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Advancing backcasting for transformative water management

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Abstract
Climate change has become one of the biggest environmental challenges the world is currently facing. Recent IPCC projections indicate that climate change impacts will increase as current incremental-based adaptation management approaches are insufficient to deal with climate-induced systemic shocks and climate uncertainties. Despite the use of advanced climate impact assessment models, some uncertainty about the nature, scale and dynamics of these impacts on water systems remains persistent. Due to this uncertainty and the complexity of these systems, a shift to transformative water management, building on transformative adaptation, is needed to accommodate disruptive futures and transformative change. We cannot rely solely on predictive forward-looking approaches that generate likely futures, which argues in favor of the complementary use of normative approaches. Backcasting is such an approach that produces desirable futures, before looking back from these futures to the present in order to develop adaptation pathways that could lead to such desirable futures. Backcasting can provide directionality to transformative change, which can guide actions and small incremental, gradual steps towards transformative change, enabling to explore a diversity of possible adaptation pathways and pathway switching, but more effort is needed to further advance backcasting for transformative water management. Based on recent insights on both transformative adaptation and the use of backcasting for climate adaptation, this paper proposes nine principles for advancing backcasting for transformative water management.

Keywords: participatory backcasting, climate change, transformative adaptation, water management

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1. Introduction

Obviously, climate change affects water management in multiple ways. In the past two decades, adaptive water management has become the main response within the water sector to the impact of climate change by making alterations in order to enhance the resilience of people and nature (Edalat & Abdi, 2018; Gawne & Thompson, 2023; Pahl-Wostl, 2020). Adaptive water management is considered as an approach for continuously improving water management policies and practices by learning from management decisions and their uncertainties regarding consequences (Foxon, 2009; Hermans et al., 2012; Pahl-Wostl, Sendzimir, et al., 2007; Schreiber, 2004). Over the last two decades, adaptive water management has proven itself as a useful approach for dealing with complex water systems with uncertain and unpredictable dynamics related to climate change (Miro et al., 2021; Westling et al., 2019).

Adaptive management is inspired by work on social-ecological-systems and tipping points in which one stable system state turns into another stable system state, which can again be related to punctuated equilibriums (Folke et al., 2004; Olsson et al., 2004). The emergence of adaptive management marked a paradigm shift from a predominantly engineering and control-based approach to a more ecologically sensitive and learning based management approach (Schoeman et al., 2014; van der Voorn & Quist, 2018). By learning together to manage together, social learning enables collaborative approaches to adaptation to include processes of intentional self-reflection and dialogue through which the stakeholders of a social-ecological system explore how the system might be made more resilient, and how that resilience might be sustained (Folke et al., 2005; Olsson et al., 2004).

As adaptive water management is increasingly challenged by recent climate change predictions and increasingly extreme weather across the globe, it raises the question of whether it will be able to adequately deal with shocks and systemic uncertainties? An adaptive and incremental optimization approach is arguably insufficient or even counterproductive to absorb more extreme weather events causing major disruptions in the functioning of critical infrastructure (Berrang-Ford et al., 2021; van Duuren et al., 2019). More fundamental changes in human-water systems (e.g., infrastructure, institutions) and their management (e.g., spatial planning) are needed for long-term climate resilient human-water systems (de Graaf et al., 2009; European Commission, 2024). Hence, more transformative approaches need to be explored to reduce long-term vulnerability to climate change (Engbersen et al., 2024; Lindegaard, 2018; Park et al., 2012; Wise et al., 2014). This would mean that current water management and its strategies need to move beyond incrementalism in order to mitigate climate risks and vulnerability in the long run (Westling et al., 2019) and to develop transformative governance capacities.

A promising way to do so, while reducing the root causes of climate risks and vulnerability, is through fundamental system changes to anticipate climate extremes while building social and ecological resilience, here referred to as transformative adaptation (Lonsdale et al, 2015). Within the long-term narrative of desired transitions, we understand transformative adaptation in this paper as strategic attempts to govern the transformation of socio-ecological systems across different scales (temporal, spatial, societal domains and levels) towards a desired endpoint (system state), addressing the root causes of vulnerability of societies and ecosystems at risk. This creates space for further learning and inter/multi/transdisciplinary dialogue around understanding transformations, adaptive transformations or transformative adaptations, and or transformative water management. Such attempts benefit from a long-term vision on system change as a starting point to identify and maximize the transformative potential of climate adaptation interventions in the short and long run.

Within the confines of transformative adaptation, transformative water management involves a systems approach to the way water resources are managed to anticipate and accommodate long-term climate change while simultaneously building social and ecological resilience and supporting ecological integrity, social equity, and economic viability. In this paper, transformative adaptation and transformative water management are different yet overlapping approaches that can coexist simultaneously. However, thinking of transformative adaptation has been further elaborated and can be used to develop transformative water management further. For instance, due to its spatial component, transformative water management aligned with transformative adaptation goes beyond established boundaries of the water system and domain. Moreover, the Dutch scientific climate council has acknowledged that pivotal decisions on water safety, flooding, fresh water supply, and heat stress are to be made at the intersection of spatial planning and the water system (WKR, 2025). In addition to this, water is traditionally managed by water managers, but it has also become an essential topic of other sectors (e.g., agriculture, land-use, navigation). This forces water managers to collaborate proactively with their counterparts from such sectors (van der Voorn, 2023). Overall, transformative water management aligned with transformative adaptation anticipates issues emerging from outside the water system and domain, but disregards the required change in the overall social-economic system. For instance, changes towards degrowth or green growth might impact the water (management) system.

Although transformative adaptation and transformative water management have experienced increasing popularity in policy debates and academic discussions (Deubelli & Mechler, 2021), a gap remains in translating both approaches into policy (Engbersen et al., 2024). It requires complementary approaches that are able to include the speculative and normative aspects of disruptive futures and how they can be related to short term choices. Participatory backcasting is such an approach that has been developed to produce such futures and can support actors to move from the more traditional to transformative water management. It also facilitates social learning by collective construction of and reflection on (i) desirable future end-states, (ii) how do we get there from the present, and (iii) which collective goals and intermediate steps can or should be taken. Moreover, backcasting also provides directionality to transformative change, as it explores a diversity of possible adaptation pathways and options for pathway switching for guiding towards desirable future end-states (section 3.1), but further development is needed.

In this paper, we therefore explore how backcasting can be used for transformative water management and what this can look like, building upon earlier evaluations of the use of backcasting, focusing on its application in climate adaptation, climate action and water management (van der Voorn et al, 2017, 2023; van der Voorn, 2023). What is clear however is that more effort is needed to make backcasting fit for transformative adaptation. This paper therefore focuses on conceptual and methodological improvements for advancing backcasting for transformative water management, by drawing key insights from publications that aim to contribute to a better understanding of the potential of backcasting for climate adaptation and how it can be applied in water management.

This paper is structured as follows. Section 2 conceptualizes transformative adaptation using recent literatures on transformation, transition and water governance. Section 3 explains the relevance of backcasting for transformative adaptation using key insights from backcasting studies. Building on these insights, we propose a set of principles for further advancing backcasting for transformative water management. Concluding remarks and potential downsides of using backcasting for transformative water management are discussed in section 4.

2. Conceptualizing transformative adaptation

2.1 The limits to adaptation

Climate change adaptation has been discussed and practiced for quite some time in relation to topics, such as adaptive water management and governance (Dolman, 2021; Pahl-Wostl, Craps, et al., 2007; Pahl-Wostl, Sendzimir, et al., 2007), spatial planning (Nadin et al., 2021; Van Buuren et al., 2013), climate resilient cities (Fu & Li, 2022; Shokry et al., 2025), including the adaptation of building codes to extreme weather conditions (Ben Ratmia et al., 2024), and agriculture (Dubey et al., 2020), including the development of drought-tolerant crops (Rakshit et al., 2022). Increasingly, scholars and practitioners alike express their concerns about the limitations of adaptation, which is incremental by nature and relies on technocratic solutions (Fedele et al., 2019, 2020; Filho et al., 2023; Filho et al., 2022; Lonsdale, 2015). Critics of this approach argue that this type of adaptation fails to address root causes of differential vulnerability, which are largely social and political in nature (Berkhout & Dow, 2023; Berrang-Ford et al., 2021). It fits within wider discussions on transformative change (Visseren-Hamakers et al., 2021) and transition governance (Hebinck et al., 2022; Hebinck & Loorbach, 2024) where the argument is made that policy in general is inclined to optimize existing societal systems and structures through innovation in an incremental way. Although the idea of transformative change has been introduced in water management (Pahl-Wostl, 2020), the concept has not yet been well developed and defined in different ways.

In the literature, transformative and transformational are often used interchangeably (Filho et al. (2023), but we here use transformative. However, Kates et al. (2012) consider transformative and transformational not as exclusive terms, as climate action can both represent transformative and transformational adaptation with similar basic characteristics[1]. It is worth mentioning that Kates et al (2012) distinguished three forms of transformative changes: (i) changes that are adopted at a larger scale, (ii) changes that are new and have never been used in a particular system, and (iii) changes that transform places and shift locations. These authors also state that transformative changes can be the outcome of either collective or individual changes, both autonomous and explicitly planned.

Either way, transformative adaptation involves integrating deep uncertainty, non-linearity and possible extremes associated with climate change into a governance approach (Hölscher et al., 2019). Moreover, it is necessary to move beyond incremental improvement of existing practices through adaptation, as this might reinforce undesirable path-dependencies and limit future possibilities for more systemic change. Following the transition governance logic by Loorbach et al. (2017) this implies adopting a long-term orientation towards social system change aligning short-term actions with a long-term vision. In this, we do not see adaptive governance as problematic per se, as long as it is combined with a transformative orientation and approach (de Geus et al., 2022; Loorbach, 2022).

2.2 Incremental versus transformative adaptation

Building on transformation and transition literature, we can distinguish between incremental and transformative adaptation, as summarized in Table 1, and contrasted as the extreme, opposing ends of seven characteristics. We argue that transformative adaptation and its inherent longer-term orientation towards system change, implies a radically different approach to policy and governance, compared to adaptive management. An orientation in which vested interests and power structures, marginalized perspective and values, and social innovations are more explicit and dealt with in different, reflexive ways.

Transformative adaptation has been differently described and defined. Pérez-Català (2014), for instance, identify two main distinctions in the literature on transformative adaptation as 'fitting to' and 'fitting with' the environment, although others refer to this as 'adapting to' and 'adapting with' change (Collins & Ison, 2009; Pelling, 2010). In the 'adapting to' description, the environment is external, and the focus is on how the existing system is responding to increased risk and vulnerability by developing adaptation responses that focus on increasing either the scale or intensity of existing approaches (Kates et al., 2012; Rickards & Howden, 2012). In 'adapting with' socio-ecological systems are co-developing responses to change and this framing thus emphasizes the need to consider the causes of vulnerability within society (Kates et al., 2012; Pelling, 2010). On a temporal scale, incremental adaptation focuses on current conditions and short-term change and future uncertainty is acknowledged (Pahl-Wostl, Sendzimir, et al., 2007). However, transformative adaptation should focus on the future, to acknowledge long-term change and uncertainty and built into decision-making (Filho et al., 2022; Lonsdale, 2015)

Lonsdale (2015) stressed the importance of learning in both incremental and transformative adaptation. In this model, single loop is associated with becoming more efficient by learning to do the same thing, which is congruent with incremental adaptation (Argyris & Schön, 1997). Double loop learning is when experience

[1] Transition and transformation are used interchangeably. Differences between both terms partially result from their etymological origins. Transitions represent the shift from one state to another, whereas transformation relates to a change in shape. Transitioning therefore implies significant transformations (Holscher, 2018).

leads to change in how something is approached or even the goal itself (Argyris & Schön, 1997). Triple loop learning occurs when the framework or context for observing and analyzing is questioned, which is the case in transformative adaptation (Pahl-Wostl, 2009).

As argued by Lonsdale (2015), most definitions of transformative adaptation address fundamental aspects of the system, including aspects of power and management. Regarding incremental adaptation, Handmer and Dovers (1996), describe the human desire to maintain the status quo where possible and return systems to a previous state after a disruption, rather than being open to major changes. In their three types typology, type I resilience refers to the resistance of a system to change. Type II resilience involves marginal changes to make a system more resilient; and Type III applies when there is a high degree of openness, adaptability and flexibility within the system (Dovers & Handmer, 1992). Type III resilience is capable of transformative adaptation due to its ability to 'change the basic operating assumptions, and thus institutional structures' (Dovers and Handmer, ibid). It thus openly challenges unfair or ineffective power structures, and strongly advocates participatory mechanisms in order to expand the responsibility and subsequent opportunities for wider inclusion in decision-making and in expanding the choice of options

Table 1. Characteristics used to distinguish incremental and transformative adaptation (updated from van der Voorn (2023)).

Characteristic	Incremental adaptation	Transformative adaptation
Description	Framed as 'complicated' (Ison et al., 2015)	Framed as 'complex', 'wicked' or 'super wicked' (Ison et al., 2015)
Scale of change	Smaller, discrete within paradigmatic changes in the water system and sector	System wide change, transcending the water system and sector and targeting the broader social-cultural context
Depth of change	Superficial changes in existing adaptation practices and ways of dealing with climate risks and uncertainties	A shift in values, identities and norms that shape the system of interest and changes its practices, structure, functions, and revisits the boundaries of the system
Temporal scale	Focus on current conditions and short-term change and future uncertainty is acknowledged (Pahl-Wostl, Sendzimir, et al., 2007)	Focus on future, long-term change and uncertainty in the future is acknowledged and built into decision-making (Filho et al., 2022; Lonsdale, 2015)
Learning	Single and double loop learning for optimization of water management (Argyris, 1978)	Triple loop learning for changing fundamental values, norms and beliefs underlying perspectives on water management (Pahl-Wostl, 2009)
Power	Generally greater control over outcome Seek to operate within the status quo to maintain and/or increase efficiency of existing systems	Outcome open ended or uncontrollable (and could be positive or negative) (Lonsdale, 2015) Addresses power imbalance and the causes of social injustice to induce a step change /radical shift to the operation of the existing system (Ziervogel et al., 2022)
Management paradigm	Reactive management of change, focusing on current conditions Management of change is focused on finding ways to optimize or keep the present system in operation Aim to address Type I resilience (resistance and maintenance) and Type II (change at	Anticipated, planned management of change (Filho et al., 2022) through long-term adaptation pathways Management of change includes questioning the effectiveness of existing systems and processes (Filho et al., 2022) Aim to address Type III resilience (openness and adaptability) (Handmer & Dovers, 1996)

	the margins) resilience (Handmer & Dovers, 1996)	focusing on the broader societal aspects to achieve broader social ecological resilience

2.3 Perspectives on transformative adaptation

In addition to the characteristics discussed above, different perspectives on transformative adaptation have been discussed over the last decade (Few et al., 2017). For example, Kates et al. (2012), were among the first, describing transformative adaptation as climate adaptation that takes place at a larger scale or intensity, is innovative, or transforms places and shifts locations. Although various scholars have attempted to define what makes climate adaptation transformative, their effort has resulted in diffuse meanings leading to confusion that hinders transformative action (Engbersen et al., 2024). Providing that the transformation literature covers both the natural and social sciences and humanities (O'Brien, 2011), Few et al (2017) focused on interpretations applied to the environmental change field and identified two main perspectives: a critical social science and an ecological perspective. Similarly, Engbersen et al (2024) identified two main perspectives have emerged that diverge in different ways since the influential work by Kates et al. (2012).

The first perspective employs an ecological perspective on environmental change emphasizes the depth, speed and scope of transformative change and include the social dimension of changes in addition to physical changes (Fazey et al., 2018; Feola, 2015; Moore et al., 2021). More specifically, the IPCC (2012) defines transformation as "*a fundamental change that often involves a change in paradigm and include shifts in perception and meaning, changes in underlying norms and values, reconfiguration of social networks and patterns of interaction, changes in power structures, and the introduction of new institutional arrangements and regulatory frameworks*". Others elaborated on the role of agency, power and politics in transformative change (O'Brien, 2015; Pot et al., 2024; Westley et al., 2013). Political and economic actors with interests and powers vested in existing infrastructural, economic, and institutional systems limit the possibility of alternative adaptation pathways and complicates long-term adaptation (Engbersen et al., 2024). Transformative adaptation is expected to disrupt the power status quo to overcome these lock-ins (Pot et al., 2024), by adopting a participatory approach for pursuing long-term adaptation pathways (Engbersen et al., 2024). Such pathway thinking helps to development of more transformative trajectories that better align with the scale of change required to address long-term climate risks and uncertainties (Haasnoot et al., 2013; Haasnoot et al., 2012; Wise et al., 2014). Evidently, transformative adaptation involves transformation of broader societal aspects to achieve climate resilience through development activities (Few et al., 2017).

The second perspective employs a social perspective emphasize that transformations tackle the root causes of current vulnerabilities of people and ecosystems that are at risk (Hellin et al., 2023; O'Brien, 2012; Ziervogel, 2019; Ziervogel et al., 2022). This perspective draws from systems ecology and consider transformation (the ability to undergo change) as a positive characteristic of resilient systems. Others (Olsson et al., 2014) elaborated on the parameters of transformation underlying transformations such as mechanisms, patterns and conditions. Few et al (2017), for instance, categorized forms of transformative change, focusing on mechanisms of change, target outcomes in relation to climate risk, and the object of change, within or beyond climate adaptation. From this perspective, transformative adaptation focuses on addressing climate risk at various scales e.g., community (Ziervogel, 2019; Ziervogel et al., 2022) or city (Pieterse & du Toit, 2025), while simultaneously addressing sustainability aspects e.g., social justice and equity (Berkhout & Dow, 2023; Solomonian & Di Ruggiero, 2021), and the root causes of risk for increased resilience (Pelling et al., 2015).

It must be noted that the both perspectives started from different original ideas, but by time, evolution, cross-fertilization they have become very similar. The next section addresses how to feed transformative adaptation thinking into backcasting for transformative adaptation and transformative water management.

3. Backcasting for transformative adaptation

3.1 The relevance of backcasting

Backcasting is a well-known normative foresight approach for generating a desirable future, followed by looking backwards from that future to the present in order to strategize and to plan how it could be achieved (Dreborg, 1996; Quist, 2007; Quist & Vergragt, 2006; Robinson, 1990). Compared to forecasting and exploratory scenario approaches, participatory backcasting and related vision-oriented normative approaches are the least applied foresight approach in climate change adaptation planning (van der Voorn et al., 2012; van der Voorn et al., 2017). Visioning is an essential part of backcasting, though visioning approaches are also applied in climate adaption without using the term backcasting (Nalau and Cobb 2022).

Backcasting is a suitable approach for addressing real-world problems characterized by complexity, uncertainty and stakeholder value conflicts for which transformative changes at a systemic level are necessary. A typical example is a climate resilient flood protection design, in which a longer time horizon (e.g., 50 - 100 years) is required for system-level changes, including the replacement of the current flood defense infrastructure, as well as climate adaptation and climate action at large (ten Harmsen van der Beek et al., 2025). The potential value of using backcasting to solve complex real- world problems lies in its strength to address normative aspects of envisioning desired futures for the transformation of complex systems (Kishita et al., 2024). Backcasting is not only about how desirable futures can be attained, but also how undesirable futures can be avoided or anticipated (Robinson, 1990). By looking backwards from these futures to the present, backcasting generates multiple pathways that can lead to these futures, while accounting for uncertainty about future developments that may decrease political and stakeholder support for and effectiveness of these pathways. Backcasting is complementary to forecasts that are based on dominant trends that assume the persistence of current problems (Höjer & Mattsson, 2000).

Backcasting is conducted through several steps, typically involving problem orientation, visioning, goal setting, backcasting analysis, pathway or roadmap development, implementation, and monitoring and impact evaluation. Although these steps are usually presented in a linear fashion over time, iteration and moving forward and backward between steps are inherently part of the process (Quist et al, 2011). Due to considerable methodological variety in backcasting approaches, there are differences in whether and how stakeholder participation has been organized, in the number of steps in which the methodology has been split, the supporting methods that are used, the kinds of topics being addressed, the nature and scale of the systems addressed (e.g. local, regional, national, consumption systems, or societal domains), the number of visions developed and how the visions have been developed, and if the focus is on learning and raising awareness among stakeholders, or on realizing follow-up and implementation (Vergragt and Quist 2011, Kishita et al, 2024). Kishita et al (2024) also argue that a backcasting methodology must be tailored to address the problems and issues considered in a given case for which a contextualized backcasting methodology needs to be developed. In their Backcasting Adaptive Management (BCAM) methodology, van der Voorn et al (2012), for instance, included the intermediate step of pathway development to make the methodology suitable for adaptive water management and climate adaptation planning.

Backcasting can be useful in engaging stakeholders in the co-creation of climate change adaptation futures (Nalau & Cobb, 2022). Backcasting is particularly useful for addressing different stakeholder interests, perceptions and perspectives to inform climate action decision making and to induce stakeholder support and commitment for climate adaptation that are guided by adaptation pathways (Bukvic & Harrald, 2019). Backcasting supports envisioning alternative futures and exploring which options and adaptation pathways enables us to reach the desired futures, which can add value to pathways approaches for adaptation planning as proposed by multiple authors (Haasnoot et al., 2013; Haasnoot et al., 2012; Wise et al., 2014). The dynamic adaptive policy pathways approach, for example, provides insights on the timing, path-dependency, and limits of combinations of adaptation options, to support longer-term and robust decision making under deep uncertainty (Haasnoot et al., 2013; Hermans et al., 2017). Muccione et al (2024:14) acknowledge that "*approaches such as backcasting complemented with dynamic adaptive policy pathways* *could be used to further explore pathways, particularly the normative aspects of pathways*".

Backcasting is also beneficiary for social learning on possible futures as well as the views and preferences of other stakeholders. This enables stakeholders to explore and open up a possibility space for empowering transformative adaptation to reach desired impact, as acknowledged in recent studies on transformative climate adaptation (Holden et al., 2016; Lonsdale, 2015; Mendizabal et al., 2021). Due to its compatibility with various types of tools and methods, backcasting has potential to address climate uncertainties in long-term decision making on climate adaptation (van der Voorn et al, 2017). Backcasting can also be linked to scenario development approaches to decision and policy makers (van Vliet et al, 2011).

These advantages of backcasting in terms of enhancing the process and creating space for transformation through diversified participation, exploring alternative futures and including external and marginalized values and perspectives, all relate to adding directionality to incremental, gradual change. In other words, backcasting can help make adaptation transformative. In transitions research, directionality is considered a core ingredient for achieving transformative change (Kemp et al., 2022; Pel et al., 2020; Pel et al., 2023). It is assumed and observed that a long term orientation on a desired future state, assuming non-linearity and systemic shifts (transition), as a starting point for action will increase the transformative potential of short term steps (Avelino et al., 2019). Backcasting is an approach and methodology that has been used, implemented and tested to support the process of thinking future-back in governance contexts and related social learning (Quist et al 2011).

3.2. Key insights from backcasting studies for transformative adaptation

This paper expands on key insights from research for advancing backcasting for transformative adaptation conducted by van der Voorn et al (2023), who evaluated and compared 10 case studies, using visioning and backcasting for climate adaptation, water management and climate action, from 3 continents. These insights help us to explore how backcasting for transformative adaptation could look like. We here build a case for backcasting for transformative adaptation, by drawing on the BCAM methodology and taking stock of lessons learnt from the use of combined use of backcasting and Adaptive Management, including pathway switching, and complemented with relevant literature and updated with recent literature.

Backcasting for Adaptive Management supports dealing with uncertainties with a direct link to social learning and experimentation. The BCAM methodology, for instance, combines the strengths of both approaches, as backcasting provides Adaptive Management a long time frame for the fulfilment of short-, middle-, and long-term management goals, whereas Adaptive Management aims to secure adaptiveness within this time frame (van der Voorn et al., 2017). However, the BCAM methodology lacks embedment of short term (incremental) actions within the long-term narrative of desired transitions. Backcasting for transformative adaptation provides directionality towards incremental, gradual change, which makes climate adaptation transformative.

Insight #1: Focus on transformation of water management itself.

Due to limited awareness of policymakers about the complex dynamics in the natural environment in which they operate, it is important for them to become more context aware ('what is happing outside?'), which helps them to think outside-in (i.e., 'how to refer to what is happening outside?' This is exactly where backcasting adds value to transformative adaptation: whereas the existing system often remains the main point of reference for such changes, backcasting has the potential to shift the debate from 'what is already there?' to "what is needed" to get "where we want to be" from 'what is already here". (Faldi & Macchi, 2017; van der Voorn et al., 2023). For water management to become transformative in relation to its environment, it first needs to transform from within culturally and structurally before it can become dominant in water management practices and beyond (e.g. 'water and soil guiding')

Insight #2: Shift focus from incremental to transformative change

Transformative adaptation involves a shift from incremental to transformative change. Backcasting supports this undertaking as it envisions fundamentally different futures and how they can be related to short and long term choices in adaptation pathways. Such futures empower transformative change, but this must be already present in visions and pathways too (van der Voorn et al., 2023). Fundamentally different futures and long term transformative pathways can guide the transformation of a system towards a desired direction and endpoint, by setting the intermediate key decision and intervention points combined with conventional or new policy instruments (Pot et al., 2024). Such futures and pathways help to prevent path-dependency to cause maladaptation, particularly when backcasting can support setting the mindset on "what is needed" to get "where we want to be" from 'what is already here".

Insight #3: Create space for social learning and co-creating transformative knowledge
Although backcasting targets at transformative change, this type of change does not come easily. This is even more the case in the context of climate adaptation, due to climate uncertainties and increasing complexity of human-water systems. Learning and co-creating transformative knowledge is thus key to designing and advancing transformative adaptation in order to obtain the level of detail and depth at which we need to understand the complexity of the systems we are dealing with (Howard et al., 2025). In transformative processes, learning should be considered a constant activity both for the stakeholders involved and for intermediaries (e.g., change agents or vision entrepreneurs) shaping the on-going process (Ziervogel et al, 2019; 2022).

Insight #4: Invest in capacity-building for transformative action
Implementing transformative adaptation is resource intensive in terms of time, budget, knowledge and skills. Without governance capacities it is difficult to move beyond incremental-based adaptation. Transformative adaptation draws on the type of capacity building that can support it and is key to co-creating transformative knowledge and contextual understanding (Wamsler, 2017). The added value of backcasting to transformative adaptation lies in building and mobilizing different types of capacity being relevant for co-creating transformative knowledge and contextual understanding as well as inclusive stakeholder participation supported by tools and methods that help stakeholders to produce meaningful outcomes (Ziervogel et al. 2019; 2022). Their participation increase legitimacy of and support for these outcomes but also required substantial capacity building efforts supporting transformative adaptation (van der Voorn et al. 2012; 2017; 2023).

Insight #5: Need for interdisciplinarity and knowledge support
Interdisciplinary research is crucial for transformative adaptation because it addresses the complex and interconnected nature of climate change impacts on systems, which requires insights from various disciplines like social sciences, natural sciences, and engineering. An interdisciplinary view on transformative adaptation helps to recognize that it is also deeply intertwined with economics, sociology, political science, engineering, involving experts and practitioners from various disciplines. Therefore, transformative adaptation could benefit from interdisciplinary backcasting studies, involving interdisciplinary teams of experts and practitioners from various disciplines to mobilize various stocks of knowledge (both scientific and non-scientific), expertise and skills needed for the use of comprehensive tools and methods for advanced system analysis, vision, scenario and pathway development (Rutting et al., 2023; van der Voorn et al., 2023).

Insight #6: Backcasting for transformative adaptation benefits from methodological innovation in climate adaptation and related fields
Advancing backcasting for transformative adaptation triggers extending the methodological repertoire of backcasting. van der Voorn et al (2023) show how essential add-ons supported conducting more advanced system analyses and developing more advanced and robust pathways. A novelty is the inclusion of robust elements for pathway switching and transformative elements and hybrid pathways (both mitigation and adaptation options) that could support transformative adaptation (van der Voorn et al 2023). Tipping points, for example, are robust elements that indicate how long adaptation pathways remain effective under specific conditions (Kwadijk et al., 2010; ten Harmsen van der Beek et al., 2025). Others have provided other examples of novel add-ons, including the combined use of quantitative and qualitative scenarios (van Vliet

& Kok, 2015) and comprehensive modelling and simulation tools and methods for advanced system analysis (Sheppard et al., 2011). These add-ons can be combined in new backcasting methodologies or added to existing ones like, for example, the BCAM methodology by van der Voorn et al (2012; 2017). Such an upgrade allows this methodology to better address fundamentally different futures and how they may relate to potential synergies or conflicts between short and long term climate adaptation and mitigation options and choices. This supports addressing the root causes of vulnerability, leading to more hybrid pathways and more options for pathway switching (van der Voorn et al., 2020). Van der Voorn et al. (2020) provide an example of such a backcasting approach. Another example is the gamification of backcasting for sustainability (Guillen Mandujano et al., 2021). Elsewhere, Sisto et al. (2022) developed an innovative methodology integrating backcasting and multi-criteria decision analysis tools.

3.3. Principles for backcasting for transformative water management

Building on the key insights in section 3.2, we propose 9 principles for backcasting for transformative water management, of which the three (transformative, enabling pathway switching and advanced modelling for transformative water management) are considered novel concepts from the transformative adaptation literature, which are listed under 1-3 in Table 2. The other six principles are derived from the existing backcasting, transition management, and climate adaptation literature.

Each of these principles support the development and application of transformative water management, including its policy integration, while as a set of principle they enable transformative water management. Backcasting for transformative water management needs to enable the co-creation of transformative futures for fundamentally different water management practices and transformative pathways, including possibilities for pathway switching, that could lead to such futures (principle 1, 2 and 8). Such visions and pathways can provide directionality (principle 6) to developing long-term transformative adaptation strategies, including long-term adaptation measures that effectively reduce climate risks. The cocreation of visions and pathways benefits from the use of different types of tools and methods (principle 9), particularly the use of advanced modelling (principle 3). In the backcasting process, different stakeholder perceptions and perspectives (principle 4) and knowledge from different disciplines (principle 5) need to be taken into account for the co-creation of contextual understanding of these visions. Visioning typically triggers social learning among stakeholders involved. Learning processes help to explore possible space for transformative change to happen, which is constrained by various aspects we discussed in the paper. By building up a broad network of stakeholders and experts from different disciplines that share the debate (principle 7), thinking and experimenting, conditions are created for up-scaling of innovation and breakthrough of innovations that are favorable for transformative adaptation and transformative water management and potentially other policy domains.

Table 2. Principles for backcasting for transformative water management

Principle	Description
1.Transformative	It is necessary to be explicit about the desired level of ambition of transformative change and the targeted scale at which change should take place within appropriate demarcation of the system under study, including broad sets of societal practices (Siders et al., 2021) (Pot et al., 2024).
2. Enabling for pathway switching	Inclusion of pathway elements such as robust elements and tipping points is essential for uncertainty management and pathway switching (van der Voorn et al. 2023; ten Harmsen van der Beek et al., 2025)
3. Advanced modelling for transformative water management	Different types of advanced modelling and simulation tools help to conduct advanced systems analyses, identify transformative elements for visions, robust elements and tipping points for pathway switching and uncertainty management and develop scenarios for robust pathways (van der Voorn et al., 2023; ten Harmsen van der Beek et al., 2025)
4. Normative	The desired level of ambition of change regarding justice, equity, and power imbalances for long-term sustainability and broader social ecological resilience needs to be aligned with societal values and needs and the process by which these needs are defined and pursued (Wamsler, 2017).

5. Participatory - transdisciplinary	Broad stakeholder engagement facilitates transdisciplinary learning processes and the co-creation of transformative knowledge for shaping and advancing climate adaptation (Wamsler, 2017).
6. Long-term perspective - directionality	A long-term perspective on fundamental, systemic changes provides directionality as described by (Loorbach, 2007; Quist, 2007).
7. Interdisciplinary	An interdisciplinary view helps to mobilize experts and practitioners from various disciplines and various stocks of knowledge, expertise and skills needed for advancing transformative adaptation (Muiderman, 2022; van der Voorn et al., 2023).
8. From vision to action – actionability	Transformative visions and adaptation pathways provide guidance to actions and small incremental, gradual steps towards transformative change (van der Voorn et al., 2017; van der Voorn et al., 2023)
9. Combining different tools and methods	Different types of tools and methods can be applied as part of the overall backcasting methodology, leading to novel add-ons that can be integrated in new backcasting methodologies or added to existing ones (e.g., BCAM methodology) (van der Voorn et al., 2017; 2023)

4. Conclusions and discussion

A major challenge for water management is how it can adapt itself to a changing environment. This is even more challenging in the context of climate change, where large uncertainties exist and persist in our understanding of the impact of climate change on complex human-water systems. It is evident that incremental-based adaptation is insufficient or even counterproductive to deal with systemic shocks and deep uncertainties, which actually requires a shift to transformative water management, which builds on transformative adaptation, to accommodate radically different futures and transformative change. Although transformative adaptation and transformative water management are gaining traction in both policy debates and academic discussions with little practical insight in the past decade, a gap remains in translating both approaches into policy.

The presented insights from recent backcasting studies show that backcasting has potential for transformative water management. As approach for transformative water management, backcasting could be used to develop, in participatory processes, studies into transformative changes and future water systems that are long-term climate resilient. But these participatory processes themselves could serve as a means to facilitate social learning: by engaging a variety of stakeholders and going through analysis of and reflection upon radically different futures and potential transformative changes. Participants can develop their own understanding of complexity of transformative change and develop an understanding of how they can contribute to transformative change.

In addition, the so far limited applications and evaluations of backcasting studies underline the need for more methodological development and experimentation. More backcasting cases on transformative change is yet needed to investigate and compare methodological and conceptual advancements in the use of backcasting for transformative water management and their transformative impact. However, it is clear that the approach is a promising and useful extension to the current adaptive and forecasting approaches now so dominant. How this potential is to be developed and how backcasting could be more institutionally embedded in models, strategies and planning is something to explore further. We also acknowledge that other approaches can be useful for transformative adaptation, especially other normative approaches such as Transition Management (Loorbach et al, 2017) and participatory visioning (Nalau and Cobb, 2022), which help to include the speculative and normative aspects of disruptive futures and how they can be related to short term choices.

In general, backcasting intends to change the existing system and/or dominant practices. In the context of climate change, it is about making human-water systems more climate resilient regarding climate shocks.

The most effective way to do so is by reducing the root causes of climate risks and vulnerability, while taking transformative adaptation measures that are appropriate for the challenge of achieving deep, systemic and sustainable change with large-scale impact. Due to a lack of financial and human resources and the power dynamics needed to move away from current business-as-usual practices, transformative adaptation and transformative water management have not yet become mainstream in present-day policymaking on climate adaptation nor water management (Fedele et al., 2019).

In conclusion, in this paper we have conceptualized how backcasting could support the development and application of transformative water management, including its policy integration. We have therefore proposed 9 principles for backcasting for transformative water management. Despite the potential of backcasting to support transformative adaptation and transformative water management, we recognize three potential downsides of backcasting that may compromise its potential. The first downside is an insufficient ambition level for change and opposition to it. The second downside is an insufficient quality of execution of backcasting studies due to a lack of knowledge, expertise and experience. Insufficient attention for equity, marginal groups and justice, and a potential shortage of resources poses the third downside. To overcome these downsides, stakeholders should commit themselves to pursuing the ambition of going beyond current business-as-usual adaptation practices by envisioning transformative futures and setting ambitious goals. This requires substantial investments in capacity building of stakeholders to increase their ability to create novelties and embed them in structures (social-cultural), practices and discourses. Capacity building effort should therefore be targeted at stakeholders groups, particularly marginal groups, that enables them to produce relevant inputs, which contributes to inclusive transformational adaptation. Their involvement may require capacity building effort as part of or prior to the backcasting study. For backcasting to generate meaningful output, capacity building effort should also be targeted at those who design and execute the backcasting process. As backcasting processes are resource intensive, sufficient resources need to be allocated to accommodate transformative change.

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Use of AI

During the preparation of this work, the authors 1, 2 and 3 did not use AI.

Conflict of Interest

There is no conflict of interest

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