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# Governing wildfire in a global change context: lessons from water management in the Netherlands

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## Abstract

**Background** Wildfire management is increasingly shifting from firefighting to wildfire prevention aiming at disaster risk reduction. This implies fuel and landscape management and engagement with stakeholders. This transition is comparable to the history of water management in the Netherlands, which shifted from fighting against water to flood risk reduction and living with water. Here, we draw lessons from water management for integrated fire management that are useful for society, agencies, and government. To this end, we review the literature on integrated and adaptive water management in the Netherlands.

**Results** Based on the results, we argue that (1) a holistic and integrated approach, (2) adaptive management, and (3) resilient landscapes through stakeholder participation are necessary to improve the resilience against and prevention of wildfires within integrated fire management.

**Conclusion** To make society more resilient to wildfires and shift to a greater focus on prevention within disaster risk reduction, there is a need to take a more long-term perspective and include a wider range of stakeholders to develop new wildfire policies. Integrated fire management should facilitate and promote community initiatives to implement fire risk reduction measures in different landscapes and the wildland urban interface (WUI) including the use of nature-based solutions. Inspired by the successes in Dutch water management, fire management needs greater participation of stakeholders and collaboration between stakeholders to share responsibility and knowledge to make wildfire prevention more attractive and implementable by society, landowners, civil protection, and policymakers.

**Keywords** Adaptive management, Wildfire, Risk management, Participation, Stakeholder engagement, Prevention, Holistic approach, Netherlands, Disaster risk reduction, Water management

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## Resumen

**Antecedentes** El manejo de fuegos de vegetación está cambiando desde el combate a la prevención, con el objetivo de reducir el riesgo de desastres. Este cambio implica el manejo del combustible y del paisaje y el compromiso de los ciudadanos interesados. Esta transición es comparable a la historia del manejo del agua en los Países Bajos, que cambió desde la lucha contra las inundaciones a la reducción del riesgo de las mismas y el aprender a convivir con el agua. En este trabajo, extrajimos lecciones sobre el manejo del agua para aplicarlas al manejo integrado del fuego y que sea beneficioso para la sociedad, las agencias y los gobiernos. Al final, revisamos la literatura sobre el manejo integrado y adaptativo del agua en los Países Bajos.

**Resultados** Argüimos que (1) una aproximación holística e integrada, (2) el manejo adaptativo, y (3) los paisajes resilientes a través de la participación de los ciudadanos interesados, son necesarios para mejorar la resiliencia y prevención de incendios dentro del Manejo Integrado del Fuego.

**Conclusiones** Para hacer que la sociedad sea más resiliente a los incendios y cambie el enfoque desde la supresión a la prevención, se necesita tomar una perspectiva a mucho más largo plazo e incluir un rango más amplio de ciudadanos comprometidos para desarrollar nuevas políticas de manejo del fuego. El Manejo Integrado del Fuego debería facilitar y promover iniciativas de la comunidad para implementar medidas de reducción del riesgo de incendio en diferentes paisajes y en la Interfase Urbano-Rural, incluyendo el uso de soluciones basadas en la naturaleza. Inspirados en el éxito de los Países Bajos en el manejo del agua, el manejo del fuego necesita de una mayor participación de ciudadanos comprometidos y de la colaboración entre ellos para compartir las responsabilidades y el conocimiento, para hacer que la prevención de incendios sea más atractiva e implementable por la sociedad, los propietarios, la protección civil, y quienes dictan las políticas en la materia.

## Introduction

Recently, there has been a considerable increase in extreme wildfire events as a result of human-induced climate change. These extreme wildfire events cause extensive damage to properties and loss of life. The number of extreme wildfire events has increased in Europe. This is not only the case in the fire-prone Mediterranean countries (Giannakopoulos et al., 2011; San-Miguel-Ayanz et al., 2020; San-Miguel-Ayanz et al., 2013), but also in less fire-prone countries, especially in the northwest of Europe (Flannigan et al., 2009). European fire regimes are moving northwards from traditionally fire-prone countries to temperate countries (San-Miguel-Ayanz et al., 2020) requiring changes in fire management in these regions.

Currently, fire management predominantly focuses on readiness and response (firefighting). This focus of wildfire policy on suppression has resulted in maladaptation to ongoing global change (Ganteaume et al., 2021) and inadequate attention given to preventing wildfires or preventing their impact (Wunder et al., 2021). To reduce impacts of future fires, there needs to be a greater focus on prevention (Moore, 2019; O'Connor et al., 2016; Rigolot et al., 2009; Tedim et al., 2015) and long-term risk reduction is needed to reduce the negative impacts wildfires have on society and the economy (Moreira et al., 2020; Tedim et al., 2015). In short, there is a need to live with fire and move from suppression to prevention

to adaptation to fire. Here, we argue that to make this change, valuable lessons can be learned from how the Dutch live with water.

## Challenges in European wildfire management

With the increase in temperatures due to human-induced climate change, there has been an increase in fire weather and more regions are experiencing longer periods of drought and therefore suitable conditions for more intense fire seasons (Tedim et al., 2015). These conditions conducive to wildfire are also spreading to traditionally non-fire-prone regions of Central and Northern Europe (Fernandez-Anez et al., 2021a; Flannigan et al., 2009; Lelouvier et al., 2021), and these regions need to be prepared for future wildfire conditions (Stoof & Kettridge, 2022).

Adding to this, in many parts of the world, the abandonment of the rural areas resulted in reduced management of fuel in the landscape and thus unmanaged land now accumulates fuel, increasing the fuel loading and continuity (De Rigo et al., 2017; Moore, 2019). Increased wildfire risks in combination with fire exclusion and limited wildfire policies in many parts of Europe have resulted in a fire-fighter trap (Collins et al., 2013; Silva et al., 2010), especially in the Mediterranean. The combination of fire exclusion policies, increased climate extremes due to global warming (Moreira et al., 2020), and landscape-scale fuel build-up (Moreira et al., 2020) is leading to bigger and more intense fires that are difficult

to control by firefighters (Bowman et al., 2017; Mcrae & Sharples, 2015) or 6th generation fires that can be completely out of control (Duane et al., 2021) and can result in large-scale damage to properties and human casualties.

Adding to increasing wildfire risk is the expansion of urban areas. This has resulted in an increased development of the wildland-urban interface (WUI), also referred to as the rural-urban interface (Tonini et al., 2018), where there is a mix of vegetation and buildings. In the WUI, the economic and social impacts of wildfires can be extremely high (Badia et al., 2019; Radeloff et al., 2005). In these areas, spatial planning needs to consider the higher risks of wildfires due to flammable vegetation, which not only includes forests but also open habitat like heathlands, given that most fires in more temperate fuels occur in such vegetation types (San-Miguel-Ayanz, 2021). There is also a need to increase the resilience of these communities by learning to live with fire and helping them to take a range of measures that reduce the risks of wildfires.

#### **The Dutch approach to risk management**

Fire and water are contrasting elements but have interesting similarities (Stoof & Kettridge, 2022). Water has been a significant risk during the development of Netherlands over the last centuries. The Dutch have been living with water for centuries and centrally managing it since the 1700's (Lintsen, 2002). Having learned from disasters, the Dutch initially focused their water management on flood prevention. In response to an increasing and more uncertain risk, water management in the Netherlands subsequently shifted to integrated water resource management (IWRM) (Commission, 2015; Correljé & Broekmans, 2015; Reinhard & Folmer, 2011). IWRM is proactive and embedded in the landscape. It follows a holistic approach to managing landscape resilience using adaptive management based on the pillars of social equity, economic efficiency, and ecological sustainability. In addition, within IWRM, there is a strong focus on adaptive, bottom-up, and participatory approaches. This Dutch approach to water management has become an export product of the Netherlands (Laeni et al., 2021) and is now implemented worldwide (Zevenbergen et al., 2013), e.g., to support Louisiana's new Coastal Plan and New Orleans's Water Plan (USA), Mekong Delta Plan (Vietnam), and the Bangladesh Delta Plan (Bangladesh).

#### **History of Dutch water and flood management**

There are three important events that have shaped the Dutch approach to water management since the start of the twentieth century. In 1953, a storm surge hit the southwestern part of the Netherlands causing large-scale

flooding that led to 1836 human fatalities, tens of thousands of animals dead, and thousands of houses destroyed (Rijkswaterstaat, 2022). To prevent such floods in the future, the Delta Commission was established 17 days after the disaster—eventually leading to the establishment of the Delta Plan. In 1993 and 1995, high river flow events forced large-scale evacuations and a disaster was only barely prevented. Although in the end the river dikes did not breach during these latter events, it was a major wake-up call that new approaches were needed to prevent flood disasters in the future. The 1990's floods created a shift from water resistance to resilience (van Buuren & Warner, 2014). Water engineers realized that dikes cannot be raised infinitely and that floods cannot be fully prevented (Roth & Warner, 2009). The new goal was to anticipate rather than react to risk (Klijn et al., 2015), thus shifting towards adapting to and living with water and not only controlling it (Correljé & Broekmans, 2015; Janssen et al., 2006). These pivotal events respectively caused a shift in thinking from flood resistance to complete protection to resilience and ultimately accepting that the Dutch need to live with water (Roth & Warner, 2009). The Second Delta Programme was adopted in 2007 and led to the Delta Act in 2013 with clearly defined roles and budget. This short history of water management in the Netherlands illustrates how the Dutch have shifted from disaster management to prevention (disaster risk management), making the country and its communities more resilient by making space for flooding in the landscape through nature-based solutions, adaptive management, and extensive stakeholder participation (Ritzema & Van Loon-Steensma, 2018) in searching for solutions.

#### **Differences and similarities between fire and water**

In Dutch, there is a saying “water en vuur zijn” which translates to being like fire and water. The saying points to the difference between the two persons or risks in this case. There are many similarities and differences between water and fire. The main difference between fire and water is that water is seen as a valuable resource and that fire is typically not. Flood events are a result of natural processes whereas wildfire (due to the predominant role that humans have in fire ignitions) is mostly caused by human activities, making fire risks more complex than that of floods. The science on future prediction of flood is more advanced than that of fire, but it must also be acknowledged that this is because fire has more variables (e.g., weather, human ignitions) and the 6th generation fires create their own weather conditions. This makes the future prediction of fire more complex and thus also more uncertain. Despite these differences, there are also

similarities we found important for this perspective to draw lessons from water for fire management. The greatest similarity is that the future with global change is uncertain and even more so for fire management. Another important similarity is that the management of the landscape has a large influence on the impact of events, both flood and fire.

As the Dutch have had to learn how to live with water through adaptive water management, we here explore what fire management can learn from these lessons on how to live with fire. For this, we reviewed the literature on integrated and adaptive water management and present three key lessons from Dutch water management that could also be applied to fire management: (1) a holistic and integrated approach, (2) adaptive management, and (3) resilient landscapes through stakeholder participation—illustrated in Fig. 1 and detailed below. We argue that the adoption of these lessons can strengthen the integrated management of fires by increasing the resilience to fire and prevention of any undesired impacts.

### Lesson learned from Dutch water management

#### Holistic and integrated approach

##### *Collaborative governance*

Collaboration between the different levels of government and the private sector is necessary to adapt to long-term climate and water-related risks (OCED, 2009). This involves collaborative governance and integrated thinking. A holistic approach is taken for water resources and flood risk management in the Netherlands to increase resilience. This holistic approach consists of multilevel governance, legal enforcement, and financial resources for flood protection while adapting to long-term climate and water-related risks (Commission, 2008; Van Alphen, 2016; Zevenbergen et al., 2018). In response to increasing and more uncertain future flood risks, the Dutch water sector shifted from a sectoral approach to an adaptive and integrated approach in which water is managed across sectors (van Herk et al., 2015). Different silos within water management are now considered at the same time—flood risk, sewerage, and water use management. To achieve the flood risk reduction objectives,



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**Fig. 1** Three key lessons from Dutch water management that can strengthen integrated fire management

multiple agendas from other sectors are connected to address the water agenda. For example, Rijke et al. (2012) observed that, in terms of integrating multiple objectives and spatial scales, the Delta Programme design and multi-level governance processes have enabled the establishment of integrated plans and designs through working with stakeholders.

From a governance perspective, the management of fire and water is not very different as both risks spread over the same scales and many stakeholders affected. A multitude of actors is involved in fire management in countries around the world, land managers, fire services, and civil protection but also governments and the education sector. Despite this, budget spending on fire management is still largely devoted to fire suppression (Hope et al., 2016; NIFC, 2021), with recent developments in Portugal (AGIF, 2020) being a promising exception to this trend. In addition, fire management touches upon so many other disciplines that governance ownership of the topic is scattered. Should it fall under the Ministry of Agriculture, Nature and Forestry, or Public Safety, or Spatial Planning, Climate Adaptation and Mitigation, and at national, provincial, or municipal level? With so many actors potentially responsible for fire management, the risk is that nobody takes the lead necessary to move this topic higher on the agenda. Water is also a complex topic, but despite this, its integrated management was successfully taken up by the multitude of actors involved. Integrated fire management could be further improved by using a similar approach where stakeholders in the landscape collaborate with the multiple levels of government to find common objectives (synergies) and develop integrated plans to manage the landscape. By seeking these synergies with other landscape management objectives such as biodiversity, erosion prevention, wood production, and the bioeconomy and collaborating with other sectors, fire can be managed as part of ongoing and existing activities, leveraging funding and support rather than requiring new initiatives and priorities.

#### ***Risk-based approach***

In the Dutch flood management, a risk-based approach is followed and acceptable standards of safety are calculated for the whole country. After the higher river flow event in the 1990's, the water managers realized flood risks had significantly increased due to large-scale socio-economic development in the Dutch delta. In response to these changed risk levels, additional measures were implemented specifically in high-risk areas to achieve an acceptable level of risk exposure. Safety standards are now calculated for all flood prevention measures in the Netherlands and are re-assessed on a regular basis (every 6 years). According to these safety standards, the

investment required in risk reduction measures is proportional to the level of risk a certain area is exposed to. These risk reduction measures were obtained by lower-level authorities through implementing different measures of risk reduction interventions based on the input of local stakeholders potentially affected by new flood prevention measures.

Integrated fire management can potentially learn from the risk-based approach to manage the forest (Rego et al., 2019) and fuels within the landscape (Davim et al., 2022). Following the water example, more investments are needed in areas with high wildfire exposure for risks to be reduced by rural development, good forest management, or fuel management initiatives (Moore, 2019; Rego et al., 2019). Acknowledging that risks are continuously changing, these risk assessments require regular updating to ensure the measures in place are in line with any ongoing changes in fire ignitions, fuels, and values at risk. The expansion of urban areas (Iglesias et al., 2021) but also developments like land abandonment (Pausas & Millán, 2019; Tedim et al., 2015) and changes in fuel management (Pausas & Millán, 2019) are relevant to consider here. And within the context of climate change, consideration of long-term changes in fire regimes is essential to ensure the landscapes and communities of the future are adequately designed now, based on this risk-based approach to fire management.

#### ***Multiple layers of safety approach***

An approach to prioritizing flood risk management is the multi-layered safety approach (Hoss et al., 2011; Rijke et al., 2014; van Herk et al., 2014). In addition to prevention, this approach focusses on integrating different types of measures into Dutch flood management and through this reducing the probability and consequences of floods. It contains of three core layers: (1) prevention of floods, (2) prevention of flood impacts through spatial design and land use planning, and (3) management of flood disasters. The implementation of this approach requires collaboration among different public authorities with different tasks, legal competencies, and resources (van Popering-Verkerk & van Buuren, 2017). Flood prevention is still the basis, and the first layer, of this approach and is achieved through risk reduction measures in the landscape and improving defense systems such as dikes. The second layer focuses on spatial solutions, through adaptive spatial planning and adaptation of buildings, so that the potential consequences and losses of floods are limited when floods do occur. This includes the assignment of places that may be intentionally flooded in case rivers are not able to carry high waters anymore, with the preference given to areas with farming or nature such that higher impact land with urban development and

high-cost industries are kept dry. In the Netherlands, this has been done in areas with high population density and limited space through the identification of strategic areas for risk reduction. The third layer focuses on disaster management, including the development of disaster plans, risk maps, early-warning systems, evacuation plans, temporary physical measures (e.g., sandbags), pumps, medical assistance, and communication of risks to the general public through websites (i.e., [www.overs-troomik.nl](http://www.overs-troomik.nl) and [www.klimaateffectatlas.nl](http://www.klimaateffectatlas.nl)). The use of the multiple layers of safety approach has led to closer cooperation between the different stakeholders that were involved in risk management by integration of the different levels and layers leading to greater risk reduction measures (van Herk et al., 2014).

When applying this water-based multiple layers of safety approach to landscape fires, one question instantly stands out: where does fire suppression fit? As indicated previously, the majority of funds in fire management is spent on fire suppression, putting fires out. This may suggest it is the first layer of defense; similar to flood management, it can be compared to the fighting of flooding with dykes (engineering interventions). Yet, suppression of a disaster fire is a form of disaster management—with the important note that only a few fires are actually disasters (Hoover & Hanson, 2021); hence, we would argue that suppression can be part of both the first and third layers of safety. Given the strong focus on prevention, the water-based multiple layers of safety approach can be an interesting way to consider how to move from a focus of fire suppression to one in which landscape management and spatial planning are prioritized:

*Layer 1* Prevention of unwanted fire (suppression) includes (1) prevention of fire ignitions and (2) prevention of fire spread through systematic and strategic fuel management using a broad toolbox including prescribed/controlled/wildfire, mechanical methods and grazing, and the creation of fire breaks, green breaks, and adoption of sustainable forest management. According to Ritzema and Van Loon-Steensma (2018), it is important to realize that disaster management and spatial planning can never replace preventative measures, which will still be the most effective measure. This would mean that in addition to the focus on suppression greater focus should be placed on prevention activities until there is a better balance. From a wildfire perspective, a multi-layer safety approach could significantly reduce risks. For this first layer, risk reduction measures in the landscape, on a community level and individual level, still need to be the first priority. This includes education, awareness, and measures to reduce ignitions but also implementation of measures in the landscape to reduce the risk and spread

of wildfires. Fire breaks and low-fuel buffer zones need to be incorporated into the landscape around communities (Ahmed et al., 2018). This is especially applicable to regions that are traditionally not fire-prone but, where the risk is becoming more prominent, also exacerbated by the effects of climate change.

*Layer 2* Prevention of undesired fire impacts, through land use and spatial planning. What kind of fires are accepted and where and how are they allowed to burn in the landscape? What does that mean for planning and design, and where should fires be extinguished immediately or can they be given the space to fulfill their natural role? Prevention of fire impacts includes adequate building codes for fire-resilient home construction (Ganteaume et al., 2021), guidelines for the design of the home ignition zone (NFPA, 2009), and potential sprayer systems (Dalmau-Rovira et al., 2020). On a larger scale, it is essential to (re)consider urban developments and particularly urban expansion in high-fire-risk areas. New developments should only be considered to be built in high-risk areas if these developments are resilient to wildfire. This means that houses should be hardened and defensible spaces in place and fire-smart land and forest management (Fernandes, 2013; Hirsch et al., 2001) measures in the landscape that reduce the wildfire risk and spread (Rego et al., 2019). Following the Dutch approach to flood management in which low-production land is designated to flood first, fire management could consider doing pre-fire planning to designate lower-value areas that (where possible) fires left to burn in order to be able to keep higher-value areas like the rural-urban interface safe. This is for instance done by the Catalan Fire and Rescue Service in Spain (Castellnou et al., 2019) and can be a valuable strategy to minimize unwanted fire impacts if fire and land management services are sufficiently trained to use these strategies and if the fire behavior is such that it is possible to direct the fire.

*Layer 3* Disaster management includes fire suppression but also management of any fire impacts and communication of risks to the general public before and during events, as well as development of disaster plans, risk maps, and early warning systems. During a wildfire event and possible evacuation, information should be available to civil society when fires start. This layer consists of information systems, insurance, etc. Communities need to have access to information and planning regarding wildfires (Moore, 2019). They need to be warned about wildfires through early warning systems; they need a source of information if a wildfire occurs and whether they should evacuate or stay at home during a particular fire. There is a need for this information to be accessible

by the public where the public can see the potential of their house being exposed to a wildfire. They can then make an informed choice if, when and where to evacuate. This is already the situation in some parts of the USA, where mandatory evacuations are executed if a wildfire is expected to move through those areas (McLennan et al., 2019).

#### **Window of opportunity/disaster events**

When there is more attention to flood risk due to a disaster event and motivation is high and memory clear, action needs to be taken like in the event of the 1953 flood, 1990's near-flooding events, and after hurricane Katrina in the USA. During crises or disaster events, attention is focused on the problem. The perception of the problem changes, and although this is temporary, it could change the urgency of political action and possibly change policies in the long term (Kaufmann et al., 2016). Policy windows can be of short duration but also cast long shadows (Zahariadis, 2014). A prime example of this is the major change in policy brought about by the devastating fires in Portugal in 2017, after which the National Plan for Integrated Wildland Fire Management developed and implemented (AGIF, 2020). This plan provides for the implementation of multiple holistic and participatory solutions and in an integrated and cross-cutting manner. After the Black Saturday fires in Australia, recommendations by the Royal Commission lead to significant changes in wildfire management (Whittaker, 2019). Utilizing such windows of opportunity after disasters means that it is essential to do research and have plans ready before disaster strikes, such that any post-disaster window of opportunity for policy change and action can be utilized without delay.

#### **"Fireboards" as per water boards**

In the Netherlands, water boards play a crucial role in water management and flood protection on a regional level. Water boards are the oldest democratic organizations in the Netherlands; the Rijnland waterschap was founded in 1255 (Groenendijk, 2015). Parties with interest in the management of water quantity and quality, like landowners, residents, and wastewater dischargers (businesses and households), elect members to the water boards but also bear the cost of services delivered by the water boards. These bodies originally started through a participatory approach. They operate according to the principle of "interest-pay-say," which means that for individuals that have an interest in an area, they pay tax in that area, and they also have a say in the management of water in that area. Water boards are entitled to raise tax and are financially self-supporting. At least 80% of the

annual costs of water management in the Netherlands are financed via local and regional levy structures (OCDE, 2014). Dutch Regional Water Authorities (water boards) benefit from a dedicated financial institution, the NWB Bank, which provides stable, predictable low-cost finance required for water-related investment (OCDE, 2014). The bottom-up and democratic approach gives democratic legitimacy to the funding and measures put in place and instills a greater degree of trust in the tax investment (Havekes et al., 2017).

Similar to water boards, fireboards could help in the development and implementation of integrated fire management plan. An example similar to this can be found in South Africa, where Fire Protection Associations have a legal mandate to engage and coordinate with stakeholders and aid in the prevention, mitigation, and suppression of wildfires according to the *National Veld and Forest Fire Act (Act 101 of 1998)*. There is also an opportunity for communities that live in or alongside the WUIs to raise funds to implement risk reduction measures. This would enable greater participation, trust, and knowledge in protecting and reducing the impact of wildfire to communities in the WUI. This could be implemented as a private collective community incentive or as a tax by local/municipal government. Organizations like these also create a network through which knowledge sharing, learning, and collective action on integrated fire management can be fostered.

#### **Long-term approach**

One of the novelties of the Dutch Delta Programme was that key decisions and regional strategies were developed with a long-term perspective: up to 2100. This long-term perspective stimulates the combination of investment agendas of different policy fields or authorities (Zevenbergen et al., 2017). A 6-year review cycle is used to assess whether adjustments are needed, to ensure that Dutch water management can anticipate and stay ahead of disasters by adjusting strategies based on climate developments and future scenarios.

This long-term approach is also needed to make a shift from fire suppression to prevention/living with fires (Stoof & Kettridge, 2022) as interventions in the landscape need to be implemented over a long period of time (Moore, 2019; Rego et al., 2019) in contrast to wildfire suppression which is a short-term solution. To adopt this long-term approach, adaptive management needs to be incorporated into integrated fire management. To bring all these layers and collaborative stakeholders together, stakeholder engagement is necessary. In Room for the River, this was done through making information available to stakeholders (Mauser et al., 2013) adding to transparency and building trust. This is also needed in fire

management (Moore, 2019; Rego et al., 2019; Stoof & Kettridge, 2022).

### **Adaptive management**

Adaptive water management was introduced to increase the flexibility and robustness of water management to deal with uncertainty. Adaptive water management explicitly acknowledges the uncertainty and complexity of water management. It is a response to the limitations of water management strategies that focus on perfect prediction and full control (Pahl-Wostl, 2007; Pahl-Wostl et al., 2020). After the 1953 flood, policies started to develop and finally a national framework was adopted based on the approach of adaptive water management. The Dutch government adopted adaptive water management as part of the Delta Programme. In the program, adaptation is not only determined by what is known or anticipated at present but also by what will be experienced and learned as the future unfolds, as well as by policy responses to social and water events (Haasnoot et al., 2012).

The future under human-induced climate change is uncertain for fire and flood risks. In the case of fire, this includes uncertainty not only around the timing and location of human-caused ignitions but also around the potential for fires to develop uncontrollable fire behavior like in the case for 6th generation fire. It is yet impossible to predict the conditions under which fires become uncontrollable, leaving great uncertainty about the fire's development. This means that adaptive management is of greater importance as the future is more uncertain thus a greater need for adaptive management (Craig & Ruhl, 2020; Haasnoot et al., 2018).

In this section, we adapt the six components of adaptive water management (van Buuren et al., 2018) to wildfire management.

### **Accept future uncertainty**

Firstly, adaptive water management accepts future uncertainty by developing scenarios and assessing the robustness of current policy strategies. When uncertainty is accepted, the future in all situations cannot only be based on what has been learned in the past: situations that have never been experienced should be considered too.

For wildfire management, there is a need to acknowledge that future fires are uncertain. It has been well established that fire regimes are changing around the world (Fernandez-Anez et al., 2021b; Kovats, 2014; Pausas & Keeley, 2021; Prichard et al., 2017). Yet, assessment of future fire risks carries uncertainty and risks are likely to change in the future depending on climate change, future land use, and socio-economic developments. It is further important to accept that it is not possible to prevent all

fires and thus the need to become more resilient to wildfires and the impacts thereof in terms of prevention, preparedness, response, and recovery. Awareness needs to be created with society, landowners, civil protections, etc., that (already and) in the future extreme wildfires cannot be controlled and therefore readiness for evacuation, landscape resilience, and home hardening is necessary for all. All the stakeholders need to contribute to being more resilient to wildfires and a new vision of the future needs to be created in this way.

### **Learning by doing**

A second key component of adaptive water management is that there needs to be more opportunities for learning and experimentation (learning by doing). Good examples of effective risk reduction measures are showcased through information services (Nishikawa, 2018) and experiments expanded to bigger scales (Wunder et al., 2021). Local governments are crucial for the implementation of adaptive management as much of the experimentation and learning takes place at the local scale (Zevenbergen et al., 2015). The Room for the River program was a good example of this. It was a 2 billion euro-pilot program that created a more flood-resilient landscape in the Netherlands. Solutions were created as the project progressed with only a safety standard as guidance of what needed to be achieved.

In the landscape fire context, learning by doing can particularly be applied in the context of landscape interventions to reduce the fuel hazards and thus wildfire risk (Wunder et al., 2021). This is especially true for Europe. Across the world, there are many examples of this already happening, e.g., the USA, Australia, and South Africa. There is also major potential for local experimentation in terms of landscape management, preventive burning, and the inclusion of local stakeholders in integrated fire management. Strategic fuel management should be tested in the landscape using a broad toolbox which includes prescribed/controlled wildfire, mechanical fuel reduction methods and grazing, and the creation of fire breaks, green breaks, and adoption of sustainable forest management.

These opportunities should be addressed through inclusive partnerships between public authorities, private sector, academic institutions, and civil society to implement disaster risk reduction measures that foster innovation, combining hard and soft measures (Faivre et al., 2018). Good examples of learning by doing in fire management include the previously mentioned Firewise program aimed to increase resilience of the home ignition zone (NFPA, 2009), initiatives to manage landscape fuels such as the Catalan Fire Flocks (stimulating livestock grazing in the landscape, [www.ramatsdefoc.org](http://www.ramatsdefoc.org))



and Working on Fire and Working for Water in South Africa, as well as initiatives to stimulate fire education and awareness like The Smokey Generation (<http://thesmokeygeneration.com/>) and Firewise (NFPA, 2009). These are valuable initiatives that require further upscaling and implementation not only in “typical” fire countries but also in emerging fire regions like for instance in temperate Europe.

#### ***Acknowledge the possibility of future shocks***

A third pillar of adaptive water management is that it acknowledges the possibility of future shocks. There is a strong sense of awareness that multiple sets of measures are needed to manage flood risks and that additional safety margins are required to account for the uncertainties that go with climate change and future uncertainty. This means that adaptation strategies for the future need to be reversible and flexible if they do not work or if the future unfolds in different directions than expected.

What this concept of acknowledging future shock means for fire is that even if future scenarios are created to anticipate and mitigate changes in climate, landscapes, communities, and wildfire danger and risk, the possibility and impact of major fires need to be accepted and resilience increased. Multiple sets of measures are needed (like in the multiple layers of safety approach) to manage the risks and create safety margins in addition to that. Acknowledging the possibility of future shocks means accounting for future (extreme) events unlike those seen in the past. This means a future with a starkly different fire regime, or the possibility for much stronger extremes, should be considered. For regions with emerging fire risk, this may not only mean increases in fire number and further lengthening of fire seasons but also (potentially drastic) changes in fire controllability, taking into account that changes may not be gradual but stepwise.

#### ***Combination of soft and hard measures***

The fourth component of adaptive water management is that the development of robust adaptation plans often includes a combination of soft and hard measures. Soft measures include matters such as awareness raising, education, development of evacuation plans, and emergency response plans. Hard measures include physical measures such as landscape development and access roads. Hard measures are often highly effective for well-defined risks but are often expensive, not very flexible, and hard to reverse. In light of this, soft measures are paramount to ensure adaptation to future uncertainties.

The soft measures listed here are similar across risks, so for fire, the same soft measures are required to develop robust adaptation plans as in water: awareness raising, education, and evacuation plans. The hard measures in

fire include fire breaks, management of the home ignition zone, and automatic detection of fires, as well as water access points. Focus on these physical measures may outshine the soft measures and societal engagement required to manage fires. They are more visible and media-genic which may give the impression to the public or to emerging fire countries that these hard measures can be used stand-alone. Yet, for effective risk management, hard measures are not completely effective without solid soft measures (Carvalho & Rabechini, 2015).

#### ***Avoid unnecessary lock-ins***

The fifth pillar of adaptive water management is that it aims to avoid unnecessary lock-ins, like building cities in areas that will likely become vulnerable to climate change impacts (more flooding) in the future. To prevent such lock-ins, development of future scenarios or so-called pathways can assist, in which consideration of the consequences of certain development decisions can help to visualize the impact of current developments on future risks. This does not necessarily mean that urban expansion must be stopped but rather that urban development must be guided in areas where there is lower future risk. In the Netherlands, there is still urban expansion in areas below sea level or near rivers and water with high flood risks, but the future risk has been considered and development has happened in a way to make it more resilient to future conditions.

Translating this concept to fire management means preventing lock-ins due to urban or industrial development into (future) high-fire-risk areas, either by preventing such developments or by taking steps to reduce fire risks in these newly developed areas. Future scenarios to be considered are any expected changes in fire danger or in the fire hazard (the fuels) in which example, certain vegetation types or landscapes could become more susceptible to fires to future droughts and heatwaves.

Another unnecessary lock-in would be to focus wildfire management and investment only on suppression resources. Again to be more adaptive, more investment is needed in different options to make the landscape more resilient through systematic and strategic fuel management as well as the creation of fire breaks, green breaks, and adoption of sustainable forest management.

#### ***Capitalize on no-regret options***

The sixth and final component of adaptive water management is that it capitalizes on no-regret options: win-win solutions that “generate net social or economic benefits irrespective of whether or not climate change occurs, as well as across a range of possible climate futures” (Phillander, 2008). Adaptive water management thereby

increases system robustness by taking easy-to-take measures that reduce risk or increase adaptive capacity and do not harm other public interests and can even lead to benefits. This positive approach to risk management when applied to fire means that landscape fuels are managed in a way that landscapes and their communities benefit from it, not just because it reduces fire risks but also because it results in gains in other fields. Ultimately, the scale of landscape management required to manage fires effectively calls for a significant change in the way rural landscapes are managed. A forest-based bioeconomy, as called for by Verkerk et al. (2018), can be the fire parallel to the no-regret options sought by adaptive water management.

Adaptive water and fire management is as much a social as a scientific process, because it requires the cooperation of stakeholders at all levels of society to be able to implement and react to change (Engle et al., 2011; Zevenbergen et al., 2013). Adoption of adaptive management in wildfire management is therefore crucial to adapt to future uncertainties and to realize the paradigm shift needed to work towards living with fire (Stoof & Kettridge, 2022).

#### Stakeholder participation to create resilient landscapes

Living with water is engrained in the landscape of the Netherlands. The Room for the River project was started as a national plan to adapt to living with water and reduce the risk of flooding as a nature-based solution (Table 1).

One of the main successes of the Room for the River program is its stakeholder engagement. The Dutch government takes full responsibility for flood protection in the Netherlands and therefore funds flood risk reduction measures out of tax funds. To bring all these layers and collaborative stakeholders together stakeholder engagement is necessary. In the Room for the River program, this was done through making information available to

stakeholders adding to transparency and building trust. Due to the interest of the stakeholders in this area, these had to be involved in the projects as they would have to live with the outcomes of the program every day. Therefore, it was crucial to engage with the stakeholders to find situations that the stakeholders were content with. Therefore, much attention was given to information and consultation meetings with local administration and stakeholders. The local government worked closely with the local residents of each project location in the Room for the River program. Together, they tried to answer the questions: “how do you want to achieve the required reduction of the water level?” During this participative process, some solutions were found with which all stakeholders were content with. During this process, the role of information and local knowledge was crucial (Marchand et al., 2019). A decision support system, called the Planning Kit, was developed to manage the information and support joint planning with stakeholders (Van der Most et al., 2018).

To adapt to future changes in fire risks, there is a need for large-scale landscape transformation throughout Europe. In addition, there are large-scale opportunities due to land abandonment and EU rural development funds. To ensure that large-scale interventions in the landscape are efficient such as controlled burning, creation of buffer zones, and placements of interventions in landscape efficient in reducing wildfire hazard and spread, stakeholder participation is important. There is a need to better connect science and practice (Moore, 2019; Stoof & Kettridge, 2022) and to define common objectives and solutions to potential problems and challenges and develop links with other rural development objectives and landscape and ecosystem services. Although there has been some use of participatory approaches in wildfire (Bilbao et al., 2019; McGee & Langer, 2019; Otero et al., 2018), there needs to be

**Table 1** Summary of the Room for the River program in the Netherlands

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The “Room for the River” program had a budget of more than 2 billion Euro and consisted of 39 different projects located along all the main branches of the river Rhine (Rijke et al., 2012). The project was started in 2007 and is expected to be finished in 2022. The main idea was to give the rivers back the space that was lost to development during the past centuries when rivers were channelized and floodplains became occupied by industries and residential areas and to reduce the number of people living in high flood risk areas. In Room for the River, instead of heightening the dikes, the dikes were moved further away from the river to give more space for the river by creating additional flood plains. This reduces the water levels during peak flow events and limits the risk that dikes would break or overtop. In addition to reducing flood risks, the Room for the River Program had many co-benefits. The floodplains are high in biodiversity and can be used for recreation in summer and support animal grazing. Resilient landscapes were created by adapting the land use to current and future flood risks. Areas with low flood risk are used for high-value activities and human settlement while in high-flood-risk areas the activities are limited to lower-value activities such as agriculture and seasonal camping grounds. The room for the rivers approach could be copied into integrated fire management by creating more room for fires. The concept of living with fire is not new, e.g., coexisting with fire in Canada (Abbott & Chapman, 2018), living with fire in the USA (Moritz et al., 2014) and Australia (Howitt, 2014). Applying the Room for the River approach to fire would mean creating deliberate zones where fires can occur and reducing the potential damage by removing properties and other higher-value buildings the impacts of fire reduce. Around the living with fire areas, low-fuel load zones can be implemented in the landscape to limit the spread and severity of fires beyond the living with fire zones. These zones can be multi-purpose and also serve in addressing the recreational needs of the communities and conserve and improve biodiversity by creating zones with different fire return periods.

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greater involvement of stakeholders to make communities and the landscape more resilient to wildfire holistically (Smith et al., 2016; Tedim et al., 2021). In integrated fire management, we need more sharing of information but also applying participatory processes to fire can aid in the design and experimentation with solutions regarding fuel management in the landscape. It is important to include knowledge of local communities affected by the interventions and exchange knowledge with scientists and include this in the planning process.

### Discussion and conclusion

Changes in land management (De Rigo et al., 2017; Moore, 2019), climate change (Moreira et al., 2020; Tedim et al., 2015), and urban expansion into the WUI have led to the potential for economic and social impacts of wildfires to be extremely high (Badia et al., 2019; Radeloff et al., 2005).

It has long been acknowledged that to address these changing risks, a sole focus on fire suppression is not sufficient and changes in fire management are necessary (Moore, 2019; Rego et al., 2019; Stoof & Kettridge, 2022). A shift is needed towards a living with fire approach in which wildfires are accepted as part of the natural environment where fire also has positive impacts on, e.g., biodiversity and landscape management. Just as the Netherlands has learned to live with water, “typical” and emerging fire-prone regions need to learn how to live with fire.

Learning from Dutch water management, to increase resilience against wildfires, there is a need for an integrated and holistic approach with a focus on collaborative governance, adaptive management, and resilient landscapes through stakeholder participation. This needs to be done by taking a long-term approach with more space for experimentation and learning-by-doing on a landscape scale and with shared responsibility and initiatives between science, practice, and society. Another lesson from water management is the consideration of multiple layers of safety with cooperation between government, NGOs, communities, landowners, and civil protection. Where fire suppression can often be managed by a central department using top-down approaches and command lines, this is not possible in integrated fire management and when taking a living with fire approach. Like water, fire is a topic that touches a multitude of actors, disciplines, and government levels. Collaboration between these entities is essential to embrace wanted or accepted fire where, how, and when it is welcome; prevent fires where they should not take place; and stop fires where they can cause undesired impacts, large-scale destruction, and loss of lives. This means that participation of stakeholders is essential and that collaboration between

stakeholders is required to share responsibility and knowledge to facilitate uptake of fire management by society, landowners, civil protection, and policymakers.

While there are similarities between living with fire and living with water, it is important to acknowledge that there are key differences between water and fire. In addition to devastation from floods caused by water, water is also an essential resource, and it is not difficult for people to see the benefits of water. Fire is still seen as a destructor causing loss of human and animal lives, properties, and natural vegetation by many. This is understandable given the type of fire that reaches the public media that tend to cover the relatively small number of extreme fire events and wildfire disasters and not the thousands and thousands of mild fires burning around the world. There is a need to better explain to key stakeholders that fire also has important benefits as a nature-based solution, especially for biodiversity (Kelly et al., 2020). Controlled or prescribed burns interventions need to be expanded in the landscape to effectively contribute to decrease the size of wildfires and aid in fire management planning and operations in general (Davim et al., 2021). Another key difference between water and fire is the role of humans in wildfire ignition. Many fires are started due to human activities while floods are mainly caused by natural processes such as storms, rainfall, snowmelt, and runoff processes. The key similarity however is that how we manage the landscape has a large influence on the impacts of the events. Avoiding development in flood plains and maintaining vegetation to limit erosion limit the impacts of floods. In the same way, avoiding development in fire-prone areas, maintaining fire breaks and sufficient prescribed fires may limit the impacts of sudden wildfires. While both future fire and flood frequency and severity are uncertain, the science on predicting floods is much more advanced compared to predicting future fires (Fargeon et al., 2020). This indicates a higher uncertainty of future fires. However, this would call for an even broader inclusion of adaptive management to deal with these uncertainties (Craig & Ruhl, 2020; Haasnoot et al., 2018). In conclusion, even given the differences between fire and water management, fire management can learn three important lessons from water management: (1) a holistic and integrated approach, (2) adaptive management, and (3) resilient landscapes through stakeholder participation. There are key changes in future fire risks that make it necessary to embrace changes in the way wildfires are managed, and there are important lessons that can be learned from water management that can guide the changes from wildfire suppression to living with fire.

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### Authors' contributions

CK, FL, CS, SP and HL conceived research. The literature review was conducted by HL and RB. HL was mainly responsible for writing with major contributions by FL and CS. The manuscript was reviewed during multiple rounds by CK, FL, CS, SP and RB. CK, FL, CS and SP were responsible for the supervision of the research. All authors have read and agreed to the published version of the manuscript.

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