

Article

Durable Freshwater Protection: A Framework for Establishing and Maintaining Long-Term Protection for Freshwater Ecosystems and the Values they Sustain

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Abstract: Long-term protection is needed to secure threatened freshwater ecosystems and the social and biodiversity values they provide. In the face of existing and future pressures, current approaches to freshwater protection are often inadequate for maintaining ecosystem values into the future. While terrestrial and marine ecosystem protection are well recognized and have area-based protection goals in global conventions, freshwater ecosystem characteristics have remained poorly represented in these goals. Freshwater ecosystems are commonly secondary or unaddressed components of area-based terrestrial protection. The design and management for terrestrial-based protection are generally inadequate for addressing freshwater ecosystem processes and attributes critical for maintaining their natural patterns and the values they provide to people and nature. Given that freshwater-dependent species are declining at a faster rate than marine and terrestrial species, and the reliance and use of freshwater ecosystems by people living around such areas, approaches to protect them must balance the needs of people and nature and accommodate these complexities.

Keywords: protection; freshwater; biodiversity; ecosystem services; communities

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1. Introduction

Freshwater ecosystems cover less than 2% of the surface of the Earth, yet harbor approximately 12% of all known species, including one-third of all vertebrate species [1]. Freshwater ecosystems directly or indirectly support most life on Earth and provide goods and services that are critical for economies and the lives and livelihoods of billions of people [2]. The biodiversity and the goods and services that freshwater ecosystems sustain are at risk. Almost one in three freshwater species are threatened with extinction, a higher risk of extinction compared to terrestrial taxa. Analyses of 3741 monitored populations across 944 freshwater species of mammals, birds, reptiles, amphibians, and fishes indicated an average decline of 84% from 1970–2016, with most declines occurring among amphibians, reptiles, and fishes [3]. Using these data, results of 1406 monitored populations across 247 species of migratory fish species show an overall average decline of 76% [4]. These data also indicate an overall average population decline of 88% for aquatic megafauna (species > 30 kg) from 1970–2012, with mega-fishes declining 94% during that time [5]. In addition, increased demand for freshwater is rated as the worst of the “Global Risks in Terms of Impact” over the next decade to political, social and economic security [6]. If there are not changes to methods and the scope to which freshwater protection is implemented, the future will remain bleak.

Protected areas continue to be a dominant strategy for conservation [7,8], yet efforts have focused mainly on terrestrial and marine ecosystems, [9–11], or have emphasized specific protection strategies, such as increasing protected area coverage [12]. While valuable, these approaches have either assumed—often falsely—that measures to protect lands will afford the same level of benefits for freshwater ecosystems or they have neglected to consider freshwater ecosystems at all [10,13]. International goals for protection (e.g., Aichi 2020 targets, Convention for Biological Diversity) have focused on terrestrial, area-based metrics. This historical approach to protection goal-setting and design has generally ignored watershed boundary-governed processes, flow dynamics, and connectivity required to sustain the integrity of freshwater ecosystems, and management plans have most often not addressed freshwater needs [14–18].

Evaluations of the effectiveness of existing protected areas have focused on area-based metrics best suited for terrestrial and marine ecosystems, generally ignoring the freshwater components of “terrestrial” protected areas [11]. Many if not most protected areas have not been delineated and managed with regards to the processes that form and sustain freshwater ecosystems. Freshwater ecosystems, particularly rivers, which can flow into and out of protected or managed areas, and are subject to flow alteration, connectivity disruptions, water pollution, habitat destruction, and over-harvesting or invasive species introductions within or outside such areas. Recent analyses have shown that many freshwater ecosystems in protected areas are not protected from upstream impacts [19,20], and that dams often exist within protected areas upon declaration or are built within them afterwards, illustrating the disregard for freshwater ecosystem protection in many of these areas [21]. As a result, we cannot rely on terrestrial protection and management mechanisms to address the specific needs of freshwater ecosystems.

Further, protected areas disproportionately occur at relatively higher elevations and tend to be distant from roads and cities [22]. This leaves freshwater ecosystems at lower elevation, including the larger river components of riverine systems, which contain higher numbers of species than upland components [23], under-represented in protected areas. In addition, human communities tend to settle in proximity to freshwater ecosystems [24] and protected area strategies are often not well suited for populated landscapes where people depend on those landscapes and waterscapes, which also tend towards lower elevations.

Recent attention has focused on Other Effective area-based Conservation Measures (OECMs) as additional important contributions to achieving long-term protection goals [25]. OECMs are defined as: “A geographically defined area other than a Protected Area, which is governed and managed in ways that achieve positive and sustained long-term outcomes for the in-situ conservation of biodiversity with associated ecosystem functions and services and where applicable, cultural, spiritual, socio-economic, and other locally relevant values.” [26]. OECMs and goals for their implementation are bounded by specific areas, commonly not related to the needs of freshwater ecosystems. It is this constraint that results in them undoubtedly suffering from the same issues regarding freshwater as protected areas do.

Due to the shortcomings in current approaches to freshwater protection, there is need for a broader scope of freshwater protection mechanisms to be implemented that are not limited in their scope of actions by designated boundaries of protected areas and OECMs. It is imperative that these mechanisms work within the complex natural and social realities of the freshwater ecosystems they are intended to protect.

As staff members of a conservation organization, the authors from The Nature Conservancy work with public and private owners of land and water, governments, indigenous and local communities, and other stakeholder groups on freshwater ecosystem protection around the world. The processes that sustain freshwater ecosystems and the threats to them, and the contexts in which protection strategies are employed are multi-dimensional and complex. The absence of a global framework for freshwater protection results in “grossly inadequate” policy responses that are not commensurate with either

the scale and urgency of the situation or the actions required to safeguard freshwater biodiversity [27]. Influential global forums such as the Convention on Biological Diversity have historically advocated for and advanced area-based protection. As we enter the next generation of global biodiversity commitments and the impacts of climate change and human development continue, it is critical that we broaden our existing principal approach to protect freshwater ecosystems. In order to bring freshwater protection to parity with terrestrial and marine ecosystems, we need to organize around a shared framework for freshwater protections that will deliver a broader suite of mechanisms that operate at appropriate spatial scales, address specific ecosystem processes and threats, and engage and empower governments, stakeholders, and communities to protect their freshwater ecosystems for generations to come.

The Durable Freshwater Protection (DFP) framework is intended to fill this gap by providing a conceptual model that freshwater conservation practitioners from different disciplines can use to stimulate more effective protection strategy development. The DFP framework is intended to prompt the right questions that are relevant to virtually any freshwater ecosystem protection effort: What is the value that you wish to protect? What ecological processes sustain that value? What are the threats to those processes? What mechanisms are available to address those threats? What mechanisms are potentially appropriate given the threats and the socioeconomic contexts for protection? How durable are the protection mechanisms? How should protection be adaptively managed over time given successes or failures of applied mechanisms and/or changes in context? As every freshwater ecosystem and community surrounding it is unique to some extent, so should be the selection, design, and implementations of the mechanisms put in place to protect it. This rings especially true when multiple mechanisms are required to mitigate or avoid distinct threats. By adopting the framework's methods of thinking about and approaching solutions targeted to avoiding threats to the processes that form and sustain freshwater ecosystems, freshwater protection can be achieved that is likely to have greater durability and effectiveness.

We define durable as having a high probability of providing dedicated, secure, and enforceable protection into the future. We suggest considering a timeline of at least 25 years. This definition is neither arbitrary nor impermanent; the quarter-century span qualifies the framework to include mechanisms that offer long-term or renewable opportunities, and explicitly provides a timeline that gives way to multi-generational (and therefore longer-lasting) investment in protection actions. We would also define implementation as durable in situations where threats may be abated and their sources no longer exist within a shorter time period, and the protection mechanism may no longer be needed.

2. Materials and Methods

To develop the DFP framework, a special project team at The Nature Conservancy (TNC) conducted a series of in-depth interviews with freshwater conservation practitioners and policy experts around the world, including in South America, India, Africa, China, Australia, Europe, and North America, to gain insight into the core characteristics that contributed, either positively or negatively, to the durability of freshwater protection projects. The team also conducted a series of analyses in the Western Balkan nations to examine the existing legal, institutional, and policy context in the greater European Union, as well as at national and local levels of governments to determine whether or how a DFP can be designed and implemented. The results of this work illuminated ideas for how to approach freshwater protection via legal mechanisms in other parts of the world. The conceptual framework herein was structured based on the lessons learned from these experiences and those from engagements in the United States in designing and implementing protection mechanisms to achieve conservation goals and objectives over the careers of the authors.

The emergent themes of these interviews, legal analyses, and experiences formed the basis for the DFP framework. This framework was further developed into a heuristic

structure for enabling better understandings of the foundations for successful and lasting freshwater protection strategies.

3. Results and Discussion

A key challenge for freshwater protection is how to engage and incorporate insights from multiple disciplines (law, policy, science, social action, cultural relationships) to develop and implement more effective, long-term, context-specific freshwater protection strategies at appropriate scales. The DFP framework illustrates the steps in a simplistic format for guiding those responsible for establishing protection strategies to appropriately engage experts from those varied disciplines in a structured manner. The Durable Freshwater Protection Framework (Figure 1) consists of five continuous analytic steps for tailoring durable protection mechanisms to the values, processes, threats, and scales of freshwater ecosystems.

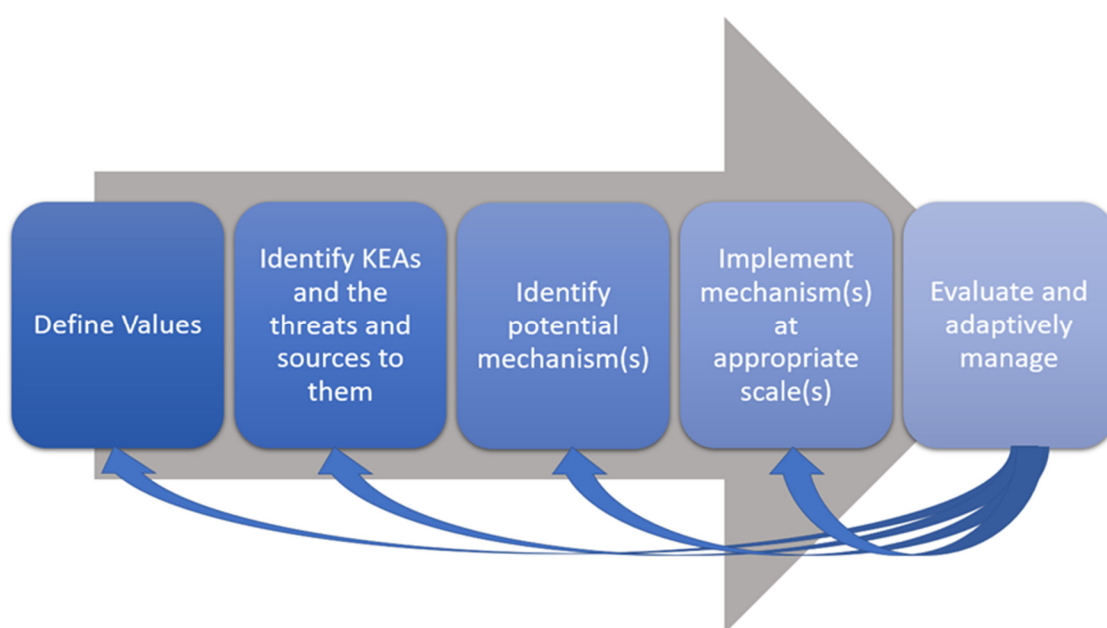


Figure 1. The Durable Freshwater Protection Framework. Moving from left to right, a series of steps are conducted that result in implementing protection mechanisms at appropriate scales and evaluating and adaptively managing all steps in the process.

Step 1. Define the values supported by freshwater ecosystems identified by society as requiring protection.

Step 2. Identify fundamental characteristics of ecosystems that are essential for the long-term persistence of those values ('Key Ecological Attributes' (KEAs)), and the threats and sources of those threats that affect KEAs.

Step 3. Identify potential protection mechanism(s) which are most likely to abate or mitigate those threats over the long-term.

Step 4. Apply the protection mechanism(s) at the appropriate scale(s) to effectively protect the value(s) and the KEA(s).

Step 5. Monitor and evaluate the status and change in condition of values, KEAs, scope and degree of threat and sources of those threats, and implementation successes or failures of the protection mechanism. Adaptively manage by improving existing mechanisms and/or applying new mechanisms as new threats emerge and circumstances change over time.

The development and implementation of protection actions are best accomplished through the realization that conservation is achieved through a social contract [28]. Durability of the protection mechanisms starts at understanding the need for community and

stakeholder engagement in all of the steps of the framework. Fully understanding and working within the complex dynamics of communities in an informed manner is paramount before defining actions for resource management and establishing a sustainable governance system [29]. Community and stakeholder engagement in the formulation of values, designing protection, involvement in governance, and enforcement all lead to enhanced success and greater potential for durable protection [30–35]. These engagements ensure that the mechanisms are formulated and seen as beneficial for local communities and stakeholders and bring ownership of the mechanisms into their ethos.

3.1. Define Values

To begin the process of constructing a durable protection strategy, we must ask what values society wants to protect, be they rare and endangered fish species or productive fisheries, recreational opportunities, scenic landscapes, or cultural and spiritual areas of importance. The process of defining these values is commonly and most successfully achieved through engagement of local communities and stakeholders, as protection is a value-driven process [36].

A wide range of intrinsic natural, social, economic, historical, and cultural values have been provided by the International Union for Conservation of Nature [37], the Ramsar Convention [38], the United Nations Development Programme [39], and the United States Wild and Scenic Rivers Act [40]. These resources provide extensive examples for initiating discussions of values to consider for protection.

Freshwater ecosystems provide a variety of important services to society, the most common of which are summarized in the Millennium Assessment to include provisioning services, regulatory services, cultural services, and supporting services [41]. Pandeya and others [42], Grazzetti and others [43], and Rinke and others [44], provide comprehensive summaries and methods for identifying ecosystem services and evaluating their monetary and non-monetary values. The valuation per unit area of lakes, rivers, swamps, and floodplains for the ecosystem services they provide exceed those of forests, grasslands, croplands, and urban areas, highlighting their importance for protection [45]. Accounting for ecosystem services has gained attention, particularly for the significance of their protection [46]. Through market-based ecosystem services payments (e.g., ecotourism, recreation charges, and sustainable resource extraction fees), intact freshwater ecosystems also provide avenues of long-term financing of protection [47].

To adequately identify the range of social values that require new or improved protection, it is also critical to engage with local communities and indigenous groups to understand individual and collective well-being, socio-cultural factors, and reciprocal human-environmental interactions [48,49] not covered by the above values. Doing so ensures that the interests of local communities are represented by future protection.

Expertise in social science, ecology, ecosystem services, economics, ethnoecology, and community outreach are helpful in this step.

3.2. Identify Key Ecological Attributes (KEAs) and the Threats and Sources of them

Freshwater ecosystems are structured, and their integrity is sustained, by a suite of natural patterns and processes [16,50,51]. We structure the DFP framework in the context of patterns and processes critical to sustaining freshwater ecosystems and the values they provide, and to guide protection mechanisms to appropriate locations and scales, as opposed to boundaries defined for non-freshwater ecological reasons such as those common to protected areas. Key Ecological Attributes (KEAs) are fundamental characteristics of ecosystems that are essential for the long-term persistence of native biodiversity values and are critical for designing and evaluating protection actions [52]. We suggest that KEAs are applicable to social values derived from naturally functioning freshwater ecosystems as well. The successful application of the DFP framework would avoid threats to KEAs,

to maintain values that society identifies as critical. The expertise listed below would provide knowledge and details on whether threats exist, and to what extent they would affect KEAs in a given context.

Threats to freshwater ecosystems occur at a range of spatial scales [53]. Current threats can be assessed using spatial data, remote imagery, and water and biota sampling data with methods commonly used to develop conservation assessments [15,54] and regional and global ecosystem condition and threats evaluations [55–58]. The potential scope of future threats and their sources can be assessed using spatial data on probable resource extraction and development locations [58–61]. Understanding the sources of those threats, their drivers, and how they're spatially represented, is critical to abate them. For instance, flow alteration as a threat may be caused by dam operations, water withdraws, and changes in land use and land cover in a watershed. The driver for these sources may include the need for more electricity, water storage for drinking or irrigation, flood control etc. The sources of threats and their drivers need to be considered when design freshwater protection strategies. Clarity on the degrees to which each source contributes to the alteration and potential for their sources to increase over time can guide priorities for addressing them. Linking KEAs, threats, and sources of threats for strategic planning can be conducted using methods and tools widely applied to conservation action planning [62].

Understanding the relationships among values, KEAs that sustain them, and the types and sources of threats provides governments, communities and stakeholders a structure to define appropriate and pragmatic mechanisms to address those threats. A simple summary of KEAs, threats, and sources of those threats is provided in Table 1 (modified after Poff and others [50], Thieme and others [16], and Tickner and others [51]). Maintaining and restoring these attributes through actions at appropriate scales is fundamental to addressing the freshwater biodiversity crisis.

Table 1. Key ecological attributes, threats to them, and examples of sources of those threats.

Key Ecological Attribute	Threat	Examples of Sources of Threat
Hydrologic regime (Timing, magnitude, duration, frequency)	Water flow and level regime alteration, water withdraws, inter-basin transfers	Dams, irrigation, energy or water resource development, land uses and land cover.
Connectivity (Lateral, longitudinal, temporal)	Dams, levees, road/stream crossings	Dams, energy or water resource development, flood-risk infrastructure development, road development/poor culvert designs
Water quality (e.g., Nutrients, dissolved oxygen, sediments, temperature regimes, pH, toxins)	Watershed runoff or point sources of excess sediments and/or nutrients, bacteria, toxic chemicals, reductions of transport of natural sediments and nutrients from dams	Agriculture, urban areas, deforestation, animal management, sewage, industry, mining, water infrastructure, changes in land uses and land cover
Habitat (Structure, distribution, abundance, condition)	In-stream and lake shoreline gravel mining, channelization, floodplain and/or riparian and other wetland destruction/conversion	Dams and other water infrastructure, development, agriculture
Biotic composition (Species composition, abundance, distribution)	Over harvesting, invasive species	Poorly managed fisheries, aquaculture, pet and landscaping trades, international transportation

Expertise in freshwater ecosystem science (hydrology, ecology, water quality, watershed dynamics), spatial analysis and modeling, and expertise in expanding threat sectors, e.g., hydropower, water storage, agriculture, mining, are helpful in this step.

3.3. Identify Potential Mechanism(s)

The mechanisms employed to protect the freshwater ecosystems must address the threats to the key ecological attributes at appropriate scale. The mechanisms we have assembled consist of legally bound ones that can be considered having high probability of durability: legislation, administrative designations, regulations, acquisition of enforceable

rights in natural resources, and judicial actions. Such mechanisms are binding and enforceable. Mechanisms can also consist of non-legally binding arrangements, which may have high probability of durability because they are economically driven or are organized and maintained by community and cultural norms (Table 2). These non-legally bound mechanisms do not have the same basis in formal laws, but operate within a structure that maintains them through time, and may in many cases be more durable because they benefit from the support of community or stakeholders and are not subject to the vagaries of political change.

Table 2. Protection mechanisms and examples of their applications.

Mechanism	Examples of Mechanism Application
Legal Mechanisms	
Legislation focusing on freshwater ecosystem protection	Protection legislation and acts
	Fishing/fisheries policies
	Interjurisdictional freshwater
	Ecosystem basin compacts
	Public policies creating financial incentives for resource protection
Administrative Designations giving special protection to a whole or portion of a freshwater ecosystem	Executive orders requiring the use of best management practices
	Protected areas designations
	OECMs
Regulation focusing on freshwater ecosystem protection	Environmental flows
	Licensing of dams
	Water rights allocations
	Riparian zoning regulations
	Fishing regulations
Acquisition of enforceable rights in land or water by a holder of those rights for the purpose of river protection	Water quality regulations
	Transfer of development rights programs
	Conservation easements
	Flowage easements
	Riparian land acquisition
Judicial action where courts with jurisdiction order some form of freshwater ecosystem protection, pursuant to actions brought by parties with standing to defend the integrity of a natural resource or feature (e.g., a river, lake, wetland, aquifer, biota, ecosystem service)	Water rights
	The “Public Trust” legal doctrine
	“Rights of Nature” initiatives
Non-Legal Mechanisms	
Indigenous peoples and local communities Collective Management of Common Pool Resources	Community-based fisheries management
	Community Irrigation systems
	Communal forest management
	Areas protected by religious or cultural institutions

Note: **Legislation** is defined as a law, directive, policy, or enabling framework enacted through an approval process by a legislative or representative governing body having widespread applicability; **Regulation** is defined as a specific rule, guideline, procedure, or order that is often designed to implement a legislative policy or law and is adopted by administrative or executive agency action with a more limited scope or application.


Identifying appropriate mechanisms also requires understanding whether, and if so, how those mechanisms can be applied at appropriate scales (i.e., that the scope of protection accounts for the processes of and threats to the freshwater ecosystem in question), and if they conform to the environmental, social, cultural, and economic contexts of the landscape in which they may be operating.

Expertise in policy, law, government relations, finance, social science, and economics are helpful in this step.

3.4. Implement Mechanism(s) at the Appropriate Scale

The core elements of the DFP framework are presented below in Table 3 to provide an overall perspective on designing durable freshwater protection strategies. The listed examples illustrate values that society wants to protect, the KEAs that support them, and their known current and/or future threats, the sources of those threats, and mechanisms that appropriately address them with examples of their applications.

Table 3. The Durable Freshwater Protection conceptual framework with examples.

Values	Threatened Key Ecological Attributes	Sources of Threats	Mechanisms	Examples of Applications of Mechanisms
				
Biodiversity Ecosystem health Variety of ecosystem services	Hydrologic Regime Habitat Water Quality	Hydropower development Water abstraction	National Legislation Regulation Designation	Norway's Water Resources Act. Protects river system and groundwater natural processes to maintain natural biological diversity and natural processes of river systems while promoting sustainable development. Requires licensing for all types of works which might cause significant damage or nuisance to community interests, including hydropower and projects that include water abstraction. Norway's Watercourse Protection Plans identify 341 river systems from hydropower development [63,64].
Biodiversity Variety of ecosystem services	Water Quality Hydrologic regime Habitat Connectivity	Land uses Point source pollution Hydropower development	National legislation Regulation Designation Rights in land	U.S. EPA Tier 3 Outstanding National Resources Waters (Class AA waters, or equivalent under state water quality standards). Water quality must be maintained and protected without exception for those waters designated by a state, territory, or tribe. Implemented through states [65]. Matrix of fee-simple land acquisition of riparian corridor lands by The Nature Conservancy and designation of AA waters by the State of Maine to protect the upper St. John River system, northern Maine, USA (Personal communications).
Biodiversity Variety of ecosystem services Historically important places	Connectivity Hydrologic Regime Habitat Water Quality	Water infrastructure development	National Legislation Regulation Designation	US Wild and Scenic Rivers Act implemented to avoid dam development and set regulations on access and resource uses in 3 branches of the Flathead River, MT, USA [66].
Fisheries	Biotic Composition	Overfishing from unmanaged fisheries	Collective Management of Common Pool Resources	Community based no-take fish reserves in Thailand's Salween River basin to protect population recruitment and feeding areas, supporting fisheries in spill over zones [67].

Biodiversity	Hydrologic Regime	Water infrastructure development and management Water withdraws	National Legislation Regulation Designation	Mexico National Water Reserves for the Environment Program. Established river basins based on high biodiversity conservation value where regulations for water withdraws were established based in environmental flow requirements [68].
Fisheries	Biotic Composition	Overfishing from unmanaged fisheries	Collective Management of Common Pool Resources	Fishing accords of local communities and fishing cooperative in the Juruá River of Western Brazilian Amazonia. Areas designated for unregulated fishing, restricted subsistence artisanal fishing only, and no fishing areas for fish stock population recruitment [69].
Freshwater Ecosystems	Hydrologic Regime	Water withdraws	International legislation	Great lakes–St. Lawrence River Basin Water Resources Agreement for 8 US Great Lakes States, and 2 Canadian Great Lakes Provinces addressing future water withdraws, diversions, and consumptive uses from lakes and rivers in the Laurentian Great Lakes and St. Lawrence River Basin [70,71].
Fisheries Wildlife, Maori culture Recreational Wild and scenic or scientific values	Hydrologic Regime Connectivity Water Quality Habitat Biotic Composition	Variety of potential sources of threats	National legislation Regulation Designation	New Zealand’s Water Conservation Orders prioritize protecting any identified outstanding features [72].
Biodiversity	Hydrologic Regime	Groundwater withdraw	Judicial action Regulation	1976 Supreme court case Cappaert v US. Resulted in regulations to groundwater pumping in the aquifer that supports the Devils Hole Pupfish in the Ash Meadows National Wildlife Refuge, Nye County, Nevada, USA which is a detached unit of Death Valley National Monument [73].
Biodiversity Variety of ecosystem services	Hydrologic Regime	Water infrastructure management and development	Legislation Regulation Designation	State of Connecticut, USA, stream flow standards and regulations enacted in 2011 protects outstanding quality freshwater ecosystems from flow alteration and subjects lesser quality systems to maintaining and restoring flows based on environmental flow requirements [74].
Riverine and wetland ecosystems	Hydrologic Regime	Water withdraws	Legislation Judicial action	Water rights that can be used to provide environmental flows for rivers and wetlands at particular locations in the state of Victoria, Australia under Rights to Rivers legislation [75].

Expertise in policy, law, government relations, social science, governance structure, finance, and community outreach are helpful in this step.

Moving left to right in Table 3 illustrates the progression from defining what to protect (values and KEAs), to understanding what needs to be addressed for protection

(threats to those values), and which protection mechanisms to consider and select to implement. Below are some examples highlighting a range of contexts for applications of mechanisms.

3.4.1. More Than one Mechanism May Be Applied Depending on the Need for Protection

Multiple mechanisms may result in a spatial matrix of areas and policies or regulations. For instance, the upper St John River in Maine has been protected through a series of land and easement acquisitions and water quality standards that have maintained the flow, water quality, connectivity, and riparian and in-stream habitats of the upper river system that was threatened from unmitigated logging practices and dam development. Outright purchase of land parcels and easement acquisitions were carried out by The Nature Conservancy. Management and uses were defined for protection of the riparian corridor, allowing hunting and fishing, rafting, and camping, with some conservation-compatible limitations. Selective logging is also carried out as part of a Forest Stewardship Council-certified sustainable land management initiative implemented by the Conservancy, which has been necessary to cover the high costs of large-scale stewardship. These activities were considered based on engagements with local stakeholders and incorporated into the overall protection strategy. The parcels provide long-term protection via private ownership through land rights. The AA designation of the upper St. John River by the state of Maine protects water quality and flow through designation and legislation [76] under the Clean Waters Act. Collectively, the land parcels and policy designation mechanisms add up to the components necessary for durable river protection.

3.4.2. Transboundary Protection Mechanisms

The Great lakes–St. Lawrence River Basin Water Resources Agreement by the Council of Great Lakes Governors and Premiers in 2005 [70] is an example of an international compact implemented through regulations in states and provinces over a large spatial scale. The compact is not focused on specific designated areas, rather, it protects all rivers and lakes within the Great Lakes and St. Lawrence River basin from significant alterations to their hydrologic regimes. This is done through licensing reviews for proposed projects that would withdraw, divert, or consume significant volumes of water out of the ecosystems. This approach benefits the outstanding freshwater resources that were already protected through other mechanisms but potentially threatened from water withdrawals or diversions. It also avoids further degradation to ecosystems in lesser condition within the basin to allow restoration activities to take place without further declines from added flow alteration.

International applications of mechanisms are needed given the transboundary nature of numerous freshwater ecosystems. Such situations are often challenging but mechanisms have been applied in these contexts. There are hundreds of protected areas adjoining at national boundaries, many with cooperative agreements making them true transboundary protected areas [77]. Improving freshwater governance of transboundary freshwater ecosystems is promoted through the Convention on the Protection and Use of Transboundary Watercourses and International Lakes, and the United Nations Convention on the Law of the Non-Navigational Uses of International Watercourses [78]. The European Union uses the Water Framework Directive [legislation] for river ecosystem management, which aims to protect and enhance the status of freshwater ecosystems and sustainable uses. It establishes a European Union-wide basis for integrated water resources management based on a river basin management approach [78].

3.4.3. Strengthen Existing Land Protection Designations to Address Gaps in Freshwater Protection

As an example, The Middle Fork of the Flathead River is situated within the Bob Marshall Wilderness area in the state of Montana, USA established under the U.S. Wilderness Act [66]. While the watershed was protected, the river itself was not, and was threatened from dam development within this protected area. The designation of the river through the U.S. National Wild and Scenic River Act legislation in 1976 protected the river from flow alteration, habitat inundation, water quality issues, development along its corridor, and has maintained its biodiversity, recreational, historical, and cultural values defined by local communities as being important to protect and to drive a productive tourism economy [66]. This additional designation of a legislative act was necessary to fill the gap in protection for the river, even though it occurs within the highest level of public land protection in the United States.

3.4.4. Providing Protection beyond the Boundaries of a Designated Protected Area

An example of implementation of a judicial action that extended beyond a defined protected area boundary to address a threat at the appropriate scale is the case of *Cappaert v the United States* in 1976. The U.S. Supreme Court decided that federal protection of Devils Hole in Nevada, and its resident Devils Hole Pupfish (*Cyprinodon diabolis*), extends to regulation of water usage around the state that drew from the same aquifer as Devils Hole, located within the Death Valley National Monument [73]. The action was taken to maintain the aquifer flow volume needed to sustain the Devil's Hole Pupfish, in the context of implementation of the US Endangered Species Act [79].

3.4.5. Community-Driven Protection through Common Pool Resource Management

In Thailand, local community design, implementation, and enforcement of fisheries protection through no-take zones in rivers have resulted in significant increases in native fish diversity, abundance, and biomass [67]. A similar implementation of this mechanism occurred in Brazil through local communities and a fishing cooperative. Floodplain lakes designated for unregulated fishing, restricted subsistence artisanal fishing only, and no fishing areas for fish stock population recruitment were established, which resulted in an increase in native fish abundance and biomass, and an increase in local fisheries production, economic levels and stability [69].

3.4.6. Adequate Funding to Ensure Implementation Is often a Challenge

Securing and managing sufficient funding for the implementation and maintenance of freshwater protection mechanisms is critical for the durability of said mechanisms [47]. Often, external funds can be procured through domestic or foreign government assistance, private voluntary donations, and other public and private environmental funds set aside for conservation purposes. Another category of funds for protection mechanism that has seen increasing use in recent years includes compensatory mitigation programs, including offsets from proposed development actions to fund protection. Finally, there are some limited cases where a party is found guilty of violating a water pollution regulation. In these cases, any penalty funds that are assessed for the violation are most often allocated to the protection of another freshwater ecosystem with the same watershed where the source of the violation occurred. Such funding sources also provide needed momentum for initiating new protection projects or new mechanisms within existing projects. Once mechanisms are implemented, they are often supported by the economic benefits of ecosystem services that they preserve; revenue sources created by protection mechanisms this way commonly include ecotourism or recreation fees (e.g., entrance charges, yearly fishing and hunting permits) and licensed, mitigated extraction of resources (e.g., sustainable forestry stewardship, commercial bio-prospecting agreements) [47]. Successfully utilizing the advantages of these ecosystem services may allow for protection mechanisms to be fiscally self-propagating to some extent and is key to ensuring long-term durability.

3.5. Evaluate and Adaptively Manage

The DFP Framework is meant to be revisited over time to ensure that freshwater protection is lasting. The evaluation of protection requires understanding whether the mechanisms are effective, ineffective, or perhaps necessary but not sufficient, or whether the design and implementation of the mechanism failed in components of their development and enforcement. Monitoring and evaluation are needed to illuminate successes and failures, trends, and guide adaptive responses from knowledge gained and to respond to dynamic situations. There is a need to evaluate status and changes in the condition of values, KEAs, and socioeconomic outcomes to assess protection effectiveness in addition to implementation [11,52,80]. Unfortunately, these have not been the focus of monitoring and evaluation, which have remained poorly resourced and implemented in most protection efforts, and these trends will continue absent stronger policies and other incentives [80].

Understanding where success and failure has occurred in the different steps is critical to revealing and addressing issues. An interdisciplinary team of social scientists, economists, freshwater scientists, lawyers, and experts in government relations and finance is necessary to provide a robust evaluation and make recommendations for adaptive responses.

As contexts change or new threats arise, adaptive management should lead to additional mechanisms being applied or changes to existing ones where necessary. Adaptive management to address both shortcomings of management actions and changes in threats can be implemented and is greatly needed for freshwater ecosystems [81].

4. Conclusions

Freshwater ecosystems and the biodiversity and services they provide are the most threatened realm on Earth. This trend will continue without concerted efforts to change and expand how freshwater protection is approached, structured and implemented. The focus on protected areas and OECMs has limited the evolution and implementation of other actions that are necessary to achieve greater quantity and quality of freshwater ecosystem protection.

The authors do not suggest that protected areas and OECMs not be considered as protection mechanisms, as they are included in the DRP framework under “Designations, and Acquisition of enforceable rights in land or water” and they are widely implemented. Improvements in their designs, management, and implementation with attention to freshwater ecosystem needs offer opportunities to contribute significantly to freshwater protection [10,14,16,81]. The framework we present is partly intended to fill gaps where possible in and around protected areas. However, given that society depends on freshwater and its services globally, and in many parts of the world water is thought of as a common use resource, implementing restrictions to access or use, as many protected areas do, could lead to conflict and failure of freshwater protection. The success of integrated approaches to sustaining freshwater ecosystems depends on striking a balance between human resource use and freshwater ecosystem protection as it has most commonly been applied [53,82]. Azevedo-Santos and others [9] suggest complete river protection through either complete declaration or a matrix of areas with varying degrees of restrictiveness for sustainable uses, comprising a mosaic of units that adequately addresses protection needs for freshwater ecosystems.

Given that the greater concentrations of freshwater biological diversity are in larger rivers, many of which are working rivers that support tens of millions of people and economies worldwide, the protection of biodiversity and services in these contexts are complicated yet greatly needed. A range of mechanisms are required to achieve protection in these contexts, including policies and regulations for energy and water infrastructure development and management, fisheries, water use, water quality, and invasive species.

Freshwater conservation challenges are complex and multi-dimensional. This framework is intended to help practitioners think about how to develop effective protection

strategies in whatever context they may be working in. Avoiding the tragedy of the commons for freshwater ecosystems requires thoughtful and patient efforts to work through challenges and conflicts in order to arrive at solutions that are broadly supported and promote societal engagement, resulting in successful protection outcomes.

Given the range of communities and stakeholders and the different values that they may highlight, there is opportunity for values that conflict. We have focused the framework here on protecting the natural processes of freshwater ecosystems; by doing so, services provided by naturally functioning ecosystems should support biodiversity as well, and vice versa. Where conflict do arise, it is the role of governance bodies to make decisions regarding them.

We propose the Durable Freshwater Protection framework to stimulate more holistic thinking about how to maximize the effectiveness and long-term persistence of freshwater protection efforts. Applications of these curated mechanisms are not new. However, a simple framework that can guide protection for those unfamiliar with the array of the steps and mechanisms has not previously been posed. Many of the mechanisms have been underappreciated and not counted towards achieving goals for freshwater protection given the focus on protected areas and OECMs. Global policy forums such as the Conference of the Parties for the Convention on Biological Diversity are opportunities to address the historically inadequate approaches to freshwater protection.

Monitoring and evaluation of the framework will be used to assess its effectiveness to identify weaknesses, gaps, or burdensome aspects to guide improvements in the future. Whether pursuing new freshwater protection efforts or improving existing ones, this framework is intended to tailor future protections to the unique processes and scales of freshwater ecosystems and the threats to their functionality, as well as to offer a broader suite of mechanisms to effectively and durably protect them.

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