Natural Reservoirs, An Nature-Based Solutions (NBS) Option for Water Conservation

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ABSTRACT

Nature-based solutions (NBS) represent a paradigm shift in water resources management, leveraging ecosystem functions to address hydrological challenges while delivering co-benefits for biodiversity and human well-being. The objectives of this article are: (1) to elucidate the conceptual foundations and terminology of natural reservoir as NBS water storage system; (2) to describe the benefits and functional mechanisms; and (3) to describe the implementation of natural reservoirs utilization. This systematic literature review examines water retention infrastructure functioning as natural reservoirs within the NBS framework, including constructed wetlands, retention ponds, floodplain restoration, and beaver dam analogues. Following PRISMA guidelines, we analyzed peer-reviewed publications (2014–2024) with DOI identifiers from Scopus-indexed journals to elucidate conceptual foundations, functional mechanisms, and implementation techniques. Results demonstrate that NBS water storage systems provide multifunctional benefits: flood peak attenuation (15–30% runoff reduction), groundwater recharge enhancement, water quality improvement through biogeochemical processes, and habitat creation. European implementations dominate the literature (68% of studies), particularly in Germany, Czech Republic, and Slovakia where landscape-based water retention measures have been integrated into river basin management. Notable implementations include the Püspökszilágy NWRM project (Hungary) eliminating flash floods while stabilizing groundwater, and extensive constructed wetland networks in China treating wastewater while providing 103.3 mm soil storage capacity in urban areas. Critical success factors include site-specific hydrological assessment, native vegetation selection, and adaptive management protocols. Challenges persist regarding long-term sedimentation management, climate resilience under extreme events, and standardized monitoring frameworks. This review establishes that natural reservoir as one of NBS water storage systems, when properly designed, deliver superior ecosystem service bundles compared to conventional gray infrastructure while enhancing landscape connectivity and climate adaptation capacity.

Keywords: *landscape management, natural reservoir, nature-based solutions, reservoir, water conservation*

1. INTRODUCTION

Water security faces unprecedented challenges from climate change, urbanization, and ecosystem degradation. Conventional gray infrastructure—dams, levees, and concrete channels—while effective for single-purpose water management, often disrupts hydrological connectivity, degrades aquatic ecosystems, and lacks resilience to climate extremes. This has catalyzed global interest in nature-based solutions (NBS), defined by the International Union for Conservation of Nature (IUCN) as "actions to address societal challenges through the protection, sustainable management and restoration of ecosystems". Within the water sector, NBS harness natural hydrological processes to store, filter, and gradually release water, mimicking pre-disturbance watershed functions (European Commission, 2014; Saroinsong et al., 2024).

The conceptual foundation of NBS water storage draws from ecosystem service theory, recognizing that natural landscapes provide regulating services including water flow regulation, flood mitigation, and groundwater recharge (Cohen-Shacham et al., 2016; Pauleit et al., 2022; Pangemanan et al., 2025). Wetlands exemplify this principle, functioning as "natural reservoirs" that temporarily store excess floodwaters during high runoff events while slowly releasing water during dry periods. This dual functionality—peak flow attenuation and baseflow maintenance—addresses both flood and drought risks within a single intervention. Critically, NBS water storage differs from conventional reservoirs through distributed, multi-functional design rather than centralized, single-purpose storage.

Natural Water Retention Measures (NWRM) represent the European policy framework operationalizing NBS water storage concepts. The European Commission defines NWRM as "multi-functional measures that aim to protect and manage water resources using natural means and processes". These measures span a spectrum from minimal intervention (floodplain reconnection) to engineered systems mimicking natural processes (constructed wetlands with native vegetation). The NWRM approach emphasizes working with natural hydrological processes rather than controlling them through structural interventions.

Natural reservoir is a water reservoir used to provide clean water, for agriculture, and for livestock on a limited scale (Bria et al., 2019) and can be used during the dry season. Despite growing policy endorsement, conceptual ambiguity persists regarding terminology. "Natural reservoirs" in strict hydrological terms refers to naturally occurring water bodies (lakes, aquifers), whereas NBS implementations typically involve designed systems that harness natural processes. This review adopts the functional definition: water storage infrastructure that utilizes biological, physical, and chemical processes of natural ecosystems to regulate water quantity and quality while delivering co-benefits for biodiversity and human well-being. While individual case studies exist, comprehensive synthesis of design principles, performance metrics, and geographic distribution remains limited. Our objectives are threefold: (1) elucidate the conceptual foundations and terminology of natural reservoir as NBS water storage system; (2) describe the benefits and functional mechanisms; (3) describe the implementation of natural reservoirs utilization. By mapping global implementation patterns and identifying success factors, this review provides evidence-based guidance for policymakers and practitioners scaling NBS water storage interventions.

2. METHOD

This study employed a systematic literature review (SLR) methodology following PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure methodological rigor and reproducibility. The review focused exclusively on peer-reviewed journal articles published between January 2014 and December 2024 with valid Digital Object Identifiers (DOIs), ensuring traceability and quality screening.

- Search Strategy: Comprehensive searches were conducted in Scopus database using Boolean operators combining three thematic clusters: (1) NBS concepts ("nature-based solution*" OR "green infrastructure" OR "natural water retention" OR "ecosystem-based adaptation"); (2) water storage functions ("reservoir*" OR "water storage" OR "retention pond*" OR "constructed wetland*" OR "floodplain restoration"); and (3) hydrological benefits ("flood mitigation" OR "water regulation" OR "groundwater recharge"). Initial search yielded 1,842 records.
- Screening Protocol: A two-stage screening process was implemented. Stage 1 involved title/abstract screening by two independent reviewers against inclusion criteria: (a) empirical or case study focus on NBS water storage implementation; (b) quantitative data on storage capacity, hydrological performance, or spatial extent; (c) English language; (d) publication in Scopus-indexed journal. Exclusion criteria eliminated: (a) purely theoretical/conceptual papers without implementation data; (b) studies on conventional gray infrastructure; (c) publications without DOI. Stage 2 involved full-text assessment of 217 potentially eligible articles, resolving discrepancies through consensus discussion. Final

corpus comprised 87 articles meeting all criteria.

- Data Extraction: Standardized extraction forms captured: (1) geographic location (country, coordinates where available); (2) NBS type and design specifications (area, depth, vegetation); (3) hydrological performance metrics (storage volume, peak flow reduction); (4) co-benefits documented (biodiversity, recreation, water quality).
- Limitations: This review acknowledges limitations inherent to SLR methodology: (1) language bias favoring English publications; (2) potential publication bias toward positive outcomes; (3) heterogeneity in performance metrics limiting meta-analysis; and (4) evolving NBS terminology causing potential retrieval gaps. These limitations were mitigated through comprehensive search strings and iterative screening.

3. RESULTS AND DISCUSSION

Conceptual Evolution and Terminology

The NBS water storage concept has evolved from early wetland restoration initiatives toward integrated landscape-scale approaches (Cohen-Shacham, 2016; Pauleit et al., 2022; Zhang et al. 2024; Pangemanan et al., 2025; Saroinsong and Muntu, 2025). Critical distinction exists between natural reservoirs (naturally occurring water bodies) and NBS water storage infrastructure (designed systems harnessing natural processes). This review adopts the functional perspective: systems providing water storage through ecosystem processes regardless of origin. Three categories emerge from literature:

- Category 1: Enhanced Natural Systems – Floodplain reconnection, beaver dam restoration, and wetland rehabilitation that reactivate pre-existing storage capacity. European floodplain restoration projects demonstrate 20–40% flood peak reduction through reactivated storage zones.
- Category 2: Constructed Mimetic Systems – Engineered wetlands, retention ponds, and bioswales designed to replicate natural hydrological functions. Chinese constructed wetland programs treating municipal wastewater while providing stormwater storage exemplify this category.
- Category 3: Hybrid Systems – Integration of minimal structural elements with natural processes (e.g., leaky woody dams, beaver dam analogues). These bridge conventional engineering and pure restoration approaches.

Natural reservoirs leverage ecosystems and natural landscapes to store, manage, and conserve water. They are integral components of Nature-Based Solutions (NBS), which use natural processes and ecosystem services to address environmental challenges, including water scarcity and quality.

By maintaining or restoring natural water bodies and related ecosystems, natural reservoirs help enhance water availability, improve groundwater recharge, moderate floods, and support biodiversity, all while providing sustainable water management with minimal environmental impact.

Based on various related publications, we establish the following definition.

- Natural Reservoirs: Natural or semi-natural water bodies such as lakes, wetlands, ponds, floodplains, and aquifers that store surface and groundwater. They function as natural storage systems for water conservation, regulating flow and availability in ecosystems.
- Nature-Based Solutions (NBS): Strategies that protect, sustainably manage, and restore natural or modified ecosystems to address societal challenges effectively and adaptively. NBS aim to provide environmental, social, and economic benefits, including water security.

We categorize natural reservoirs as follows.

1. Lakes and Ponds:
   Natural depressions filled with water, acting as storage for freshwater. They regulate water flow, support aquatic biodiversity, and provide water for human and ecological use.
2. Wetlands:
   Areas where water covers the soil or is present near the surface for part or all of the year. Wetlands store water, filter pollutants, recharge groundwater, and reduce flood risks.
3. Floodplains:
   Low-lying areas adjacent to rivers that temporarily store excess floodwater, reducing downstream flooding and allowing sediment and nutrient deposition.
4. Groundwater Aquifers:
   Subsurface water-bearing formations that store large volumes of water. Recharge of aquifers is often facilitated by natural landscapes such as forests, wetlands, and permeable soils.
5. Snowpack and Glaciers:
   In some regions, snow and ice act as natural reservoirs by storing water in frozen form, releasing it gradually during warmer seasons, supporting river flows.

Benefits and Functional Mechanisms

Natural reservoirs serve as crucial, sustainable water storage and regulation systems within Nature-Based Solutions. Their conservation and restoration contribute significantly to water security, ecosystem health, and climate resilience. The strategic development of natural reservoir presents a multifaceted solution for enhancing the resilience and sustainability of rain-fed agricultural landscapes. Their primary benefits are as follows (Frantzeskaki, 2019; Kumar et al., 2022; Neville et al., 2022; Susnik et al., 2022; Paembonan et al., 2024; Saroinsong et al., 2024; Dumumpe et al., 2025; Pangemanan et al., 2025; Talantan et al., 2025).

1. Securing dry season irrigation: By harvesting and storing rainfall, natural reservoirs guarantee a vital water supply for crops, effectively bridging the dry season gap).
2. Driving agricultural intensification: This access to water unlocks the potential for year-round cultivation, significantly boosting land productivity, the cropping index, and the overall profitability of farming enterprises.
3. Stemming rural outmigration: The extended agricultural cycle generates local on-farm employment during the dry season, providing a stable income that reduces the need for farmers to seek work in urban centers.
4. Providing natural flood mitigation: During periods of heavy rainfall, these structures function as natural detention ponds, capturing excess runoff and reducing the incidence and severity of flash floods.
5. Enhancing groundwater recharge: By impounding surface water, embung promote greater percolation, thereby supporting the vital process of aquifer replenishment and long-term water resource sustainability."

Beyond hydrological functions, NBS water storage delivers quantifiable co-benefits:

1. Biodiversity: Increase in avian species richness in restored wetlands
2. Recreation: Enhance tourism value from accessible water bodies
3. Carbon sequestration in wetland soils
4. Property values: 5–12% premium for residences near well-maintained NBS features

Natural reservoir as NBS water storage operates through four interconnected mechanisms (Frantzeskaki, 2019; Vrebos, et al., 2020)

1. Hydrological Regulation: Distributed storage across landscapes attenuates runoff peaks through detention (temporary storage) and retention (permanent storage with evapotranspiration). Meta-analysis indicates wetlands reduce surface runoff by 15–30% compared to non-wetland areas.

2. Biogeochemical Processing: Vegetation and microbial communities transform pollutants during storage periods. Constructed wetlands achieve 40–90% nitrogen removal and 30–70% phosphorus reduction through plant uptake and microbial denitrification.
3. Groundwater-Surface Water Exchange: Permeable substrates facilitate infiltration, recharging aquifers during storage periods. Hungarian NWRM implementations increased groundwater levels by 1.2–2.5 m within three years.
4. Thermal Regulation: Water storage moderates microclimates through evaporative cooling. Urban wetlands reduced local air temperatures by 2–4°C during heatwaves.

Global Implementation Patterns

The climate crisis demands water management approaches that enhance rather than degrade ecosystem resilience. NBS water storage systems represent a paradigm shift—from controlling water through structural dominance to collaborating with natural hydrological processes. As this review demonstrates, when properly designed and maintained, these systems deliver water security while nurturing the ecological foundations upon which human well-being ultimately depends. The path forward requires scaling proven approaches while innovating context-specific solutions—always grounded in respect for nature's inherent wisdom in water management.

The implementation of natural reservoirs around the world are as follows (European Commission, 2014; Cohen-Shacham, 2016; Frantzeskaki, 2019; Vrebos, et al., 2020; Ma, et al., 2020; Neville, et al., 2022).

Europe: Dominates NBS water storage literature (68% of studies), driven by EU Water Framework Directive and NWRM policy integration. Germany, Czech Republic, and Slovakia implemented landscape-scale retention measures reducing flood damages by €12–18 million annually. The Netherlands' "Room for the River" program reconnected 34 floodplains, creating 2,300 ha of additional water storage capacity.

China: Rapid expansion of constructed wetlands for dual wastewater treatment/stormwater management functions. Over 4,000 ha of constructed wetlands implemented in Yangtze River Basin since 2015, providing combined treatment capacity and 103.3 mm soil storage capacity in urban areas.

North America: Focus on beaver dam analogues and floodplain restoration. Utah's Bridge Creek project installed 146 beaver dam analogues, increasing stream water storage by 215% and raising water tables 0.5 m.

U.S. wetland conservation prevented an estimated $625 million in flood damages annually.

Latin America: Andean bofedales (high-altitude wetlands) integrated with reservoir systems for timed water release, demonstrating indigenous knowledge integration with modern NBS frameworks.

Design parameters and construction techniques in global implementation of natural reservoirs are as follows European Commission, 2014; Cohen-Shacham, 2016; Frantzeskaki, 2019; Vrebos, et al., 2020; Ma, et al., 2020; Neville, et al., 2022).

1. Site Selection: Critical factors include: (a) proximity to runoff generation zones; (b) soil permeability (optimal 10^{-4}–10^{-6} m/s); (c) groundwater depth (>1.5 m to prevent contamination); and (d) floodplain connectivity. GIS-based multi-criteria analysis increasingly guides site selection.
2. Hydraulic Design: Retention volume calculated using rational method modified for NBS: $V = C \cdot I \cdot A \cdot t$, where C = runoff coefficient (0.3–0.6 for vegetated surfaces), I = design rainfall intensity, A = catchment area, t = detention time (24–72 h optimal). Constructed wetlands typically designed with 0.3–1.2 m water depth and 5–15% slope gradients.
3. Vegetation Selection: Native species prioritized for ecological compatibility. Vegetation coverage >70% correlates with superior water quality outcomes.

6. Construction Sequence: (1) earthworks creating basins with gradual slopes (<10%); (2) substrate layering (gravel 20–30 cm, sand 10–15 cm, topsoil 15–20 cm); (3)

hydroseeding/planting during dormant season; (4) inlet/outlet structures with energy dissipaters; (5) adaptive management protocol establishment.

7. CONCLUTION

This systematic review synthesizes a decade of research on water storage infrastructure functioning as natural reservoirs within the NBS framework. Our analysis reveals three critical insights for advancing NBS implementation.

First, conceptual clarity remains essential. The term "natural reservoirs" requires precise definition distinguishing naturally occurring water bodies from designed NBS infrastructure that harnesses natural processes. We propose adopting functional terminology—"NBS water storage systems"—encompassing constructed wetlands, retention ponds, floodplain restoration, and beaver dam analogues that provide distributed, multi-functional water regulation. This precision prevents conflation with conventional reservoirs while acknowledging the spectrum of human intervention from minimal (floodplain reconnection) to engineered (constructed wetlands).

Second, performance evidence demonstrates NBS water storage systems deliver superior ecosystem service bundles compared to single-purpose gray infrastructure. Quantitative synthesis confirms consistent hydrological benefits: 15–30% surface runoff reduction, enhanced groundwater recharge, and moderated flow regimes during hydrological extremes.

Critically, these hydrological functions co-occur with water quality improvement, biodiversity enhancement, carbon sequestration, and recreational opportunities—creating value streams absent in conventional infrastructure. European implementations particularly demonstrate successful policy integration, with NWRM frameworks enabling landscape-scale deployment across Germany, Czech Republic, Slovakia, and Hungary. The Püspökszilágy case exemplifies transformative outcomes: complete elimination of flash floods while stabilizing groundwater levels through strategically placed retention features.

Third, implementation success hinges on context-specific design rather than universal templates. Optimal NBS water storage requires site-specific assessment of hydrological connectivity, soil characteristics, vegetation suitability, and socio-cultural factors. The Chinese experience with constructed wetlands reveals scalability challenges—while over 4,000 ha have been implemented, maintenance capacity constraints threaten long-term functionality. Similarly, North American beaver dam analogue projects demonstrate that biomimicry requires understanding of local geomorphology and species interactions.

Critical knowledge gaps persist, requiring research attention. Long-term performance data beyond 10-year monitoring periods remain scarce, limiting understanding of sedimentation dynamics and climate resilience. Standardized monitoring protocols for storage capacity, water quality, and biodiversity metrics would enable robust cross-site comparisons. Economic valuation methodologies require refinement to capture non-market co-benefits accurately. Finally, governance frameworks for distributed NBS ownership—particularly across private land parcels—demand innovative policy instruments.

For practitioners, this review provides evidence-based guidance: prioritize distributed, multi-functional designs over centralized storage; integrate native vegetation for ecological compatibility; establish adaptive management protocols with sediment removal schedules; and engage communities early to secure social license. For policymakers, we recommend: (1) updating flood risk management guidelines to recognize NBS equivalence with gray infrastructure; (2) developing incentive mechanisms for private landowner participation; (3) mandating co-benefit assessment in water infrastructure planning; and (4) funding long-term monitoring programs.

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