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Critical pathways of coupled human–water systems for understanding unintended consequences of human interventions

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ABSTRACT

Water management interventions are designed to mitigate undesirable aspects of coupled human–water systems (CHWS). However, due to the nonlinear feedback mechanisms inherent in CHWS, these interventions sometimes lead to unintended consequences that exacerbate the very issues they aim to resolve. To develop a generalized understanding of the underlying mechanisms behind such unintended outcomes, this study conducts a meta-analysis of 37 case studies from around the world. We identified six core subsystems and defined a critical pathway showing how hydrological perturbations propagate in a CHWS and lead to unintended consequences of interventions. By analysing case storylines, we identified the critical pathways and harmonize them into prevalent critical pathways, which most frequently lead to unintended consequences for specific phenomena, together with the key variables. The results of this study can support more sustainable and resilient water management, as it is the critical pathways that must be altered to avoid unintended consequences.

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1 Introduction

Integrated Water Resources Management (IWRM) is a widely endorsed framework for water governance that promotes the coordinated development and management of water, land, and related resources. Among the tools it employs, scenario-based analysis is commonly used to anticipate future environmental and socioeconomic conditions that may influence both water supply and demand (Warwick *et al.* 2003, Savenije and Van der Zaag 2008). However, many scenario-based approaches treat human behaviour as exogenous or represent it in overly simplified terms, particularly when accounting for changing social expectations. This limitation constrains the capacity of IWRM to anticipate the full range of consequences resulting from human actions.

To address this gap, a growing body of research calls for making human behaviour endogenous to water system frameworks. Coupled Human–Water Systems (CHWS) offer a way to represent the mutual and nonlinear interactions between human and water (Sivapalan *et al.* 2012, Konar *et al.* 2019, Tian *et al.* 2025). Recognizing that evolving human expectations, values, and decisions can dynamically alter both supply and demand, this approach marks the emergence of a new paradigm in water management – one that aims not only to manage risk but also to reduce the occurrence of unintended consequences in real-world systems (Pahl-Wostl *et al.* 2008, Schwabe *et al.* 2020, Callejas Moncaleano *et al.* 2021, Suckling *et al.* 2021).

In practice, interventions in CHWS are typically motivated by management goals such as flood protection, drought mitigation, or transboundary cooperation. These interventions may take physical forms, such as dam construction or irrigation infrastructure (Khalkheili and Zamani 2009), or nonphysical forms, such as regulatory policies for water use or environmental protection (Hanjra *et al.* 2012). Although such actions are intended to address specific water-related challenges, they often produce unintended consequences due to the complex feedback loops inherent in CHWS. For instance, levees designed to reduce flood risk may inadvertently encourage settlement in vulnerable areas, leading to increased overall risk – a dynamic known as the "levee effect" (Di Baldassarre *et al.* 2009). Similarly, technologies aimed at improving irrigation efficiency can paradoxically lead to greater total water consumption, a phenomenon referred to as the "irrigation efficiency paradox" (Grafton *et al.* 2018).

These examples highlight the need for a deeper understanding of how interventions propagate through CHWS, and under what conditions they may generate unintended or adverse outcomes. Addressing this need requires tools that can capture

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the dynamic and interconnected nature of these systems, beyond static or sector-specific analysis.

Achieving such a deeper understanding depends on the ability to identify common mechanisms across diverse CHWS types. These include systems shaped by flood control infrastructure and risk perception (e.g. human–flood systems), drought-driven water allocation and technological adaptation (e.g. human–drought systems), irrigation-dependent production and trade dynamics (e.g. agricultural water systems), and those governed by shared institutions across geopolitical boundaries (e.g. transboundary river basins). Despite these contextual differences, many of these systems exhibit similar dynamics, such as feedback loops between institutional responses and societal behaviour, or between physical infrastructure and environmental outcomes. Identifying these shared mechanisms requires a common analytical structure capable of revealing deep similarities in system behaviour. However, developing this kind of integrative understanding has been complicated by the inherently interdisciplinary nature of CHWS research. The field spans hydrology, ecology, political science, and economics, with studies often employing divergent terminologies, conceptual frameworks, methods, and scales. As a result, the knowledge base remains fragmented, and insights from one context are not easily transferable to others (Sivapalan *et al.* 2012).

To overcome this fragmentation, this study proposes a unified analytical framework that captures both the structural and feedback elements of CHWS. By enabling systematic comparison across different system types – such as human–flood, agricultural, and transboundary water systems – the framework facilitates the identification of shared patterns and structural consistencies. This makes it possible to develop a generalized anatomy of CHWS that supports comparative analysis, cumulative knowledge building, and integrative modelling.

This paper aims to contribute to that integration by uncovering the mechanisms through which unintended consequences emerge in CHWS. Drawing on Ostrom's (2009) Social–Ecological Systems (SES) framework, we develop a unified structure based on a meta-analysis of published case studies. This six-component framework is designed to capture the essential anatomy and key interactions that shape system dynamics in CHWS.

The remainder of this paper is structured as follows: Section 2 introduces the six-component analytical framework for CHWS and presents the methodology for identifying and coding critical pathways based on a meta-analysis of 37 case studies. Section 3 summarizes the key results, including the classification of second-level variables and the identification of prevalent critical pathways across multiple CHWS phenomena. Section 4 explores the relationship between empirical pathways and system dynamics representations, highlighting how narrative-based analysis complements causal loop diagrams. Section 5 concludes by outlining the theoretical and practical implications of the critical pathway approach for advancing CHWS research and designing more resilient water management strategies.

2 Methods

2.1 Harmonizing the main components of CHWS

2.1.1 Three-component concept

To enable a systematic understanding of the effects of interventions across diverse case studies, it is essential to first harmonize the way CHWS are conceptually represented – particularly the components from which they are composed. While individual studies often adopt unique perspectives shaped by disciplinary traditions and contextual constraints, a common analytical structure is required to draw meaningful comparisons and extract generalizable insights.

Ostrom's (2009) multilevel and nested framework for social-ecological systems provides an important foundation in this regard. This framework conceptualizes systems as comprising multiple interacting core subsystems – such as users, governance systems, and resource systems – embedded within broader ecological and societal contexts. This structure emphasizes that outcomes emerge through feedback loops among these subsystems and offers a starting point for integrating diverse human–nature interactions into a unified analytical perspective.

Building upon this, Sivapalan *et al.* (2014) proposed a three-component framework within the field of socio-hydrology that is particularly well suited to CHWS. This framework identifies three essential dimensions (see the inner circle of Fig. 1: 1) structure and dynamics, which encompass the biophysical and institutional features of the system, including hydrology, infrastructure, policies, and economic structures; 2) human wellbeing outcomes, which represent the goals or impacts of interventions, such as flood security, food security, or peace; 3) norms and values, which refer to the underlying cultural, ethical, and political orientations that influence both human behaviour and system design. This conceptual triad offers a parsimonious yet

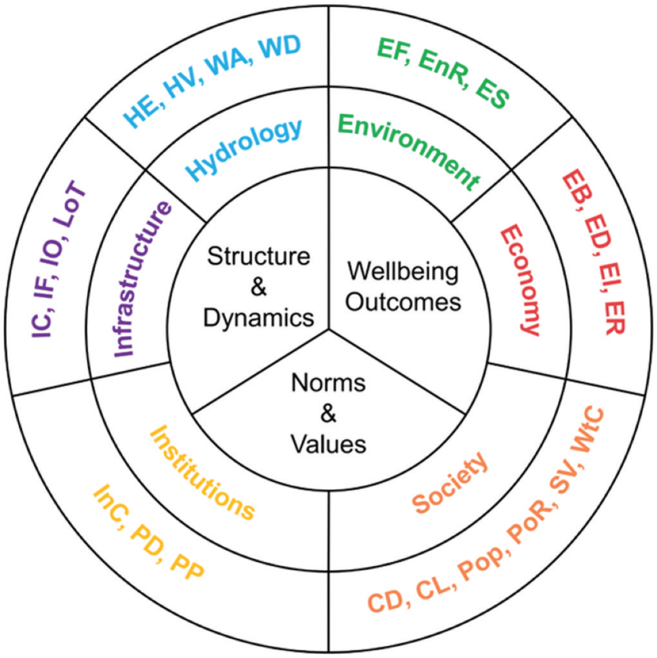

Figure 1. Evolution from the three-component to the six-component framework of coupled human–water systems.

comprehensive anatomy of CHWS that captures both material and normative dimensions of human–water interactions.

Table 1 synthesizes the CHWS components identified across the case studies reviewed and organizes them according to this three-component structure. For example, in human–flood systems, the structural and dynamic elements include hydrology and flood control infrastructure; the wellbeing outcomes target flood security and equity; and the prevailing values include risk aversion and a desire for fairness. Similarly, transboundary systems combine infrastructure, treaties, and legal institutions with aspirations for regional peace and values of good neighbourliness.

By mapping case-specific components onto this shared framework, we are able to compare otherwise disparate cases in a coherent and systematic manner. The three-component concept thus serves as the foundational lens through which we interpret the anatomy and dynamics of CHWS across scales and contexts.

2.1.2 Six-component concept

To build a more consistent and nuanced understanding of CHWS, this study extends the traditional three-component model proposed by Sivapalan *et al.* (2014) into a refined six-component framework. While the original structure – comprising Structure and Dynamics, Human Wellbeing Outcomes, and Norms and Values – has been effective in a variety of contexts, it lacks the specificity required to delineate the complex and overlapping components observed in real-world systems. For example, Human Wellbeing Outcomes can refer to economic prosperity, environmental health, or social equity, each with distinct implications. Likewise, infrastructure and institutions may straddle multiple categories depending on the context.

To address this ambiguity and enhance analytical clarity, we introduce a six-component CHWS anatomy, which is initially inspired by the human-flood framework proposed by (Barendrecht *et al.* 2017). In this study, the new six-component anatomy, which is applicable to various types of CHWS, was derived from a meta-analysis of empirical case studies. As illustrated in Fig. 1, this expanded framework retains the conceptual foundation of the original triad (at the centre of the structure) and extends it outward to include six clearly defined core subsystems: Hydrology, Infrastructure (physical systems), Institutions (social infrastructure), Society, Economy, and Environment.

These six components were not selected arbitrarily. They emerged inductively through the systematic synthesis of CHWS elements observed across diverse case studies (see Table 1). Each component reflects a recurring thematic domain that shapes system structure, mediates interventions, and influences outcomes. Collectively, these subsystems offer a disaggregated yet integrated anatomy that is well-suited for tracing feedback loops, emergent behaviours, and intervention pathways across spatial and temporal scales.

This refined framework offers several important advantages. First, it establishes clearer subsystem boundaries, allowing for greater precision in identifying causal pathways and feedback loops. Second, it preserves alignment with the original three dimensions: Hydrology, Infrastructure, and Institutions map to Structure and Dynamics; Economy, Environment, and Society align with Human Wellbeing Outcomes; and Society and Institutions intersect with Norms and Values. Third, it is specifically tailored to the complexities of water-centred social–ecological systems, enhancing its utility for integrated water resources management and policy-relevant modelling.

Figure 1 depicts the evolution from the original three-component structure (inner circle) to the proposed six-component model (middle circle). The outer layer introduces second-level variables that represent context-specific expressions of each core subsystem. Detailed discussion of how this six-component anatomy was developed and validated is provided in Sections Section 3.1.1 and Section 3.1.2.

By adopting this nested and unified structure, we aim to provide a robust analytical basis for understanding CHWS as intricately coupled systems of human and environmental interactions – systems in which interventions, responses, and unintended consequences must be examined in relation to interacting hydrological, societal, institutional, economic, and environmental dimensions.

2.2 Critical pathway analysis

2.2.1 Conceptualizing the propagation of unintended consequences through critical pathways

In this study, we introduce the concept of critical pathways as a targeted approach to understanding how unintended

Table 1. Classification of CHWS components across case studies according to the three-component framework of structure and dynamics, human wellbeing outcomes, and norms and values.

CHWS Types	Structure & Dynamics	Human Wellbeing Outcomes	Norms & Values
Human–flood	Hydrology, Flood control infrastructure (levee, dam, human action to reduce flood)	Flood-secure, Flood-resilient, Equity	Risk averseness, Striving for equity
Human–drought	Inter-basin transfer, Regional planning, Water rights	Drought-secure, Drought-resilient	Environmental awareness, Lifestyle
Agriculture	Hydrology, Irrigation systems, Economy, Trade	Food security, Economic health, Environmental health, Equity	Environmental awareness, Striving for equity
Transboundary	Hydrology, Infrastructure, National boundary, Treaties, Institutions (legal system), Trade	Peace, Regional water security	International reputation, Good neighbourliness
Global	Climate gradient, Price gradient (trade), Wellbeing gradient (migration)	Global water security	Sustainability, Environmental awareness

consequences emerge in CHWS. Unlike conventional causal loop diagrams (CLDs), which illustrate entire systems of feedback loops and interactions, critical pathway analysis focuses on specific propagation chains through which hydrological perturbations – mediated by human interventions – lead to adverse outcomes.

A critical pathway is defined as the sequence of interactions within a CHWS most directly responsible for triggering an unintended consequence. It represents a condensed subset of broader system linkages often found in CLDs. When the same sequence appears across multiple case studies, it is termed a prevalent critical pathway.

CLDs are commonly employed to depict systemic feedback mechanisms and behavioural dynamics (Richardson 1986, Elshafei *et al*. 2014). However, their comprehensiveness can obscure the identification of the most influential causal chains. In contrast, critical pathway analysis isolates these key sequences, offering a clearer lens through which to identify leverage points for system redesign.

Figure 2 illustrates this distinction. Black arrows represent the general feedback loops within a CHWS, while green arrows highlight a specific critical pathway. This pathway does not aim to capture the entire system's behaviour but rather pinpoints the most impactful propagation of a hydrological disturbance triggered or intensified by human activity. It reflects the strongest trajectory along which interventions ripple through the system and result in unintended consequences. Therefore, modifying or disrupting this pathway is essential to avoiding such outcomes. Critical pathways are defined as the dominant sequences through which interventions lead to unintended outcomes. These are identified through a multiphase coding of case studies. Each case is analysed for variables in the six-component framework, and second-level descriptors are used to trace critical pathways from perturbation to outcome. These empirical sequences are then synthesized into prevalent critical pathways.

2.2.2 Method for identifying critical pathways and prevalent critical pathways

To operationalize this concept, we conducted a meta-analysis across 11 distinct phenomena characterized by unintended consequences in CHWS contexts, including flood management, drought response, agricultural systems, and transboundary water governance. Meta-analysis enables the categorization of large volumes of qualitative and quantitative data into structured groups using predefined coding rules.

The analysis was grounded in a unified, multilevel framework developed specifically for CHWS (see Section 2.1.2). Case studies were examined to extract the variables involved in intervention-driven perturbation propagation. These variables were then organized into pathways, from which the most recurrent (prevalent) critical pathways were identified.

The identification procedure is visualized in Fig. 3, which outlines the major steps taken to move from narrative case study analysis to the abstraction of critical and prevalent critical pathways.

2.2.3 Selection of case studies for identifying critical pathway

A two-phase protocol was used to select 37 representative CHWS case studies. First, keyword-based literature screening targeted both system categories (e.g. human–flood, human–drought, agricultural, transboundary, global) and known phenomena (e.g. levee effect, reservoir effect, pendulum swing). Second, case studies were screened for methodological alignment and scope. Inclusion criteria required that studies: (1) be peer-reviewed, (2) present empirical or model-based analyses, and (3) explicitly address interactions among variables within the CHWS.

The final sample (see Appendix Table A1) includes diverse spatial scales, from local catchments to regional basins, and captures a range of well-known emergent behaviours. These include: levee effect (8 cases), reservoir effect (3), call effect (1), flood adaptation (4), rebound effect (7), pendulum swing (5), collective action (2), unemployment paradox (1), poverty trap (2), water injustice (2), and system collapse (2).

2.2.4 Coding table design

To extract and compare system dynamics across case studies, we developed a coding table structured around the six core CHWS components: hydrology, environment, economy, society, institutions, and infrastructure. This structure reflects the multidimensional nature of CHWS and enables analytical

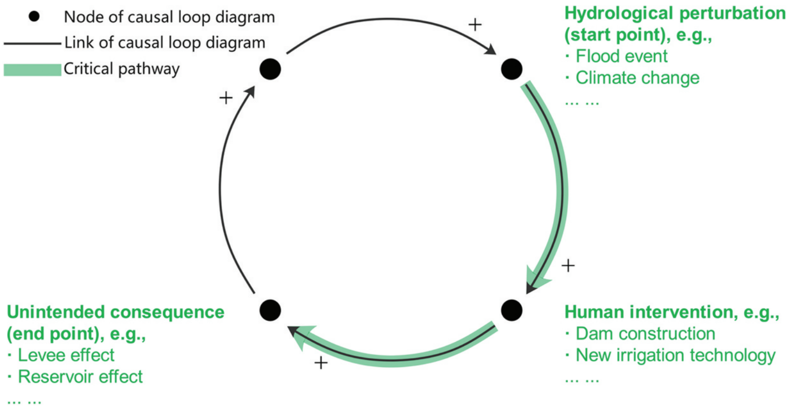

Figure 2. Critical pathway (green) in a Coupled Human-Water System, with causal loop diagram (Black) shown. The critical pathway represents the trail of an intervention made to the system, i.e. how the intervention propagates.

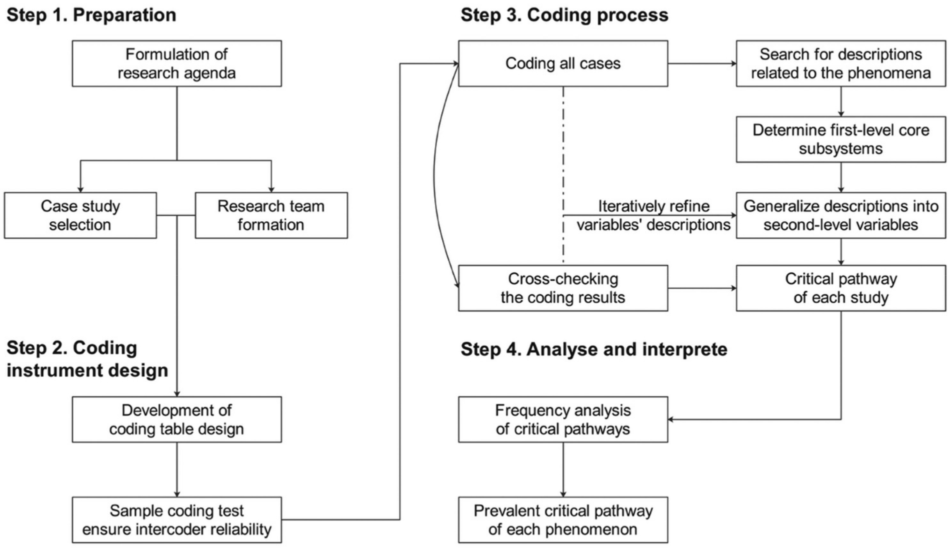

Figure 3. Stepwise workflow for extracting critical pathways and prevalent critical pathways from narrative-based meta-analysis of CHWS case studies.

consistency across diverse cases while preserving flexibility for contextual adaptation.

As shown in Table 2, the coding table is divided into two main sections. The first captures basic study information, including publication year, location, and phenomenon type. The second traces the intervention pathway by identifying first-level subsystems and second-level variables. These second-level variables were not predefined, but derived inductively through an iterative process of close reading, simplification, and generalization of narrative descriptions in the case studies. This approach ensured that the coding scheme remained grounded in empirical evidence while allowing for abstraction across cases.

To construct critical pathways, we compared variables across cases to identify recurrent patterns of interaction. For an example of the pendulum swing phenomenon, in the case study of the Kissimmee River Basin in Florida (Chen *et al.* 2016), we derived the pathway HE → PP → IC → EF → SV → PP → EnR. This pathway begins with a hydrometeorological event (HE), which prompted shifts in policy priority (PP). These policy changes led to enhancements in infrastructure capacity (IC), which in turn affected the environmental footprint (EF) of the system. Over time, shifts in social values (SV) catalysed a renewed institutional focus on environmental remediation (EnR).

Table 2. Structured coding table for a representative CHWS case study. This example illustrates how narrative data from the Kissimmee River Basin case study was systematically coded into the six core CHWS components.

Basic Information	ID of case study	(E.g.) 1	
	Publication year	2015	
	Author	Chen *et al.*	
	Study period (If applicable)	1948 ~ 2012	
	Geographic location	Kissimmee River Basin in Florida	
	Phenomena	Pendulum swing	
	Description of phenomena	The Kissimmee River Basin underwent river channelization in the 1960s followed by ecological restoration in the 1990s, demonstrating a systemic shift from flood control to wetland rehabilitation.	
	Pathway	HE-PP-IC-EF-SV-PP-EnR	
Coding contents			
First-Level Variable (Core Subsystem)	Original Text	Primary Descriptive Variable	Second-Level Variable
Hydrology	. . . suffered from repeated floods . . .	Flood intensity	Hydrometeorological Event (HE)
	The flood risk equation . . .	Flood risk	Hydrometeorological Event (HE)
Environment	. . . the population of wetland species have drastically declined . . .	Environmental footprint	Environmental Footprint (EF)
	. . . from flood protection to wetland health	Ecosystem service shift	Environmental Remediation (EnR)
Economy	–	–	–
Society	Change of values within human society . . .	Social preference	Social Value (SV)
	. . .	. . .	. . .
Institutions	In 1976, the Florida Legislature passed the Kissimmee River Restoration Act . . .	Policy priority	Policy Priority (PP)
	. . .	. . .	. . .
Infrastructure	. . . USACE initiated the Kissimmee River Channelization Project . . .	River engineering work	Infrastructure Capacity (IC)

This pathway was deemed critical because it encapsulates the full trajectory of change – from an initial environmental perturbation through multiple system components, ultimately culminating in institutional transformation and ecosystem recovery. It was selected over alternative pathways due to its completeness and its demonstration of feedback loops involving both social and ecological subsystems. This example illustrates how narrative evidence was systematically coded to reveal causally significant chains of interaction central to the emergence of unintended consequences.

The resulting dataset of coded pathways formed the basis for identifying critical and prevalent critical pathways across the broader set of 37 case studies.

2.2.5 From critical pathways to prevalent critical pathways

Unlike systems-based causal loop analysis, which depends on complete model representations, our approach relied on qualitative content analysis rooted in narrative descriptions from the literature.

Our coding protocol, inspired by Ratajczyk *et al.* (2016), involved manually tracing transitions between variables using spreadsheets. Each trace began with a known hydrological perturbation and followed the sequence of system responses as described in the study narrative. This manual, narrative-based method proved both intuitive and scalable, particularly for synthesizing implicit insights from heterogeneous case studies.

Meanwhile, even for the same phenomenon, the critical pathways identified by the narrative-based method vary with different case studies. In this case, we identify the most frequently occurring causal links from these critical pathways, and these causal links would constitute the most representative prevalent critical pathway of this phenomenon.

The critical pathways identified were visualized using circular plots (see Section 3.2). These plots illustrate both the full spectrum of observed interactions and the most frequently occurring chains – termed prevalent critical pathways – responsible for driving unintended outcomes.

3 Results

3.1 Common variables in coupled human–water systems

Understanding the dynamics of Coupled Human–Water Systems (CHWS) requires a detailed characterization of the key variables that govern interactions across hydrological, social, institutional, economic, and ecological domains. Drawing from 37 case studies, we identified a consistent set of second-level variables nested within six core subsystems – hydrology, infrastructure, institutions, society, economy, and environment. These variables serve as the building blocks of the system's internal feedback loops and intervention pathways.

Within the hydrology subsystem, variables such as hydrometeorological events, hydrologic variability, water availability, and water demand capture both natural fluctuations and human-induced pressures on the water cycle. These variables establish the baseline conditions that often trigger and guide interventions.

The environment subsystem is characterized by variables such as environmental footprint, environmental state, and remediation efforts. These variables reflect the dual realities of human impact on ecosystems and the subsequent actions taken to restore or mitigate environmental degradation.

In the economy subsystem, variables account for both the negative and positive consequences of water-related phenomena – such as economic damage and benefit – as well as drivers like economic incentives and employment conditions, all of which influence the socio-economic resilience of affected communities.

The society subsystem includes variables such as population dynamics, perception of risk, social values, and cooperation-related factors. These variables affect not only the demand imposed on water resources but also the collective societal response to risk, including the willingness and capacity for coordinated action.

Institutional dynamics are represented through variables such as policy priority, institutional capacity, and power dynamics. Together, these shape the regulatory environment and influence the governance mechanisms employed in response to water-related challenges.

Finally, the infrastructure subsystem reflects the technical capacity and operational performance of physical systems designed to manage water. Relevant variables include infrastructure capacity, operational regimes, system failures, and the overarching level of technological advancement embedded within system design.

Table 3 and the utmost layer of Fig. 1 summarizes these second-level variables, each of which has been repeatedly observed to shape key feedback loops and unintended outcomes within CHWS. While the specific choice of variables for analysis may vary depending on the research question and system context, this structured typology enables a consistent lens through which diverse case studies can be compared and synthesized.

3.2 Critical pathways of the propagation of interventions to unintended consequences

Table 4 summarizes the critical pathways identified across the 37 CHWS case studies analysed in this study. Each entry in the table corresponds to a distinct case, organized by the emergent phenomenon it represents – such as the levee effect, reservoir effect, rebound effect, or pendulum swing – and its geographic context. The final column lists the specific variable pathways extracted from the narrative of each study, tracing how hydrological perturbations propagate through various system components to result in unintended consequences. Where sufficient case volume allows, a consolidated critical pathway is derived for each phenomenon and highlighted accordingly.

Beyond cataloguing individual cases, this table reflects broader system-level insights. Despite wide variation in geographic and socio-political context, certain propagation patterns – such as those involving shifts in risk perception, institutional response, and infrastructure capacity – appear repeatedly across case types. This convergence of pathways suggests that while the dynamics of CHWS are locally

Table 3. Second-level variables under core subsystems.

First-level Core subsystems	Second-level variables	Definitions
Hydrology	Hydrometeorological Event (*HE*)	Number, intensity, and risk/impact of hydrometeorological events causing disasters
	Hydrologic Variability (*HV*)	Natural and dynamic variations in the hydrological cycle
	Water Availability (*WA*)	Accessibility and quantity of water resources
	Water Demand (*WD*)	Quantity of water required for various purposes
Environment	Environmental Footprint (*EF*)	Impact or burden imposed on the environment by human activities
	Environmental Remediation (*EnR*)	Process of addressing and restoring environmental contamination or degradation
	Environment State (*ES*)	Overall condition, quality, and health of the natural surroundings and ecosystems
Economy	Economic Benefit (*EB*)	Positive outcomes, advantages, or gains
	Economic Damage (*ED*)	Negative impacts, losses, or harm incurred by hydrometeorological events
	Economic Incentive (*EI*)	Financial or material reward, advantage, or stimulus
	Employment Rate (*ER*)	Proportion of the employed population to the total labour force
Society	Cooperation Demand (*CD*)	Downstream countries seek cooperation from upstream countries for addressing shared water-related challenges
	Cooperation Level (*CL*)	Extent to which relevant countries engage in collaborative efforts, mutual understanding, and joint decision-making processes
	Population (*Pop*)	Overall fluctuation or variation in the size, composition, and distribution of a population over a specific period
	Perception of Risk (*PoR*)	Subjective assessment and understanding of the potential dangers, impacts associated with hydrometeorological events
	Social Value (*SV*)	Intangible benefits and impacts that result from initiatives, projects, or policies
	Willingness to Cooperate (*WtC*)	The willingness of the countries to cooperate towards common goals or solutions
Institutions	Institutional Capacity (*InC*)	Overall strength, competence, and resilience of an organization, institution or country
	Power Dynamics (*PD*)	Shifting and evolving nature of power relationships
	Policy Priority (*PP*)	Strategic focus and significance assigned to a particular policy area or issue
Infrastructure	Infrastructure Capacity (*IC*)	Ability of water conservancy facilities systems
	Infrastructure Failure (*IF*)	Occurrence of significant disruptions, malfunctions, or collapses in water conservancy facilities systems
	Infrastructure Operation (*IO*)	Management and control of water flow, storage, and release activities in a dam or reservoir system
	Level of Technology (*LoT*)	Improvement of productive forces through scientific knowledge, technological advancements, and innovation

embedded, the mechanisms by which interventions lead to unintended outcomes are often structurally similar. Recognizing these shared pathways provides a foundation for generalizable lessons in water governance and CHWS modelling.

The following sections visualize the critical pathways associated with four representative CHWS phenomena, each supported by at least three case studies. These phenomena include the levee effect, the reservoir effect, the rebound effect (linked to the system dynamics archetype fixes that fail), and the pendulum swing (aligned with the limits to growth archetype). Each is illustrated using circular plots presented in Fig. 4 through 7.

In these visualizations, dashed circles indicate the origin points of the pathways – typically where hydrological perturbations occur – while solid circles represent the endpoints where unintended consequences materialize. Grey arrows denote all identified connections between variables derived from the meta-analysis. The thickness of each arrow reflects the frequency with which a given link appeared across the case studies. The thickest path represents the most prevalent trajectory and is designated as the critical pathway for that phenomenon. Variables marked with a star symbol are those most frequently implicated in the emergence of unintended outcomes and serve as key leverage points for intervention.

3.2.1 *Levee effect*

The levee effect describes a counterproductive feedback in which structural flood protection (most commonly through the construction or raising of levees) reduces the perceived risk of flooding. This perceived security encourages increased development in flood-prone areas, thereby escalating exposure and vulnerability when future hydrological events exceed the designed capacity of the infrastructure.

This phenomenon is documented across eight case studies, including two from Italy (Di Baldassarre *et al.* 2009, 2013), four from the United States (Kates *et al.* 2006, Montz and Tobin 2008, Ludy and Kondolf 2012, Liao 2014), one from Australia (Bohensky and Leitch 2014), and one from Bangladesh (Ferdous *et al.* 2019). These cases span both urban and rural floodplains, underscoring the ubiquity of this dynamic in coupled human–water systems (CHWS).

As illustrated in Fig. 4, all critical pathways associated with the levee effect originate from hydrometeorological events (HE), which act as initial perturbations. Several alternative causal chains emerge, involving links between infrastructure capacity, infrastructure operation, institutional capacity, policy priority, population, risk perception, economic damage, and economic benefit. For instance, in some cases, population growth may precede a decline in risk perception, while in others, institutional or infrastructural responses play intermediate roles. These variants are depicted by thinner grey

Table 4. Critical pathways of the 37 case studies.

No.	Phenomena	Study area	Critical Pathways
1	Levee effect	Po River (Italy)	$HE \to IC \to PoR \to Pop \to ED$
2		Po River (Italy)	$HE \to IC \to PoR \to Pop \to ED$
3		Yuba County, California (USA)	$HE \to IC \to PP \to PoR \to Pop \to ED$
4		New Orleans (USA)	$HE \to IC \to InC \to PoR \to Pop \to ED$
5		Stockton, California (USA)	$HE \to IC \to PoR \to Pop \to InC \to ED$
6		Brisbane (Australia)	$HE \to IC \to PoR \to IO \to ED$
7		King County, Washington (USA)	$HE \to IC \to PoR \to Pop \to ED$
8		Jamuna River (Bangladesh)	$HE \to IC \to Pop \to EB \to ED$
		Prevalent critical pathway	$\boldsymbol{HE \to IC \to PoR \to Pop \to ED}$
9	Reservoir effect	Athens (Greece)	$HE \to IC \to PoR \to PP \to WD$
10		the extended Jaguaribe Basin (Brazil)	$HE \to PP \to IC \to PoR \to Pop \to WD$
11		Australia	$HE \to IC \to PoR \to Pop \to WD$
		Prevalent critical pathway	$\boldsymbol{HE \to IC \to PoR \to Pop \to WD}$
12	Call effect	France	$HE \to PoR \to InC \to Pop \to ED$
13	Flood adaptation	Meuse River (Netherlands)	$HE \to PoR \to InC \to ED(\downarrow)$
14		Bangladesh	$HE \to IC \to PoR \to Pop \to ED(\downarrow)$
15		Global	$HE \to IC \to PoR \to InC \to ED(\downarrow)$
16		Upper Brahmaputra River plain (India)	$HE \to PoR \to InC \to IC \to ED(\downarrow)$
17	Rebound effect	Las Vagas (USA) Melbourne (Australia)	$HE \to IC \to SV \to Pop \to WD$
18		Rajasthan (India)	(1) $WA \to PP \to EI \to LoT \to SV \to WD$ (2) $SV \to InC \to WD$
19		Non-specific	$PP \to EI \to LoT \to WD$
20		Morocco	$WA \to PP \to EI \to LoT \to WD$
21		Limarí Basin (Chile)	$HV \to WA \to IC \to PP \to EI \to LoT \to WD$
22		Upper Rio Grande Basin of North America (Brazil)	$WA \to PP \to EI \to LoT \to WD$
23		Non-specific	$WA \to PP \to EI \to LoT \to WD$
		Prevalent critical pathway	$\left.\begin{matrix} HV \to WA \\ HE \to IC \end{matrix}\right\} \to \boldsymbol{PP \to EI \to LoT \to SV \to WD}$
24	Pendulum swing	Kissimmee River Basin, Florida (USA)	$HE \to PP \to IC \to EF \to SV \to PP \to EnR$
25		Murrumbidgee River Basin (Australia)	$WD \to PP \to IC \to EF \to SV \to PP \to EnR$
26		Lake Toolibin catchment (Australia)	$WD \to PP \to EF \to SV \to PP \to EnR$
27		Tarim River Basin (China)	$HE \to PP \to IC \to LoT \to EF \to SV \to PP \to EnR$
28		Loess Plateau (China)	$WD \to PP \to EF \to SV \to PP \to EnR$
		Prevalent critical pathway	$\left.\begin{matrix} HE \\ WD \end{matrix}\right\} \to \boldsymbol{PP \to IC \to EF \to SV \to PP \to EnR}$
29	Collective action	Lancang–Mekong River basin	(1) upstream: $IC \to IO \to HV \to EB \to WtC \to CL \to IO$ (2) downstream: $IC \to IO \to HV \to EB \to CD \to CL \to IO$ (3) basin-wide: $InC \to \left\{\begin{matrix} CL \\ EB \end{matrix}\right.$
30		Columbia River Basin (USA, Canada)	(1) upstream: $InC \to IO \to EB \to WtC \to CL \to InC$ (2) downstream: $InC \to IO \to EB \to CD \to CL \to InC$ (3) basin-wide: $IO \to EF \to WtC$
31	Unemployment paradox	Murrumbidgee River Basin (Australia)	$PP \to EnR \to EB \to Pop \to ER$
32	Poverty trap	Bago city (Myanmar)	$HE \to ED \to Pop \to ED$
33		Rı´mac River valley (Peru)	$HE \to ED \to Pop \to ED$
34	Water injustice	Jakarta (Indonesia)	(1) Elite:$C \to WA \to \left\{\begin{matrix} EB \\ EF \end{matrix}\right.$(2) Poor Residents: $\left.\begin{matrix} InC \to IC \\ EF \end{matrix}\right\} \to WA(\downarrow) \to EB(\downarrow)$
35		Cape Town (South Africa)	(1) Elite: $\left.\begin{matrix} HE \\ InC \to IC \\ WD \end{matrix}\right\} \to WA$(2) Poor Residents:$InC \to IC \to WA(\downarrow)$
36	Collapsing	Maya (Latin America)	$HE \to IC \to PoR \to Pop \to WD \to Pop$
37		Mesopotamia (Middle East)	$\left.\begin{matrix} \left.\begin{matrix} Pop \to WD \\ InC \end{matrix}\right\} \to IC \\ HV \end{matrix}\right\} \to EF \to IF$

arrows in the figure, indicating their lower frequency across the dataset.

The prevalent critical pathway, highlighted by the thickest arrows, follows the sequence: $HE \to IC \to PoR \to Pop \to ED$. This dominant pathway shows that a flood event often prompts upgrades in infrastructure capacity (IC), such as levee reinforcement. These physical protections as a mean of human intervention lower the perception of risk (PoR), giving residents and developers a false sense of security. As a result, population (Pop) and infrastructure density increase within the floodplain in the long term. When extreme events exceed the levee design threshold, the resulting economic damage (ED) is amplified due to the increased exposure.

A key insight from this pathway is the central role of Perception of Risk in shaping long-term vulnerability. Once a community begins to rely on levees, its sense of safety grows, often outpacing the actual capacity of the infrastructure. For example, in Brisbane, Australia, the presence of additional upstream flood infrastructure (e.g. Wivenhoe

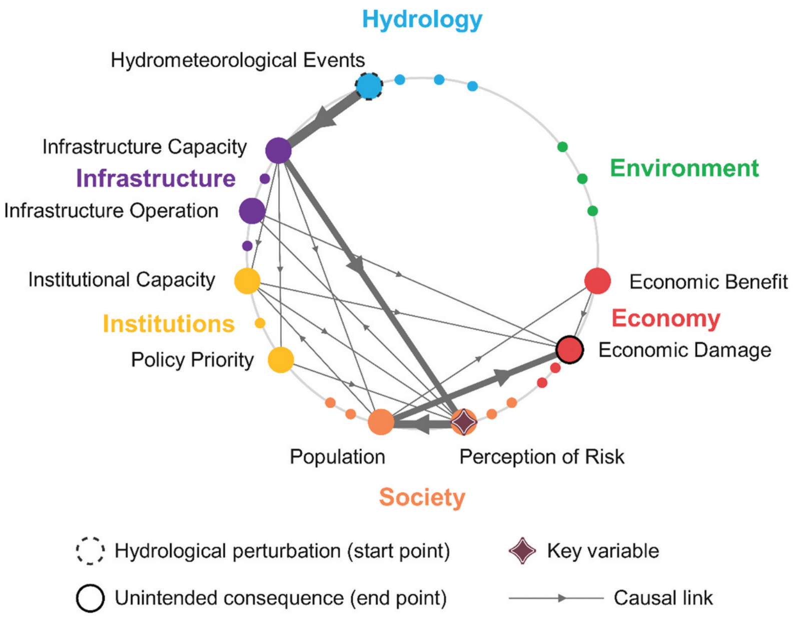

Figure 4. Critical pathways of the levee effect phenomenon, starting from hydrological perturbation (with dashed outline), going through variables of human intervention, and ending in unintended consequence (with solid outline). Thickness of lines indicates frequency.

Dam) contributed to complacency in flood preparedness. This ultimately led to heightened damages during unprecedented flood events in 2011 (Bohensky and Leitch 2014).

To mitigate the levee effect, CHWS governance must go beyond structural measures and integrate non-structural interventions such as public risk communication, land-use planning, and institutional safeguards that reinforce long-term awareness of residual flood risk. By focusing on key variables like risk perception, such interventions can disrupt the feedback loops that lead to escalating exposure and vulnerability.

3.2.2 Reservoir effect

The reservoir effect refers to a systemic feedback in which reliance on water storage infrastructure (particularly reservoirs) paradoxically increases a system's vulnerability to drought. Although reservoirs are built to stabilize supply and buffer hydrological variability, their presence can reduce public awareness of drought risk and stimulate long-term growth in water demand that outpaces supply resilience.

This phenomenon is evidenced in three case studies from Greece (Di Baldassarre *et al.* 2018), Brazil (Medeiros and Sivapalan 2020), and Australia (AghaKouchak *et al.* 2021). These examples illustrate how interventions intended to mitigate scarcity can unintentionally exacerbate system fragility when social, institutional, and behavioural responses are not fully accounted for.

As visualized in Fig. 5, all identified pathways begin with hydrometeorological events (HE) (typically prolonged droughts) as the initiating perturbation. The prevalent critical pathway, highlighted by the thickest arrows, follows the sequence: $HE \rightarrow IC \rightarrow PoR \rightarrow Pop \rightarrow WD$. In this dominant pathway, a drought event leads to increased infrastructure capacity (IC) through reservoir development or expansion. This intervention improves short-term water availability but diminishes the perception of risk (PoR) associated with future droughts. Lower risk perception, in turn, encourages population growth (Pop) and/or greater water use intensity, resulting in a long-term rise in water demand (WD). The system becomes increasingly vulnerable when subsequent droughts exceed the reservoir's storage and regulatory capacity.

Similar to what we discovered in the levee effect phenomenon, the variable Perception of Risk emerges as a key leverage point in this dynamic. By masking the underlying scarcity, reservoirs foster behavioural and demographic changes that create a demand trajectory incompatible with environmental constraints. For example, in the Brazilian case, infrastructure-driven water security encouraged population growth due to agricultural expansion and urban development that ultimately heightened drought exposure when water storage limits were surpassed (Medeiros and Sivapalan 2020).

Managing the reservoir effect thus requires a dual focus: maintaining physical infrastructure while simultaneously preserving social awareness of risk. Non-structural interventions, such as drought education, adaptive planning, and regulatory mechanisms, can help ensure that infrastructure investments do not inadvertently reinforce unsustainable growth trajectories within CHWS.

3.2.3 Rebound effect

The rebound effect describes a counterintuitive outcome in which technological improvements designed to increase efficiency end up driving higher overall resource consumption. In the context of CHWS, this is commonly observed as the irrigation efficiency paradox: the adoption of more efficient irrigation technologies leads not to reduced water use, but to increased total irrigation water demand.

This phenomenon is supported by seven empirical case studies from diverse contexts, including Las Vegas (Di Baldassarre *et al.* 2018), the Upper Rio Grande Basin (Ward and Pulido-Velazquez 2008), Chile (Scott *et al.* 2014),

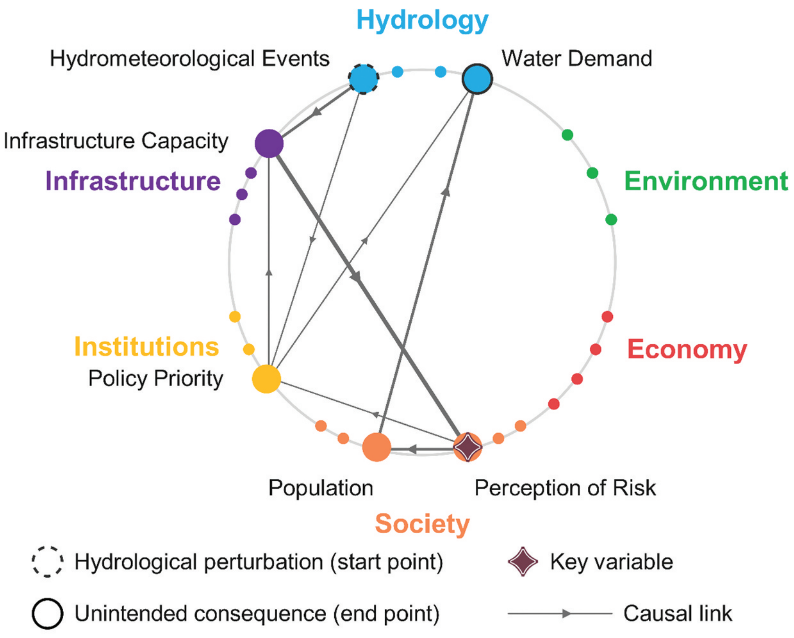

Figure 5. Critical pathways of the reservoir effect phenomenon.

Rajasthan (Birkenholtz 2017), Morocco (Molle and Tanouti 2017), and Melbourne (Di Baldassarre *et al.* 2018). Two theoretical studies (Whittlesey 2003, Grafton *et al.* 2018) further support the conceptual basis for the analysis.

As visualized in Fig. 6, the critical pathways associated with the rebound effect begin with Hydrological Variability (HV) or Hydrometeorological Events (HE), which lead to change in water availability, prompting Infrastructure Capacity (IC) development or adoption of new technologies, particularly efficient irrigation systems (Level of Technology, LoT). This intervention triggers shifts in Social Value (SV), as users prioritize productivity gains over conservation, resulting in increased Water Demand (WD).

The prevalent critical pathway follows the sequence: $\left.\begin{matrix} HV \rightarrow WA \\ HE \rightarrow IC \end{matrix}\right\} \rightarrow PP \rightarrow EI \rightarrow LoT \rightarrow SV \rightarrow WD$. This dominant pathway reflects how water-saving technologies (e.g. drip irrigation) were originally intended to conserve water. However, due to prevailing social values that emphasize agricultural expansion and yield maximization, the efficiency gains are often reinvested into scaling up irrigated land or intensifying production. As a result, total water consumption increases, sometimes surpassing previous levels. It is worth noting that HV and HE are still included in the prevalent critical pathway even if they are not frequently mentioned in case studies. This is because we treated them as implicit driving factors of the

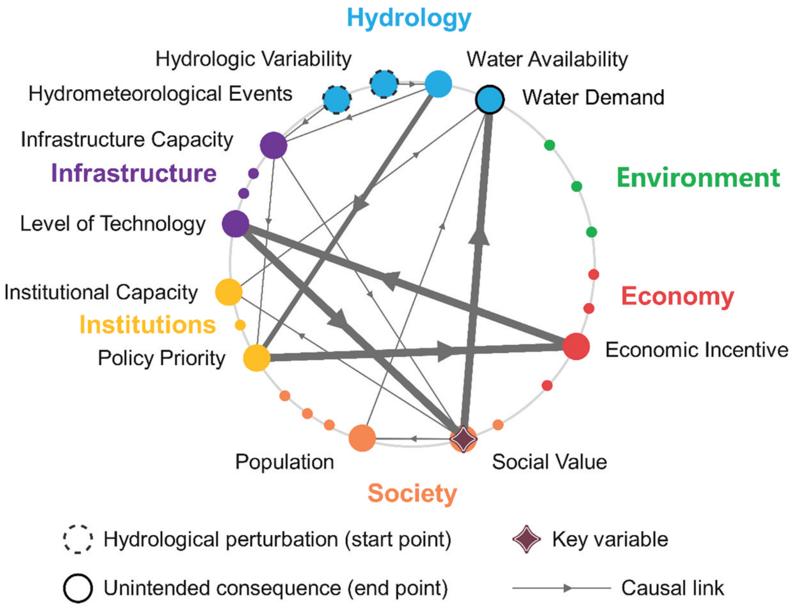

Figure 6. Critical pathways of the rebound effect phenomenon.

agricultural human-water interactions, which can be ignored in textual description of case studies that describe only the key process of the phenomenon. There are also secondary pathways, shown as thinner grey arrows, involve less frequent interactions – such as indirect institutional influences, or responses modulated by population.

The key variable Social Value plays a central role in this rebound dynamic. Case studies such as Rajasthan (Birkenholtz 2017) show that without strong institutional alignment around water conservation, users tend to interpret efficiency improvements as opportunities for greater resource use rather than restraint. Additionally, weak institutional capacity or misaligned economic incentives may further reinforce this unintended outcome.

Addressing the rebound effect requires a shift in both technological framing and societal expectations. Interventions must go beyond engineering solutions to explicitly engage with social norms, governance structures, and incentive systems that shape how efficiency gains are interpreted and applied in practice.

3.2.4 Pendulum swing

The pendulum swing phenomenon captures the cyclical transition between phases of intensive development and subsequent environmental restoration. It reflects how societal and institutional priorities shift over time in response to feedback loops from environmental degradation. In CHWS, this dynamic is often observed in regions that experience rapid agricultural or infrastructural expansion followed by policy-driven environmental recovery efforts.

This phenomenon is documented across five case studies: the Kissimmee River Basin in the USA (Chen *et al.* 2016), the Murrumbidgee River Basin and Lake Toolibin in Australia (Kandasamy *et al.* 2014, Elshafei *et al.* 2015), the Tarim River Basin in China (Liu *et al.* 2014), and the Loess Plateau in China (Wu *et al.* 2020). Each case reflects a common structure of system evolution through alternating states of exploitation and remediation.

As illustrated in Fig. 7, the pathways associated with the pendulum swing begin with a hydrological perturbation – either Hydrometeorological Events (HE) or rising Water Demand (WD). These pressures prompt a shift in Policy Priority (PP), which initially favours infrastructure development to enhance supply and support agricultural or economic growth. As Infrastructure Capacity (IC) increases, the resulting expansion accelerates environmental degradation, captured by a rise in Environmental Footprint (EF).

Over time, the visible consequences of environmental decline shift Social Values (SV), which then influence a new round of policy prioritization (PP), now oriented toward ecological recovery. This leads to Environmental Remediation (EnR), the final stage of the critical pathway and the unintended consequence of the initial development focus.

The prevalent critical pathway, $\left.\begin{array}{l} HE \\ WD \end{array}\right\} \rightarrow PP \rightarrow IC \rightarrow EF \rightarrow SV \rightarrow PP \rightarrow EnR$ is represented by the thickest arrows in the diagram. It captures the full cycle of systemic transformation, showing how institutional and social feedback loops mediate transitions between growth and restoration phases.

Two key variables, i.e. Policy Priority and Social Value, play pivotal roles in this process. Policy Priority acts as a double-edged mechanism: it first accelerates expansion and then becomes the tool through which environmental goals are implemented. Social Value serves as the tipping point, where societal recognition of environmental risks catalyses the shift toward remediation. Both are marked as key variables in Fig. 7.

The pendulum swings emphasize the need for adaptive governance in CHWS – governance that can recognize when a system is approaching ecological limits and respond proactively to avoid irreversible damage. Managing these dynamics requires policies that balance development with long-term sustainability, guided by evolving societal values and institutional flexibility.

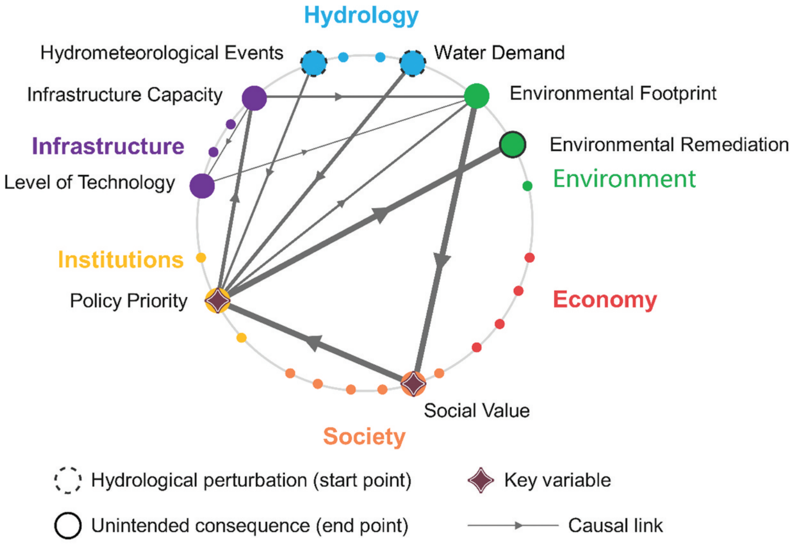

Figure 7. Critical pathways of the pendulum swing phenomenon.

4 Discussion

Causal Loop Diagrams (CLDs) have long been employed to visualize feedback processes in socio-environmental systems. These diagrams help conceptualize how various subsystems interact through reinforcing or balancing loops. However, while CLDs capture a system's broad dynamic structure, they often lack the resolution to trace the specific sequences by which hydrological perturbations lead to unintended consequences – particularly those mediated by human interventions. This is where critical pathway analysis (CPA) offers distinct value.

As discussed in Section 2, a critical pathway is a focused subset of causal links that depicts the most significant chain of propagation from an initiating perturbation to an unintended system outcome. Whereas CLDs tend to generalize system functioning based on theory or expert synthesis, critical pathways are empirically derived through meta-analysis of case narratives. They reflect observed propagation patterns, making them well-suited to identifying actionable intervention points.

To highlight these differences, we compare empirical critical pathways to theoretical CLDs using the examples of the "levee effect" and the "reservoir effect". Figure 8 illustrates the levee effect. In the theoretical harmonized CLD organizing the six core CHWS subsystems (Fig. 8(a)), flood protection infrastructure reduces flood risk and promotes a sense of security, which in turn encourages settlement in floodplains, leading to higher eventual flood damage – a classic reinforcing feedback consistent with the "fixes that fail" archetype.

However, the empirical critical pathway (Fig. 8(b)) shows a more targeted narrative. It begins with a hydrometeorological event (HE) that triggers infrastructure enhancement (IC). This, furthermore, lowers perception of risk (PoR), encourages floodplain development, and ultimately culminates in increased economic damage (ED). Notably, the role of institutions is explicit in this empirically grounded pathway, whereas they are often overlooked in the theoretical CLD. This discrepancy highlights the non-negligible nature of institutional dynamics as causal agents in real-world cases – a finding consistent with literature that emphasizes governance as a modulator of CHWS resilience (e.g. Pahl-Wostl *et al.* 2008).

Figure 9 presents a similar comparison for the reservoir effect. The theoretical harmonized CLD (Fig. 9(a)) depicts a reinforcing loop in which increased storage capacity reduces water stress, which encourages economic expansion and raises future water demand – again culminating in system stress when drought exceeds storage capacity. The empirical critical pathway (Fig. 9(b)), however, places greater emphasis on the role of policy. Here, drought (HE) prompts not only infrastructural (IC) but also institutional (PP) responses, which reduce risk perception (PoR) and increase dependence on reservoir systems. This leads to population growth and rising water demand (WD). Again, the institutional variable "policy priority" is more prominent in the empirical account than in the abstract loop.

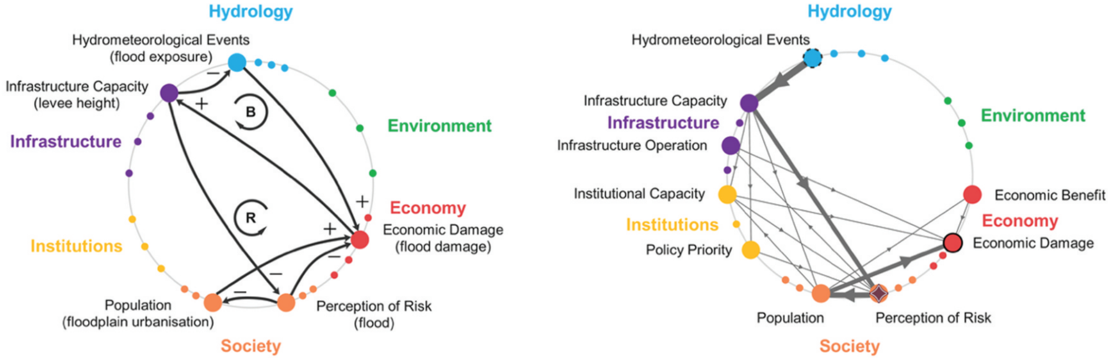

Figure 8. Levee effect phenomenon: (a) Theoretical harmonized causal loop diagram, a way of organizing the structure from normal causal loop diagram into the six core subsystems. (b) Empirical critical pathway based on the narratives of 8 case studies, highlighting the most important trail of levee construction. B – Balanced feedback loop; R – Reinforced feedback loop.

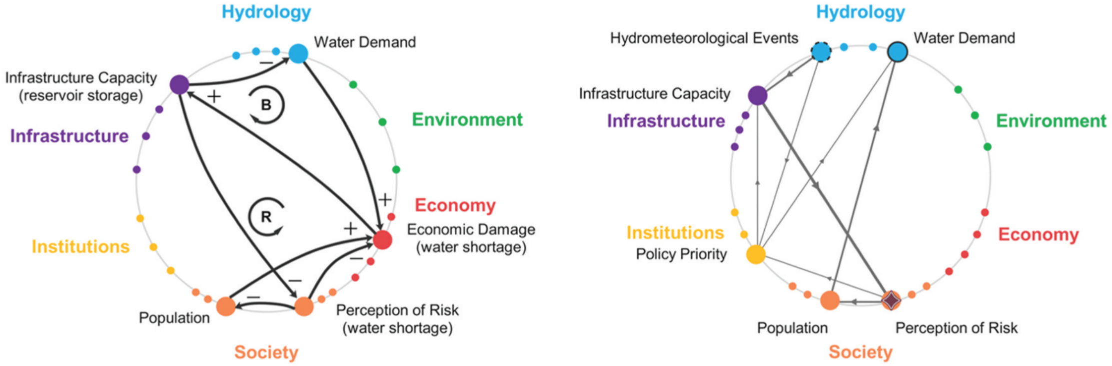

Figure 9. Reservoir effect phenomenon: (a) Theoretical harmonized causal loop diagram, a way of organizing the structure from normal causal loop diagram into the core subsystems of the new unified structure. (b) Empirical critical pathway based on the narratives of 3 case studies, highlighting the most important trail of reservoir construction. B – Balanced feedback loop; R – Reinforced feedback loop.

These examples underscore the complementarity of the two approaches. CLDs offer a macroscopic view of system feedback loops, while critical pathways trace the microscopic progression of interventions and responses. Importantly, CPA reveals causal agents – such as "Perception of Risk" and "Policy Priority" – that may be underrepresented or oversimplified in generic system models.

Furthermore, as summarized in Section 3.2, key variables identified through CPA – such as Perception of Risk, Social Value, and Policy Priority – frequently serve as the origin or amplification point for these unintended consequences. Recognizing and targeting these leverage points could therefore serve as a strategic entry for more sustainable and adaptive CHWS governance.

Overall, while causal loop diagrams offer valuable insights into potential feedback mechanisms, critical pathways derived from real-world cases offer empirical grounding and guiding entry points for solutions. The differences between the two approaches reflect the contrast between theoretical, bottom-up model construction and top-down, evidence-based synthesis. When used together, they enrich our understanding of how interventions propagate in CHWS and help identify the variables most critical for preventing unintended consequences.

5 Conclusion

This study provides new insight into how unintended consequences emerge and propagate within Coupled Human–Water Systems (CHWS), highlighting the need for a shift from general system-wide models to more focused, evidence-based pathways of change. Through meta-analysis of 37 real-world case studies, we identified recurring structures and interactions that give rise to such outcomes, and introduced a practical framework (i.e. the critical pathway) to trace these causal chains with greater precision.

The critical pathway represents the dominant trajectory by which a hydrological perturbation, shaped by human intervention, travels through a CHWS to produce adverse effects. Unlike traditional causal loop diagrams (CLDs) that depict abstract feedback structures, critical pathways capture empirically grounded sequences of cause and effect. These paths often converge around a small number of influential variables – such as Perception of Risk, Policy Priority, and Social Value – which repeatedly emerge as triggers or amplifiers of system vulnerability.

Our findings reveal that it is not single decisions or components, but specific combinations of interacting subsystems, particularly involving infrastructure, institutions, and societal perceptions, that drive the persistence and escalation of unintended consequences. Recognizing and targeting these key variables is essential for designing interventions that do not merely shift problems elsewhere in the system, but resolve them at their root.

To support comparative learning across diverse CHWS contexts, we developed a unified six-component anatomy, comprising Hydrology, Environment, Economy, Society, Institutions, and Infrastructure, within which second-level variables were systematically coded. This anatomy offers a common language for mapping both feedback loops and intervention pathways, bridging the gap between theoretical CLDs and real-world system narratives through the use of harmonized causal loop diagrams.

Ultimately, the critical pathway is not just a diagnostic tool – it is a strategic roadmap. If we want to avoid unintended consequences, these pathways must be the focus of change. Starting from the key variables that anchor them, water managers and policymakers can better anticipate system responses, design more adaptive strategies, and build resilience into the heart of CHWS governance. As more empirical studies emerge, this framework can be expanded and refined, offering a scalable foundation for future water sustainability research and practice.

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Appendix

Table A1. Case study list for meta-analysis.

No.	Phenomena	Authors	Year	Study area
1	Levee effect	Di Baldassarre *et al.*	2009	Po River (Italy)
2		Di Baldassarre *et al.*	2013	Po River (Italy)
3		Montz and Tobin	2008	Yuba County, California (USA)
4		Kates *et al.*	2006	New Orleans (USA)
5		Ludy and Kondolf	2012	Stockton, California (USA)
6		Bohensky and Leitch	2014	Brisbane (Australia)
7		Liao	2014	King County, Washington (USA)
8		Ferdous *et al.*	2019	Jamuna River (Bangladesh)
9	Reservoir effect	Di Baldassarre *et al.*	2018	Athens (Greece)
10		Medeiros and Sivapalan	2020	the extended Jaguaribe Basin (Brazil)
11		AghaKouchak *et al.*	2021	Australia
12	Call effect	Grelot and Barreteau	2012	France
13	Flood adaptation	Wind *et al.*	1999	Meuse River (Netherland)
14		Di Baldassarre *et al.*	2014	Bangladesh
15		Kreibich *et al.*	2017	Global
16		Hazarika *et al.*	2016	Upper Brahmaputra River plain (India)
17	Rebound effect	Di Baldassarre *et al.*	2018	Las Vagas (USA) Melbourne (Australia)
18		Birkenholtz	2018	Rajasthan (India)
19		Grafton *et al.*	2018	Non-specific
20		Molle and Tanouti	2017	Morocco
21		Scott *et al.*	2014	Limarí Basin (Chile)
22		Ward and Pulido-Velazquez	2008	Upper Rio Grande Basin of North America (Brazil)
23		Whittlesey	2003	Non-specific
24	Pendulum swing	Chen *et al.*	2016	Kissimmee River Basin, Florida (USA)
25		Kandasamy *et al.*	2014	Murrumbidgee River Basin (Australia)
26		Elshafei *et al.*	2015	Lake Toolibin catchment (Australia)
27		Liu *et al.*	2014	Tarim River Basin (China)
28		Wu *et al.*	2020	Loess Plateau (China)
29	Collective action	Lu *et al.*	2021	Lancang–Mekong River basin
30		Shrestha *et al.*	2021	Columbia River Basin
31	Unemployment paradox	Roobavannan *et al.*	2017	Murrumbidgee River Basin (Australia)
32	Poverty trap	Kawasaki *et al.*	2020	Bago city (Myanmar)
33		Adams	2016	Rı´mac River valley (Peru)
34	Water injustice	Zwarteveen *et al.*	2017	Jakarta (Indonesia)
35		Savelli *et al.*	2021	Cape Town (South Africa)
36	Collapsing	Kuil *et al.*	2016	Maya
37		Jacobsen and Adams	1958	Mesopotamia