and other associated features will greatly assist with overall site resiliency and successful achievement of success criteria, goals, and objectives (CWCB 2020).

SUMMARY: Through the thoughtful integration of traditional and nature-based approaches, EWN offers a sustainable approach to deliver economic, environmental, and social benefits to improve resiliency for coastal and inland projects. Increasing the frequency, resolution, and competency of EWN approaches for river restoration and flood risk management through a systems-based approach has strong application to riverine systems. Accordingly, it is recommended that USACE address data gaps through focused research and development to better understand and manage inland riverine systems through workshops, web-meetings, podcasts, development of interactive tools, technology transfer, enhanced socio-economic, further develop biological and ecological modeling capabilities, and a more thorough incorporation of watershed health and science.

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