Ponderful

PONDS FOR CLIMATE

Ponds and Pondscapes

A TECHNICAL GUIDE TO THE USE OF PONDS AND PONDSCAPES AS NATURE-BASED SOLUTIONS FOR CLIMATE CHANGE MITIGATION AND ADAPTATION

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Executive summary

This technical handbook provides practical advice on the protection, management, restoration and creation of ponds and pondscapes to mitigate and adapt to the impacts of climate change. It was created by the EU Horizon 2020 funded project **PONDERFUL**, which ran from December 2020 to 2024.

Ponds are small standing waters with a surface area from 1 m^2 to 5 ha that may be permanent or temporary, man-made or naturally created. When grouped together they form pondscapes, comprising ponds of different sizes, shapes and depths. Ponds deliver a range of Nature's Contributions to People, defined by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) as the positive and negative impacts of nature on people's quality of life. Collectively they are vital for helping us to tackle major societal challenges.

Perhaps because of their small size, ponds have long been overlooked in freshwater science, policy and practice. Despite this, in many parts of the world they are collectively the richest part of the water environment and provide a refuge for many endangered species. They are numerically the most abundant freshwater habitats, found from the tops of mountains to the depths of forests, lining the floodplains of our biggest natural rivers and providing oases of water in the driest of lands. They make up an estimated 30% of global standing water but, as they are often undetectable on satellite images, it is difficult to evaluate their abundance with certainty.

Because ponds are individually small, they are easy to work with and have immense potential as nature-based solutions: habitats whose management, restoration and creation benefits both nature and people. From individual tiny ponds supporting rare amphibians and endangered invertebrates, through to ponds providing water for livestock and holding back flood water, and including the immense networks of ponds in some of the world's biggest wetlands, ponds are ubiquitous and vital. The natural biological richness of ponds means that they have a disproportionately large role to play in the maintenance of humanity's options for the future.

Ponds are a natural habitat which has existed for billions of years but in the modern human-dominated world they are often created by people. Although they have been long-overlooked by freshwater science, this handbook benefits enormously from the growth in our knowledge of ponds over the last 20 years. This includes the work of **PONDERFUL**, which brought this together for the first time to inform practical landscape management across Europe – and beyond.

The threats to ponds and pondscapes are familiar: habitat loss, pollution, invasive species and the overarching impact of climate change. The ecosystem services provided by many ponds have been impaired or eliminated by land-use change, especially urbanisation and the intensification of agriculture, and are further at risk because of climate change. In this handbook, we describe practical approaches to stop, adapt to or mitigate these impacts.

Ponds and pondscapes do not exist in isolation but form a network of freshwater habitats with other types of waterbody. Although many species are unique to ponds, others are shared with rivers, lakes and wetlands. In **PONDERFUL**, we have developed new modelling tools, landscape scenarios and a multi-criteria decision making tool to help policy makers and managers exploit these networks and plan the use of ponds and pondscapes to deliver Nature's Contributions to People as effectively as possible.

Chapters 1 and 2 of the handbook introduce the role and nature of ponds and pondscapes and of the ecosystem services, nature-based solutions and Nature's Contributions to People they provide. In Chapter 3 we summarise how ponds and pondscapes provide six broad classes of ecosystem service which address 11 of the societal challenges identified by IUCN, including the need for biodiversity enhancement, disaster risk reduction, human health improvement, climate change mitigation and adaptation, better water management, improved food security and social and economic development. At first sight, it might seem implausible that these small freshwaters could influence such large problems, but in this handbook we show how ponds and pondscape can provide many different Nature's Contributions to People.

We have grouped the Nature's Contributions to People supplied by ponds into the following categories to give practical guidance on delivering these effectively:

- ***Adapting to and mitigating the impacts of climate change.*** Ponds are major sources and sinks of greenhouse gases and carbon. Their abundance and high levels of biogeochemical activity means that they have a significant role to play in the management of the carbon cycle. **PONDERFUL** and other data show that we can reduce greenhouse gas emissions to the lowest level from ponds and pondscapes by ensuring that they are as free from pollution as possible, whilst capitalising on their potential to store carbon.

- ***Regulating hazards (including flood and heatwaves).*** Ponds have a long history of helping to regulate hazards from flooding but can also ensure that water is present for longer in the landscape during increasingly frequent hot and dry weather. Ponds and pondscapes can also help to cool landscapes, especially in urban areas.

- ***Regulating freshwater quality and quantity.*** Ponds are widely used to 'clean up' polluted water running into other freshwater habitats by holding back and purifying water as it flows through catchments. We provide practical advice to ensure that this clean up service does not impair the underlying biological contribution that must be made by nature-based solutions. We also show how creating new clean water ponds, protected from pollutant sources, is a quick and easy way of bringing more clean water into the landscaped rather than relying on ponds only to clean up pollution. In turn, by strengthening the network of freshwater habitats ponds can in turn increase terrestrial biodiversity, particularly in arid regions. New evidence from the **PONDERFUL** projects suggests easy ways to achieve this through a combination of pond management, restoration and creation.

- ***Supporting pollination.*** Ponds support populations of organisms that pollinate crops. Managing or restoring overgrown and neglected ponds can substantially increase numbers of pollinators and farmed landscapes should benefit substantially from this service.

- ***Learning and inspiration, human health and wellbeing.*** Ponds are well known for their ability to inspire people's awareness of nature, increasing their wellbeing. The handbook provides guidance on the practical techniques for pond management, restoration and creation that can be used to support these health and psychology related Nature's Contributions to People.

- ***Habitat creation and maintenance.*** Central to the value of ponds is their importance as habitats, and for maintaining freshwater biodiversity. We summarise the key practical measures needed to protect, manage, restore and create ponds and pondscapes to maximise the habitat creation and maintenance benefits they provide.

Central to the delivery of all of the Nature's Contributions to People provided by ponds and pondscapes are the practical methods for protecting, managing, restoring and creating ponds and pondscapes. In Chapter 4 we provide detailed information for site managers on measures to achieve this. This includes guidance on how to plan and prioritise pondscape projects and how to risk assess the different options for managing, restoring or creating ponds. There is advice on how to ensure that work with ponds fits into the 'mitigation hierarchy' so that damage to ecosystems in infrastructure and other building projects is, as far as possible, designed out of projects. We summarise the key concepts for effective pond and pondscape management including understanding the pond catchment, the importance of 'clean water', the role of different water sources for ponds and how this influences the delivery of different Nature's Contributions to People. In addition, we review the practical issue of long-term management of ponds and pondscapes.
We describe the practical techniques and pros and cons of management, restoration and creation, including the concept of resurrecting so-called 'ghost' ponds.

Modification of ponds and pondscapes through management or restoration ranges from low impact, frequent, management at one end of the spectrum to high impact, infrequent, pond restoration at the other end of the spectrum. Pond and pondscape management often mimics natural forms of disturbance which may no longer occur in the modern landscape. Restoration, in contrast, commonly involves a high level of disturbance including dredging to remove sediment and vegetation or removing extensive tree and shrub growth, including felling large trees.

Many of the problems limiting the potential of existing ponds to provide Nature's Contributions to People are concerned with pollution and we describe the methods which can be used to prevent land management practices from polluting ponds. Any intervention needed to manage ponds and pondscapes is likely to have both positive and negative effects. We therefore also provide detailed practical guidance on risk assessing pond and pondscape work.

The value of new ponds is described, along with the method for creating new ponds which optimise benefits for biodiversity and the delivery of other ecosystems services. Creating new ponds simulates ancient and natural processes, which have operated over millions of years, providing in the most natural way Nature's Contributions to People. New ponds can be created in the optimum location for providing these ecosystem services whereas existing ponds are often constrained by their location and surroundings. Creating new unpolluted clean water ponds makes a major contribution to the creation of freshwater habitats and we provide detailed guidance on the pond creation process to ensure that the use of new ponds as nature-based solutions provides the greatest benefits for biodiversity. We provide detailed guidance on how to locate sources of clean water for high quality ponds, how to protect ponds from pollution and a simple practical checklist of design stages.

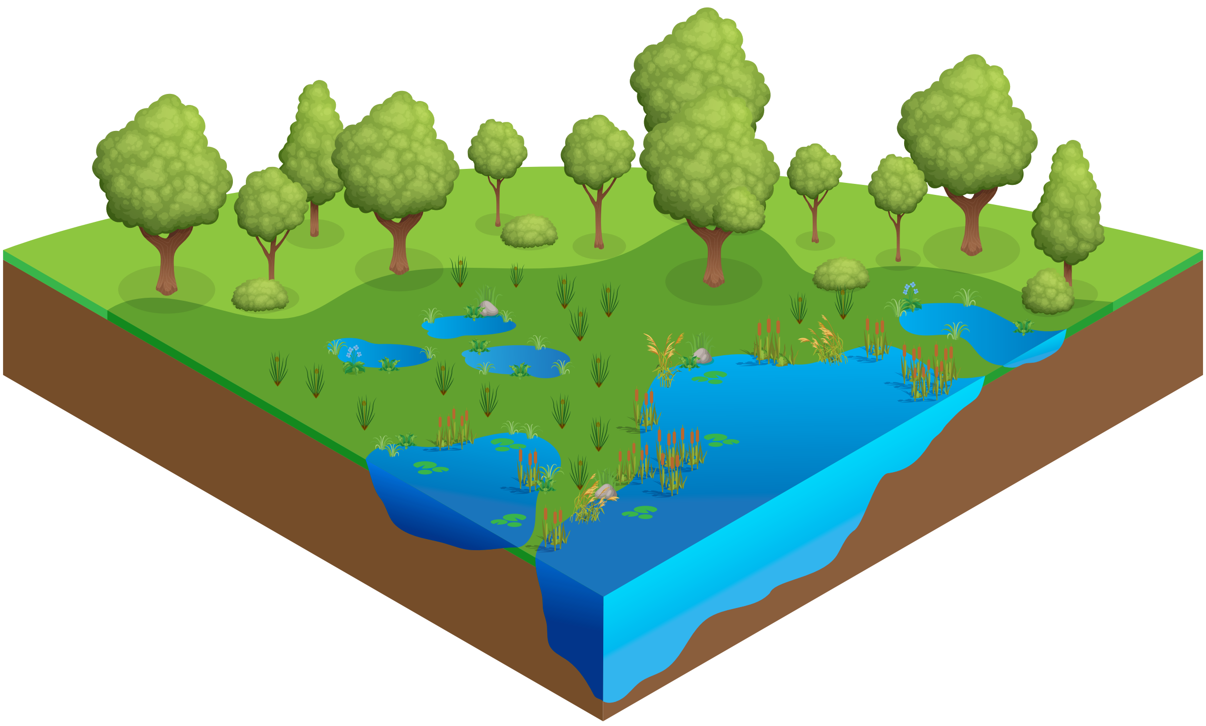
We introduce the concept of CLIMA-ponds, developed through **PONDERFUL**. These are ponds designed specifically to mitigate the problems caused by climate change, addressing the three major problems we are facing: loss of biodiversity, excess greenhouse gases in the atmosphere and the maintenance of a variety of Nature's Contributions for People and ecosystem services.

To ensure that the use of ponds and pondscapes as nature-based solutions benefit both people and nature, monitoring is important. We summarise monitoring methods for ponds and pondscapes and the ecosystem services they provide. Monitoring of ponds is most commonly concerned with assessing ecological status. This is fundamental to ensure that they are playing their role fully as nature-based solutions and generally involves a combination of physico-chemical methods and biological surveys. To assess the effectiveness of other Nature's Contributions to People it is usually necessary to adopt methods that are more widely applied and not specific to ponds (e.g. flow modelling and monitoring to assess the effectiveness of flood control; questionnaire surveys to assess the extent to which ponds deliver psychological or physical benefits for people). We note that new methods for assessing Nature's Contributions to People are still being developed and recommend that site managers and practitioners engage with researchers to ensure that new methods meet their needs.

We place special emphasis on designs needed to protect, maintain and restore biodiversity in the face of climate change because it is a fundamental requirement of all nature-based solutions that they benefit nature. We are fortunate that there is good evidence of what does and does not make a difference for biodiversity, which allows us to confidently predict how to design ponds and pondscapes which truly benefit both people and nature.

In Chapter 5, we provide a short section on financing and promoting pondscapes. Sourcing funding for ponds can be challenging because their role and value has been under-appreciated. However, with growing understanding of the importance of ponds and pondscapes – and the urgency of the freshwater and climate crises – we expect that this 'resource squeeze' may be gradually relaxed. Key drivers in local, national and international policy which highlight the value of ponds include the recently adopted EU Nature Restoration Law and the Convention on Wetlands resolution on the Conservation and management of small wetlands.

Chapter 6 features success stories from **PONDERFUL** demonstration sites. These case studies show the wide variety of ways in which ponds and pondscapes deliver Nature's Contributions to People.



Forewords

In every corner of the globe, people and wildlife have always depended on wetlands. Now, as climate change reshapes our daily lives and our natural landscapes, these freshwaters have become even more important for biodiversity and human health.

Ponds – small but remarkably important freshwater wetlands – are biodiversity hotspots, supporting a rich diversity of plants and animals. During a recent visit to the United Kingdom in early 2024, I learnt about how ponds that had disappeared in agricultural landscapes were being restored with a surprising return of plant and insect species that were believed to have disappeared. These small, yet vital ecosystems, also provide us with a host of ecosystem services: from filtering pollutants to protecting against floods, as well as playing a central role in our wellbeing.

Sadly, ponds, like many small wetlands, are threatened by pollution and changing land use. Climate change is adding further pressure on these habitats, while simultaneously increasing our need for high quality, clean freshwaters. Reflecting this, the recent recognition of their importance by the Convention on Wetlands, through the adoption of Resolution XIII.21: Conservation and management of small wetlands, is an important step in the protection and wise management of these vital systems.

Ponds are found in every country of our 'blue planet' and their restoration should be a priority for governments and other stakeholders. To ensure the future health of our ponds and wetlands, landowners also need to understand how to restore, manage and create high quality ponds and pondscapes. This knowledge and collaboration will be crucial in our collective efforts to adapt to a changing climate.

By working together to restore, manage and create ponds and pondscapes, we can continue to benefit from the enormous benefits these small but mighty ecosystems provide.

Dr Musonda Mumba, Secretary General of the Convention on Wetlands

There is hardly any day without news about extreme weather events, heatwaves or landslides. We are facing a planetary emergency caused by interdependent climate change and biodiversity loss. We urgently need to accelerate the implementation of technological and nature-based and societal solutions.

This requires interdisciplinary teams and knowledge. We need to continue and scale up fruitful collaboration and foster implementing nature-based solutions from small scale to large scale in rural and in urban areas, while at the same time further advance our knowledge.

However, for now we are still in a vicious circle where emission ambition is still too weak to reach the Paris Agreement objectives and increasing biodiversity loss and ecosystem depletion weakens their climate capacity. We can change this by aligning and strengthening climate and biodiversity ambition, we can enter a virtuous circle where strong emission reduction helps to reduce climate impact on ecosystems, which in turn deliver the essential services in which societies and economies depend. At the same time, we need to stop excessive human pressure on our ecosystems and biodiversity so that they and we can better cope with the impacts of climate change.

Limiting global warming to ensure a habitable climate and protecting biodiversity are mutually supporting goals and their achievement is essential for sustainably and equitably providing benefits to people. Treating climate, biodiversity and human society as coupled systems is key to successful outcomes from policy interventions.

The **PONDERFUL** project has shown how ponds and pondscapes as nature-based solutions can address social, economic and environmental challenges. This user-friendly handbook for anyone working in pond protection, management, restoration or creation will encourage creating, restoring and protecting ponds.

The practical considerations on how to implement nature-based solutions are timely and highly relevant. As a policy-maker I warmly recommend the quick guide to the use of ponds and pondscapes as nature-based solutions.

We know what needs to be done, we have the knowledge, we have the means, we have the commitment expressed on highest political levels. In my view the biggest challenge is time. The question is no longer what and how. The question is will we manage to do what has to be done in the short time available.

We still have the choice whether we continue stealing the future from our children and grandchildren through continuation of unsustainable development, consumption and production patterns or whether we will heal the future for them through protection, conservation, restoration, sustainable use and management of ecosystems through an equitable and decarbonised economy with people and nature at the heart and centre. As a mother and grandmother, in my view only the second option is acceptable.

Karin Zaunberger, International Relations Officer, European Commission DG Environment

Who the guidance is for

This guide is for people involved in planning, designing and implementing practical projects that use ponds and pondscapes as nature-based solutions for addressing social, economic and environmental challenges. For policy makers and legislators, a quick guide to the use of ponds and pondscapes as nature-based solutions is provided by the **PONDERFUL Policy Guidance document**. If you require detailed scientific information about the role and use of ponds and pondscapes, have a look at the References and Further Reading at the end of the document. For more technical introductions to the ecology of ponds, read 'Ponds, Pools and Puddles' (English) and 'Mares et Étangs: Ecologie, conservation, gestion, valorisation' (French).

WHAT YOU WILL FIND IN THIS GUIDANCE AND WHAT YOU WILL NOT FIND.
In the guide we provide an introduction to the use of ponds and pondscapes as nature-based solutions to tackle seven societal challenges identified by IUCN: climate change adaptation and mitigation, disaster risk reduction, environmental degradation and biodiversity loss, human health, socioeconomic development, food security, and water security.

OUTLINE OF THE DOCUMENT.
The text is organised into five main chapters:

- Overview of the issues and use of ponds and pondscapes as nature-based solutions
- Ponds and pondscapes as nature-based solutions: a detailed introduction
- Practical techniques for managing, restoring and creating ponds and pondscapes as nature-based solutions
- Costs and practical constraints
- Success stories: example of the use of ponds and pondscapes as nature-based solutions.

HOW TO READ THE DOCUMENT.
We recommend that readers start by reading the Executive Summary to get a quick overview of the context, followed by Chapter 2. We then suggest selecting success stories from Chapter 6 that match your interests, and finally examining the detailed guidance in Chapters 3, 4 and 5.

To quickly locate ways to use ponds and pondscapes as nature-based solutions, look out for the '**Best practice' tips** throughout the manual.

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1. Introduction - setting the scene

PONDERFUL (POND Ecosystems for Resilient Future Landscapes in a changing climate) was a Horizon 2020 'Research and Innovation Programme' project. It investigated how ponds and pondscapes can be used as nature-based solutions for climate change adaptation, and for delivering ecosystem services and Nature's Contributions to People (including biodiversity conservation). Ponds are small standing waters, up to five hectares in area, which may be permanent or seasonal, created naturally or human-made. A pondscape is a network of ponds, spread across the landscape, providing habitats for freshwater biota, and multiple ecosystem services for people.

The **PONDERFUL** project ran from 2020 to 2024 and was funded by the European Union Horizon 2020 programme under the topic 'Inter-relations between climate change, biodiversity and ecosystem services'.

Ponds are the most numerous type of waterbody on Earth, perhaps representing 30% of the total area of standing water. In Europe, ponds support around 70% of freshwater species. They also support a larger proportion of rare, endemic and threatened species than lakes or rivers. Despite this, ponds have traditionally been undervalued.

Led by the University of Vic - Central University of Catalonia (Spain), **PONDERFUL** provided new data and guidance to make more and better use of ponds and pondscapes as nature-based solutions to the challenges facing society.

1.1 WHAT ARE NATURE-BASED SOLUTIONS?

This handbook focuses on how ponds and pondscapes can be protected, managed, restored and created to provide nature-based solutions that help reduce the effects of global change. But what does this mean? In simple terms, nature-based solutions are measures put in place to address some of the challenges facing society. They use the natural functions of healthy ecosystems to protect the environment and to provide economic and social benefits. These range from environmental issues, such as climate change and biodiversity loss, to food and water security, human health and people's wellbeing. In this guide we link the definitions used by IUCN, the EU and the UN in treating nature-based solutions as measures which must provide benefits both for biodiversity and for human wellbeing.

- United Nations: Nature-based solutions are: 'Actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems, which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human wellbeing, ecosystem services and resilience and biodiversity benefits.'

- European Commission: Nature-based solutions are: 'Solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systemic interventions.'[1]

- IUCN: Nature-based solutions address societal challenges through actions to protect, sustainably manage, and restore natural and modified ecosystems, benefiting people and nature at the same time.

In this guide we use these definitions of the services provided by nature-based solutions synonymously alongside the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) defined Nature's Contributions to People.

Of course, no single pond can address all of the challenges facing society. However, a network of ponds – or 'pondscape' – can provide multiple benefits. In this handbook, we focus on ponds at the landscape scale – the pondscape – and guide you through setting clear and realistic objectives for each individual pond in that pondscape.

This handbook shows how you can deliver nature-based solutions by protecting, managing, restoring and creating ponds, and how, with ponds, you can deliver Nature's Contributions to People. In Chapters 2 and 3, we take a detailed look at how ponds can help us address societal challenges. Chapter 4 describes in detail practical methods for working with ponds and pondscapes to deliver ecosystem services and Nature's Contributions to People. Chapter 5 briefly reviews policy and financing issues that affect the use of ponds as nature-based solutions and in Chapter 6 we provide success stories about the use of ponds and pondscapes as nature-based solutions.

Box 1. Societal challenges, nature-based solutions, ecosystem services and Nature's Contributions to People

The enormous urgency of the biodiversity and climate crises has spawned an often bewildering jargon used by specialists to describe the benefits and 'services' we get from nature. In this manual we have applied this terminology as correctly as possible, while making it accessible to practitioners.

IN BRIEF:
Societal challenges are the threats we all face (drought, lack of food, lack of water, loss of biodiversity); we use a definition from IUCN to define these challenges. Many of these threats can be reduced and controlled with nature-based solutions, practical techniques based on habitats and species that make the most of the essential qualities of ecosystems to address societal challenges, helping both people and nature (we use the definition from IUCN and also take account of the EU and UN definitions of nature-based solutions, which are similar). Examples of nature-based solutions include creating new ponds or restoring rivers to reduce floods.

Nature-based solutions that address societal challenges provide us with services from nature that we benefit from. Two classifications have been used to categorise these benefits: ecosystem services and, most recently, Nature's Contributions to People.

1.2 WHAT ARE ECOSYSTEM SERVICES AND NATURE'S CONTRIBUTIONS TO PEOPLE?

Ecosystem services are the many benefits provided to people by the natural environment, and can be divided into provisioning, regulating, supporting and cultural services (see Figure 1). Some are direct contributions, such as water, clean air, food and raw materials. Others provide indirect benefits to people, such as physical and mental health, tourism, knowledge and learning. Ecosystem services provided by ponds also include environmental contributions, such as healthy soils and habitats for wildlife.

These benefits are likely to be increasingly referred to as 'Nature's Contributions to People', a term introduced by IPBES. These include both the positive and negative impacts of nature on people's quality of life. The positive contributions are similar to those described as ecosystem services, while negative contributions can include disease transmission or predation that damages people or their assets. In this guide we have primarily used the IPBES terminology, but have occasionally referred to 'ecosystem services' to help the reader understand the context.

Nature's Contributions to People are not generated from nature alone, but through a series of social-ecological functions and interactions. Nature-based solutions are part of, or facilitate, many or all stages of this co-production process to secure the supply of Nature's Contributions to People. In the manual we have focused on 11 Nature's Contributions to People which are most relevant to ponds and pondscapes: habitat creation and maintenance, pollination, regulation of freshwater quality, regulation of freshwater quantity, regulation of hazards and extreme events, regulation of climate, physical and psychological experiences, learning and inspiration, supporting identities, maintenance of options, and food and feed.

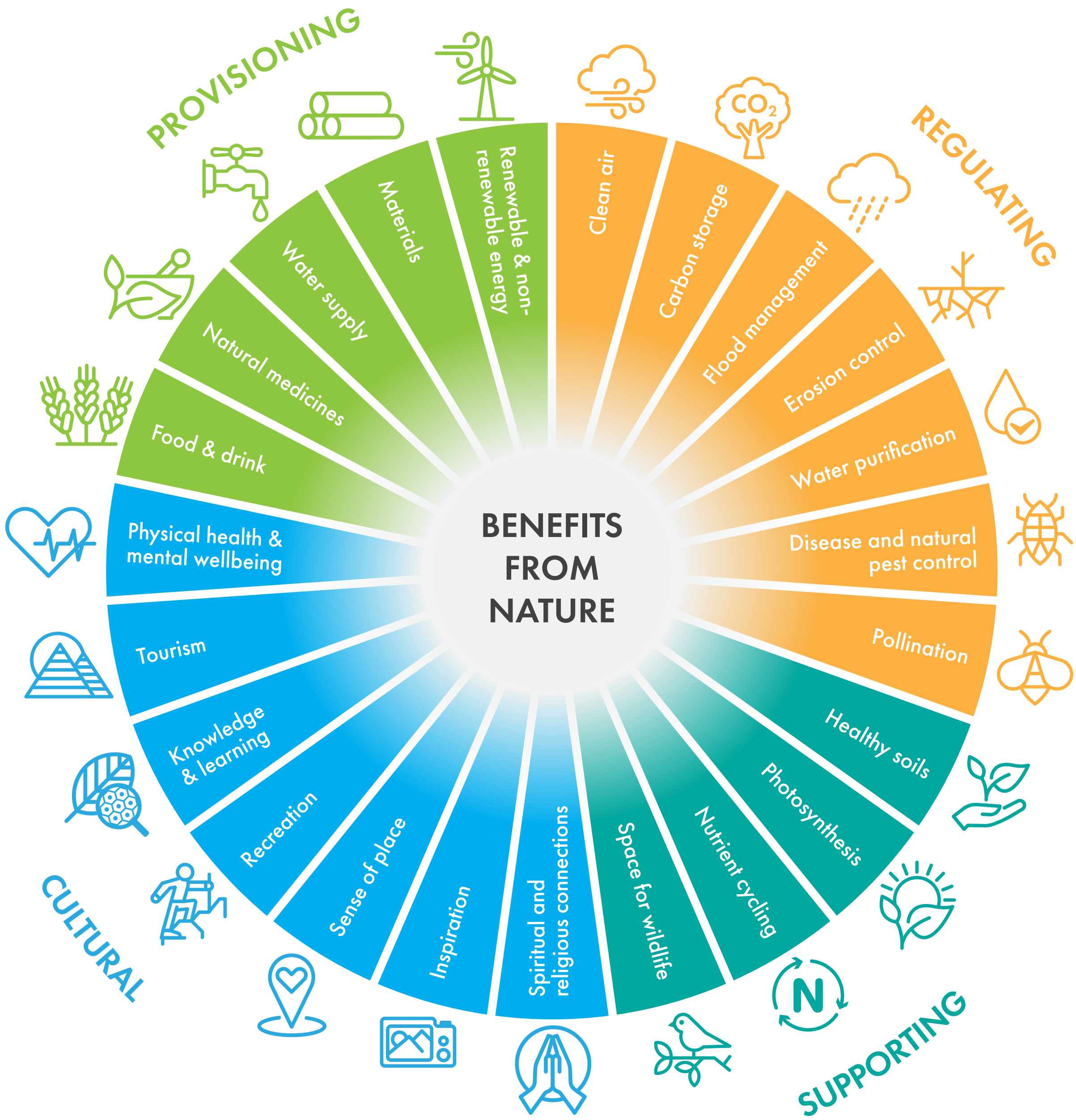

Fig. 1 - Ecosystem services are the benefits that people derive from healthy ecosystems, including ponds and pondscapes.

Table 1 - Nature's Contributions to People provided by ponds and pondscapes

REGULATION OF HAZARDS AND EXTREME EVENTS

Definition: Reduction, by ecosystems, of the impacts on humans or their infrastructure caused by e.g. floods, wind, storms, hurricanes, heat waves, tsunamis, high noise levels, and fires.
Contribution: Ponds and pondscapes can be used to regulate flood hazards, hold water in the landscape during dry weather and provide cooling in high temperatures (especially in cities).

REGULATION OF FRESHWATER QUANTITY

Definition: Regulation, by ecosystems, of the quantity, location and timing of the flow of surface and groundwater used for drinking, irrigation, transport, hydropower, and as the support of non-material contributions.
Contribution: Ponds store water, making them valuable for runoff management and the provision of natural flood control.

REGULATION OF FRESHWATER QUALITY

Definition: Regulation, through filtration of particles, pathogens, excess nutrients, and other chemicals, by ecosystems or particular organisms, of the quality of water used directly or indirectly.
Contribution: Every pond has purification potential, which increases with size and depth. Therefore, the cumulative impact of many ponds can mean a large pondscape with high pond density has substantial potential for purifying water.

REGULATION OF CLIMATE

Definition: Climate regulation by ecosystems (including regulation of global warming) through positive or negative effects on emissions of greenhouse gases (e.g. biological carbon sequestration, methane emissions from wetlands).
Contribution: Ponds and pondscapes play a substantial role in storage of carbon and regulation of greenhouse gases; managing ponds and pondscapes is essential for management of the carbon cycle.

FOOD AND FEED

Definition: Production of food from wild, managed, or domesticated organisms, such as fish, beef, dairy products, edible crops, wild plants, mushrooms, and honey.
Contribution: Water storage supporting wild and domesticated animals and crops is probably one of the most ancient nature-based solutions linked to ponds in agricultural landscapes.

POLLINATION

Definition: Facilitation by animals of movement of pollen among flowers, and dispersal of seeds, larvae or spores of organisms beneficial or harmful to humans.
Contribution: Large numbers of pollinators around and near ponds, and in pondscapes, facilitates pollination.

PHYSICAL AND PSYCHOLOGICAL EXPERIENCES

Definition: Provision, by landscapes, seascapes, habitats or organisms, of opportunities for physically and psychologically beneficial activities, healing, relaxation, recreation, leisure, and tourism, and aesthetic enjoyment based on the close contact with nature.
Contribution: Ponds provide a range of experiences, including contact with water (e.g. swimming) and nature (tourism and leisure).

LEARNING AND INSPIRATION
Definition: Provision, by landscapes, seascapes, habitats or organisms, of opportunities for the development of the capabilities that allow humans to prosper through education and knowledge
Contribution: Ponds and pondscapes are important resources for learning about, and drawing inspiration from, the natural world.

SUPPORTING IDENTITIES
Definition: Landscapes, seascapes, habitats or organisms being the basis for religious, spiritual, and social-cohesion experiences.
Contribution: Ponds support social cohesion (e.g. Toads on Roads campaigns, UK), regional identity (e.g. fish ponds, CZ), and 'Fêtes des Mares' celebrating ponds (FR).

HABITAT CREATION AND MAINTENANCE
Definition: The formation and continued production, by ecosystems or organisms within them, of ecological conditions necessary to, or favourable for, living beings of direct or indirect importance to humans.
Contribution: Ponds are substantial contributors to freshwater and terrestrial biodiversity at waterbody and whole landscape scale.

MAINTENANCE OF OPTIONS
Definition: Capacity of ecosystems, habitats, species or genotypes to keep options open in order to support a good quality of life.
Contribution: By maintaining biodiversity, ponds and pondscapes can play a substantial role in maintaining options for future management of the environment.

1.3 WHO IS THIS TECHNICAL HANDBOOK FOR AND HOW SHOULD IT BE USED?

This technical handbook is for anyone working in any aspect of pond protection, management, restoration or creation including:

- Landowners
- Land, water and biodiversity managers
- Engineers and landscape architects involved in water management
- NGOs and civil society organisations
- Policymakers and legislators
- Businesses investing in the natural environment
- Educators, teachers, students and researchers
- Local, regional and national governments.

In this book, we share knowledge from across the **PONDERFUL** consortium to guide anyone seeking to protect, manage, restore or create ponds and pondscapes for the benefit of biodiversity and people. Based on the latest evidence, this handbook includes results from innovative research carried out for the **PONDERFUL** project and the extensive experience of the **PONDERFUL** team based on over 30 years of work on ponds. Throughout the handbook we have set out to ensure that all of the advice is scientifically informed with the most up-to-date evidence, making use of the wide range of new data obtained by **PONDERFUL**. The manual takes account of the growing recognition of the critical role of ponds and pondscapes in providing ecosystem services, Nature's Contributions to People and, not least, helping to address the freshwater biodiversity crisis.

We will help you identify the objectives for protecting, managing, restoring and/or creating your pond or pondscape. Additionally, we set out key principles for designing and managing a pond or network of ponds – known as a 'pondscape'. Importantly, we have included examples from the **PONDERFUL** demonstration sites – a diverse range of pondscapes across Europe, with additional examples from the Middle East and South America.

We hope this technical handbook will inspire you to protect, manage, restore and create high-quality ponds and pondscapes for biodiversity and people.


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2. Ponds and pondscapes - an overview

There is now broad consensus that ponds and other small waters are a critical but vulnerable part of the freshwater landscape and that their protection and management needs to be fully integrated within the existing legislative framework. A key objective of the **PONDERFUL** project was to recognise the importance of these small ecosystems, in the same way as rivers and lakes are recognised.

The significance of ponds for biodiversity and ecosystem services has long been underestimated and they have largely been ignored by scientists and policymakers. However, despite their small size, ponds play a crucial role in supporting biodiversity and in providing many other ecosystem services. We expect that this manual will help accelerate their adoption as a mainstream environmental solution.

2.1 WHAT IS A POND?

Throughout this handbook, we introduce you to a diverse range of waterbodies that are classified as ponds. They range from bodies of water created to provide a blue space for recreation or education, the provision of water for many different purposes (including reduction of flood risk, pollution control, fish production) to natural countryside ponds in places seldom visited by people, but which are rich in biodiversity.

In this technical handbook, ponds are defined as:

> **Small standing waters with a surface area from 1 m^2 to 5 ha that may be permanent or temporary, man-made or naturally created.** [2, 3]

This definition includes semi-permanent and temporary ponds. Common throughout Europe, but best known in the south, these types of ponds often dry up in summer, but both can support specialised pond communities, including many rare and threatened species. In our definition we also include ponds with brackish waters. Ponds are usually shallow (up to 5 m deep), but occasionally deeper examples occur.

2.2 WHAT ARE PONDSCAPES?

A pondscape is a group of ponds, often of different sizes, shapes and depths, spread across the landscape to form a network, providing habitats for more species than a single waterbody of the same size and multiple ecosystem services for people. The pondscape may comprise anything from a handful to hundreds of ponds. Biologically, the ponds will form a habitat network, even if they are not physically connected to each other, because freshwater plants and animals are adapted to dispersing between them, forming a landscape with ponds.

The ponds will also be part of the network of other freshwaters in the landscape, like streams, rivers and wetlands: although some freshwater species depend on a specific kind of waterbody, many can live in all of these habitats. As well as this network being vital for biodiversity and the maintenance of species populations, it is also essential for delivering a variety of ecosystem services in the landscape. Pondscapes include both the aquatic habitats that make up the ponds themselves and the terrestrial habitats where these waterbodies are located.

When thinking about ponds as nature-based solutions, bringing benefits both for biodiversity and human wellbeing, it is important to consider the whole pondscape. This means, for example, you could design or manage some ponds to be leisure destinations for people or for pollution interception, and therefore too disturbed or polluted for sensitive plants and animals, while zoning other ponds purely for biodiversity.

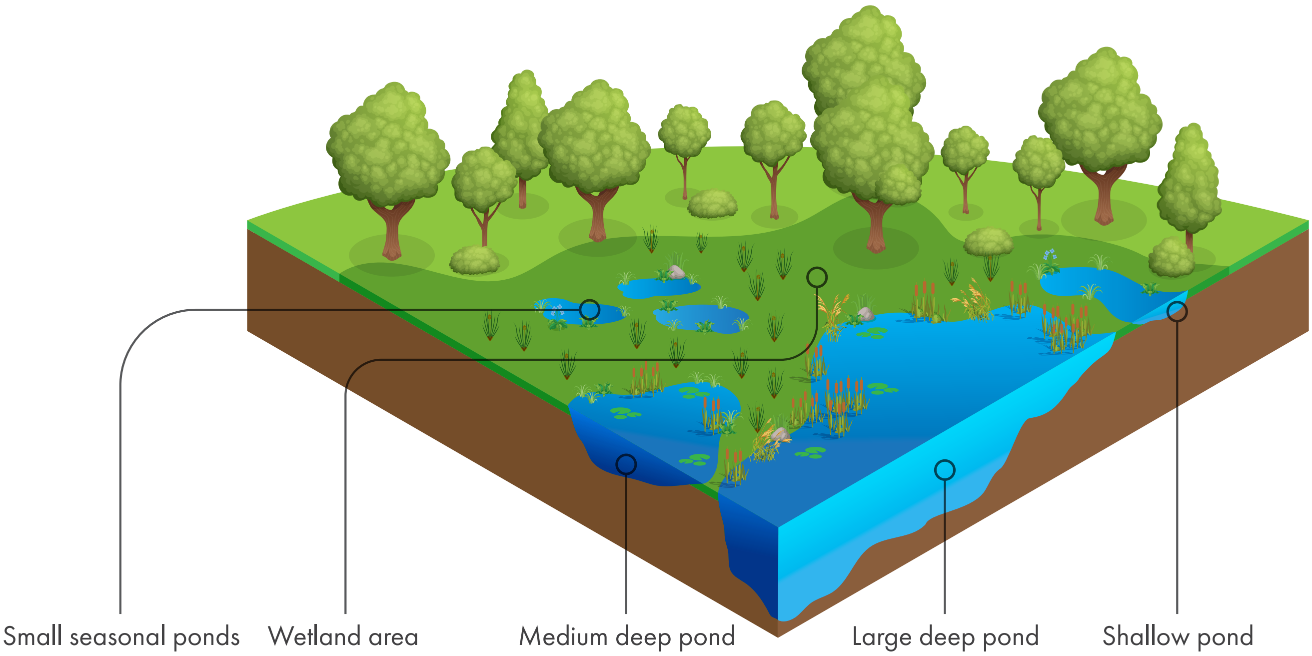

Fig. 2 - A pondscape comprises a diverse range of ponds of different ages, sizes, shapes and depths.

2.3 THREATS TO PONDS AND PONDSCAPES

Estimates suggest that we have lost between 50% and 90% of Europe's ponds in the last century, mainly due to habitat destruction through intensification of agriculture and urbanisation. Put simply, our environment was historically much wetter than it is today, with many more ponds. Added to this, most of the remaining ponds are now affected by pollution. In this section we will explore the impact of the loss of ponds and the main threats to ponds and pondscapes.

Habitat loss

The loss of freshwater habitats has had devastating effects on our wildlife. The 2022 Living Planet Report, published by WWF[4], states that, globally, monitored freshwater populations have declined by 83% since 1970. This loss is greater than for terrestrial or marine species. Many species that were once common in Europe's ponds are now threatened or at risk of extinction. Loss of ponds also reduces pond density, removing links in the network of habitats provided by pondscapes. This increases the risk of local, regional or national species extinctions, and reduces the number of ponds delivering ecosystem services.

Though perhaps more difficult to measure, habitat loss has impacted society, too. Many of the ponds and pondscapes we have lost were once at the heart of communities. As well as providing water for people, agriculture and livestock, they were also spaces for cultural activities. With research now pointing to the importance of 'blue spaces' for human health and wellbeing, we are beginning to understand the effect that the loss of ponds and pondscapes has had on people and cultures.

Pollution

Pollution is one of the greatest threats to ponds, the biodiversity they support and to other ecosystem services they provide (e.g. by increasing greenhouse gas emissions). Freshwater biodiversity needs clean water to survive, and it only takes a tiny amount of pollution to damage habitats, harming the most sensitive plants and animals. Although net pond loss has slowed or reversed, pollution remains pervasive, and there is evidence of on-going whole-landscape losses of pond biodiversity, even while pond numbers remain constant.

Water quality is affected by pollution from human activities, including agriculture, livestock farming, tourism, housing and construction of infrastructure (roads, railways, etc.). According to the European Environment Agency, 22% of Europe's rivers and larger lakes, and 28% of the groundwater area, are significantly affected by diffuse pollution from conventional agriculture, both by nutrients (nitrates and phosphates) and pesticides. Although there are no EU-wide statistics on pond pollution, the situation is probably at least as bad for ponds. Around 80% of sites surveyed by **PONDERFUL** had high nutrient concentrations, suggesting pollution by nitrogen and phosphorus is widespread.

Poor water quality damages the whole freshwater environment, but ponds are particularly vulnerable; due to their small size and because they are shallow, they have a low volume of water to dilute pollutants. To make the situation worse, much of their biodiversity is highly sensitive to water pollution (e.g. amphibians, dragonflies, mayflies, etc.). Ponds that are linked to streams and ditches are at even greater risk because these watercourses often bring in polluted water.

Habitat destruction and water pollution are threats to ponds and pondscapes.

Climate change

We are already seeing the impacts of climate change on the freshwater environment. Rising sea levels, for example, are likely to damage coastal wetlands, including ponds, and the communities of specialist plants and animals that inhabit them[5]. Higher average temperatures and shifting seasons are leading to changes in breeding behaviour and lifecycles for pond-associated species, and to shifts in their geographical distribution ranges.

Extreme weather events are also a threat to ponds and pondscapes. For example, high rainfall and flooding can increase pollution inputs to all kinds of ponds. On the other hand, temporary ponds, which depend on regular drying out, are already experiencing extended periods of drought caused by climate change[6] both in southern Europe and at higher latitudes. Severe droughts are expected to reduce the time that temporary ponds hold water, damaging the plant and animal communities they support, especially in Mediterranean regions where some pondscapes have dried up completely. Even where they do not dry out completely, semi-permanent and temporary ponds may become shallower as a result of reduced rainfall and increased evaporation rates, and associated with this may be increased eutrophication as dissolved chemicals become more concentrated.

Functional changes in pond communities caused by climate change (more drought tolerant species, fewer collector and shredder invertebrate functional groups) are likely to subtly alter the functioning of pond ecosystems. This is likely to cause serious losses of freshwater biodiversity and restrict the ecosystem services provided by temporary ponds (e.g. reduced water supplies for livestock and increased carbon emissions as ponds dry more frequently).

Invasive species

Invasive species threaten freshwater ecosystems worldwide, including individual ponds and whole pondscapes. Ponds are affected by both non-native plants and non-native animals which can outcompete indigenous species for space and resources.

Invasive aquatic plants like *Crassula helmsii* compete with native plants for space and resources. Non-native fish, such as *Carassius auratus*, which has the ability to reproduce very rapidly, can cause the decline of fish and other aquatic species. Wetland plant communities in Mediterranean temporary ponds may also be damaged by the invasive non-native Red Swamp Crayfish *Procambarus clarkii*. Invasive species may introduce diseases or parasites, with particular risks to native species, especially in the case of amphibian populations. Non-native crayfish are also problematic in other areas of Europe, though ponds are less impacted because they are generally more isolated from the river network. Non-native terrapins (e.g. Common Slider *Trachemys scripta*) are also widely present in European ponds.

Controlling established invasive species in ponds is often very difficult or impossible. This means that preventing the introduction of non-native species is crucial. Swift action to eliminate invasive species as soon as possible after they have colonised ponds can sometimes be successful in preventing establishment and spread.

© Rhododendrites

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Examples of pond invasive species: *Trachemys scripta* (above), *Crassula helmsii* (left), *Carassius auratus* (right)

Changes in land use and management practices
Ponds and pondscapes were traditionally used for a wide range of purposes in agriculture, forestry and industry. The waterbodies were actively managed accordingly. Since the intensification of land use and industry, pond management has been abandoned in many areas, leading to terrestrialisation, silting up and overshading, and the loss of biodiversity at both the pond and pondscape scale. This is particularly the case in regions where livestock grazing was replaced by intensive arable practices, leading to pond loss and lack of or poor management of the remaining ponds. Lack of disturbance (e.g. fencing that excludes livestock) or too much disturbance (e.g. overgrazing) can both reduce the biodiversity value of ponds. Lack of management can also affect the functionality of ponds for water management or pollution control.

2.4 MANAGING, RESTORING AND CREATING PONDS

Existing ponds often need to be managed or restored, either to maintain their value as a nature-based solution or to reintroduce functions into the landscape where this is technically and practically feasible (see Section 4.1 for definitions of pond management and restoration, including resurrection of 'ghost' ponds'). Good management practices, protection from pollution and, where needed, pond creation, are all essential measures at pondscape level to ensure that the diversity of pond types and the range of pond successional stages are maintained in the landscape.

Ponds and pondscapes in policy
Ponds remain insufficiently represented in environmental legislation although some progress is being made. In Europe, three main pieces of legislation provide varying degrees of support for the protection and management of ponds and pondscapes:

- Nature Restoration Law
- Water Framework Directive
- Habitats Directive

Individual EU member states, and countries outside Europe, also have national and regional laws to protect small waters.

The Convention on Wetlands recently adopted a resolution on the conservation and management of small wetlands, including ponds (Resolution XIV.15 "Enhancing the conservation and management of small wetlands"). Ponds are also represented in its Global Wetland Outlook 2018 and Global Wetland Outlook 2021, where the Convention incorporates ponds in its definition of wetlands.

The topic of ponds and pondscapes in policy is covered in detail in the **PONDERFUL** Policy Guidance document: Using ponds and pondscapes as nature-based solutions.

Mayfly © Erik Karits

3. Ponds and pondscapes as nature-based solutions to address societal challenges

3.1 INTRODUCTION TO PONDS AND PONDSCAPES AS NATURE-BASED SOLUTIONS

Ponds and pondscapes can provide solutions to a range of societal challenges. These include biodiversity protection and enhancement, disaster risk reduction (e.g. reducing flooding, fire-fighting), protecting human health (e.g. improving physical health and mental wellbeing), climate change mitigation and adaptation, water resources for livestock or irrigation, and social and economic development, including leisure (hiking, water sports), nature experiences (wildlife-watching) and food production (fish, livestock). As largely developed in this manual, these nature-based solutions are particularly adapted for addressing several major concerns raised by climate change.

In this manual, we apply the framework developed by IUCN which recognises the growing scientific consensus that 'nature is essential for human existence and good quality of life'. Failure to recognise this fact not only results in a model of economic growth that undermines future economies and significantly contributes to the loss of biodiversity, but also misses the opportunity to use nature to help resolve major societal challenges such as climate change, human health, food security and disaster risk reduction. Here we explain how ponds and pondscapes are capable of providing multiple benefits in many different contexts, while simultaneously supporting the protection of the natural freshwater resource base. This means that protection and management of ponds and pondscapes has an important contribution to make to addressing societal challenges and securing the role of biodiversity in 'business as usual' within other sectors.

The societal challenges that can be addressed with ponds are determined by the character of the pond (the unique combination of soil and geology, hydrology and climate of the area where it is located) and the local cultural, economic and socio-political context. Many ponds and pondscapes are attractive leisure destinations and are often used for recreation, and can play a key role in environmental education. They may be important local features because of their biology (ponds located in nature reserves), archaeology (e.g. medieval fish ponds in England and stone tombs in Catalonia[7]) or recent history (bomb crater ponds formed during World War II). Managers should be aware of specific local information about these established characteristics of ponds. For example, guides exist to the management of fish ponds in aquaculture[8] and the protection of ponds which are of archaeological interest.

Thanks to the efforts of land managers and scientists, we are increasingly recognising the diverse benefits of ponds and pondscapes. As well as traditional uses of ponds (garden ponds, farmland ponds and fish ponds), we are gradually seeing ponds designed or maintained for new uses. These include contributing to people's wellbeing and recreation in or around towns and cities, water pollution management (e.g. sustainable urban drainage) and maintaining biodiversity. These newer uses illustrate the dynamic relationships between societies and ponds in the 21st century.

Anyone involved in managing ponds and pondscapes needs to consider a range of issues including the social, ecological, political (local, regional and national), cultural and economic context for delivering Nature's Contributions to People or ecosystem services, both now and in the future. That is why it is necessary to engage as many stakeholders and users from relevant sectors as possible, including people operating at all levels of pond management. Negotiation is often needed to find constructive and effective trade-offs for conflicting uses – see Chapter 4.

For the long-term success of nature-based solutions which make use of ponds, we need wider public awareness and acceptance of the benefits provided. One way to achieve this is to build in the views and ideas of local people when designing your work on ponds. This feedback can help anticipate potential problems. It can also help prioritise the objectives for your pondscape management, restoration or creation projects. In this way, projects using ponds as nature-based solutions are more likely to improve quality of life and promote environmental sustainability. A useful guide to the techniques of mobilising civil society is the EU's 'Do it yourself (DIY) manual for mobilising and engaging stakeholders and citizens in climate change adaptation planning and implementation'.[9]

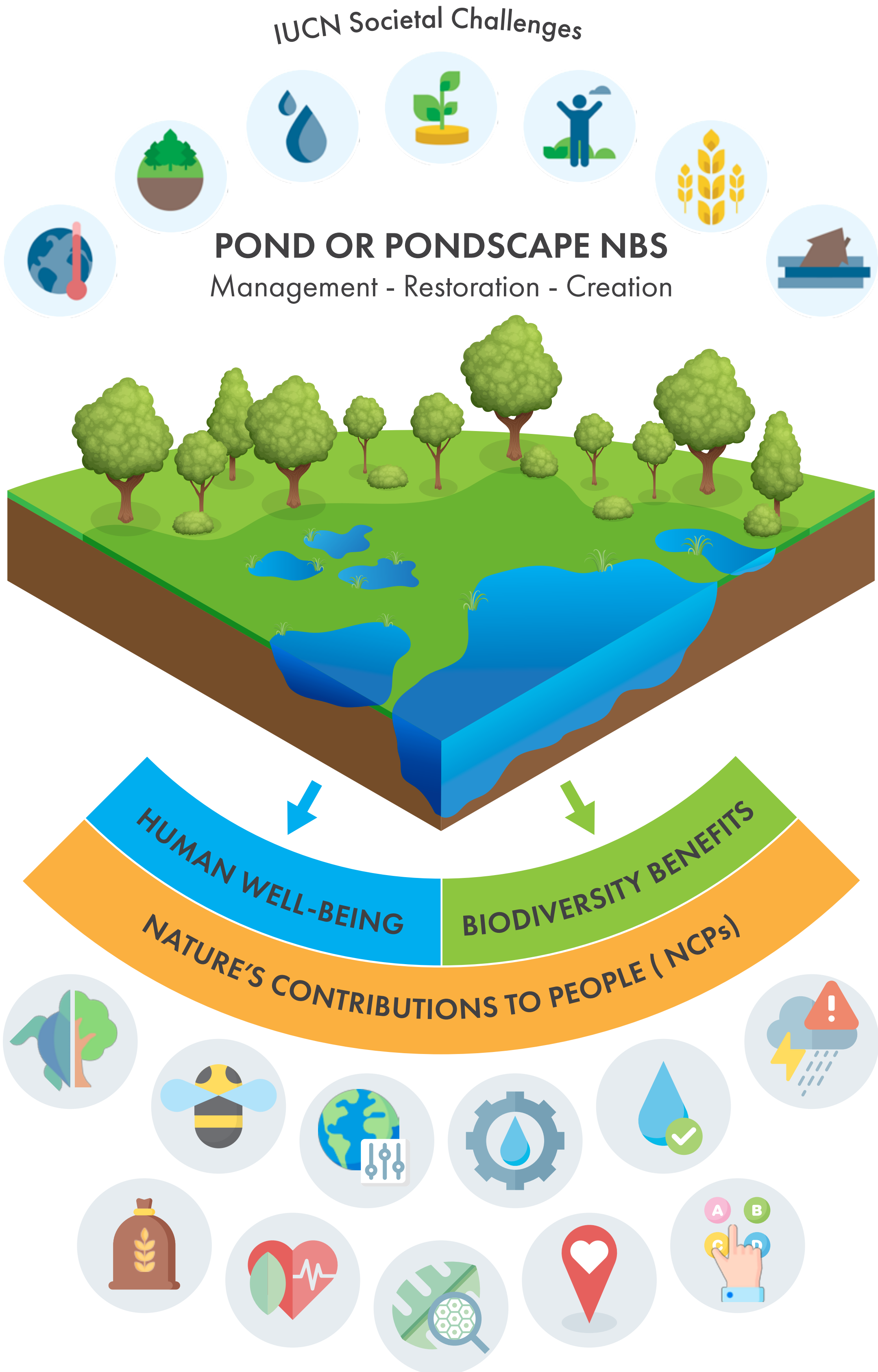


Fig. 3 - Ponds and pondscapes are nature-based solutions (NBS) for climate change adaptation and mitigation, providing many human wellbeing and biodiversity benefits.

Table 2 - Ponds and pondscapes represent efficient nature-based solutions for addressing the seven global societal challenges identified by IUCN.

ENVIRONMENTAL DEGRADATION AND BIODIVERSITY LOSS	Ponds are remarkably important for biodiversity conservation, and pondscapes represent biodiversity hotspots. Despite this, ponds have been widely neglected and generally undervalued.
DISASTER RISK REDUCTION	Ponds and pondscapes play a fundamental role in mitigating flooding and also constitute a water reserve to fight fires.
HUMAN HEALTH	Ponds and pondscapes provide a wide range of co-benefits for human societies, such as support for human health and quality of life, spaces for physical activities or social interaction, but also aesthetic experiences and educational and recreational activities.
CLIMATE CHANGE MITIGATION AND ADAPTATION	Given their abundance and their high productivity, ponds significantly influence the carbon cycle by acting as both carbon sinks and sources.
WATER MANAGEMENT	Pondscapes provide a water reserve that is particularly important in the context of water scarcity. It is particularly useful for providing a water source for animals and for irrigation.
FOOD SECURITY	Ponds and pondscapes are ecosystems which can produce food directly (e.g. crustaceans, fish, amphibians, water birds). Furthermore, they are used for watering animals and also wildlife.
SOCIAL AND ECONOMIC DEVELOPMENT	Most ponds and pondscapes have a close relationship to society. Therefore, many socio-economic activities are developed, linked, for example, to leisure (hiking, water sports), nature experiences (wildlife-watching) or food production (fish, livestock).

3.2 PONDS AND PONDSCAPES AS PROVIDERS OF ECOSYSTEM SERVICES AND NATURE'S CONTRIBUTIONS TO PEOPLE: OVERVIEW

Ponds and pondscapes benefit biodiversity, collectively supporting more species than rivers, streams or lakes, and can also provide a large range of ecosystem services and Nature's Contributions to People. These services include water provision, flood control, groundwater recharge, pollution reduction, recreation, physical and psychological experiences and tourism. The potential for one pond to provide multiple ecosystem services means ponds and pondscapes can be excellent nature-based solutions. Healthy pondscapes are likely to be more resilient to disturbance (such as from wildfire or droughts). Damage to biota or ecosystem processes in some ponds can be recovered if other healthy ponds exist in the pondscape.[10]

The ecosystem services a pond can provide are dependent on its unique character and ongoing management. A single pond, considered in isolation, already offers valuable habitats for wildlife, and may also provide several other ecosystem services. From the 18 categories of Nature's Contributions to People identified by IPBES, ponds are particularly efficient for addressing 11 of them. A survey carried out across the **PONDERFUL** demonstration sites found that local people and stakeholders mainly expect pondscapes to provide habitats for biodiversity and cultural services (physical and psychological experience, learning and inspiration). Because of this, managers may need to raise people's awareness of the other benefits which often go unrecognised.

No single pond is likely to address all the societal challenges or Nature's Contributions to People covered in this manual. In addition, some of the benefits ponds provide will be restricted by their small size. However, when considered collectively, the cumulative benefits of several ponds providing the same ecosystem services, or many ponds providing different ecosystem services (multifunctionality), makes a pondscape particularly valuable for climate change adaptation and mitigation, biodiversity conservation, and the delivery of other Nature's Contributions to People and ecosystem services.

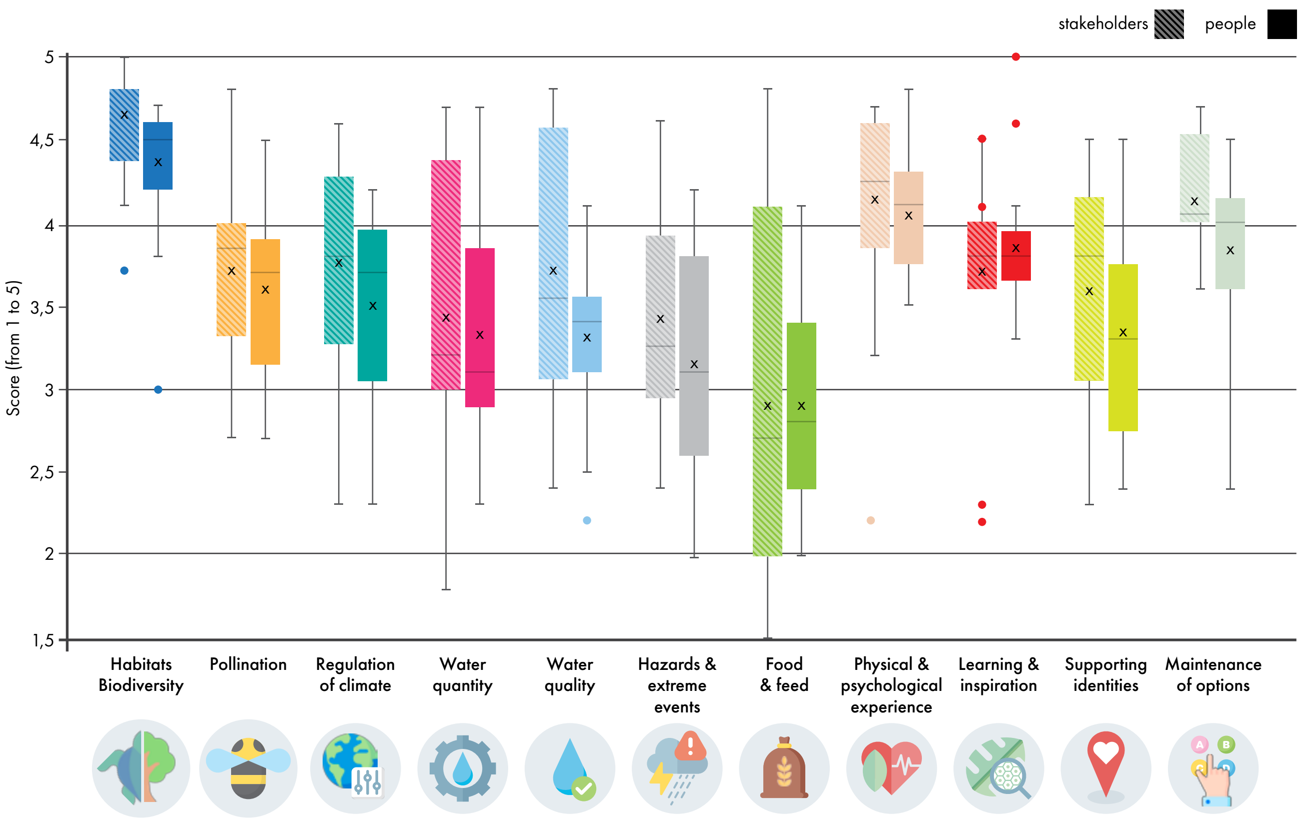


Fig. 4 - The stakeholders and the general public expressed their expectation about Nature's Contributions to People delivered by ponds and pondscapes (**PONDERFUL** survey). The box-plots represent the syntheses of the scores (from 1 to 5 - from very low to extremely high expected contribution) provided by 108 stakeholders and 703 persons (from UK, SP, CH, DK, BE, GE, TR, UY). The cross represents the mean, and the horizontal bar the median.

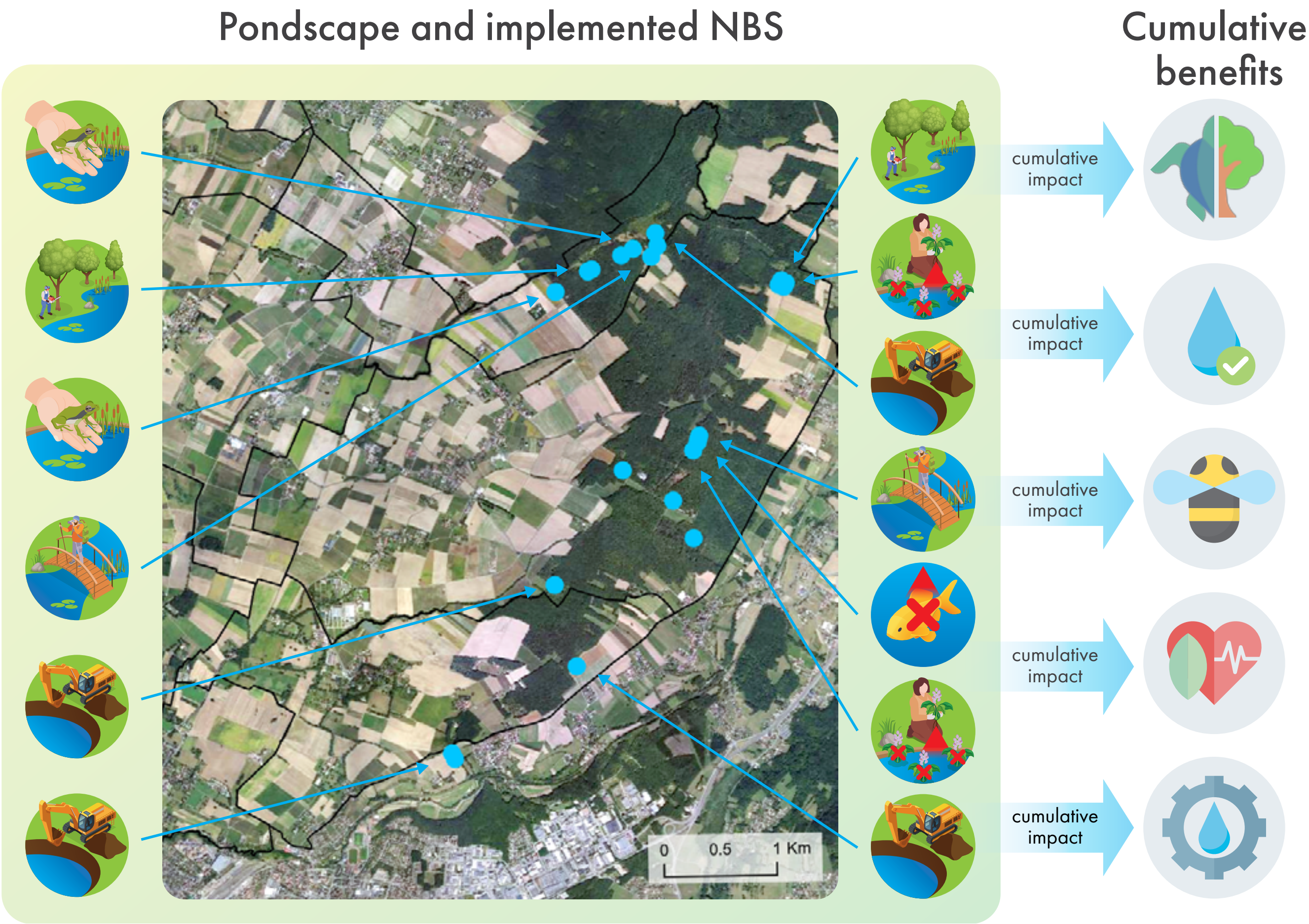


Fig. 5 - Ponds provide multiple Nature's Contributions to People (or benefits) derived from the implemented nature-based solutions at Bois de Jussy, a pondscape in Switzerland. See success stories 6.1 and 6.3.

3.3 PONDS AND PONDSCAPES AS NATURE-BASED SOLUTIONS FOR CLIMATE CHANGE ADAPTATION AND MITIGATION

Ponds and pondscapes deliver services contributing to climate change adaptation and mitigation

Climate change is a major factor in the challenges facing society today. Several impacts linked to climate change lead to a reduction in human wellbeing:

- Disaster risk is increased, with increasing frequency and intensity of flood events and fires.
- Water quantity decreases, with lower availability for ecosystems or human needs. This water stress is made worse by pollution of the water.
- Food security is impaired by lower water availability and by lower water quality.
- The biodiversity decline is getting worse as species and habitats suffer changing conditions in temperature and hydrology, together with land use changes which damage habitats.

Ponds and pondscapes can be used to efficiently address these challenges. Specifically:

- Climate change (and temperature increases) can be mitigated by managing ponds to reduce their greenhouse gas (GHG) production.
- Cooling leisure activities (e.g. hiking, swimming, resting) can be increased and diversified by the creation of ponds.
- Water quality will be improved by the creation of ponds able to purify water.
- Water quantity will benefit from the creation of new water reserves.
- Flood risk can be reduced by the creation of stormwater ponds, and fires can be fought with water stored in ponds.
- Food production (cattle, fish) will benefit from ponds providing water and the creation of fish ponds.
- Biodiversity will gain from the creation of all types of new ponds if they are suitably designed, are protected from pollution, and offer diversified habitats.

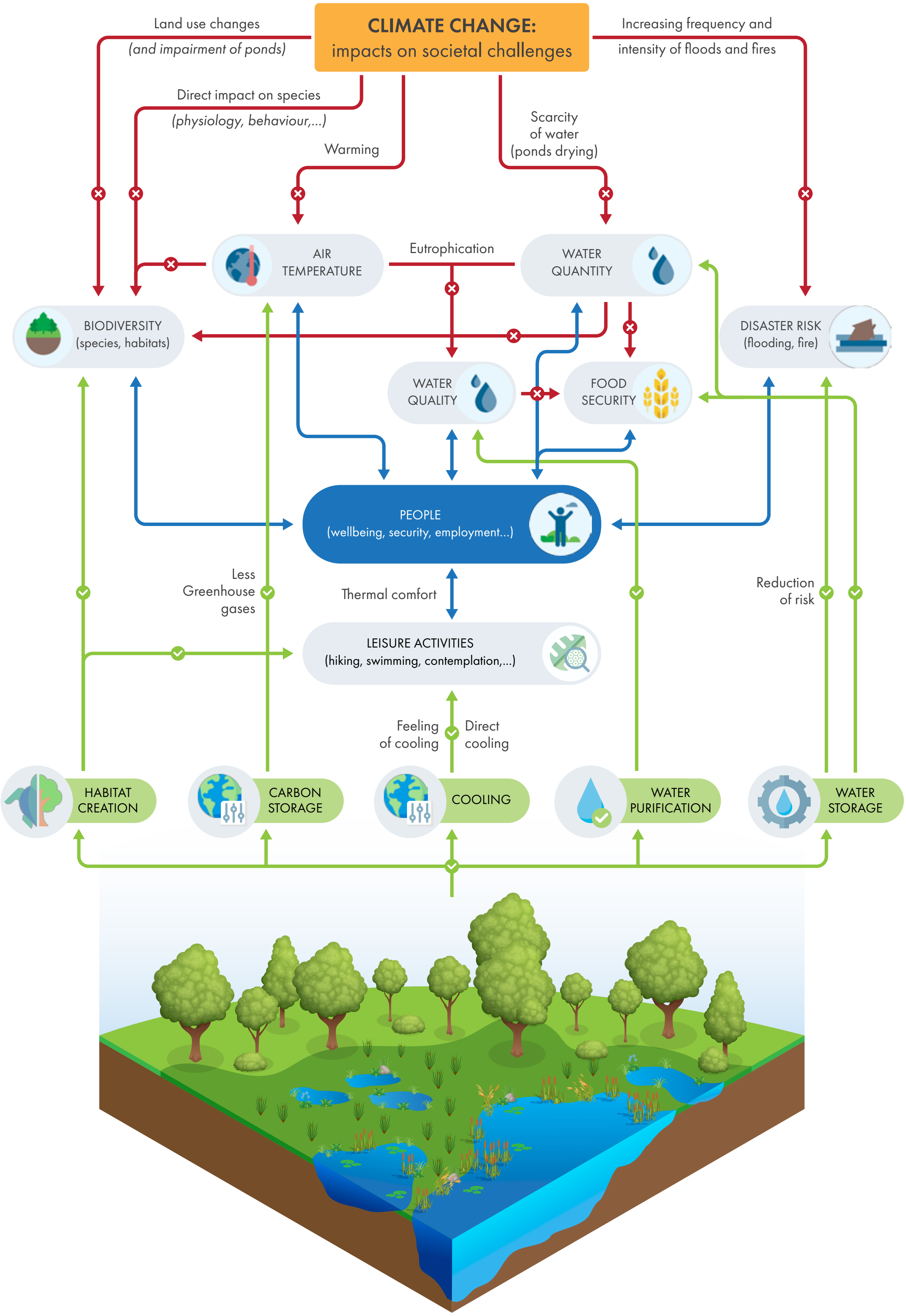


Fig. 6 - Pondscapes can help us address many of the societal challenges we face as a result of climate change and provide many Nature's Contributions to People.

Role in stemming biodiversity decline due to climate change: dispersal, refuges, regional species pool

Pond management, restoration and creation are nature-based solutions that have a crucial role to play in stemming freshwater biodiversity decline due to climate change, particularly through:

- Enhancing habitat connectivity for aquatic and terrestrial organisms
- Providing climate refuges
- Maintaining regional species pools
- Counteracting the effects of climate change which are likely to increase droughts and the extent of polluted water.

As the most diverse part of the water environment in many landscapes, ponds make a vital contribution to maintaining the variety of freshwater life in all the locations where they are found. The conservation, creation and sustainable management of ponds is therefore essential for maintaining and enhancing freshwater biodiversity in a changing climate.

Enhancing habitat connectivity

Ponds serve as important landscape features which connect different habitats. They can act as stepping stones or corridors, allowing animals and plants to move and disperse across fragmented landscapes. They assist dispersal by providing pathways for the movement of individuals, and also allow migration to cooler regions in scenarios of climate change, helping to preserve or improve gene flow between populations. This genetic exchange is crucial for maintaining healthy populations as it can enhance adaptive potential and improve resilience to changing environmental conditions, including those associated with climate change.

Dispersal is particularly important in allowing biota to adapt to climate change as many species will need to shift their geographical ranges, e.g. to higher latitudes or altitudes. The diversity of life in ponds means that these small waterbodies can also help repopulate nearby areas which experience biodiversity loss due to climate change impacts, making landscapes more resilient to freshwater biodiversity loss.

A good example of the significance of dispersal is the recolonisation of two lakes in Sicily from surrounding ponds. Lake Biviere di Gela has a dense network of hundreds of permanent and temporary ponds around it; Lake Pergusa has none. Both had dried out as a result of regional groundwater overuse, which had lowered water levels. As they were refilled, the lake with the dense network of surrounding ponds established a richer algal flora than the lake with no adjacent ponds. It appears that, just like many bigger organisms, phytoplankton in pond networks were able to maintain a more diverse community of algae than were present in an area with fewer ponds.[11]

Providing climate refuges

Because ponds collectively provide a wide variety of habitats, they naturally provide refuges for a wide variety of species. This variety of habitats can be due to differences in hydrology from pond to pond (permanent or temporary), local differences in substrate (some dominated by clay, some by sands) or differences in shading and vegetation density (some ponds with sparse vegetation, some dense). In the face of climate change, where larger, more uniform, freshwater habitats (e.g. lakes, rivers) become unsuitable for many species, the diversity of habitats found in groups of ponds means that they are more likely to continue providing conditions that allow the survival of a diverse flora and fauna because they vary so much from place to place, even in quite small areas.

In the United Kingdom, an example of the creation of ponds as a climate refuge can be seen in the case of the White-faced Darter Dragonfly (*Leucorrhinia dubia*), which requires a cool climate and is currently retreating northward in the United Kingdom. Competition from other dragonfly species expanding their range due to climate change may have played a role in its decline, while laboratory studies show that White-faced Darter larvae have reduced growth rates in warmer conditions. In north-west England, creation of new high-quality ponds in acid bog, combined with correct terrestrial habitat management, is thought to be preventing regional extinction of the species due to climate warming. Creation of new ponds is providing additional habitat to strengthen small populations of this species, as long as the overall climate envelope for the species remains suitable.[12]

Increasing the density of pond networks also enlarges the sizes of the metapopulations of most species using the ponds, enhancing their resilience to the impact of climate change. Throughout Europe, but especially in the south, hydroperiod (the length of time ponds are filled) is expected to be more unpredictable and decrease substantially. For this reason, the maintenance or creation of pond diversity in the landscape is crucial to continue providing conditions that allow the survival of a diverse aquatic flora and fauna. Ponds are also important for terrestrial biodiversity because they are one of the few sources of water in some arid regions.

Maintaining regional species pools
To ensure the resilience of freshwater populations, maintaining regional species pools is likely to be important. An example of this function can be seen in Switzerland in high altitude pond complexes that maintain the assemblage of cold water adapted species, even though water temperatures are rising.[13] In central Europe, high-quality clean-water pond creation has helped maintain the regional species pool by providing habitat for threatened amphibians which cannot survive in the 'ordinary' pond landscape. Even though ponds are already abundant in this landscape, they are not of sufficient quality to maintain uncommon species without reinforcement of the pondscape with new high-quality ponds.

Box 2. What is 'clean water'?

Clean water is defined as water which has a chemistry and biology which would be normal for a given area in the absence of human disturbance. This is commonly referred to as 'the reference condition', 'minimally impaired water quality' or 'natural background levels'. This definition of clean water is equivalent to the EU Water Framework Directive (WFD) 'High' status.

Counteracting the effects of climate change which are likely to increase the extent of polluted water
Rising temperatures will lead to more intense nutrients enrichment effects. Therefore, adding low-nutrient water to the landscape through the creation of new clean-water ponds is likely to be an important climate change mitigation tool. An example of this phenomenon can be seen in the **PONDERFUL** demonstration site Water Friendly Farming. This provides a practical example of the way new ponds add clean water to the landscape, with pond creation roughly doubling the area of clean water in the landscape (see success story 6.4).

3.4 POND AND PONDSCAPES AS NATURE-BASED SOLUTIONS FOR HABITAT CREATION AND MAINTENANCE

Ponds are rich and biodiverse habitats. Collectively, they support more freshwater and wetland species than any other freshwater habitat. They also support rich assemblages of terrestrial plants and semi-aquatic animals. Collectively, ponds also support more uncommon and endangered species than other freshwater habitats.

Ponds support all the main groups of freshwater plants and animals, and only fish and bird communities are more diverse in bigger waterbodies. Ponds are vital habitat for amphibians and a wide range of invertebrates, they support a large proportion of all freshwater and wetland plants, and are probably unrivalled in the diversity of their algal communities. Only insect groups which are particularly associated with cool running water (e.g. stoneflies, mayflies, caddisflies) are less diverse in ponds than in running waters or lakes. In large river floodplain systems, ponds which are permanently or intermittently connected to the main channel are important for fish.

Many uncommon and threatened freshwater species make use of ponds, and often depend on them. In Europe, examples include threatened invertebrates such as the tadpole shrimps *Triops baeticus* and *T. vicentinus* found in Mediterranean temporary ponds in the Iberian peninsula, the Dark Spreadwing damselfly (*Lestes macrostigma*), a species found in brackish coastal and inland ponds and lakes, and the water beetle *Graphoderus bilineatus* found in northern European ponds and small lakes. Additionally, ponds support 33 amphibian species and eight lentic species of Odonata on Annex 4 of the Habitats Directive, and 29 aquatic plant species on Annex 2 of the Habitats Directive.

Endangered water plants found in ponds include Mediterranean temporary pond specialists such as Dwarf Pillwort (*Pilularia minuta*), *Isoetes setaceum*, and Lusitanian Water Clover (*Marsilea batardae*). In central Europe, the Near Threatened Starfruit (*Damsonium alisma*) is mainly found in ponds. Further north, ponds provide habitat for species such as Pigmyweed (*Crassula aquatica*), *Lythrum thesioides,* Floating water-plantain (*Luronium natans*) and Slender naiad (*Najas flexilis*).

Amphibians associated with ponds include endangered species with very restricted ranges such as the Appenine Yellow-bellied Toad (*Bombina pachypus*), the Tyrrhenian Painted Frog (*Discoglossus sardus*) and the Italian Agile Frog (*Rana latastei*), as well as several more widespread threatened species listed in the EU Habitats Directive (e.g. Yellow-bellied Toad (*Bombina variegata*), Great Crested Newt (*Triturus cristatus*) and Natterjack Toad (*Epidalea calamita*).

Although fish communities are normally less diverse than those in larger lakes, ponds on or near natural river floodplains may still support fish assemblages as diverse as those found in the river channels. Ponds which are not permanently connected to the main river channel can also be important for fish. Ponds support endangered fish (e.g. European Eel (*Anguilla anguilla*) and Iberian Toothcarp (*Aphanius iberus*), and uncommon birds such as the European Red-listed Black-necked Grebe (*Podiceps nigricollis*) and Northern Pintail (*Anas acuta*) use ponds for breeding.

As well as being rich aquatic habitats, there is increasing evidence that pondscapes – the area of land around the ponds – are also richer in biodiversity than they would be without ponds. Pondscapes include all kinds of terrestrial habitats, from the tops of mountains to the depths of forests. Pondscapes can be urbanised, farmed or pristine natural environments. Management of this land, as is the case for all freshwaters, has a fundamental impact on the ponds. Equally, the ponds affect the landscape. For example, bats are more likely to use woodland habitats with ponds, insects emerging from ponds provide food for insectivorous birds, and amphibians congregating at ponds provide food for vertebrates like White Storks (*Ciconia ciconia*) and Honey Buzzards (*Pernis apivorus*).

Ponds also support endangered fish (e.g. European Eel (*Anguilla anguilla*) and Spanish Toothcarp (*Aphanius iberus*).

Yellow-bellied Toad (*Bombina variegata*)
© Benny Trapp

Great Crested Newt (*Triturus cristatus*)
© Pieter Jan Alles

European Pond Terrapin (*Emys orbicularis*)
🅭 João Manuel Lima

Three species typical of ponds which are threatened in Europe (listed on the EU Habitats Directive annexes)

Starfruit (*Damasonium alisma*)‡
© Beat Oertli

Tadpole shrimp (*Triops baeticus*)
🅭 jmneiva

Tyrrhenian Painted Frog (*Discoglossus sardus*) endemic to the Tyrrhenian Sea basin*. © Benny Trapp

Three uncommon species typical of Mediterranean temporary ponds which are threatened in Europe (Vulnerable or Endangered on IUCN Red List for Europe‡‡ or on Annex IV of the Habitats Directive*).

Several types of pond meet the criteria for EU Annex 1 Habitats Directive habitat types which, in the EU28, Iceland, Norway, Switzerland and the Balkan countries, should be maintained at, or restored to, favourable conservation status. In the United Kingdom, ponds originally identified as needing protection under the Habitats Directive remain Priority Habitats under the Natural Environment and Rural Communities Act 2006. These are:

- 3110 Oligotrophic waters containing very few minerals of sandy plains (*Littorelletalia uniflorae*)
- 3130 Oligotrophic to mesotrophic standing waters with vegetation of the *Littorelletea uniflorae* and/or Isoeto--Nanojuncetea
- 3140 Hard oligo-mesotrophic waters with benthic vegetation of *Chara* spp
- 3150 Natural eutrophic lakes with Magnopotamion or Hydrocharition – type vegetation
- 3160 Natural dystrophic lakes and ponds
- 3170 Mediterranean temporary ponds
- 3180 Turloughs (mainly Ireland)
- 2190 Humid dune slacks
- 21A0 Machairs (in Scotland and Ireland).

Although not all of these Annex 1 habitat names include the word 'pond' in the title, all of the habitat descriptions do list ponds. However, although large numbers of ponds fall into Priority Habitat categories, precise mapping of their locations has yet to be undertaken.

The biological richness of ponds probably reflects several different factors. They are an ancient, abundant and natural type of freshwater habitat which has existed throughout the evolutionary history of freshwater organisms. This has, perhaps, allowed the diversification of species since life first colonised freshwater. In many natural landscapes, ponds would probably have been the most numerous freshwater habitats. Temporary ponds, in particular, have provided habitats for millions of years.

The largest concentration of ponds are often found in areas described as wetlands. These are, in effect, complexes of permanent and temporary ponds closely intermingled with lakes, running waters and terrestrial habitats. Examples in Europe include the Doñana National Park in Spain, the Biebrza River in Poland and the Hortobágy National Park in Hungary. In most European 'lake districts' (areas where lakes are common), ponds are actually the most numerous freshwater habitats (although lakes have larger area and volume). The extensive bog systems of northern Europe probably have millions of ponds.

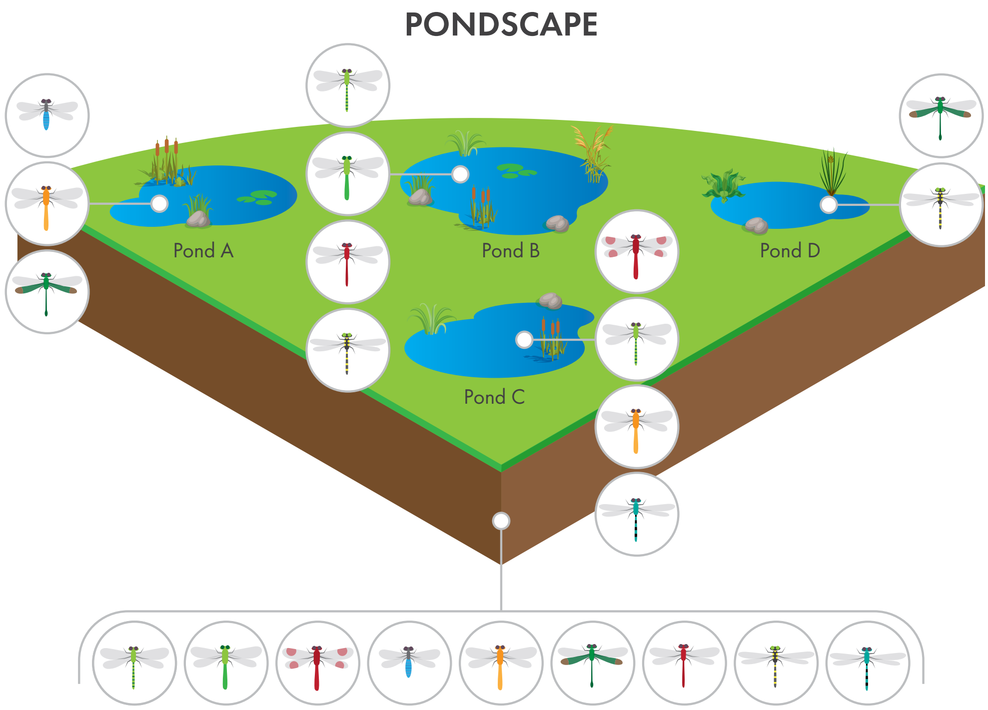


Fig. 7 - Example of how biodiversity is boosted in a pondscape. The four different ponds (A, B, C, D), each presenting different physical and chemical characteristics, each host two to four species of dragonfly (alpha richness). As each community is different, with slight overlap in species composition, the beta diversity (i.e. difference between ponds) is high and consequently the accumulated richness of the pondscape (gamma diversity; A+B+C+D) is markedly higher, reaching in total nine species.

Collectively, ponds make up a high proportion of the remaining near-pristine waterbodies in many landscapes, particularly in areas dominated by pollution-generating farmed or urban land. Because ponds usually have small catchments, it is common for these catchments to be entirely composed of land which is near-natural (heathland, low input grassland, woodland and forest, moorland and unfertilised meadows) with little or no exposure to human-generated impacts (e.g. fertilisers, pesticides, sewage and other pollutants). In contrast, waterbodies with larger catchments are much more likely to be exposed to these damaging factors.

This also adds to the richness of groups of ponds by providing refuges for species requiring pollutant-free (clean) water, now widely absent in larger waterbodies. The characteristic richness of ponds, protection from stressors, and heterogeneity all come together in pondscapes to contribute to their unusual biological richness and diversity.

Pondscapes compared to other freshwater habitats

Ponds are naturally physically and chemically diverse, compared with running waters. This helps drive the variety of freshwater organisms they support.

Evidence of the richness of ponds first became apparent in the early 2000s with the work of Freshwater Habitats Trust in the United Kingdom [14]. Contrary to expectation, it was shown that ponds in a typical European farmed landscape collectively supported more species of freshwater plants and aquatic macroinvertebrates than rivers, lakes, streams or ditches (Fig. 8).

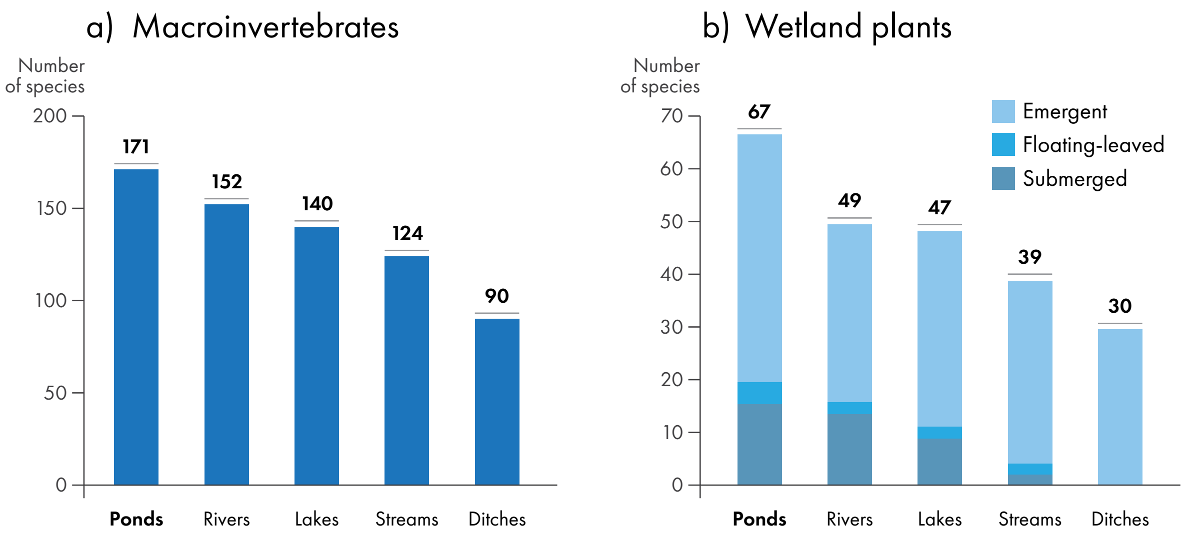


Fig. 8 - A study by Freshwater Habitats Trust (UK) in a farmed landscape found that, collectively, ponds supported more species of freshwater plants and aquatic macroinvertebrates than other waterbodies.[14]

This pattern was further demonstrated in upland and lowland landscapes of the UK and also in Denmark, Germany and France, as well as in Poland, China and Bhutan. The **PONDERFUL** demonstration site Water Friendly Farming provides perhaps the best example yet of the high contribution made by ponds to the freshwater biodiversity of the whole landscape (see Water Friendly Farming success story in Chapter 6). It is not yet known if this pattern also occurs in the southern hemisphere or the tropics.

Opportunities and constraints for using ponds to protect freshwater biodiversity

Ponds provide enormous opportunities for the effective protection of freshwater biodiversity from human impacts, including the effects of climate change. The main practical opportunities provided by ponds are:

- **The richness of ponds:** Ponds provide habitats for a very wide range of freshwater species, including many that are at risk of local, regional, European or global extinction.

- **Protecting and creating high-quality habitats:** Although freshwater management typically focuses on improving damaged habitats, many ponds remain in good condition and require protection. The creation of new ponds in strategic locations is a good way to establish new high-quality freshwater habitats. This is harder to do for rivers and lakes.

- **Good ecological outcomes:** There is excellent evidence of the effectiveness of ponds in enhancing freshwater biodiversity. This contrasts with much work on the management of rivers and lakes, where evidence for biodiversity benefits is less consistent.

- **Engaging with people:** Ponds can be found and created in a wide range of locations. This gives many different people the opportunity to protect freshwater biodiversity.

- **Small size can mean lower costs:** Ponds are relatively small, meaning that the cost of protection (e.g. micro-reserves), management and creation is lower than for bigger waters. Combined with their greater effectiveness when management and creation is done well, they provide a very attractive option for freshwater biodiversity protection and restoration.

The main constraints to using ponds to protect freshwater biodiversity and reduce the impacts of climate change are:

- **Money:** Despite its low costs, funding for pond creation and management is very limited compared to the funds available from public and private sectors for the protection of larger waters and some terrestrial habitats.

- **Policy and law:** Water policy is still heavily biassed against small waters, although change is now occurring. Most pond habitats are not included in water and conservation directives and laws, and this lack of protection is a major cause of their decline. More appropriate national and international laws protecting ponds, as well as financial incentives to pond conservation and creation, are crucial. There are three key policy issues to be addressed:
  - Ensuring inclusion of ponds in legislation to protect the water environment. At present, ponds are best represented in nature conservation policy (e.g. in Europe, EU Habitats Directive). There is a lack of general protection for ponds as freshwaters in the EU due to the manner in which the Water Framework Directive is generally implemented. This prioritises the System B typology, which excludes millions of small lakes and ponds less than 50 ha in area from effective regulation. Similar exclusions from water policy law in North America are being addressed by the identification of 'Vulnerable waters'. This includes non-floodplain wetlands (comparable to European 'ponds') and headwater streams.
  - Ensuring that policy makers always think about both small and larger waters. The long-established tendency to assume large waters are more important than small waters has distorted policy and badly affects practical support for the use of ponds in protecting freshwater biodiversity.
  - Ensuring that freshwaters are considered in policy as networks of habitats. Although it has long been known that freshwater plants and animals use multiple habitats across the landscape, it is only recently that the idea of networks of habitats has started to become embedded. Two examples of this are the concepts of the Freshwater Network (UK) and Freshwater Ecosystem Mosaics (North America).

- **Identifying ponds of existing high value:** Practically, it is vital to prioritise conservation effort on ponds where freshwater biodiversity is of greatest importance or most vulnerable. However, there is still a general lack of national standardised monitoring and assessment methods, reflecting the long tradition in freshwater ecology of overlooking small waters. Nevertheless, policies to recognise and map high-value ponds are developing with the UK policy to identify 'Priority Ponds', the inventory of ponds in Lower Belgium, the Federal Inventory of Amphibian Spawning Sites of National Importance in Switzerland and a range of initiatives in France (e.g. Loir-et-Cher Interactive Pond Map) providing good examples.

  These programmes are identifying the most important ponds (there are probably hundreds of thousands of biologically important ponds in Europe overall) to ensure that the existing high-quality habitats are retained. This is the same principle as the 'no deterioration' concept of the Water Framework Directive, where the highest priority is to protect waterbodies that are already in good condition, and the second priority is to repair degraded habitats.

3.5 BEST STRATEGIES AND TIPS TO IMPROVE ECOSYSTEM SERVICES AND NATURE'S CONTRIBUTIONS TO PEOPLE DELIVERED BY PONDS

In this section we summarise the ecosystem services and Nature's Contributions to People provided by ponds and pondscapes. Wherever possible, we provide data, helpful tips, and success stories (Chapter 6) from the **PONDERFUL** project or from the work elsewhere of the **PONDERFUL** project team.

Regulation of hazards and extreme events: Natural Flood Management
Ponds and pondscapes can store large quantities of water, especially if ponds have large drawdown zones, shallow margins and/or a buffer area which can be temporarily flooded. This makes ponds and pondscapes valuable for run-off management. The potential volume of water which can be stored across a pondscape may be very large, and is likely to be cheaper to provide than engineered structures. Through the cumulative benefit of individual ponds, pondscapes can significantly decrease flood risk because the storage provided will delay and flatten the storm hydrograph and reduce peak flows (see Fig. 9).

As well as mitigating hazard risk due to flooding, holding water in the landscape can reduce the effects of extreme droughts, including providing water for fire-fighting.

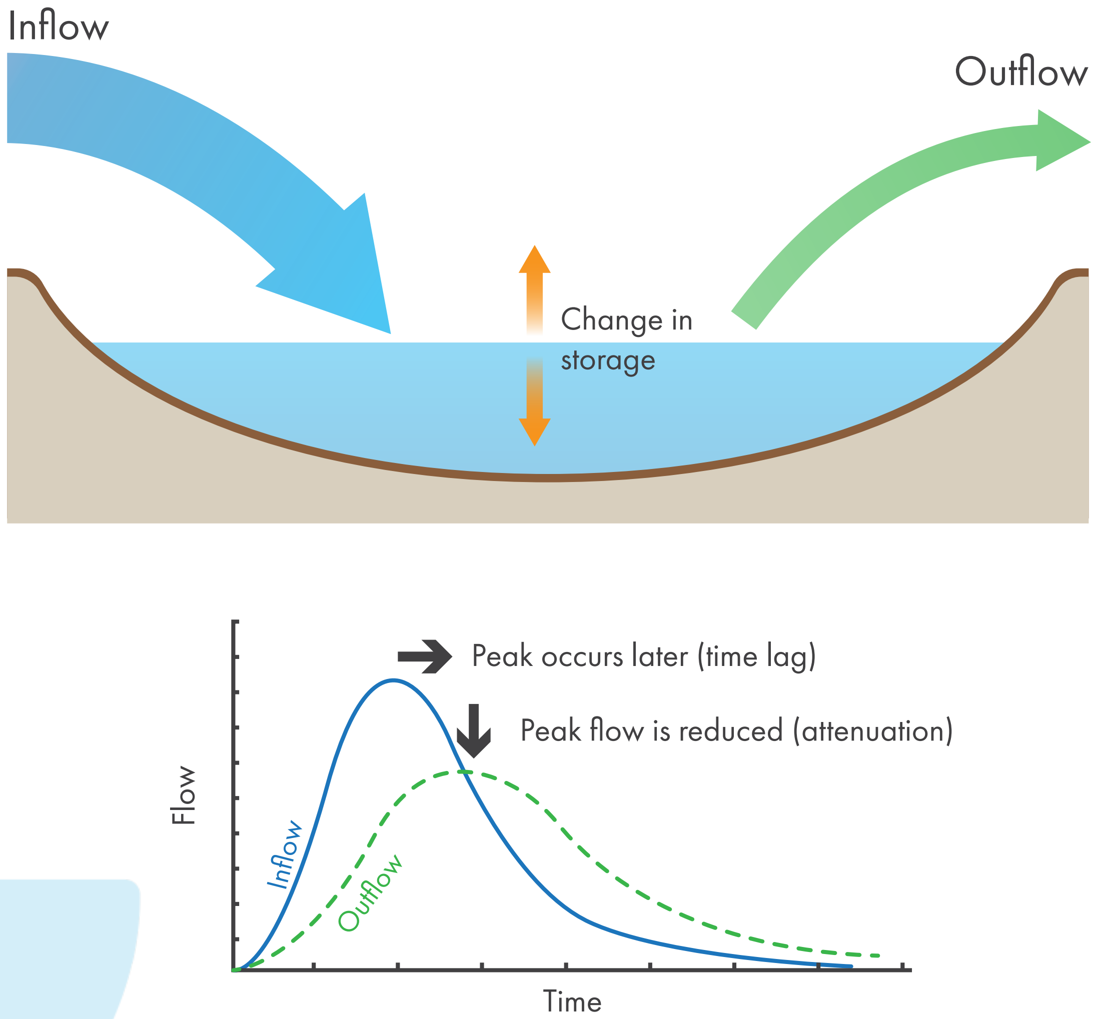


Fig. 9 - Ponds can significantly reduce and delay peak flows during flood events.

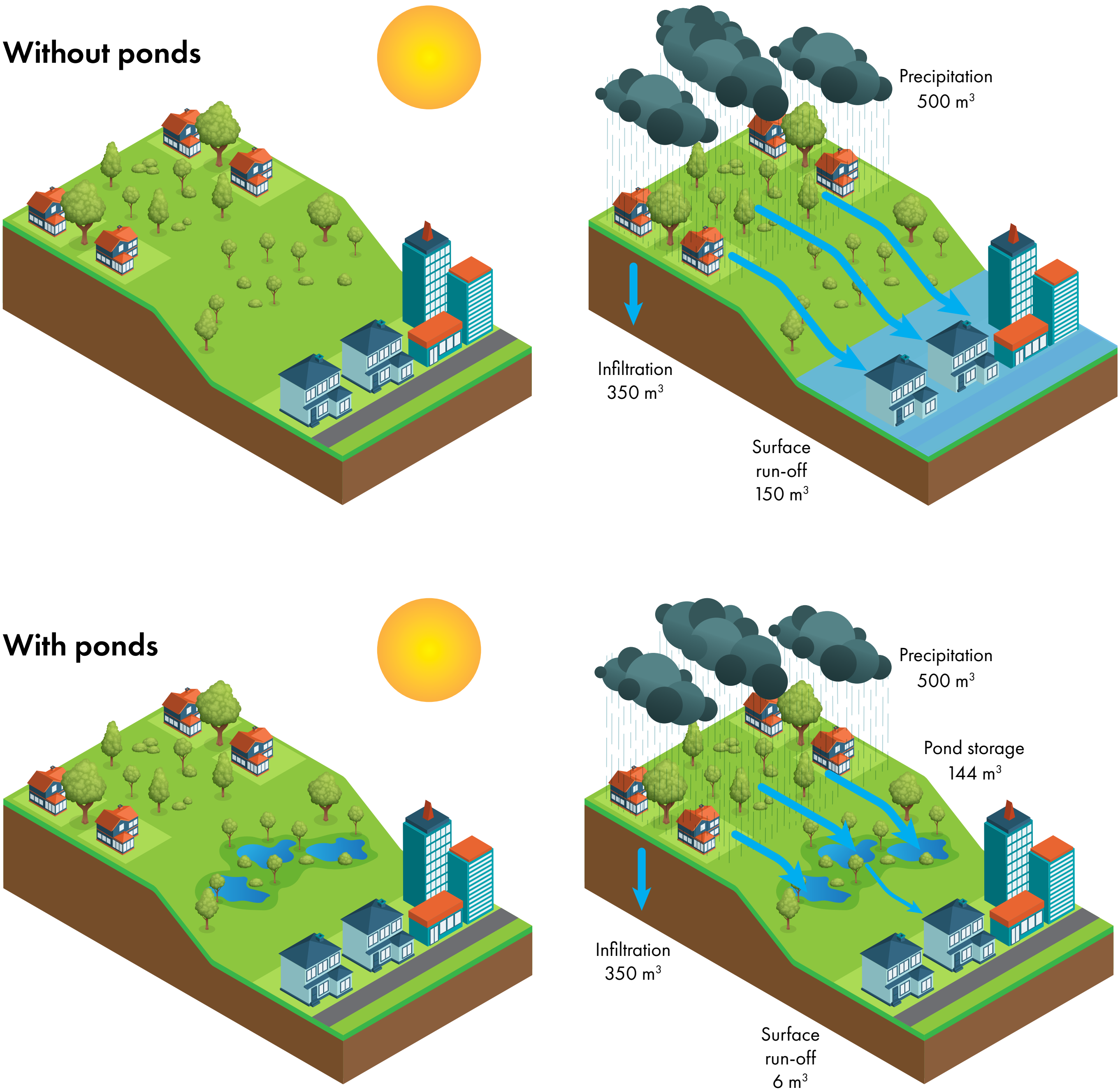


Fig. 10 - Simplified illustration of the benefit provided by a small pondscape situated in the catchment of an urban area during a storm event. The upper figure presents the situation without the pondscape, before (left) and after (right) a storm event. The lower figure presents the same situation, but with the benefit of the pondscape of three ponds of 300 m^2 with a drawdown zone that is able to store 144 m^3 of rainwater, reducing flood risk.

TIPS FOR IMPROVING WATER STORAGE:

- Dense pondscape (numerous ponds). Create as many ponds in the pondscape as possible and, if possible, try to harvest rain and stormwater from rooftops or by using ditches or swales that take advantage of the topography to direct water to ponds.
- Pond areas and depths optimised (as big as possible)
- Large drawdown zone for each pond (with large floodable area)
- Hydraulic calculations and models can help design the ponds and pondscapes.

SEE SUCCESS STORY 6.2

Regulation of freshwater water quantity

Ponds hold water in the landscape and this provides several Nature's Contributions to People, including hazard regulation (see previous example), provision of water supplies for agriculture, livestock and wildlife, for food and feed production, and for biodiversity (Section 3.5).

Ponds represent about 30% of the water surface on the planet. Water storage is probably one of the most ancient nature-based solutions linked to ponds in agricultural landscapes. It includes not only the direct use of water by animals (cattle, wildlife) or for watering crops, but also the provision of habitats for wild animals (amphibians, bats, dragonflies, other invertebrates) that control pest insects and farmed animals (fish, turtles, frogs, ducks, invertebrates) or plants (e.g. watercress, mint) exploited by people for food. Water storage in ponds is also an important drinking resource for wild animals, especially in southern areas of Europe (e.g. Mediterranean) and in scenarios of climate change. Ponds and pondscapes have been created all over the globe for this purpose. Today, this service is of increasing importance given the predicted scarcity of water.

Efficient nature-based solutions must, by definition, benefit biodiversity, so water storage ponds will also benefit from being designed to create good habitats for biodiversity. Two factors are important: if the water stored is unpolluted this will provide a substantial benefit for biodiversity. Secondly, the more natural the bank and bed of the pond, the better: water storage ponds are often created using artificial materials (concrete, plastic liners) leading to rather poor-quality habitats. If possible, ponds should be dug into clay, gravel or sand as these natural substrates lead to the creation of ponds that provide better-quality habitats. Management at the pondscape scale can also promote a mix of pond types, with some used for food production and others for protecting wildlife.

◀ Many pondscapes were created during the Middle Ages for fish production (e.g. The Dombes, France).
Still managed for this purpose today, they represent local biodiversity hotspots. © Joël Robin

Cattle watering is often a feature of ponds, with pondscapes hosting a high biodiversity. © Freshwater Habitats Trust ▶

◀ Large artificial systems, such as this reservoir used for irrigation, could be replaced with nature-based solutions. 🅭 Lio Voo

TIPS FOR IMPROVING ECOSYSTEM SERVICES OF FISH AND CATTLE PONDS:

- If livestock pressure is high in the pondscape, fencing the most biodiverse ponds (either partially or completely) can be beneficial. Note that for many ponds, gentle grazing pressure is vital and natural.
- A simple drinking trough can be installed downstream of a pond, allowing livestock pressure and wildlife to be more precisely managed.
- Fish ponds benefit from having shorelines dominated by emergent vegetation, providing spawning areas for fish and habitats for other biota (e.g. birds, amphibians, invertebrates) and helping to reduce nutrient levels in the pond; fish densities should be close to those of natural fish communities.
- Fish ponds with too high a density of fish should be avoided because the water quality will suffer, impacting both the fish and biodiversity generally.

SEE SUCCESS STORY 6.5

Water quality improvement

Every pond has water purification potential, which usually increases as the abundance of aquatic vegetation increases, and the pond size and depth increases. The cumulative impact of many ponds can mean that a large pondscape with a high pond density has exceptional potential for purifying water. Pondscapes have therefore been implemented as nature-based solutions to improve water quality in both agricultural and urban landscapes (e.g. in Ireland, the Dunhill Integrated Constructed wetland).[15] Purification addresses not only nutrients, but also a range of other pollutants, such as: suspended solids, heavy metals, pesticides, polychlorinated biphenyls, polycyclic aromatic hydrocarbons, endocrine-disrupting chemicals, salts and bacteria.

To maximise the value of the pondscape for pollution control, purification ponds should be located between sources of pollution and the waterbodies to be protected (either ponds, streams or rivers). This will often be at the top of the watershed, but also in 'downstream' riparian and floodplain locations. Using ponds to intercept pollutants may increase the area of clean-water habitats of all types, if the ponds are well designed and managed.

Ponds with the highest purification potential have a large surface area and volume, a long retention time and dense vegetation. For example, the dense vegetation of beds of Common Reed (*Phragmites australis*) means that they are widely promoted for their purification potential.

Climate change, with higher water temperature and increased water scarcity, will worsen the effects of eutrophication. Pondscapes therefore represent a solution for improving the quality of water across catchments and landscapes, both by pollution interception and by the creation of new clean waterbodies.

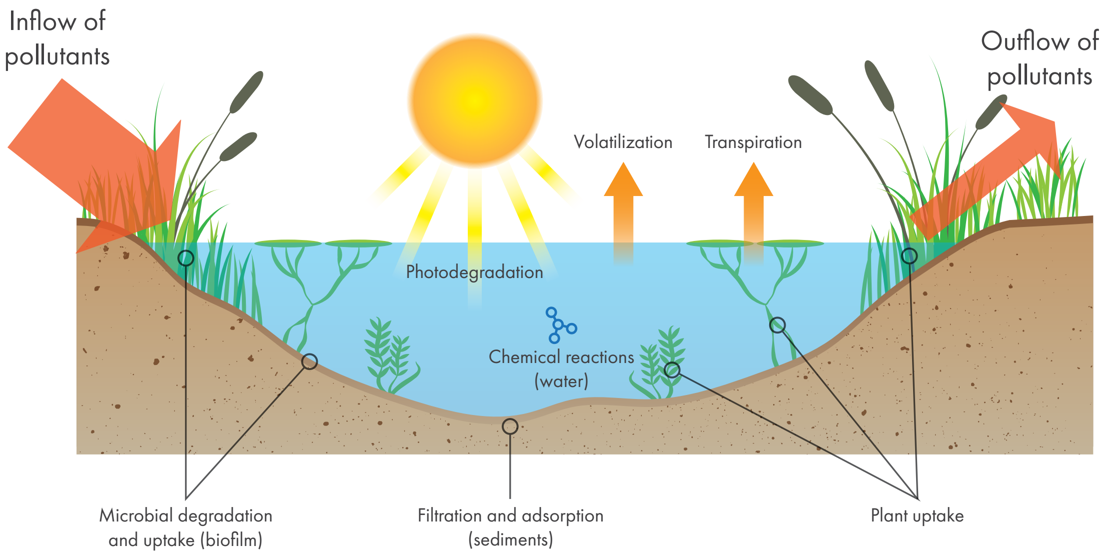


Fig. 11 - Purification in ponds is linked to the cumulative effect of various processes: filtration, chemical degradation (e.g photodegradation, hydrolysis), microbial degradation, volatilisation, adsorption on sediments, vegetation and organic matter, and plant and microbial uptake.

TIPS FOR IMPROVING WATER QUALITY:
- Dense pondscape (numerous ponds)
- Pond areas and depths optimised (as big as possible) – high water detention time in the ponds
- Regular cut of emerged vegetation to help the uptake and elimination of pollutants
- Avoid the use of fertilisers and pesticides in the pond catchment
- Large areas of plant beds, especially emerged vegetation (e.g. reeds)
- Infiltration and vertical flow can also be promoted.

SEE SUCCESS STORY 6.3

Climate regulation: carbon sequestration

Ponds are the most numerous freshwater habitats on the planet and are often very productive systems with dense vegetation and high rates of photosynthesis and respiration. This leads to substantial trapping of carbon by algae and vascular plants, which is then deposited in the pond sediments. Nevertheless, ponds are also sources of large quantities of greenhouse gases (e.g. carbon dioxide and methane), especially when polluted, meaning that ponds have an important impact on the global carbon cycle. So, we need to adequately understand and quantify how these processes occur in ponds and the ways to maximise carbon sequestration and minimise other greenhouse gas emissions. Therefore, knowledge of the ways in which management can help ponds act more as carbon sinks than carbon sources is crucial.

What are these greenhouse gases and how are they produced or trapped in ponds?

Many processes operating in ponds will produce or trap the three main greenhouse gases: carbon dioxide, methane and nitrous oxide. These processes are linked to both vegetation and microbial communities' activities, but also to the physico-chemical conditions (in particular the abundance of oxygen and nutrients) and the quantity of organic matter. The global warming potential is highest for nitrous oxide (265 times more potent than carbon dioxide), although methane has 28 times greater warming potential over 100 years than carbon dioxide.

The processes which produce or trap greenhouse gases in a pond are: photosynthesis, respiration, organic matter decomposition, microbial activity (including methanogenesis, methanotrophy and denitrification), sedimentation and chemical reactions (e.g. oxidation, reduction) (see Fig. 12). There are two main processes by which greenhouse gases are released into the atmosphere: diffusion (molecule exchanges between air and water of methane, carbon dioxide and nitrous oxide) and ebullition, which consist of the emission of bubbles formed in the sediment, which have a very high concentration of methane. Ebullition only happens in shallow water less than 10 m deep and is the dominant type of methane emission in ponds.

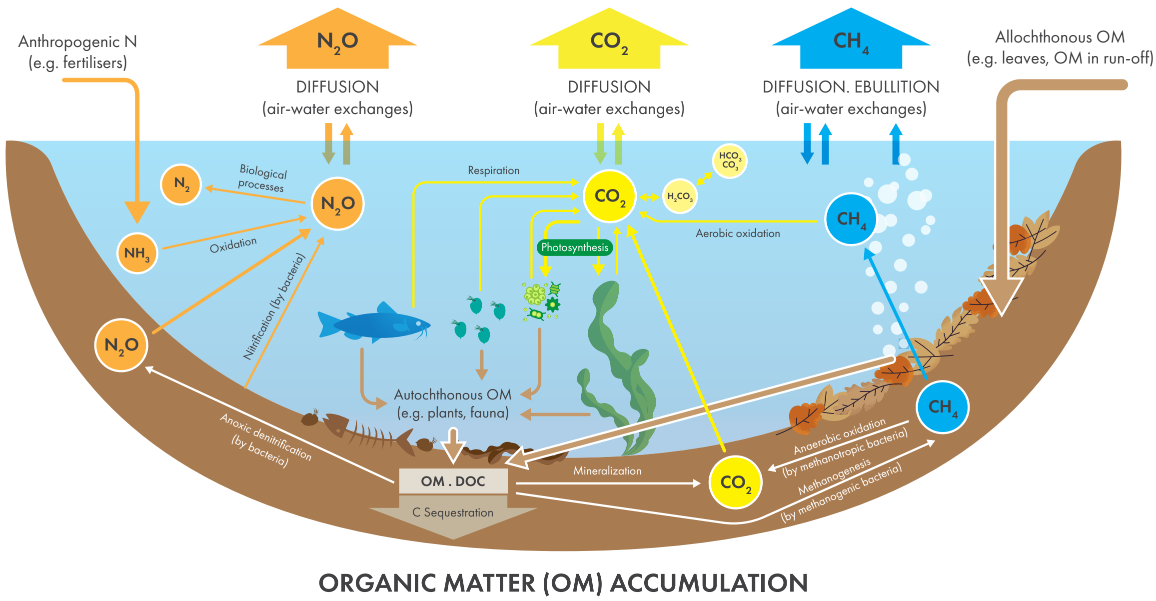


Fig. 12 - Processes occurring in the pond leading to the emission by diffusion or ebullition of the three greenhouse gases (above: N_20 – nitrous oxide; CO_2 – carbon dioxide; CH_4 – methane) and to the sequestration of carbon in the sediments (below). OM – Organic matter; DOC – Dissolved Organic Carbon; N – Nitrogen.

Methane is chiefly produced in anaerobic situations (when oxygen is absent). The gas is produced when archaea process the organic matter in the sediment and water column by methanogenesis. In the presence of oxygen, methane can be transformed into carbon dioxide by methanotrophic bacteria. Methane can also be oxidised to form carbon dioxide under anaerobic conditions.

Carbon dioxide is a by-product of respiration, a process which all plants, animals, fungi and bacteria use. It is also produced by pH-mediated alterations to carbonate chemistry and photo-oxidation of dissolved organic carbon (which is partly produced by organic matter decomposition). Carbon dioxide production is also linked to oxidation of methane, as explained above. During daylight hours, carbon dioxide is used up by phytoplankton, algae and aquatic plants through photosynthesis and released at night when respiration is the dominant process.

Nitrous oxide is produced by bacterial activity (denitrification or nitrification) under nitrogen-rich conditions. High levels of nitrogen in waterbodies are often caused by human pollution, including the use of agricultural fertilisers and sewage disposal. Studies have shown ponds can be both a source and sink of nitrous oxide. There have been a number of studies, including the **PONDERFUL** data, that find that ponds are sinks of N_20.

What's the balance of accumulation of carbon vs emission of greenhouse gases?
Ponds are probably the most efficient ecosystems per unit area of the planet for trapping carbon but also for producing greenhouse gases, as highlighted by **PONDERFUL** investigations. There is also considerable variation in seasonal patterns, with evidence of emissions tending to be higher in summer but with substantial variation between sites.

As ponds can both store and release carbon, it is important to consider the balance of CO_2 sequestration vs CO_2 emission in order to calculate their overall effect. **PONDERFUL** survey and mesocosm experiments show that increased temperatures combined with raised nutrient levels make a pond more likely to be a net emitter. Thus, in the face of increasing temperatures, it is vital to keep nutrient levels as low as possible. In addition, abundant rooted submerged plants appear to encourage net sequestration. Conversely, ponds with high dissolved oxygen concentrations and low total nitrogen levels (phosphorus appears to play less of a role in this relationship) are more likely to be a sink rather than a source of greenhouse gases. In further developing our understanding of ponds' role in the carbon cycle, ponds with higher net sequestration rates will be particularly useful for further study to learn how management can direct the system towards carbon storage.

PONDERFUL's analysis of c180 pond nature-based solution actions, implemented across 93 ponds/pondscapes from 24 countries, found that, at present, pond nature-based solutions implemented by managers primarily focused on climate change adaptation (especially regulation of hazards and extreme events, and maintaining water quantity) rather than mitigation. No measures were reported that were specifically used for reducing greenhouse gas emissions or enhancing the ability of ponds to be carbon sinks.

Which types of ponds present low greenhouse gas emissions?
The emission of greenhouse gases is affected by nutrient concentrations, and dissolved oxygen. Low dissolved oxygen levels are associated with increased emissions of methane and carbon dioxide both on the annual and seasonal scales. Nutrient enrichment, particularly by nitrogen, was found in the **PONDERFUL** dataset to be associated with increased emissions of both carbon dioxide and methane.

TIPS FOR REDUCING GREENHOUSE GAS EMISSION FROM PONDS:
- Create ponds which have well oxygenated water columns (e.g. open to the wind to encourage mixing of the water column)
- Manage the landscape to create 'clean' catchments for ponds, ensuring that ponds are low in nutrients

SEE SUCCESS STORY 6.4

Pollination

Of the ecosystem services and Nature's Contributions to People provided by ponds, pollination is frequently overlooked by managers. However, stakeholders in the **PONDERFUL** demonstration sites often noted pollination as a significant service which could be provided by ponds, reflecting growing awareness of this issue. Indeed, several studies (for example in the United Kingdom, Sweden, Germany and Switzerland) have reported a higher abundance of pollinators near farmland ponds, which may have a positive impact on crop pollination. Pollinator abundance is especially high when ponds have a flower-rich aquatic vegetation belt (see Fig. 13).

Most species of bee and hoverfly (the main group of pollinators) do not develop in the water. Instead they regularly use the ponds and vegetated shoreline for valuable pollen and nectar (from flowers), and water for drinking. The mosaic of habitats along the shoreline and surrounding areas also provides many species with sites for nesting. For example, bare soil is essential for several solitary bee species, while deadwood and other decaying plant matter can provide breeding and nesting habitat for bees, wasps, ants and hoverflies.

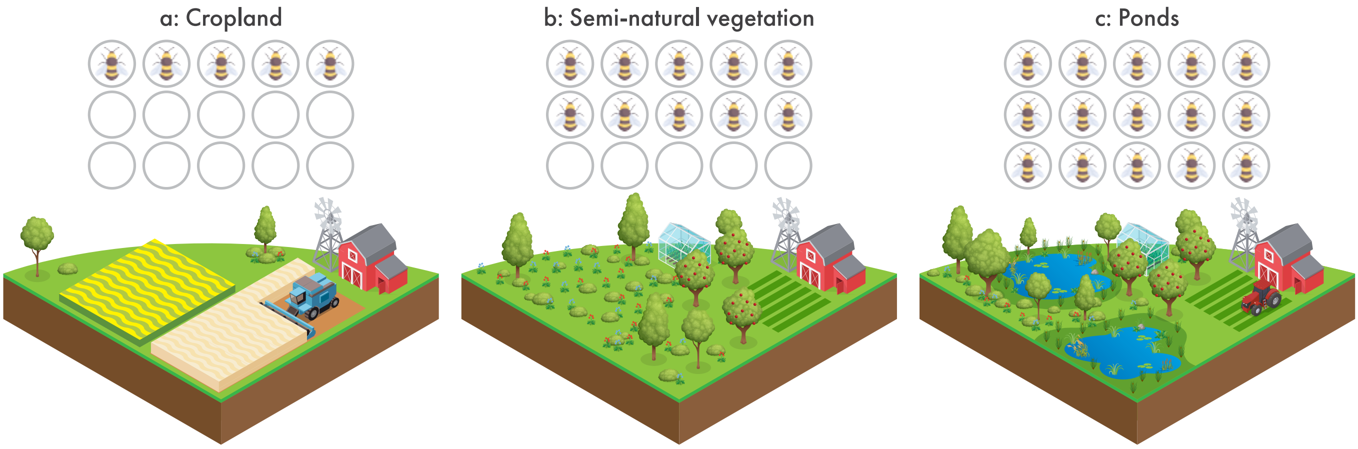


Fig. 13 - In the rural landscape, the area around a pond (c) can potentially host three times more pollinators (abundance of bees and hoverflies) than an arable field (a). This habitat also hosts markedly more pollinators than semi-natural terrestrial vegetation without standing water (b).

TIPS FOR IMPROVING POLLINATION:

- Promote the presence and diversity of aquatic plants in the margins, when possible with species that flower at different periods.
- Maintain a large surrounding belt of flower-rich emergent vegetation (e.g. *Mentha* spp., *Lysimachia* spp., *Lotus* spp., *Potentilla* spp., *Galium* spp., *Alisma* spp., *Epilobium* spp., *Lycopus* spp., *Cirsium* spp.).
- Promote a high proportion of early successional, open-canopy ponds in the pondscape. Woody vegetation should be managed and removed.

IMPORTANCE FOR LEARNING AND INSPIRATION, HUMAN HEALTH AND WELLBEING

(a) Physical and psychological experiences

Natural environments, including freshwaters, are now widely recognised as providing important benefits for people's health and wellbeing and for providing physical and psychological experiences. 'Blue spaces' have also been linked to stress and anxiety relief and a recent meta-analysis which quantified the health impacts of blue spaces concluded that it is comparable to the health-promoting capacity of green space.[16, 17]

Physical and psychological experiences linked to ponds were reported as the second-most important service provided by pondscapes in **PONDERFUL** surveys of stakeholders and local people (see section 3.2). These experiences are largely linked to biodiversity and the presence of water. With climate change, the association of ponds with these experiences will doubtless increase, partly due to the potential cooling effect of pondscapes. Many activities are associated, directly or indirectly, with pondscapes. They include wildlife-watching, hiking, picnics, cycling, contemplation/relaxation, fishing, hunting, boating, swimming, nature photography and creating art.

◀ Picnics © Beat Oertli

▼ Leisure activities such as boating © Sílvia Martins

Contemplation, contact with nature © Freshwater Habitats Trust

(b) Education and inspiration

Ponds are a valuable tool for environmental education, especially when they are part of a landscape with other connected waterbodies. The advantages of ponds for educational activities are their small size and accessibility (making them easier to explore than larger waters) and their high diversity of species (which are easy to observe, and display spectacular variety and singularity of forms, ecology and biological features).

In addition, the physical (e.g. temperature) and chemical (e.g. nutrients, conductivity) characteristics of ponds can be measured to help people learn more about ecosystems. They also provide hands-on easy access to understanding other more complex topics (e.g. carbon flows, productivity, trophic chains, life cycles, metamorphosis, etc.). This means that ponds offer learning opportunities for students of all ages, as well as for the general public. In urban environments, many ponds are created with the objective of education and inspiration, especially in schools, but also in private gardens.

TIPS FOR IMPROVING EDUCATIONAL VALUE:

- Information panels are important and popular education tools. A wide range of options are available (e.g. different sizes and designs, some with interactivity) to suit all audiences and budgets.
- Organising outdoor educational activities using ponds to promote close contact with, and identification of, plants and animals, helping to develop relationships with the waterbody and an understanding of the richness of ponds.
- Creating ponds in school yards, public city gardens and pedagogic farms provides valuable educational resources. Ponds and pondscapes are perfect places for people to get involved in citizen science activities, such as species inventories, water quality measurements and even eDNA sampling.

SEE SUCCESS STORY 6.7

Many NGOs regularly organise events at ponds as educational tools because they are common, widespread and important. © Freshwater Habitats Trust

Information panels can be set up around pondscapes, covering various themes related to biodiversity and the functioning of these waterbodies. © Beat Oertli

Bird hides are greatly appreciated by the general public. © Freshwater Habitats Trust

COOLING EFFECT

Large ponds and dense networks of waterbodies can provide a cooling effect. These ponds or pondscapes can reduce air temperature by 2–3 °C, though this is dependent on the time of day as warming can be observed during the night. The most marked benefit can be seen when blue infrastructure (including running waters) is coupled with green infrastructure (e.g. trees, shrubs, hedges, meadows). The cooling effect can be as much as 6 °C Physiological Equivalent Temperature if the pondscape is covered by trees. The blue-green matrix is particularly efficient at reducing temperatures in cities where this nature-based solution can improve the urban ‘heat island’ effect.

Smaller ponds (less than c.2500 m^2) do not have a significant impact on air temperature. However, they do have recognised positive impacts on people, creating a feeling of cooling which contributes to improved wellbeing. This psychological impact is linked to seeing, hearing (e.g. fountains, water jets), touching or being close to water (bridges, stepping stones). This can be achieved at small urban waterbodies as well as ornamental ponds.

Swimming is particularly popular in large, naturalistic, ponds during the summer months. The demand for new bathing areas is growing fast and has been linked to the increased frequency and duration of heatwaves.

Direct contact with water (e.g. swimming) provides cooling.
© Adrienne Sordet

Proximity of water (e.g. bridges and benches) provides a cooling feeling that is especially appreciated by people during heatwaves. © Beat Oertli

In more natural pondscapes, the coupling of the ponds with green infrastructure (e.g. trees) is particularly efficient for reducing the air temperature.
© Markus Spiske

TIPS FOR ACHIEVING A COOLING EFFECT:

- Coupling ponds with green infrastructure (carefully located trees near, but not overshading the pond, particularly on the south side).
- Implementing features that bring people closer to water (e.g. bridges, stepping stones, open shores, platforms, pathways, benches).
- Providing facilities to help swimming.

SUCCESS STORY 6.11


© Shogun

4. Practical techniques for managing, restoring and creating ponds and pondscapes for climate change adaptation

4.1 THE PRINCIPLES OF MANAGEMENT, RESTORATION AND CREATION FOR PONDS AND PONDSCAPES

This chapter describes how to plan and design a practical programme for managing, restoring and creating ponds and pondscapes to help us adapt to our changing climate and reduce its effects. These interventions are needed to get the greatest benefit from ponds and pondscapes as nature-based solutions. Without them, the value of ponds and pondscapes will decline, reducing their ability to provide us with services which help us to adapt to and reduce the impacts of climate change.

A guide to the whole process is provided, from setting objectives to creating and managing individual ponds or pondscapes. This chapter also includes new designs for CLIMA-Ponds created through **PONDERFUL**, ponds designed specifically to provide climate mitigation and adaptation benefits (see Section 4.6).

OVERVIEW OF KEY OBJECTIVES AND PRINCIPLES FOR PRACTICAL POND AND PONDSCAPE NATURE-BASED SOLUTION PROVISION

What are pond and pondscape nature-based solutions?
Ponds and pondscapes are nature-based solutions that provide a range of benefits for people and wildlife, including climate change adaptation and mitigation. To qualify as nature-based solutions, actions, measures and interventions must provide benefits both for people and nature, including economic benefits.

Measures that can be applied to ponds and pondscapes to enhance their role as nature-based solutions broadly fall into three categories:

- **Management of ponds as nature-based solutions:** applying practical measures to existing ponds or pondscapes to maintain their function as nature-based solutions. This can involve regular management of aquatic vegetation, invasive species or shade to encourage particular plant or animal species, or maintaining a good viewpoint for wildlife-watchers or nature-lovers. Management may also be used to slow or reverse successional change in ponds. Pollution by nutrients usually accelerates the process of pond succession, so more frequent management is often needed in polluted ponds. In this guide, protection of existing high-quality ponds is regarded as a subset of pond management work. Measures to protect ponds include: granting a pond protected status (e.g. nature reserve, regional or national park), addressing issues such as pollution in the broader pond catchment, creating buffer zones around the ponds or removing drains bringing in polluted road runoff. Management at the landscape scale also includes protecting existing high-quality ponds.

- **Restoration and 'resurrection' of ponds as nature-based solutions:** where ponds have lost their function, or to recreate habitat for a particular species, more intense intervention may be required. This could include clearing trees and scrub and dredging long-accumulated sediment. This is usually called restoration, although management and restoration are really two ends of a continuum. Restoration can also involve the 'resurrection' of 'ghost' ponds, re-establishing old ponds which have been deliberately filled in.

Note that there is considerable overlap between restoration and management, and these terms are sometimes used interchangeably.

Creation of ponds as nature-based solutions: digging or building a new pond in a location where there was no pond before brings this nature-based solution into the pondscape. Creating new ponds increases the amount of clean water in the landscape or pondscape, increases freshwater habitat connectivity and reverses the effects of pond loss.

Which technique should be used to ensure ponds and pondscapes provide a nature-based solution: management, restoration or creation?

All types of interventions – management, restoration and creation – are valid, depending on the nature of the pondscape. Your project may focus on managing or restoring existing ponds or on creating new waterbodies. In many pondscapes, it will be necessary to use all three approaches, with management used to maintain ponds in good condition, and restoration to initially shift a pond which has deteriorated back into a condition where management can maintain the services it provides. New ponds then extend the network and provide services which existing ponds cannot fulfil (e.g. extending whole landscape freshwater biodiversity; providing habitat for declining species; intercepting nutrients). Remember, it is the range of waterbodies within a landscape that delivers multiple benefits.

Fundamental to managing, restoring and creating ponds is ensuring that they have the 'right' hydrology. In many cases, this means ensuring that hydrology follows natural seasonal fluctuations, with 'permanent' pond-water levels falling in summer to provide rich drawdown zones, semi-permanent ponds drying occasionally (one year in ten) and temporary ponds drying annually. In other situations, water levels must be managed to provide the ecosystem service or Nature's Contributions to People for which the pond or pondscape is intended. For example, fish ponds and pollution interception ponds may need to be regularly fully drained to remove sediment.

Managing ponds and pondscapes

Pond management is needed to mimic natural disturbance processes that are lost from large parts of the landscape and to reduce or minimise detrimental impacts that result from the way the pond catchment is used (e.g. controlling the effects of nutrient enrichment). Good management can maintain ponds at a particular succession stage for specific plants or animals. This could include, for example:

- Regular cutting or grazing of aquatic vegetation, removal of invasive species and, if necessary, removal of excess organic matter and sediment.
- Using management at pondscape level to ensure that the range of ponds' successional stages are present in the landscape.
- Maintaining the range of habitat in a single pond and preventing domination by a few plant species (e.g. *Typha* spp.).
- Maintaining clean water, by catchment or pondscape land management, in a temporary pond for an endangered water plant community.
- Ensuring that pondscapes have a mixture of ponds with and without fish, to provide environments for species that need or co-exist with fish, and those that cannot tolerate fish predation.
- Keeping ponds free of alien species, especially in the case of ecosystem engineer species, such as crayfish (e.g. *Procambarus clarkii*) or tubeworms (e.g. *Ficopomatus enigmaticus*).
- Maintaining a pond for aesthetic reasons, including maintaining a good viewpoint for wildlife-watchers or nature-lovers.
- Ensuring a pond has a protection status (e.g. local, regional or national nature reserve), because this often creates obligations to establish a management plan.

At the pondscape level, the ideal is to manage 'biodiversity ponds' in a way which maintains a range of different pond types in the landscape (open, new, grazed, wooded, densely vegetated by emergent plants, temporary, semi-permanent, at different successional stages etc.). This is particularly important because freshwater plants and animals will often benefit from both a high density of ponds and the availability of a range of pond types. All clean, unpolluted ponds can provide valuable habitats for wildlife, including shaded and silted-up ponds, because different types of ponds are expected to host different species sets, and as such contribute to pondscape biodiversity. Management at the pondscape scale also includes protecting existing high-quality ponds e.g. managing livestock to ensure appropriate grazing densities.

Urban pond management in Porto, Portugal, where management is obvious. © JT/Charcos com Vida

Ponds that have a primary objective other than maintaining biodiversity, such as water purification, water storage or human wellbeing, will also require ongoing management to maintain that function. For example, ponds that trap sediment or nutrients will need regular dredging, and vegetation management will be required in swimming ponds to maintain open water.

Restoration

Some ponds are physically still present in the landscape but have either become largely dry, have accumulated very large quantities of sediment, have become very substantially overgrown by trees and scrub or been deliberately filled in (so-called 'ghost ponds'). Others may no longer perform their intended function as nature-based solutions. For example, although the pond basin may still exist, land drainage, diversion of the pond-water source, water over-abstraction or the failure of a dam, may mean that the original hydrology (either natural or engineered in the case of dams) is no longer maintained.

Restoration normally implies stronger actions to remove excess growth of woody plants and trees, invasive species or large accumulations of sediment that have degraded the pond's functions, biodiversity or ecosystem services. It can also mean repairing dams or removing drains. In many cases, heavier machinery, such as backhoes and excavators, is needed to be planned and involved in the action.

Restoration by woody vegetation and sediment removal work can greatly enhance both aquatic and terrestrial biodiversity in pond landscapes dominated by highly shaded, scrub-covered ponds. 'Pond resurrection', by re-excavating so-called 'ghost ponds', can successfully return biodiverse ponds and associated rare species.

Creating new ponds in a pondscape

If there is space, then it is almost always worth adding ponds to a pondscape. In urban areas, new ponds can provide many ecosystem services for people and wildlife. They can be created as part of new urban developments if they are included in the design stage or constructed in remaining green spaces. In towns and cities, where the original ponds have been filled in or badly polluted, making new ponds can reduce some of that loss.

In rural areas, it is estimated that, overall, we have lost about half of the ponds that existed at the beginning of the 20th century. In some rural regions losses can be much higher, with 100% of ponds now lost. Adding new ponds to the landscape in these areas will help restore pond density, bringing back vital habitats for freshwater biodiversity.

A critical advantage of new ponds is that they can be designed and located specifically to provide particular ecosystem services. For example, for ponds where biodiversity is the priority, new ponds can be located in areas where a supply of unpolluted clean water can be guaranteed to fill them if they are located in catchments which have no surface or groundwater pollution sources. This is the biggest single practical advantage provided by pond creation: for other freshwater habitats (e.g. rivers, lakes, streams) it is much harder to create catchments which do not generate pollution.

New ponds can help restore connectivity for aquatic wildlife and, with good design and clean water, provide new habitat for existing wildlife. In addition, they can act as receptor sites for native species reintroduction. New ponds can also be placed precisely to address specific issues such as maximising flood storage, pollutant interception or the need for water for irrigation (see Chapter 3). Again, in these instances, good design and planning is key to ensuring that the new ponds meet the objectives of the scheme.

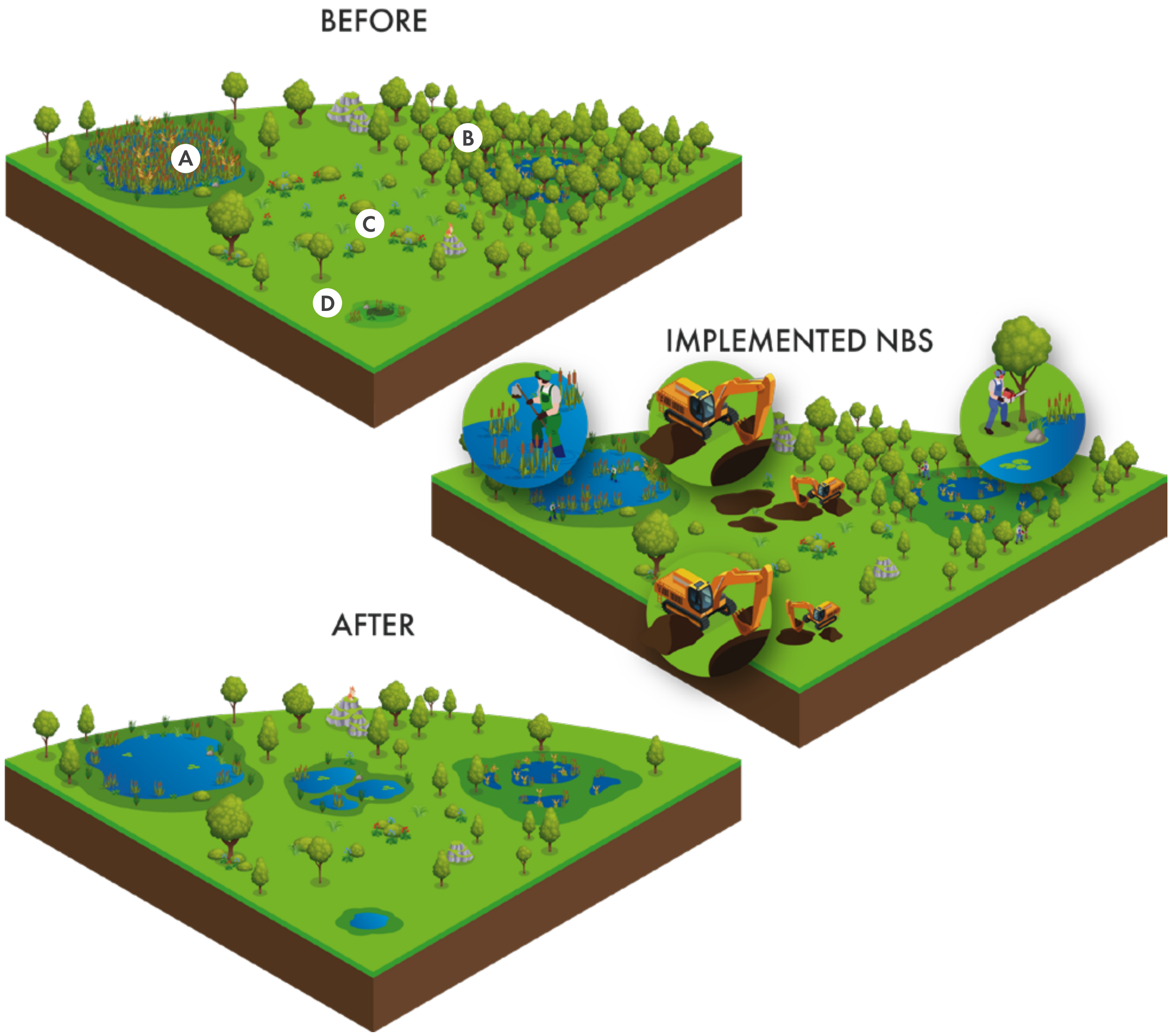


Fig. 14 - A pondscape before (A – overgrow of aquatic vegetation, B – overgrow of trees, C – lack of ponds, D – ghost or silted pond) and after nature-based solutions (NBS) are applied.

Understanding policy and social context for ponds and pondscapes
One of the first steps in deciding which nature-based solution benefits we aim to obtain from ponds and pondscapes is to understand the broader context. Consider:

- What are the current characteristics and value of the pondscape and its individual ponds, and how are individual ponds or the whole pondscape impaired?

- What policies (international, national, regional or local) could help to deliver pond management, restoration and creation?
- Which is the level of social awareness or concern for the good ecological state of ponds (either for specific ponds or the whole pondscape)?
- What potential sources of funding are available?

To begin planning your project, important questions are:
- How is the pondscape defined (its extent or boundary) and how many ponds are in the pondscape?
- What is the condition of each pond in the pondscape in terms of biology, physico-chemistry and ecosystem services provided?
- Are there any current or future pollution or degradation sources or threats?
- What Nature's Contributions to People does the pondscape already provide or potentially provide with appropriate management?
- How are the pondscape and individual ponds used by people?
- What is the biodiversity of the pondscape and individual ponds? Are threatened species or invasive species present in the ponds?

Depending on resources, some of these questions can be difficult to answer in detail. However, even a relatively subjective assessment exercise can define objectives. This process is crucial in identifying the measures needed to maximise benefits for people and wildlife.

Applying the mitigation hierarchy

This handbook is concerned with providing advice on how to manage, restore and create ponds and pondscapes. In projects which damage or destroy ponds or pondscapes, the information provided here can be used to guide the different stages of the mitigation hierarchy which are:

- **Avoid impacts:** the first step of the mitigation hierarchy comprises measures taken to avoid creating impacts from the outset, such as careful spatial placement of infrastructure, or timing construction sensitively to avoid disturbance. Examples include the placement of roads outside rare habitats or key species' breeding grounds. Avoidance is often the easiest, cheapest and most effective way of reducing potential negative impacts, but it requires biodiversity, and other Nature's Contributions to People provided by ponds, to be considered in the early stages of a project.

- **Minimise impacts:** these are measures taken to reduce the duration, intensity and/or extent of impacts that cannot be completely avoided. Effective minimisation can eliminate some negative impacts, such as measures to reduce noise and pollution or building wildlife crossings on roads.

- **Restore or rehabilitate habitats affected by impacts:** the aim of this step is to improve degraded or removed ecosystems following exposure to impacts that cannot be completely avoided or minimised. Restoration tries to return an area to the original ecosystem that was present before impacts, whereas rehabilitation only aims to restore basic ecological functions and/or ecosystem services. Rehabilitation and restoration are frequently needed towards the end of a project's life cycle, but may be possible in some areas during operation.

- **Offset:** if earlier stages cannot mitigate all impacts, compensate for any residual harm through habitat creation or restoration. Ponds and pondscapes are good examples of habitats which can be used to compensate for losses elsewhere. There is good evidence of the effectiveness of this approach.

Guidance on the Mitigation Hierarchy is available from many sources. A good English-language starting point is CSBI (2015).[18]

Defining clear objectives and setting targets

When you are planning to manage, restore or create a pond or pondscape, the first question to ask is, 'What do we want to achieve?' It is vital to be clear about your objectives, as this will determine the aims of pond management plans and designs for new ponds. Decide why you want to create or restore a pond or pondscape. Is it primarily for people or for biodiversity? By definition, a nature-based solution has to be beneficial for both, which can also be considered at the pondscape scale (some ponds are targeted to biodiversity and others to human services).

You may need to involve a range of stakeholders in making this decision and setting objectives for your pond. Involving stakeholders at the earliest stages can also avoid problems (which sometimes cannot be solved) in the following stages. Deciding on your objectives at a very early stage will help you prioritise expenditure and avoid unnecessary work.

A good understanding of the whole pondscape is also critical to avoiding potential conflicts between the needs of people and freshwater biodiversity. For example, if a waterbody provides a good wildlife habitat, then improving access to people to provide an ecosystem service (such as supporting physical and psychological wellbeing) may disturb or degrade the pond. This could include non-native species being introduced, trampling of shoreline vegetated habitats or habitats being disturbed by pet dogs. In this case, it is often better to make new ponds to provide a particular ecosystem service, rather than trying to make all ponds perform all functions. In this way, multiple benefits can be provided effectively across a pondscape: for example, constructed ponds can contribute to regulating hazards and high-quality habitat creation, whereas existing ponds can be used to preserve biodiversity and provide opportunities for learning and inspiration.

A crucial part of defining objectives for pondscapes which involve new pond creation is ensuring that water, of suitable quality, is available. In many pondscapes, pollution of water sources means that this will require careful evaluation and choices made between groundwater, surface water or ditches and stream inflows.

In this nature reserve pond in southern England, dogs and their owners had access to the right-hand side of the pond, but were excluded by a fence on the left-hand side. The difference is striking. © Jeremy Biggs

Ponds can be created or restored as nature-based solutions, but no single pond can provide all benefits and some objectives may be incompatible. For example, the same pond may be able to provide both nutrient interception services and habitat for wetland plants that require or tolerate high nutrient levels. However, if it is desirable to have fish in a pond, that pond cannot also increase the population size of both *Triturus cristatus* and *Bufo bufo* because the former usually requires freedom from fish predation, whereas the latter is tolerant of fish. For this reason, at the pondscape level, multiple objectives are much easier to achieve by assigning different 'roles' to different ponds.

It is also useful to consider the relationship of the ponds in the pondscape to other freshwaters and to terrestrial fauna (including both wildlife and game). Ponds may help maintain the biological value of other freshwaters in a variety of ways, including providing:

- Fish breeding and refuge habitats on river floodplains
- Refuge for lake-dwelling water voles under predation pressure from non-native American mink, with water voles surviving in the landscape in ponds near the lake[19]
- Additional breeding habitats for amphibians requiring high-quality ponds in pondscapes which already have existing impaired/polluted ponds[20]
- Areas where dragonflies can breed in pools maintained or created in raised bogs
- Areas of calm, slow-moving, water in river or stream wetland systems diversifying the river corridor biota
- Increased freshwater habitat diversity in 'lake districts', providing small standing waters that support different species to those found in lakes, perhaps because they are temporary and consequently free of predators; ponds can also help birds using the whole freshwater environment (i.e. both lakes and adjacent littoral ponds).

The decision support chart (Fig. 15) can be used to plan the process of managing a pondscape, and is designed to help managers implement nature-based solutions at the pondscape scale and plan a pondscape management plan.

Conceptually, the aim is to: (i) define the role of the existing ponds in the pondscape in providing different ecosystems services or Nature's Contributions to People, (ii) risk assess any impacts that management to provide or modify these services could cause and (iii) determine whether new ponds should be added to the pondscape to provide additional ecosystem services.

The stages of the pondscape management plan development are to:
- Identify the extent of the pondscape and define its objectives
- Identify existing individual ponds and assess the ecological condition (biodiversity and physico-chemistry, functioning and impairment) of each pond
- Identify threats to the ponds and the Nature's Contributions to People they provide
- Assess the ecosystem service/Nature's Contributions to People to be provided by each pond in the pondscape
- Assess the need or opportunities for new ponds
- Risk assess the management or restoration process to ensure existing ecosystem services/Nature's Contributions to People are not reduced
- Manage, restore, create or protect ponds.

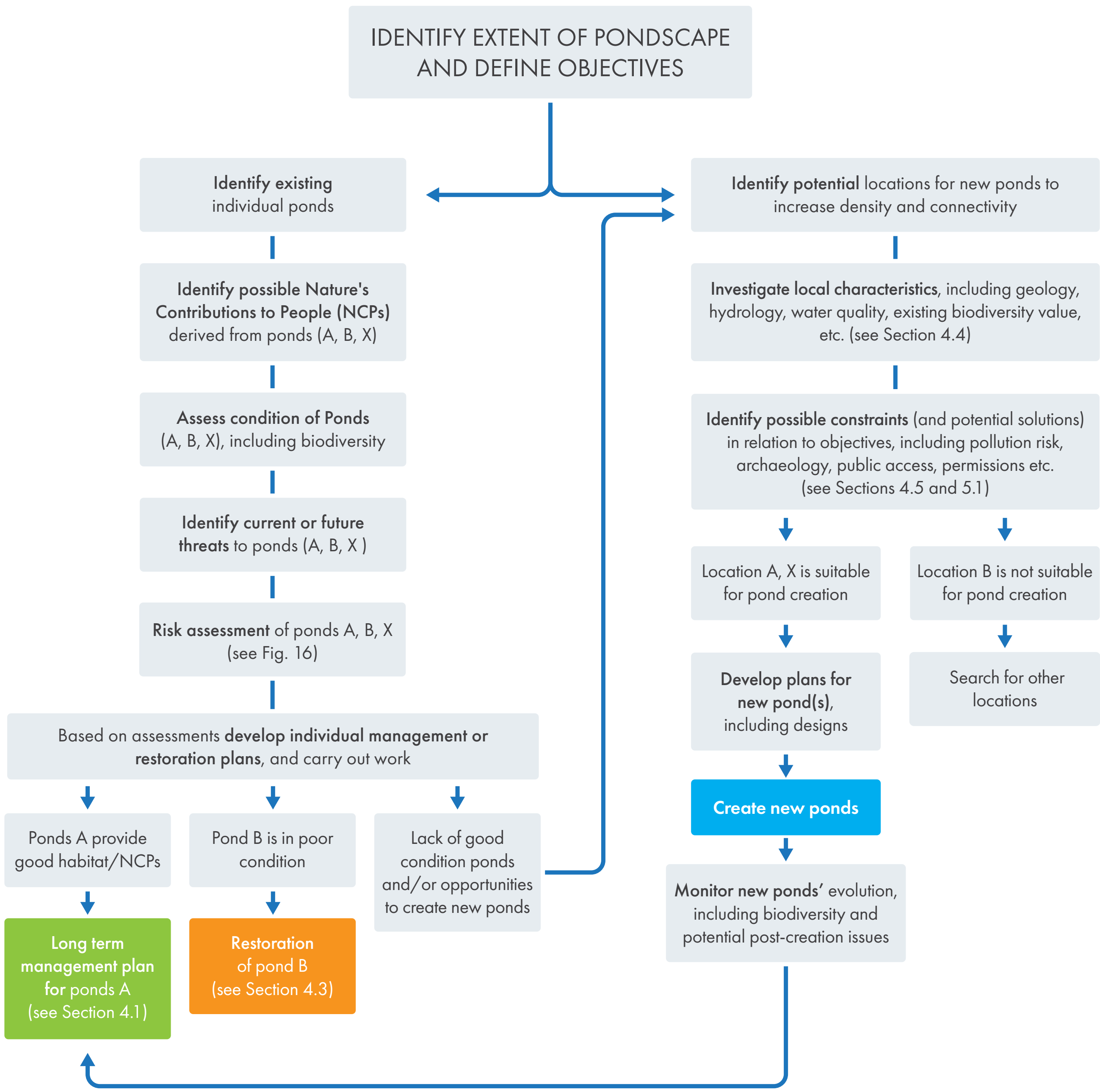


Fig. 15 - Decision-making flowchart for managing, restoring and creating ponds.

POND MANAGEMENT RISK ASSESSMENT

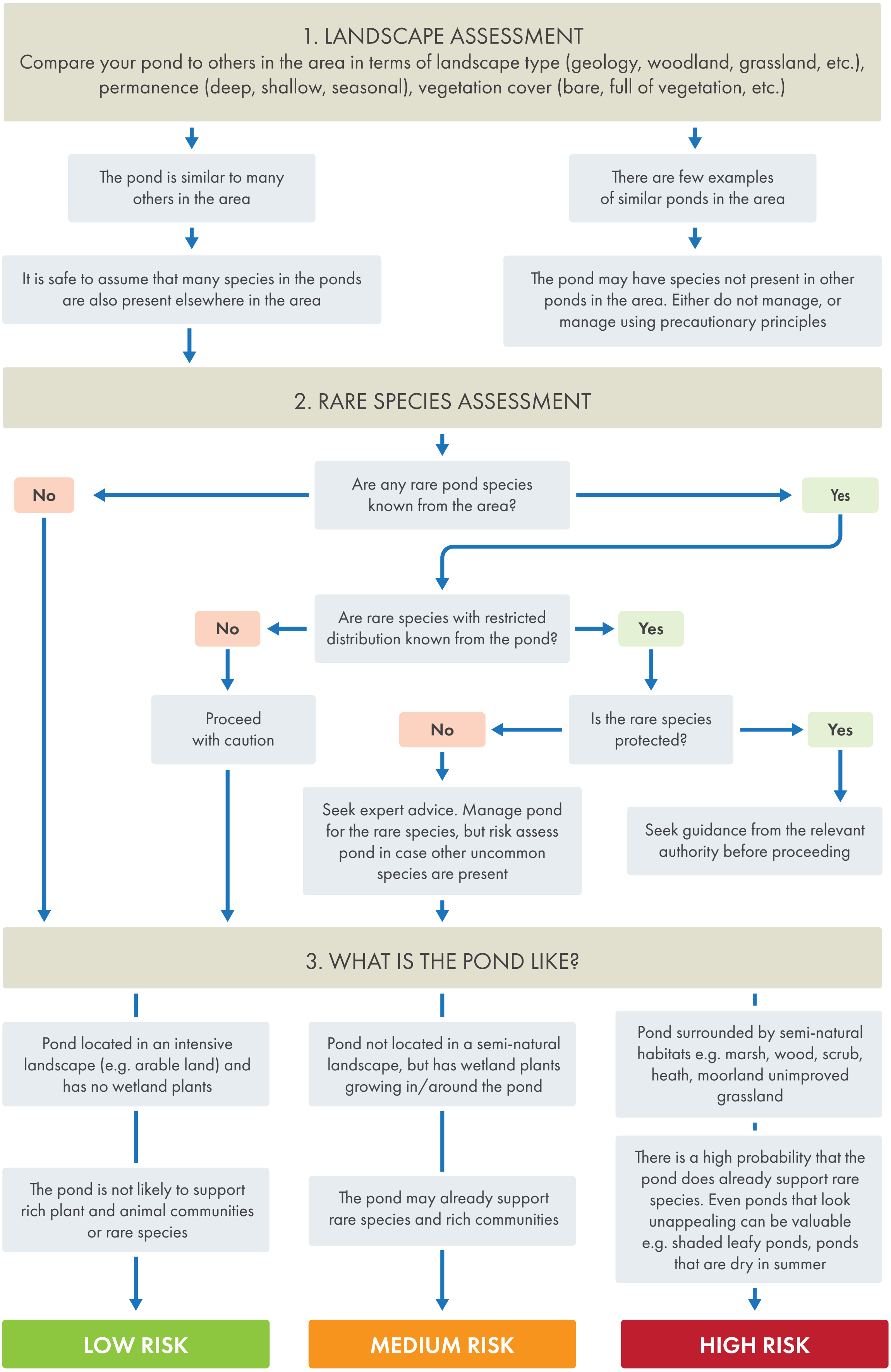


Fig. 16 - Pond management risk assessment flowchart (adapted from The Pond Book, Freshwater Habitats Trust)

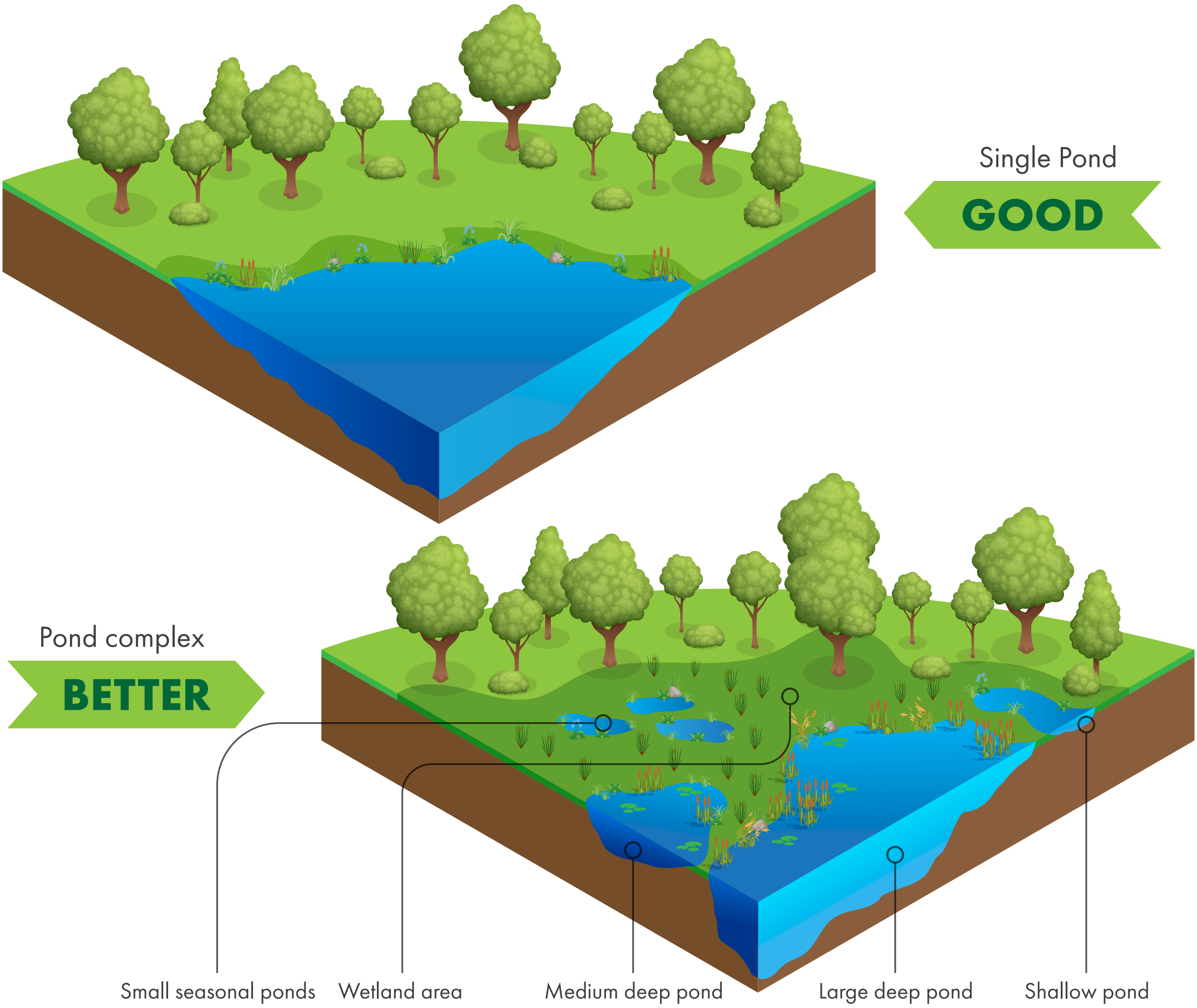


Fig. 17 - Making single new ponds with clean water is good for freshwater biodiversity; making a complex of ponds is better.

Setting targets for your pond or pondscape can help you measure your success in achieving your objectives. Targets could include:

- Restoring half the ponds in a degraded pondscape.
- Creating ponds to double the number of unpolluted ponds in the pondscape to enhance the network of freshwater habitats and regulate water quality.
- Ensuring all ponds in the pondscape are managed over a 10 year period, including defining which actions you will perform on each pond.
- Encouraging a particular species to colonise your pond or pondscape.
- Removing or reducing an invasive species from your pondscape.
- Supporting or meeting a particular policy or initiative in your area (e.g. targets for increasing the range of Habitats Directive species). This could be particularly important for receiving funding for your project.
- Managing or restoring half the ponds in the pondscape to provide additional pollination sources.
- Managing all ponds in the pondscape to reduce risks to climate (i.e. increase sequestration, reduce emissions).
- Establishing a network of floodwater interception ponds on each flow pathway in the pondscape.
- Attracting a certain number of visitors or particular groups (e.g. people with disabilities) or demographics (e.g. cultural minority groups) to your pondscape.
- Providing facilities to allow direct physical interaction with the ponds (e.g. swimming).
- Providing educational resources to facilitate understanding of the pondscape for learning and inspiration.
- Working with land managers and farmers to continue traditional pond management, and exploitation to support cultural identities.

Ensure you have access to the relevant expertise when setting targets. This could include working with a range of advisers. For example, a local ecologist can advise on the suitability of your site for a particular species, but you may need an engineer if you are planning to create ponds with dams or water-management systems with a complex system of sluices.

Decide on a timeframe for your targets. You may want to achieve some in the first few months, while others may be linked to future plans for the pondscape, such as creating more ponds in phases.

KEY CONCEPTS FOR POND AND PONDSCAPE DESIGN AND MANAGEMENT

The pond catchment

All waterbodies have surface-water catchments, also called the watershed. This is the land surrounding a pond which drains into it. For ponds fed by streams or ditches, the catchment includes the catchments of those streams and ditches as well. Ponds usually have fairly small catchments, typically tens of hectares, but sometimes as little as a few hundred square metres. In contrast, large lakes may have catchments of hundreds or thousands of square kilometres. Note that it may be difficult to define the catchment area of groundwater-fed ponds.

Identifying the pond catchment and its land use is critical when developing pond schemes because it determines the pond's hydrology and water quality. For example, ponds which receive water from intensively managed agricultural land tend to be polluted by sediments, nutrients and pesticides. Similarly, if a pond is fed by a stream that receives water from septic tanks or animal waste lagoons further up in the catchment, the quality of the water in that pond will be impacted by pollution. When designing a new surface-water fed pond on a clay substrate, the catchment of the pond needs to be large enough so that it fills and retains water for long enough to function adequately and meet the project aims.

Understanding the extent of a pond's catchment also supports decision-making at the pondscape level and helps prioritise resources. For example, pond restoration or management measures for wildlife ponds are best applied to ponds where sources of pollution can be removed or controlled to maximise benefits for aquatic wildlife. Note that polluted ponds may still be useful for terrestrial species, but the pollution will probably cause management problems.

Pondscape, National Trust Coleshill, UK. © Freshwater Habitats Trust

Even though the catchments of ponds are usually small, defining their extent can be difficult. The use of the tools appropriate for lakes or rivers (e.g. GIS) must be complemented by a field approach to identify the microstructures that divert runoff into or out of the catchment (e.g. ditches, paths, scree, accumulation of material, etc.). This fieldwork stage is best carried out after heavy rainfall which allows surface runoff to be visualised.

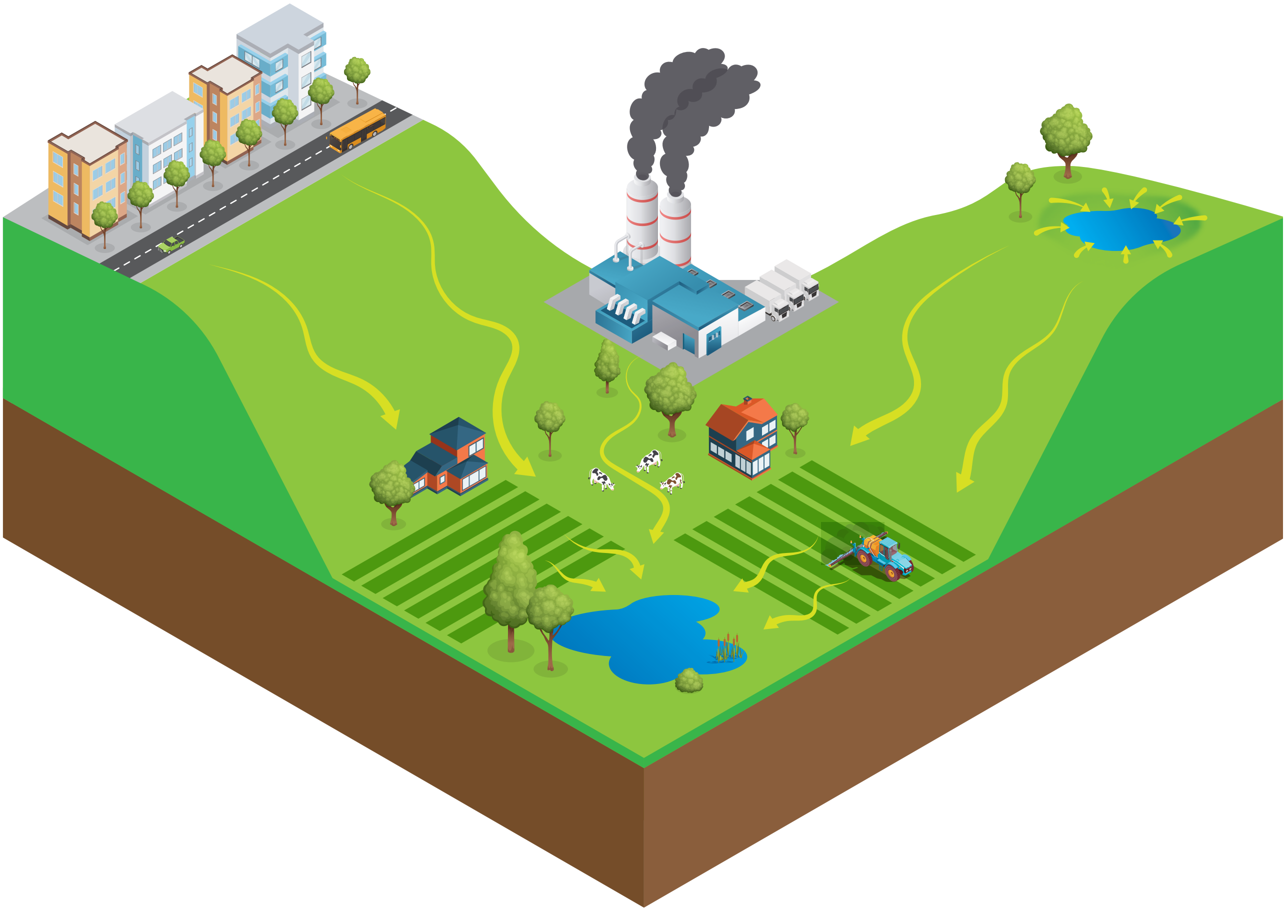


Fig. 18 - Understanding a pond's catchment is important in order to inform the location and design of new ponds, and to understand where water pollution might come from.

Clean water

Clean water is water that has a chemistry and biology that would be normal for an area in the absence of significant human impact. It is equivalent to 'High' status in the EU Water Framework Directive and 'Good' status in the UK PSYM* system for assessing the quality of ponds and small lakes (see Section 4.2). It is sometimes called the 'natural background', 'minimally impaired' or 'the reference condition'.

Unfortunately, clean water is now rare in many intensively managed or urbanised landscapes throughout the world. For example, in London, UK, 97% of running waters (streams and rivers) and 55% of standing waters (ponds and lakes) were polluted by nutrients.[21] In the **PONDERFUL** project, where ponds are primarily located in agricultural landscapes, only 25% of ponds had nutrient levels which met clean-water criteria. Ultimately, assessing levels of pollution accurately requires laboratory analyses of pollutants. However, recently, rapid techniques for making preliminary assessments of pollution level in ponds have been developed, which can make pollution assessment more achievable.

Clean water is critical for sensitive freshwater plants and animals, and is one of the most important features of any pondscape or pond scheme for biodiversity and people. Polluted water is unsuitable for ponds used for public swimming and may also promote harmful blue-green or filamentous algal blooms. There can also be health and safety issues resulting from bacteria and viruses that originate from organic pollution caused by sewage or livestock waste discharges.

* Developed by **PONDERFUL** partner Freshwater Habitats Trust, PSYM provides an assessment of the ecological quality of a pond compared to ponds nationally. It requires basic environmental information including pH and identification of plant species and/or invertebrate families.

New clean water pond © Jeremy Biggs

Clean water will inevitably be compromised in ponds that are specifically designed to reduce pollution or manage flooding in intensive agricultural or urban areas. Treatment ponds will only provide habitat for species that are not sensitive to pollution, and their diversity will be reduced compared to clean-water ponds in the same pondscape. Evidence from the **PONDERFUL** Water Friendly Farming demonstration site shows that ponds providing nature-based solutions for pollution and water retention make a substantially smaller contribution to landscape-level freshwater biodiversity than unpolluted ponds; they also support three times fewer uncommon and sensitive species.

In urban park or village ponds, people often enjoy feeding wildfowl or fish. However, the combination of a polluted water supply from the urbanised environment, the supply of nutrients in foods and the high populations of artificially fed ducks and fish means that water quality is usually poor. Furthermore, dog faeces, unless collected by owners, can be carried in runoff to ponds in these locations. These situations will invariably support species-poor aquatic plant and animal communities, and algal blooms may develop[†].

Although biologically these ponds are degraded, many people of all ages enjoy feeding and seeing fish and waterfowl in urban ponds, helping to create beneficial connections for people with nature. While this use can be supported in small numbers of waterbodies, we strongly advise encouraging better understanding of the natural richness of ponds, and educating people so that they can enjoy the more natural environment provide by unpolluted ponds. In this way, they can begin to discover some of the hidden secrets of natural and clean-water pond biodiversity, including the mating dances of newts, frogs chorus fighting and the egg-laying behaviour of dragonflies and damselflies.

Information and advertising campaigns can help people understand that feeding fish and ducks is not the best solution to pond management as it causes pollution and reduces biological quality. This means that, at the individual pond level, it fails to achieve the basic objective of a nature-based solution: to improve nature. However, at the pondscape scale, these potential conflicts between biodiversity, learning and psychological experiences can be easily addressed by having different types of ponds in different areas, and good engagement with the public.

[†] Although nutrient polluted ponds may be poor for vascular plants and have low diversity aquatic invertebrate communities, there is some evidence they may support diverse algal communities.

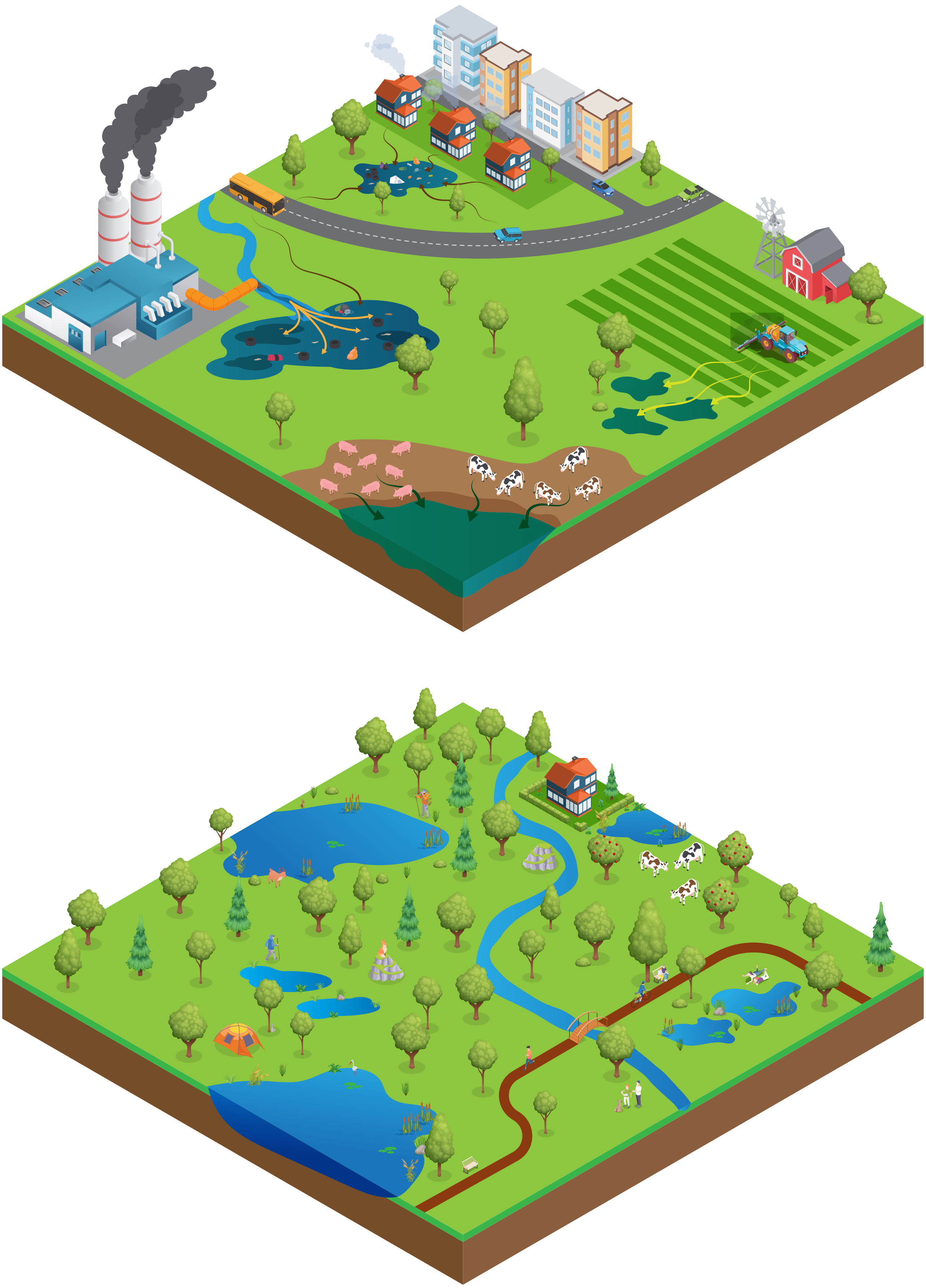


Fig. 19 - Water draining urban areas or intensively farmed land tends to be polluted. Ponds in less intensively used landscapes (woodland, unfertilised meadows, heaths) usually have good water quality.

Understanding the hydrology and water sources of new or existing ponds is critical for the development of practical management and creation plans. There are a number of different water sources for ponds:

- Rainwater: This includes both the direct contribution of rainwater falling on the pond and rainwater harvesting, which can be an important source of water for urban ponds e.g. collecting, storing and directing rooftop water. Rainwater is usually a clean water source compared to surface water and groundwater, although it is not completely free of contaminants, and can be a significant nitrogen source.

- Surface water: Ponds on clay geology or with an impermeable liner, with no inflow or outflow, are fed by the rainwater draining from their catchment. If the pond is surrounded by semi-natural land use, then this water will be 'clean' (see Box 2), reflecting the natural chemistry of the water draining from the pond catchment. If there are pollution sources in the catchment (e.g. nutrients, pesticides, micropollutants) then water quality in the pond is likely to be degraded. Depending on the topography of the pondscape and the services required of the pond (biodiversity, water treatment, flow interception), ditches or swales can be excavated to direct surface runoff to ponds, also reducing the risk of its passage to, or accumulation in, other areas. In the case of contaminated waters, banks, bunds and ditches can be used to direct contaminated water away from ponds intended for biodiversity, or into those used for pollution treatment.

- Groundwater: Ponds which are located where the water table is high, with geology comprising sands, gravels or peat, are usually groundwater-fed. Groundwater is generally cleaner and less polluted than surface water because it is filtered as it passes through the rocks. In some places, nitrogen pollution can also be removed from groundwater by the process of denitrification as it flows through gravels and sands. However, not all groundwater is clean: for example, on the floodplains of polluted rivers or in shallow aquifers below intensive farmland, groundwater can still be polluted. Surveys using boreholes can be used to determine how far below ground level the water table is located, but the presence of aquatic vegetation, such as reeds, or the regular accumulation of puddles in parts of the land, can give good indications of where groundwater is likely to be found. Note that groundwater levels will vary according to seasons and rain patterns, and are likely to be highly impacted under climate change scenarios.

- Streams, ditches or springs: Ponds filled by rivers, streams and ditches will be affected by the quality of the water they carry and of their catchments, and they can quickly be filled by sediments. Unless land use in the catchments is of low intensity or made up of near natural habitats (e.g. native woodland, traditionally managed semi-natural grassland, heathland) water from these sources will normally be polluted, making it advisable not to build ponds using these water sources (unless the main aim of the pond is water purification). If available, ***unpolluted*** springs and fountains can be excellent water sources, providing a continuous water flow and allowing the construction of ponds without impermeable liners. In some cases where ponds have ***higher*** nutrient or other pollutant levels than inflowing streams, pond-water quality can be improved by stream inputs, even if it is polluted. In these cases, streams may dilute and export pollutants from the pond.

- The sea: In some coastal locations, brackish water fills ponds close to the seashore. Ponds may be filled by sea water, either by superficial inputs from sea storms or via subterranean sources flowing through beach sand. Brackish water ponds have a highly specialised fauna, including endangered species.

- Substrates: Ponds are normally found on substrates which have low porosity (clay, alluvium) or which hold groundwater (sands, limestone, peat). The substrates on which a pond is located will determine its hydrology and understanding this will be important for managing water quality and water levels. It is much easier to create new ponds on impermeable substrates or in rock strata that contain groundwater. Ponds can be created on permeable substrates with artificial liners, though these have high cost and a limited lifespan. To evaluate substrate suitability for holding water:
  - Initially examine geological maps and look at existing ponds in the pondscape; note that geological maps are often not sufficiently detailed to describe small-scale variation in geology needed to identify potential pond locations.
  - Check any local sources of information about the pondscape's hydrology (such as boreholes maintained by water-management agencies); although designed for monitoring large waterbodies they may provide information useful for pond management.
  - Create 'trial pits' to evaluate substrates and determine whether there is groundwater present; information on geology is obtained by inspecting the trial pits. To assess hydrology, and particularly seasonal variations in groundwater levels, it may be necessary to observe the trial pit for 1–2 years.

- Alternatively, contractors with specialist drilling equipment can be hired to create a geological 'log' of the substrate and near surface geology, and install hydrological dip wells for longer-term monitoring.
- It is often useful to assess whether the pondscape has been drained; field drains exist very widely in agricultural regions and may not be obvious.

At the pondscape scale, ponds with different water sources can exist close together or even on the same site, depending on the local geology.

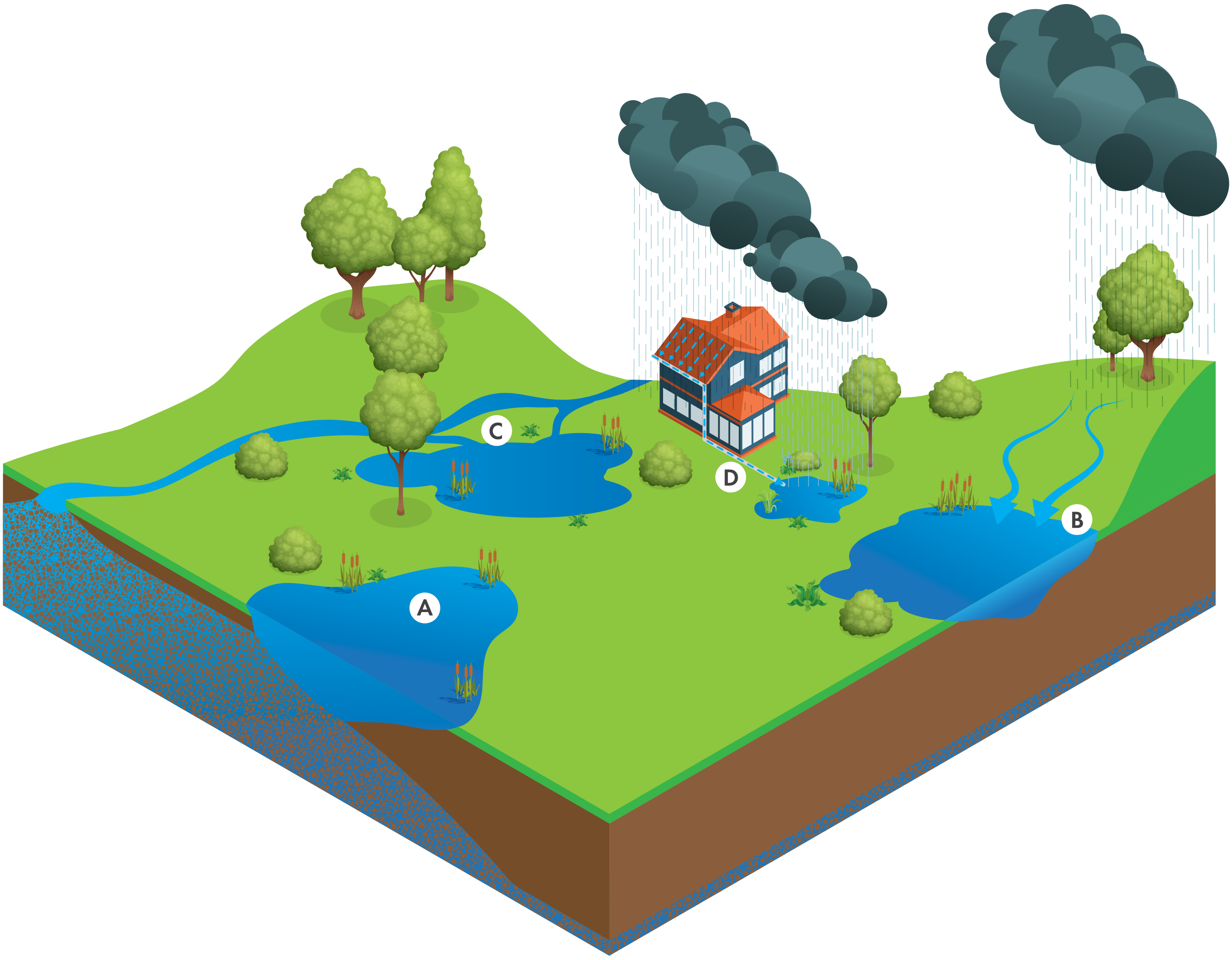


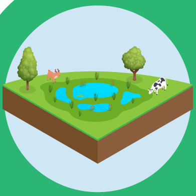
Fig. 20 - Pondscapes can have several different water sources, including groundwater (A), surface water (B) and river catchment (C). Rainwater harvesting (D) can also be used in more urban situations.

LONG-TERM MANAGEMENT CONSIDERATIONS

In any pond scheme, it is important to think early on in the scheme's development about the long-term management of the ponds once the initial work, whether management, restoration or creation, has taken place. With good planning, it is possible to make future management easier and reduce the frequency of future interventions. In planning long-term management of either existing or new ponds, the surrounding land use is a key consideration (Table 3).

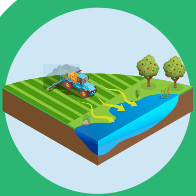
It is also important to take into account scenarios of climate change when considering the best measures to apply for ponds and pondscapes. For example, in arid regions, larger interventions may be required to maintain the functionality of ponds (e.g. deepening or removing agricultural drainage to restore pond hydrology).

Table 3 - Managing ponds: the key principles



PONDS IN NATURAL/SEMI-NATURAL LANDSCAPES WITH GRAZING (DOMESTIC LIVESTOCK OR DEER)

- Low-intensity grazing provides the optimum management for many existing and new ponds, and removes the need for manual maintenance.
- If pond banks are steep, consider fencing to keep people and livestock safe.
- Consider fencing if cattle density or disturbance is high. Fencing a larger buffer around ponds and providing a gate means livestock grazing intensity and timing can be managed.
- Carry out regular terrestrial scrub control around fenced ponds.
- Consider offset or partial fencing so that some parts of the pond are open for grazing and others only when water levels are high. This may also be beneficial to diversify grazing pressure.
- Where topography is favourable (e.g. hilly environments), drinking troughs can be installed to manage livestock visiting frequency.

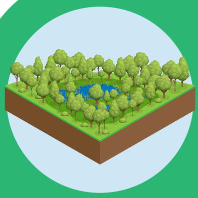


PONDS IN AGRICULTURAL LANDSCAPES WHICH ARE INTENSIVELY CULTIVATED

- Aim to minimise the exposure of ponds to modern agricultural practices (arable farming, intensive grass production).
- Pollution-sensitive species, like nutrient-sensitive water plants, and some amphibians and dragonflies, will usually not survive in these areas, though tolerant species persist.
- Consider creating ponds in blocks of land in the pondscape that are permanently removed from cultivation that uses agrochemicals.
- Remember that farmland is often rotated between pasture and crops. Ensure you understand the crop rotation patterns, and which agrochemicals are used, before planning a pond scheme on agricultural land.
- Be prepared for more management, or more frequent restoration of ponds, in a catchment which uses ploughing, fertilisers and pesticides. These ponds are likely to be polluted, so aquatic vegetation will grow more vigorously and ponds will silt up faster.
- Create the largest possible buffer zones around ponds: 50 m is good, but be aware that buffers may not be completely effective if there is heavy rainfall after fertiliser or pesticide spreading.
- To reduce pollution risks, consider constructing ditches or barriers to prevent surface water flowing into the pond from intensively managed land.

PONDS CONNECTED TO FLOWING WATER

- When inflowing water enters the pond, sediments settle out, causing silting. Be prepared for much more frequent (and costly) management than is needed for surface or groundwater-fed ponds.
- Flowing water carries surprisingly large amounts of sediment in suspension, and ponds fed by inflows fill with sediment 100 to 1,000 times faster than those without inflows.
- Consider designing silt traps into pond schemes (effectively a sacrificial pond before the main pond). They need regular desilting and, unless this is done, quickly become ineffective.
- If you are managing, restoring or creating ponds near rivers which are polluted, support fish populations or have invasive species, be prepared for careful management to reduce damage (pollution, alien species) or create useful habitats (floodplain ponds intermittently connected to river channels for fish).

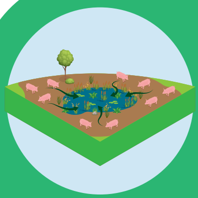


PONDS IN WOODLAND

- Ensure you have a tree management plan to maintain optimal pond conditions. Small ponds in woodland can quickly become heavily shaded, reducing suitability for some species. Tree management may require expensive specialised workers.
- On smaller ponds, consider collecting leaves manually, with wide mesh nets or rakes, during the autumn and early winter. The impacts of such interventions have not been evaluated, but might be beneficial.
- In woodland, consider creating larger ponds or ponds in clearings or alongside trackways. This can help maintain more open conditions without the need to manage overhanging trees. Note that large quantities of organic matter accumulating in ponds as a result of leaf and branch fall may increase the production of methane and other greenhouse gases.

RESTORED OR MANAGED PONDS

- Remember that vegetation of all types (emergent and aquatic plants, terrestrial trees and shrubs) will usually become established more quickly in restored or managed ponds than in new ponds, so management may be required sooner.
- Consider introducing low-density livestock grazing to manage vegetation growth and plan for future management works (including logistical and financial requirements) when designing a pond scheme.
- Evaluate the growth of vegetation annually to adjust the maintenance periodicity.

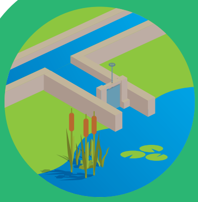


PONDS DESIGNED FOR POLLUTION MANAGEMENT

- Be prepared to carry out regular desilting and vegetation clearance for ponds which are intended to trap polluted water and sediments. Pond size influences how frequently desilting will be required – this could be anywhere from five to 30 years.
- Note that sediments, particularly polluted sediments, may have special disposal requirements which can be extremely expensive.
- Ensure that pollution management ponds are designed with the expected desilting regime carefully planned and financed.

PONDS WHERE PUBLIC ACCESS IS ENCOURAGED

- Remember that appearance and public safety will be especially important where public access is encouraged. Litter can build up if a site is not managed, and infrastructure (e.g. paths and boardwalks) will require regular maintenance.
- Avoid creating ponds with steep margins as this increases the risks of accidents. Where steep slopes are used, put them well back from the water on dry ground.
- Ensure ponds have wide shallow margins with very gently shelving edges or horizontal platforms for people to approach safely.
- Consider the number of people using a site and which areas are most heavily accessed.
- Carry out frequent checks to ensure that the pond is accessible and safe.
- Consider investing in signage to manage public expectation and encourage responsible enjoyment.
- Fencing, planting or wood piles could be used to manage disturbance levels where information signs are not successful.
- Make some ponds ‘low or no access’ to complement more accessible ponds in the same pondscape, in order to ensure biodiversity maintenance.
- Avoid encouraging fish and domestic ducks in urban ponds or create sacrificial fish and duck ponds.



MANAGEMENT OF POND WATER LEVELS

- Remember that for many ponds and pondscapes the optimum management method for delivering ecosystem services and Nature's Contributions to People will be to allow the natural hydrological regime to prevail. This leads to seasonal variations in water levels, which are valuable for maintaining a pond's ecosystem function.
- For a number of ecosystem services (e.g. water supply, food and feed, physical and psychological experiences) plan for how you will control water levels with dams, sluices and weirs.
- If you are managing, restoring or creating fish ponds or ponds used to intercept pollutants, consider draining the pond completely to remove accumulated sediments.

MONITORING

- Ensure that monitoring is planned, funded and undertaken at regular, relevant, intervals. This should take account of short-term early changes and longer-term management effects.

When budgeting for a pond scheme, it is important to include monitoring and additional funds to improve the pondscape. Regular monitoring is very important and often lacking. By visiting ponds often in the first six to 12 months after management, restoration or creation, you can learn a lot about a pond and identify areas for improvement. For example, you might notice that some ponds are consistently turbid, which may suggest that disturbance is too high and that fencing is required. For new ponds, frequent early visits are also useful for monitoring for invasive species which, if found and removed quickly, may be successfully eradicated. In general, monitoring is essential for adaptive management.

Longer-term monitoring is also important and can provide information about factors which influence pond function. For temporary ponds, how much of the year does the pond hold water for? In the case of permanent ponds, how much do water levels fluctuate? Both are likely to be determined by climatic variation.

These observations may reveal that further works are required to meet the project aims. For example, in the case of creating breeding ponds for amphibians, if monitoring reveals that the pondscape has consistently dried before young have left the pond, deepening several ponds, finding alternative water sources to direct into the pond, storing water or putting in an impermeable layer, may be necessary to extend the time the pond stays wet. Conversely, in pondscapes where ponds remain wet in all years because they are too deep, it may be possible to add new temporary and semi-permanent ponds to provide additional temporary water habitats.

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Regular monitoring will provide information about the effectiveness of site management (vegetation, livestock, pollutant accumulation, physical infrastructure etc.) which may require modifications to management plans. While it is possible to plan ahead and predict management, the plans also need to be flexible and informed by ongoing monitoring.

Fig. 21 - Lack of management can cause ponds to become completely overgrown with trees and other vegetation. Low intensity livestock grazing can be an effective means of managing ponds and pondscapes, reducing the need for manual vegetation control.

Ponds and mosquitos

In some areas, such as touristic regions or urban and suburban landscapes, there may be concerns that managing, restoring or creating ponds could encourage the spread of mosquitos which can transmit serious human or livestock diseases. Note that mosquitos that do not transmit diseases can also be a concern simply because they are abundant, e.g. in Camargue (FR).

Generally, mosquitos in ponds are controlled by a battalion of natural predators. Mosquito larvae are consumed in the water by water beetles, water boatmen, dragonflies and newts, and their adults are caught around the pond by frogs, bats, birds and other predatory flies. Because of this, mosquitos usually comprise only a small part of the pond fauna. They are only likely to be abundant in very small and temporary rainwater pools because these habitats lack biodiversity.

All mosquitos are more likely to be associated with artificial container habitats that are free of predators, especially plastic water barrels and tyres, where they reproduce in large numbers. Such containers should be removed from pondscapes as far as possible. If rainwater is collected in open containers to supply ponds, use it before mosquito larvae can emerge, or consider using filters. Mosquito-control programmes, including for species that present disease risks (malaria, dengue and zika), such as the Asian Tiger Mosquito (*Aedes albopictus*) and *Anopheles* sp., should particularly focus on removing small water containers from the pondscape, and encouraging the vital help of pond biodiversity to control mosquito reproduction.

In pondscapes where mosquitos are abundant (e.g. coastal marshland) their biting can seriously disturb people's activities. Under scenarios of climate change it is expected that disease-vector mosquitos may shift gradually to northern latitudes. If detected, these mosquito populations may need to be the subject of specific monitoring and control programmes, including control with the natural insecticide *Bacillus thruringiensis* (Bti). Information on control measures is available from the European Centre for Disease Prevention and Control. Use of Bti for mosquito control is described in the La Pletera **PONDERFUL** demonstration site success story (section 6.6).

4.2 ASSESSING AND MONITORING PONDS AND PONDSCAPES

This section provides an overview of the methods that can be used to monitor and assess ponds and pondscapes through both one-off assessments and longer-term monitoring.

There are many reasons to evaluate ponds including: to assess the conservation value of individual ponds, to monitor changes in the number and value of ponds as nature-based solutions (such as for intercepting pollutants), to monitor the populations of threatened species, to look at the distribution of different pond types in the landscape or to monitor impacts (for example, if the number of visitors or livestock using ponds is increasing). These monitoring programmes may be driven by regional, national, EU or international policies.

There are two issues worth considering when choosing from the many methods that can be used to assess and monitor ponds:

- What do you want to find out? It is important to be clear about the answer(s) that you need in order to plan and collect the most appropriate data, and not waste resources on unnecessary measurements.
- Are there standard methods that you can use? There are significant benefits from using pre-existing methods rather than developing your own new ones, including the fact that:
  - you can build on other peoples' knowledge: there are many factors involved in developing methods – everything from the best time of year to survey, to the materials and skills needed, and the different ways things can be measured.
  - you may be able to compare your results with others' data collected using the same method, in order to discover if your results are typical or unusual.

The use of existing methods has to be done with caution, especially between different regions and climatic zones. Some methodologies are region dependent and, even though the designers of the methods adequately describe their limits, sometimes people do not take this into account. In regions with climatic conditions that are different to those where the methodology has been developed, or with differences in other important environmental factors, the use of one specific methodology may not be adequate. In these cases, adapting methods to take into account the effects of the different environmental conditions can be a solution.

Assessing and monitoring Nature's Contributions to People delivered by implementing nature-based solutions

There is a large range of options for measuring the benefits arising from ponds and pondscapes as nature-based solutions. Any assessment needs to define specific indicators, depending on the particular Nature's Contributions to People (NCP) to be monitored, and then describe the way these indicators can be measured in the field. For example, for biodiversity, a set of bioindicator taxa could be chosen and the methods for quantifying their abundance described (water samples, direct observation, etc.). The section below summarises typical approaches.

Biodiversity (NCP: Habitat Creation and Maintenance): Pond biodiversity is most often measured using a combination of the number of pond species and the occurrence of rare and threatened species in a pond. The typical groups assessed are amphibians, wetland plants and/or larger (macro)invertebrates. However, diatoms, microarthropods (like zooplankton), reptiles, fish, mammals and birds are sometimes surveyed, especially in larger water bodies. Methods are discussed in detail in Sections 4.2.1 and 4.2.2.

Water storage (NCPs: Regulation of hazards; Food and feed): Ponds can be useful for storing water in periods of flooding, for fighting fires, for watering livestock, for providing water for wild animals and for preventing or slowing the entry of water into rivers and flooding downstream areas. Monitoring could include assessing the volume of water retained and the period it is retained for. For example, flood storage capacity is the extra volume of water above normal water levels that a pond can hold before it overflows. It can be measured by multiplying the drawdown area by its height, in order to estimate the volume of water the pond can hold.

Pollution interception (NCP: Regulation of freshwater quality): Ponds are often used to help intercept pollutants and prevent them entering other waterbodies. The most common way of calculating their effect is by comparing the levels of relevant pollutants in pond inflows and outflows. Most commonly, this includes nutrients (phosphorus and nitrogen), but also organic matter, bacteria, pesticides and metals (such as copper in agricultural areas, or heavy metals in urban areas), but analysis costs can be high. It can also include emerging pollutants and microplastics.

There are also biodiversity assessments and indexes to estimate water quality. Regular water samples, with extra collected during wet weather, are vital. Monitoring will probably need to be long term and include storm events, in order to properly evaluate effectiveness (noting that many pollution interception ponds are not effective).

Carbon storage and climate change mitigation (NCP: Regulation of climate): Assessment of pond greenhouse gas emissions and carbon sequestration requires careful field measurement using advanced methods. It is currently a research-level activity. Methods used for **PONDERFUL** are described in Davidson et al. (2024)[22] and comprise floating gas samplers for measuring emissions and sediment traps or cores for assessing carbon burial.

Value for education, amenity, health and wellbeing (NCPs: Physical and psychological experiences; Learning and inspiration): Numerical data is usually assessed in terms of visitor counts. The perceptions of visitors and other stakeholders can be assessed through questionnaires, interviews, and focus groups with semi-quantitative assessment through Likert scale questions.

4.2.1 ASSESSING AND MONITORING INDIVIDUAL PONDS

Detailed assessments of ponds usually include collecting a mix of physical, chemical and biological data. The biological data provides information about the biodiversity value of the pond and may provide information about pond quality (i.e. how degraded the pond is). Physical and chemical data are used to better understand pond quality, help interpret the biological findings, and evaluate success or constraints on Nature's Contributions to People.

Assessing pond biodiversity

Pond biodiversity measures aim to show how valuable a pond is for wildlife, i.e. the conservation value of the pond. Ponds are very rich habitats and it is almost impossible to identify all the species present. Because of this, biodiversity measures usually focus on particular groups, such as wetland plants or amphibians. Selecting the group to survey involves weighing many factors, such as whether the group(s) will be representative of the wider pond and the cost of undertaking the survey. It is also valuable to assess which group(s) are good for communication with the public (i.e. 'flagship' species). The pros and cons of using different groups are summarised in Table 4.

To be representative of the pond as a whole, the best choice is likely to be a combination of plant and animal groups that contain many species. The ultimate choice will depend on the aims of the project and skills available. However, a typical choice is to survey wetland plants, macroinvertebrates and amphibians (Table 4). If costs mean that only one group is possible, then the best choice is likely to be wetland plants because they are a species-rich group which is quick to survey, can be used to calculate quality indices, and are the focus of many European pond-type assessments. An intermediate option which was applied by the **PONDERFUL** project is to combine wetland plants plus some animal groups (taking into account different traits and phylogeny) such as zooplankton, molluscs, water beetles, caddisflies, stoneflies, mayflies, dragonflies and amphibians.

Pond biodiversity is typically assessed in terms of species richness and rarity. Species richness is a count of how many species are present within the groups surveyed. The abundance of species is often, but not always, useful. The presence of species with a national or international rarity status, or which are protected under legislation, is useful for assessing site status. Pond type can also be an important way to identify ponds of conservation importance, particularly if the pond falls within one of the European Habitats Directive Annex I list of rare and vulnerable habitats.

Rarity measures are generally based on country and international assessments of species threat-based IUCN categories (Endangered, Vulnerable etc.) and, in Europe, on the European Habitats Directive Annex II list. This includes freshwater habitat codes: 3110, 3120, 3130, 3140, 3150, 3160, 3170, 3180, and 3190. It also includes 2190, which includes dune slack pools, and 7110 and 7150, which include pools in peat and acid bogs.

However, individual countries often have specific national and sometimes regional rarity lists. Rarity indices, which rank species based on their rarity, can be useful when comparing rarity values between ponds.

Other biodiversity measures: Other measures, such as species diversity (a measure that combines the number of species and their abundance) and measures of ecosystem function, are sometimes used but are generally more difficult to interpret and use for practical pond conservation evaluation. However, diversity indices may be very relevant for analysing ecological processes at community level. For example, diversity indices may help to determine whether, after management or restoration, pond communities show a tendency to become more, or less, like a desired target pond-community type.

Assessing pond ecological quality
Pond ecological quality is an assessment of the overall condition of the pond: its physical and chemical condition, and the health of its plant and animal communities. Pond ecological quality is most often assessed using a combination of physico-chemical water quality data and biological survey data.

Water-quality monitoring. Water-quality impairment from pollution is one of the commonest factors that degrades ponds and reduces their ability to deliver Nature's Contributions to People. Water samples are generally analysed for nutrients which are critical pollutants, especially nitrogen and phosphorus. Nutrients are ideally assessed using laboratory analysed samples measuring Total N and Total P collected in late winter/early spring. However, 'nitrate' and 'phosphate' data measured with rapid test kits are also useful. Chlorophyll data (a measure of the abundance of green algae) and phycocyanin (a measure of blue-green algae) are sometimes collected, but measures have to be repeated frequently during spring and summer, as these parameters fluctuate a lot.

Organic carbon, dissolved oxygen and sulphates are sometimes measured to assess organic pollution, but, because ponds naturally accumulate carbon, interpretation of these data as 'pollution' is not straightforward. Suspended solids provide an indication of pond-water cloudiness, and transparency can be measured with a Snell tube. pH is an important measure if there is a risk of acidification. Heavy metals, e.g. copper, zinc and lead, can be important pollutants, particularly in urban areas and pondscapes with vineyards.

Biocides can also be important, but analysis requires knowledge of the specific biocide of interest and is expensive. Other chemical variables are generally measured to provide background information about the pond, rather than assess its quality, e.g. alkalinity, pH, calcium, magnesium and sodium.

For site managers, three practical options for water-quality assessment, increasing in complexity, cost and information obtained, are:
- *Low cost, easy:* test nutrient levels using rapid test kits (an example is the PackTest range, but others are available); measurements made once or twice annually
- *Intermediate:* laboratory analysis of selected nutrients (e.g. species of nitrogen and phosphorus or Total N and Total P, pH, conductivity, dissolved oxygen)
- *Complete, more costly:* laboratory analysis of nutrients, anions, cations, pesticides, heavy metals, suspended sediments, chlorophyll a and phycocyanin, all collected on several occasions during the year.

Biological measures can also be used as indices of pollution, and they have the benefit of helping to measure the direct effect of pollution on wildlife, rather than using chemistry as a proxy. For example, if a plant survey is undertaken, each species can be allocated an Ellenberg nutrient (N) score, and the average score per pond used to identify sites with high N scores, which are likely to be polluted.

Biological quality monitoring. For a moderately rapid species-based conservation assessment, a good approach is to undertake a wetland plant survey of the pond. This requires specialist plant-identification skills, but experienced surveyors can usually survey a pond within one to one and a half hours during a single summer visit. Data on plant richness and rarity can identify ponds which are particularly important, particularly poor, or which support unique species. A wetland plant list can be generated quickly and with high accuracy in one visit and reflects the quality of the pond (i.e. the species completes its entire life cycle in the pond). It is also a good surrogate for other biotic groups and represents a reasonable proportion of the biota.

Amphibian species surveys can be also a good option, as there are a relatively small number of species and in most cases these are easy to identify and are sensitive to pond water and vegetation quality. Disadvantages are that amphibians represent a small proportion of the biodiversity present, do not correlate well with other biota, can be time consuming to survey and spend a large part of their life cycle on land, so do not so closely represent the pond quality. Dragonflies and other macroinvertebrates, although usually demanding more experienced surveyors, specific sampling techniques and laboratory identification, are also often selected as indicators of pond biodiversity. The groups selected for survey will ultimately depend on whether the aims are to assess pond ecological quality, the occurrence of specific protected species or to highlight organisms attractive to the public.

Biological data can now also be obtained using environmental DNA (eDNA); this involves collecting a water sample and sending it for laboratory analysis. The sample collection can be quick (often around one hour) and can be undertaken by non-specialists. However, sample analysis can still be expensive, and interpretation of the results requires substantial biological expertise, particularly to ensure that the results are robust (e.g. ensuring no records of species absent from the region are included and sense-checking results against traditional survey data).

Currently (2024), eDNA surveys are best developed for identifying fish and amphibian species. These groups are important in their own right, but comprise comparatively few species, so are less useful than plants as indicators of overall biological status or conservation value. At the time of writing, eDNA tests are less useful for invertebrates and plants. Biological indices which can be used to measure the overall quality of a pond have also been developed, although all are country or region specific (e.g. PSYM for the UK, PLOCH and IBEM for Switzerland, QAELS for Catalonia).

Table 4 - A summary of the pros and cons for choosing different species groups for biodiversity surveys

Biotic group	**Skill required to undertake surveys.** Estimated in terms of training time needed to become proficient: 1: <1 day 2: Days to weeks 3: Months 4: Many months to years	**Time required to complete an adequate survey** 1: around 1hr 2: 1hr-1 day 3: 1-2 days 4: 2+ days	**Value as indicator of pond biodiversity** Number of readily identifiable species typically found in ponds: 1: very high 2: high 3: moderate 4: few species
Wetland and aquatic plants	3	1	2
Macroinvertebrates*	4	4	1
Dragonflies	2	4	2
Zooplankton	4	3	1
Diatoms and other algae	4	3	1
Amphibians and pond reptiles	2, eDNA = 1	4, eDNA = 1	3
Fish	2, eDNA = 1	3, eDNA=1	3
Mammals	2	4	4
Water birds	2	2	3

*Macroinvertebrates are a large group, and surveys will usually focus on sub-groups, particularly water beetles and dragonflies, plus others such as caddisflies, water bugs, mayflies and snails.

Environmental data

Information about the pond environment is enormously valuable. It can be used to help interpret biological results and identify possible reasons for pond degradation; it informs management decisions and is essential if longer-term monitoring is undertaken to demonstrate and interpret change. It will inform management decision for the delivery of a range of Nature's Contributions to People (see below).

Key variables which have consistently been shown to be important factors affecting pond species, pond communities and pond ecological quality are: location (latitude, longitude), area (pond area, estimated using the maximum winter water level, and water area at time of survey), altitude, geology, permanence, water depth, drawdown, shade, vegetation cover, grazing, presence of an inflow, surrounding land use, connectivity (i.e. presence of nearby waterbodies or wetlands), turbidity, presence of fish and disturbance factors, such as pond management, and the impact of waterfowl, people and dogs.

Information should be collected at pond scale and pondscape or landscape scale to provide the regional context. Regional measures include geology, land use and connectivity (i.e. presence of nearby waterbodies and wetlands).

4.2.2 MONITORING AND ASSESSING PONDSCAPES

Monitoring whole pondscapes is more challenging than monitoring individual ponds. Although many of the methods are the same, here we summarise the main approaches that can be used to monitor and assess multiple ponds in a pondscape.

The commonest **reasons for monitoring pondscapes** currently are:

- Counting and identifying ponds to find out how many there are and identifying the connectivity among them.
- Assessing the biodiversity value of ponds in the pondscape, especially the value for wildlife and/or to understand more about pond condition, such as water quality (e,g. nutrient levels, conductivity) and pond characteristics, such as morphology (e.g. size or depth).

In ***future*** we also expect there will be a greater need to evaluate the effectiveness of ponds in providing public benefits, such as Nature's Contributions to People. Methods for doing this are described below.

Pondscapes will usually contain a considerable number of ponds, so appropriate methods will usually be broad scale and relatively quick to undertake because of limited resources. Of course, given enough funding, more detailed assessments of the sort described for individual ponds (above) can also be used.

Counting and identifying ponds
For pond counts, it is important to define what is meant by a pond at the outset. Are temporary ponds included? What are the upper and lower size limits for ponds? Initial pond number assessments can be made using a combination of map data and interpretation of satellite images. However, these often miss ponds in woodland, as well as small and temporary ponds. Accurate counts therefore need to combine remote methods with field surveys on the ground.

The use of remote sensing images from different years and GIS analyses can provide valuable estimates of the decrease of pond density at a regional scale. For very large regions (e.g. district, country, biogeographical area), a sample-based approach is often used, based on surveys of randomly selected 1 km squares.

Assessing pond biodiversity value in pondscapes
Useful tips for effective monitoring at pondscape scale are to maximise the use of existing data, make remote assessments (with satellite data and aerial photographs), to select indicator groups or species (though options are limited) and to measure habitat factors that shape pond communities (seasonality, age, land use, shade, livestock).

Maximise the use of existing data: As a first step, it is worth collating existing records, including rare and threatened pond species, which are available from species atlases, national and regional recording groups, record centres, scientific papers or survey reports. Many online biodiversity databases now store valuable information about species observation data, including a growing number of citizen science, scientifically curated, biodiversity platforms. Plotting the results spatially (e.g. site species richness, number of threatened species) may show clustering of records and identify particularly high-quality ponds or landscapes.

Remote assessments: It is not currently possible to accurately assess pond conservation value remotely. However, a first assessment can be made based on land use assessed using satellite and other imagery. Areas of semi-natural land use (e.g. woodland, moorland, unimproved grassland, heathland) are commonly found to support ponds of higher biological quality and are therefore more likely to deliver a wide range of Nature's Contributions to People.

▲
PONDERFUL demo site Water Friendly Farming, Leicestershire, UK
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In general, pond conservation value decreases with greater land use intensity, or if ponds have inflow streams that drain these landscapes. However, such sites may have greater potential to intercept pollutants or store water. Generally, in such situations ponds are less likely to fulfil a basic requirement of nature-based solutions: that they benefit both biodiversity and provide other valuable ecosystem services.

Biodiversity indicators and groups: In theory, identifying a small number of indicator species for assessing overall pond biodiversity would be convenient for monitoring and assessing whole pondscapes. However, the diverse nature of ponds makes it challenging to find such universal indicator species, except within specific pond types, and there is good evidence that the use of so-called flagship species is of limited value for pond assessment.[23]

Pond and habitat type surveys: If the aim is to manage ponds across a pondscape, but there is no potential to gather biological data, one approach is to study the variation in the natural factors shaping pond communities, in order to provide the data needed to ensure habitats suitable for a broad range of species are present. Factors to consider measuring (the list is not exhaustive) include:

- Seasonality: ensuring a balance of temporary, semi-permanent and permanent ponds.
- New and old: ensuring there are new or newly restored ponds (or both) with little sediment and low plant cover, as well as mature ponds which are heavily vegetated.
- Ensuring there are ponds in different (semi-natural) land use types and different geology and soil types (which affects water chemistry).
- Varying shade levels and access to livestock. For instance, if there are mostly heavily shaded ponds, adjust management to achieve a better balance of shaded, partly shaded, and unshaded ponds.

Variations in pond type may also provide information on the diversity of Nature's Contributions to People, although the reliability of advice on the delivery of these services is still at a fairly early stage.

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4.2.3 ASSESSING WATER STORAGE, WATER QUALITY, CARBON AND ENGAGEMENT SERVICES PROVIDED BY PONDS AND PONDSCAPES

Unlike biodiversity assessments, assessment of other ecosystem services provided by ponds and pondscapes makes use of more generic techniques developed for a wide range of different environments, which can be adapted for use with ponds and pondscapes. Here we summarise the most widely used methods which can be used to assess the delivery of the following Nature's Contributions to People: regulation of water quantity, regulation of water quality, regulation of hazards (floods), regulation of climate (cooling), physical and psychological experiences and learning and inspiration.

At present there are no routinely applicable methods for assessing pond and pondscape contributions to the following Nature's Contributions to People: supporting identities, maintenance of options, food and feed, and pollination. All of these remain the domain of research activities.

For further information on the assessment of nature-based solutions the European Commission handbook 'Evaluating the impact of nature-based solutions' is a valuable information source.[24]

Water storage
Ponds can be useful for storing water in periods of flooding, preventing it from entering rivers and flooding downstream areas. Flood storage capacity is the extra volume of water, above normal water levels, that a pond can hold before it overflows. To be most effective in providing flood storage, ponds should be dry between storms and drain quickly to continue to provide short-term water storage. Pond capacity is normally designed using computer models.

Specific indicators to be measured
- Pond volume
- Downstream peak flow reduction (compared to situations without ponds)
- Modelled catchment effect of ponds
- For larger pondscapes, pond storage is likely to be implemented as part of a wider catchment scheme. Impact on flooding will be modelled using catchment models (e.g. Soil and Water Assessment Tool created by the US EPA).

Pollution interception
Ponds are often used as part of sustainable urban and rural drainage schemes to help intercept pollutants and prevent them entering other waterbodies. The commonest way of calculating their effect is by comparing the levels of relevant pollutants in pond inflows and outflows. Effectiveness of individual ponds shows substantial variation. More sophisticated assessments will evaluate whole-catchment effects of multiple interception ponds.

Specific indicators to be measured
Almost any potential pollutant can be intercepted by pond systems, but the commonest specific indicators include:
- Nutrients (phosphorus and nitrogen)
- Ammonia
- Organic matter and suspended sediments
- Pesticides and metals, such as copper in agricultural areas
- Heavy metals in urban areas.

Regular water samples will be needed with high frequency during storm events, in order to assess effectiveness.

Carbon storage and climate change mitigation
Assessment of pond greenhouse gas emissions and carbon sequestration requires careful field measurement using advanced methods. Measurement of gas emissions is normally undertaken by floating chambers capturing gases emitted from the water. Gases may also be measured in the water column. Carbon sequestration is normally estimated by sediment core sampling but can also use sediments traps on the pond bottom. Gas and sediment samples are analysed by gas chromatography or using infrared gas analysers. The overall process comprises:
- Site selection: Choose representative ponds based on size, depth, and surrounding land use.
- Baseline data collection: Measure physico-chemical parameters of the pond (e.g. temperature, pH, dissolved oxygen).
- Installation of equipment: Set up floating chambers or other measurement devices.
- Regular sampling: Conduct periodic sampling to capture temporal variations in gas emissions.
- Data analysis: Analyse the collected samples and process data to calculate gas fluxes.
- Reporting: Compile the results and interpret the findings.

Value for education, amenity, health and wellbeing
To assess the value of ponds and pondscapes in providing Nature's Contributions to People relating to health, wellbeing, education and physical/psychological experiences, it is normally necessary to undertake before and after assessments of site usage, people's changing attitudes and financial value of engagements.

Specific indicators
- Number of people visiting a site
- Duration and frequency of visit
- Changes in attitudes resulting from visiting or using a pond or pondscape
- Improved mental health of people accessing ponds and pondscapes.

Practical methods include various types of questionnaire, interviews, and focus groups with semi-quantitative assessment through Likert scale questions.

4.3 MANAGING AND RESTORING PONDS AND PONDSCAPES

The value of managing and restoring existing ponds

Existing ponds need to be managed or restored, either to maintain their value as a nature-based solution or to reintroduce functions into the landscape, where this is technically and practically feasible (see Section 4.1 for definitions of pond management, restoration and resurrection). Before management starts, ensure that there is a previous diagnosis or monitoring of the pond to be restored (following flowchart in Figure 15). Creating new ponds may be a better option than restoring existing ponds when specific criteria need to be met or when the restoration actions imply a risk of loss of a threatened species.

Restoring existing ponds by carefully considered woody vegetation and sediment removal has been shown to be effective in enhancing both aquatic and terrestrial biodiversity in farmed landscapes. Pond restoration, and the associated concept of resurrecting 'ghost' ponds', both work well because they harness the long-lived nature of wetland plant seedbanks, which, especially when water is clean (see Box 2), can lead to rapid pond recovery. Both these approaches are essential (in conjunction with pond creation – see below) for increasing the number of early succession ponds in the landscape and for helping to ensure a mix of successional stages that much research shows maximise freshwater biodiversity at the pondscape level.

PONDERFUL case-study data showed that ponds restored by removing accumulated sediments and woody vegetation had markedly reduced greenhouse gas emissions, at least in the short term. However, at present the climate impact of excavated sediments is not known. The project's pond management case study also showed that 'open' early succession ponds had generally lower greenhouse gas emissions than later succession ponds.

Managing and restoring ponds normally involves modifying the existing pond to improve its ability to deliver ecosystem services. Note that protection is also a management option, where 'doing nothing' is a management measure. In this case, management is more concerned with defining the pond or pondscape's status and managing the pondscape (e.g. by maintaining low-intensity landuse) than with specific types of physical action on individual ponds. In some cases, the management for such sites may be complete non-intervention, with no physical disturbance of ponds undertaken at all.

Typically, the amount of modification required with management or restoration ranges on a scale from low impact, frequent, management at one end of the spectrum, to high impact, infrequent, pond restoration at the other end of the spectrum (Fig. 22). Low disturbance management might include only cutting down a few branches of a tree at the edge of a pond to reduce shading in order to maintain its present condition, or maintaining very low stock density grazing. Management of this type often mimics natural forms of disturbance. In some cases no additional management inputs are needed at all (e.g. pools developing naturally in peatlands).

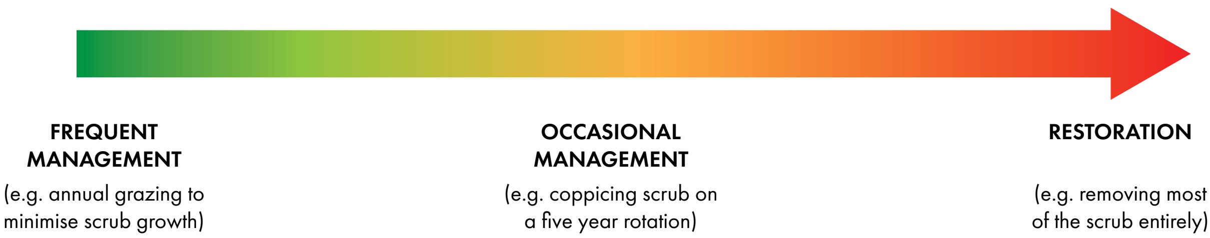

Fig. 22 - The pond management-restoration continuum. The same action (e.g. scrub management) can be considered as either management or restoration, depending on the level of disturbance and frequency of intervention.

At the other end of the spectrum, complete restoration commonly involves a high level of disturbance, including dredging a pond to remove sediment and vegetation, removing extensive tree and shrub growth, including felling large trees and, potentially, modifying the shape of the pond to enhance its biodiversity value. In this case, management is often concerned with resetting the successional stage. To take into account the risks of loss (as a consequence of the management or restoration) of any existing natural value or services the pond provides, managers must consider the effects of disturbance in the planning of management or restoration work.

For historic ponds, archaeological advice should be sought as needed, depending on the proposed scale of intervention. The approach taken depends entirely on project objectives and resources. These should be defined according to the local conditions, the historic asset to be preserved and what improvement you want to make for wildlife and/or people.

Any intervention is likely to have both positive and negative impacts. That is why it is critical to understand both the pond and the surrounding environment (pondscape) before doing anything. The main aim of interventions is normally focused on protecting or enhancing any existing value: the pond may already be important for rare species, play a key role in natural flood management or might be an historic feature of the landscape. If in doubt, seek expert advice before proceeding, using the pondscape decision-making flowchart (Fig.15) as your guide.

Reasons for undertaking pond management and restoration may include:

- Maintaining or increasing diversity of habitats within the pondscape so that there are ponds at different successional stages.
- Avoiding unwanted changes in pond vegetation abundance and excessive sediment accumulation.
- Reducing the detrimental impact of human influence (for example, changing land use).
- Conserving or improving habitat for a particular (often protected or rare) species.
- Allowing local aquatic plant or animal populations to recover from dormant seedbanks or eggbanks.
- Improving water quality in individual ponds.
- Maintaining ponds that provide aesthetic or recreational benefits for people.
- Maintaining other existing pond functions that are supplying Nature's Contributions to People e.g. history and heritage and support for identities (see Section 3.4 and examples in Chapter 6).

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Expert advice should always be sought before restoring or managing ponds, using the risk assessment shown in Fig. 16. Ponds which are particularly at risk from management include those that:

- Are in high distinctiveness or high nature-value habitats (e.g. woodland, species-rich grassland, heathland)
- Have abundant wetland plants
- Are in nature reserves, or sites designated for nature conservation
- Support rare or protected species (including non-aquatic plants or animals)
- Have significant heritage value (not only natural values, but cultural ones).

Damage to high conservation value ponds by inappropriate management intended to improve delivery of Nature's Contributions to People is an issue of importance in terms of biodiversity protection. Frequent gentle management is often the best way to preserve high value ponds at their peak and may mean that more invasive, laborious and costly restoration work is never required.

Key principles of pond management and restoration

When planning pond management or restoration, it is essential to consider the wider pondscape, not just the individual pond, and the benefits the proposed management will bring to that pondscape. A good aim is to create a diverse pondscape, maximising the range of habitats and ecosystem services provided by the ponds in the area.

There can be major trade-offs in delivering different types of Nature's Contributions to People in ponds. Although the evidence is currently limited, it has been shown that making ponds for runoff interception and pollution control makes little difference to landscape level freshwater biodiversity, whereas creating clean water ponds, not connected to pollution sources, increases it quickly.[25] Exploiting the full potential of different opportunities in the landscape, rather than trying to make 'every pond do everything', is therefore essential. For this reason, considering the pondscape scale creates valuable opportunities.

Consider how you can optimise the Nature's Contributions to People 'Habitat Creation and Maintenance' and the delivery of other Nature's Contributions to People, by manipulating the following factors:

- **Surface area:** different species will make use of different sized ponds. For example, birds generally need larger ponds than invertebrates or algae. Also note that large ponds often have higher habitat heterogeneity and therefore higher biodiversity (although this is a general pattern with exceptions).

- **Depth:** ponds of any depth can support rich wildlife. In some areas, shallow ponds can be the richest in wildlife, although waterfowl and aquatic mammals often prefer deeper ponds, and deep ponds can be some of the biologically richest. Ponds which do not dry out are more likely to sequester carbon.

- **Water permanence:** although on average temporary ponds support fewer freshwater species than permanent ponds, they can still support large numbers of species, and are often critically important for rare and uncommon species. Options will be determined by the region where the pond occurs, the pondscape's hydrology and future climate (e.g. groundwater versus surface water and climate increasing rainfall run-off). Species that require more permanent water will not be able to use temporary ponds, so having different hydroperiods in a pondscape could be advisable.

- **Bank angle:** steep banks may be dangerous on sites with public access, but the presence of steep or near-vertical banks may encourage specific species to use ponds (e.g. *Arvicola terrestris*).

- **Shade:** design management regimes to vary the amount of shading of ponds. Open sunny ponds are often rich in freshwater wildlife, but shade is natural, often adds diversity, and brings many benefits. Grazed ponds, or ponds near woodland rides, will be sunnier than ponds in dense woodland.

- **Public access:** some ponds may be restored for people, but ponds intended primarily to maintain biodiversity often benefit from being completely protected from excessive disturbance.

Some of these factors are influenced by direct action (e.g. surface area and depth), but others can be influenced by changing the wider land use. Other factors that impact the pondscape diversity are land use (ponds in different habitats), geology (affecting water chemistry and plant communities), altitude and wind regime.

Table 5 - Example management actions. Table setting out how ponds and pondscapes can be managed and the benefits this provides. Note that you should always consider the existing value of a pond before undertaking any action. In some cases, action might be damaging (e.g. removing emergent vegetation in a biodiverse pond, or increasing disturbance by people and dogs). Note that measures recommended at the pondscape scale may also be applied to the management of individual ponds.

Pond-level action	Potential benefits	Potential disadvantages	Methods
Managing emergent vegetation	Increasing the area of open water may help maintain habitat for specific species, reducing shading and raising water temperature, and help maintain and enhance biodiversity. Where different emergent plant species are mixed together, this can be a very rich habitat, so you might want to wait until there is well over 50% emergent cover before removing plants.	May eliminate valuable biota or habitats, increase water temperatures and light penetration. Note that emergent vegetation supports a range of terrestrial species.	Can be undertaken in three main ways: • Livestock grazing: cattle, horses, sheep, goats can be used to graze ponds • Management by hand tools (can be done as conservation action with citizens) • Mechanical removal: vegetation dredge or cut with excavators.
Removing terrestrial vegetation	Reducing shading, improving accessibility. Note that there is a balance between managing and damaging sensitive ponds, particularly in semi-natural areas.[25]	May increase water temperature reducing beneficial shading; in nutrient enriched ponds can allow nutrient tolerant species (algae, duckweeds) to increase in abundance. May eliminate species of importance using woody vegetation (e.g. rare fungi).	Can be undertaken in two main ways: • Management by hand tools (can be done as conservation action with citizens) • Mechanical removal: remove terrestrial vegetation with excavators or forest management machinery.
Removing silt and sediment	Increases water depth and permanence and may add new habitats. Desilting will reverse succession, prolonging the open water phase. Exposing the original pond base may encourage aquatic plant growth and temporarily reduce pollutant levels. It can help prevent complete colonisation of the pond basin by helophytes such as *Phragmites*. Retaining some of the upper pond sediment layer may help ensure the preservation of invertebrate eggs and seed/ spore banks.	May damage existing biota, release greenhouse gases and destroy archaeological or palaeoecological remains.	Undertaken with mechanical excavators following drawdown; in some ponds with controlled water levels, the pond can be drained and sediments allowed to oxidise.
Repairing engineering features (inc. pond liners)	Ensures water permanence and improves aesthetic appearance of pond, restoring historic value.	No obvious disadvantages.	Normally undertaken by specialist contractors/ engineers.
Repairing board walks, signage and dipping platforms	Improved access for people, increases educational value.	Can lead to increased access and disturbance (e.g. facilitating introduction of non-native species, disturbing breeding wetland birds).	Normally undertaken by specialist contractors/ engineers.
Modifying the shape of the pond	Changing bank angle (by increasing broad shallow drawdown zones), better for wildlife, safer for livestock or people. If possible, remove artificial substrates.	No obvious disadvantages if ponds are properly surveyed before any work is undertaken.	Use mechanical excavator; may require trailers to remove spoil from site.

Pond-level action	Potential benefits	Potential disadvantages	Methods
Deepening the pond	Deepening ponds in central area will increase water permanence and modestly increase water retention. CAUTION! Do not deepen temporary ponds unless they are in danger of drying up completely as a result of climate change.	May lead to unnecessary deepening of temporary ponds, which is highly undesirable because it may damage or replace existing biota associated to temporary ponds.	Use mechanical excavator; may require trailers to remove spoil from site. Where deepening is vital to prevent complete drying up, novel approaches to protecting seed, spore and egg banks may be needed. In these situations, remove, store and later replace pond base sediment before the pond is deepened, or grow/culture critical species in off-site facilities, and return to the pond later. Note that these approaches are all experimental. Alternately, create new, deeper, ponds very close to existing ponds which are drying up, and allow sensitive species to spread naturally.
Removing introduced non-native fish	Could reduce turbidity and increase value for other wildlife.	No obvious disadvantages, depending on the method used for fish removal.	Use specialist fisheries management contractors to net and remove fish.
Removing other invasive non-native species (plants, invertebrates)	Removing invasive plants may allow native plants to increase in abundance, and animals to increase in diversity. Note effects may often be subtle.[26]	May lead to elimination of habitats used by native or endangered species.[26]	May be controlled by: • Physical removal • Herbicides • Pesticides • Biological control agents. Discuss with local state agencies to determine methods which will be allowed in your specific situation (e.g. pesticides permitted for use; methods applied successfully in a specific region). Methods for controlling non-native species are sign-posted by national and international bodies.[27,28]
Creating terrestrial habitats for amphibian species (accumulation of dead wood, stones)	Provides essential habitats for amphibians which may be absent in more intensively managed pondscapes.	No obvious disadvantages for freshwater ecosystems.	Follow standard guidance on creation of amphibian refugia produced by NGOs. Install with volunteers or private companies.

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Pondscape-level action	Potential benefits	Potential disadvantages	Methods
Stop spreading fertilisers, pesticides or other pollutants within the pond catchment; as a minimum create large buffer areas (at least 50 m) around pond to reduce fertiliser and other agrochemical inputs. If this is not possible, **PONDERFUL** evidence suggests buffer of 10-20 m will bring some water quality improvements	Should improve water quality, especially if associated with dredging and desilting of contaminated sediments, with improved aesthetic appearance of ponds (fewer algal blooms) and increased overall value for biodiversity. Note that narrow buffer strips are notoriously variable in effectiveness on running waters (where most data is available).	No obvious disadvantages for freshwater ecosystems.	Develop joint, collaborative, actions with land managers and farmers in your pondscape. Discuss and negotiate options including: • Identifying financing mechanisms • Reducing or eliminating application of fertilisers and biocides • Participating in agri-environment schemes to remove land from arable farming or create large buffer zones etc.
Redirect polluted water away from ponds	Improved water quality, aesthetics and value for wildlife; can be difficult to achieve.	No obvious disadvantages; may increase pollution of downstream habitats.	Normally undertaken by specialist contractors/ engineers; includes managing land drainage.
Removing fencing around ponds, allowing livestock to graze ponds	Gentle (1–2 animals / ha) grazing facilitates management of terrestrial and aquatic vegetation and is usually good for freshwater biodiversity. Ponds can be used as drinking water supply for livestock.	Could lead to excessive trampling of waterbodies.	Plan co-ordinated local actions with land-owners and land managers, and consider the landscape scale and target species.
Reducing livestock densities or amount of time they have access to ponds	Low-density grazing simulates ancient natural grazing process on ponds; may reduce turbidity associated with very intensive trampling, improve aesthetic appearance of pond, increase value for wildlife as low intensity grazing usually very good for freshwater biodiversity. There is little information about the effects of different densities of stock on ponds, but densities of 1–2 cattle per hectare are often used as a rule of thumb (observe how the site progresses with this level of grazing pressure). However, using stocking density alone can also be misleading. The number of cows trampling around the pond is more critical. For a pond in a large field (more cattle) the stocking density should be lower, or the pond bigger, than for a pond in a small field (fewer cattle).	Could lead to insufficient disturbance of pond by livestock.	Develop joint, collaborative, actions with land managers and farmers in your pondscape. Discuss and negotiate options including: • Identifying financing mechanisms • Reducing or eliminating application of fertilisers and biocides • Participating in agri-environment schemes to remove land from arable farming or create large buffer zone etc.
Enforcing responsible use of ponds by people (by education or fencing)	Will reduce risk of invasive species introduction and of vandalism, lower turbidity, improved aesthetic appearance of ponds, better value for wildlife and public appreciation.	Reduces awareness of the importance of ponds as Nature's Contributions to People.	Develop awareness raising campaigns with local partners. Develop funding programmes to finance the measures required.

Pondscape-level action	Potential benefits	Potential disadvantages	Methods
Stop ploughing within pond catchment	Will reduce or eliminate pollution sources affecting pond associated with agricultural runoff.	No obvious ecological disadvantages, though could reduce landowner income.	Develop joint, collaborative, actions with land managers, farmers and water management/nature conservation agencies in your pondscape. Discuss and negotiate options including: • Planning and developing programme • Identifying financing mechanisms • Reducing or eliminating application of fertilisers and biocides. Participating in agri-environment schemes to remove land from arable farming or create large buffer zones etc.
Tree planting, removal of ditches or other changes to the wider landscape around ponds; restoring the terrestrial and aquatic habitats of wider landscape	Increases habitat diversity, refuge and food availability for pond fauna, value for wildlife, flood resilience, aesthetic appearance and recreation.	Could modify terrestrial ecosystems in undesirable ways (e.g. wooded landscapes allow more predators to survive, with unexpected consequences).	Develop pondscape plan to identify the main actions to be undertaken at landscape scale. Plan could be for a small site (10 ha) or a whole water catchment (10,000 ha).
Enhance pondscape scale connectivity for amphibians (e.g. tunnels under roads; ditches)	Supports persistence of amphibians in the landscape.	There are some potential disadvantages to increasing pondscape-scale connectivity for amphibians. In a few special situations, increased connectivity could risk spreading diseases or bringing together species which compete (e.g. *Bufo bufo* and *Epidalea calamita*). There is recent evidence of potential for pollutant accumulation in road tunnels, which might increase exposure of amphibians to toxic chemicals.[29]	There are numerous practical guides available for the design of connectivity measures for amphibians.
Apply mosquito control measures, including treatment with *Bacillus thuringiensis* (Bti)	Reduces disturbance to people using the pondscape.	May damage other aquatic and terrestrial biota.	Managers should note that, depending on study design and duration, Bti effects on non-target organisms and higher trophic levels have been demonstrated. Managers may need to consider alternative, more environment-friendly, but more costly, mosquito-control techniques.[30]

Ghost ponds

By reviewing old maps, or talking to older residents, it is often possible to identify ponds which have been deliberately filled in. These are known as 'ghost ponds'. Restoring ghost ponds can be an excellent opportunity to recover local heritage and improve biodiversity on a site. In some cases, rare plants can be recovered from seeds and spores within the pond sediments – some may be over 100 years old!

When excavating a ghost pond, it is important to pay close attention to the substrate layers. The aim should be to remove backfill and restore the pond to its original shape, size and depth. Dig slowly and do not dig deeper once you have reached the old pond sediments; these are usually dark, fine to the touch and contain lots of decomposed leaves and, in calcium rich landscapes, often shells of water snails.[31]

Ghost pond before restoration. © Carl Sayer

Ghost pond after restoration. © Carl Sayer

For further information about ghost ponds, see Chapter 7: Further reading and practical resources.

4.4 CREATING PONDS AND PONDSCAPES

The value of new ponds

Whilst managing and restoring ponds is essential, pond creation can be more effective when:

- Ponds are rare in a landscape.
- Existing ponds are polluted or badly affected by invasive species, and it is not possible to remove the pollution source or eradicate the invasive species.
- Natural new pond creation processes have otherwise been stopped by human activity.
- Existing ponds are poorly suited to your project aims (i.e. you want to create ponds for wellbeing or education, but existing ponds are hard to access).
- Existing ponds belong to the same type (i.e. only deep or only permanent), as a consequence of disappearance of several pond types due human activities (desired goal: favour habitat heterogeneity).
- The management aim is to diversify the pondscape environment, creating new pond types (shapes, sizes, hydrological functioning, etc.)
- You want to increase habitat availability for specific species.
- It is necessary to increase pond diversity to deliver specific Nature's Contributions to People.

Remember, new ponds can be designed to better suit the specific aims of your project, while many existing ponds will be constrained in some manner by their characteristics or locations. Creating new clean water, ponds is great for biodiversity. Increasing the density of ponds within a landscape not only increases the amount of high-quality wildlife habitat, but also improves connectivity by allowing less mobile species to move from pond to pond (like stepping stones). In the **PONDERFUL** Water Friendly Farming demonstration site (success story 6.1), clean water pond creation resulted in a 16% increase in the number of wetland plant species found in the demonstration pondscape, with 83% increase in uncommon species. This shows that adding new wildlife ponds to the landscape can reverse large-scale freshwater species declines.[25]

Evidence from this work shows that creating new clean water ponds has led to some of the most substantial, and quickest, increases in freshwater biodiversity yet seen for any water management technique. Pond creation also increases species' metapopulation sizes (even of the most common), reinforcing their resilience to impairment. New ponds are also important for people, providing services such as water storage, pollution control and mental health benefits (see Chapter 3).

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Key features to create in new ponds

All the key features of a pond need to be considered when designing and creating new ponds. These include:

- **Surface area:** There is no ideal pond surface area. The whole range of pond sizes – from very small (2 m^2) to very large (2 ha or more) – can benefit people and wildlife depending on the pondscape, the Nature's Contributions to People objectives, and target species. Avoid making only very small ponds: there is clear evidence[32] that, particularly in urban areas, while small ponds bring much pleasure in gardens and provide habitats for widespread and robust species, they do not add to whole landscape freshwater biodiversity, often have a high proportion of alien species contributing to their spread, have poor water quality, and probably generate an excess of greenhouse gases because of this. Indeed, making high-quality very small ponds is one of the most difficult parts of pond design.

- **Depth:** Pond maximum depth often affects how long a pond will hold water during the year (although very shallow ponds in groundwater can be permanent – see the **PONDERFUL** demonstration site Pinkhill Meadow). For this reason, water permanence will also depend on the pond's water source and its catchment area. Annual drying is desirable for some species and some Nature's Contributions to People objectives. It is a feature of all temporary ponds, including the EU Habitats Directive priority habitat 'Mediterranean temporary ponds'.

- **Margins and bank angles:** The pond margins are a very important element to think about at the planning and designing stage. Generally, pond biodiversity, accessibility and security benefit significantly from wide shallow margins. Pond biodiversity can sometimes be increased by irregular shorelines and low islands (the latter are better if close to the water line and flooded in winter).

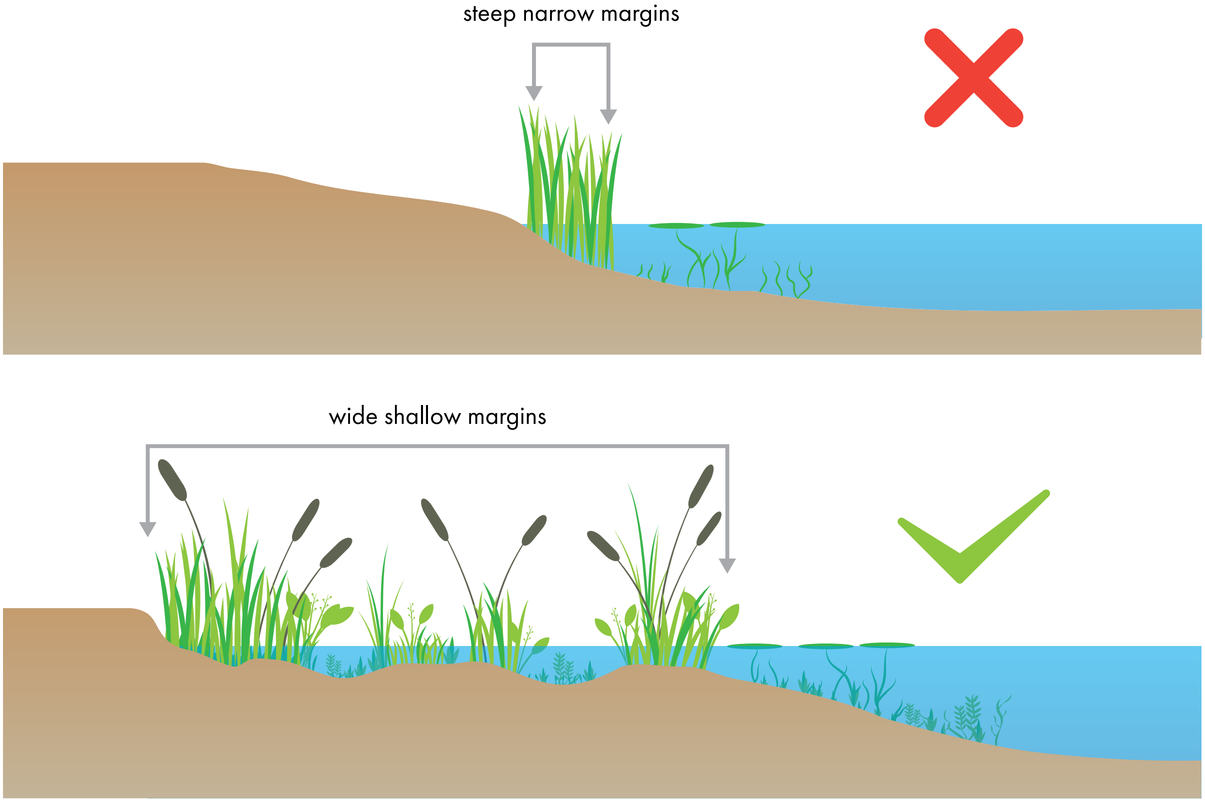


Fig. 23 - A narrow drawdown zone (steep narrow margins; top) and a wide drawdown zone (wide shallow; bottom). The drawdown zone is the richest part of the pond for wildlife.

- **Shallows:** The shallows are the part of the pond which are about 10 cm or less in depth when water levels are at their maximum (in the northern hemisphere usually in the late winter or early spring). Shallow water is usually one of the most biodiverse parts of the pond, with many animal and plant species only ever found in shallow water. Amphibian reproduction (e.g. egg masses or, in some species, tadpole habitat) is quite dependent on shallow pond zones. Some ponds can be entirely made up of shallow areas (often these will also be temporary), while others have shallow areas and sections of deeper water.

- **Drawdown zone:** This is the area between the pond's maximum water level and minimum water levels (Fig. 23). Fluctuating water levels are natural and are crucial for some species, including a variety of endangered plant and animal species. The drawdown zone is the most diverse part of the pond in terms of the number of species found. It is also important for reptiles, birds and mammals as a feeding area, and for semi-aquatic invertebrates, such as ground beetles and true flies.

- **Inflows/Outflows:** Inflows, including ditches and streams, often bring polluted water into ponds; they can also be a source of invasive plants and fishes. This is disadvantageous for ponds intended to maximise biodiversity and should be avoided. For ponds designed for water treatment, pollution control or flood mitigation, correct calculation of the size of inflows and outflows will be essential for the main service provided by the pond.

- **Immediate surrounds:** A pond is not an island separated from its surroundings: the adjacent land usually supplies the pond with water, and is part of the habitat of many species using the pond for some of their lifecycle (e.g. dragonflies, Diptera, amphibians). This means that it is vital that the land around the pond is considered early on when designing new ponds. For example, the new pond may need to be located close to other wetlands or ponds which already support the endangered species that it is hoped the new pond(s) will attract. However, it is also important to consider whether it may be important not to increase pond connectivity; if isolated ponds support rare or threatened species, it is important to avoid the arrival of potential predators or competitors. Pond designs should take into account the surroundings which are part of the pond environment. For example, fencing may be required to protect new terrestrial scrub and woodland habitat in the pond's surroundings, in order to protect it from excessive disturbance by dogs in areas of open access and to maintain good cover for dragonflies and amphibians. If the pond does not have an entirely natural catchment, the pond surroundings may also be important in creating a buffer area between the pond and more intensive, pollution generating, parts of the pondscape.

Should new ponds be planted?

It is natural to think that new ponds need a helping hand to stop them from remaining 'empty habitats' in their first few months or years. However, there are many reasons why it is often better not to plant up new ponds, but to leave them to colonise naturally instead. The first reason is that new ponds are a very distinctive habitat, used by plants and animals that are not found in more mature ponds. Usually these are species that either (a) prefer bare sediments or (b) do not compete well with others. Artificially maturing sites by adding plants hastens the end of the 'new pond' stage and stops the ponds from providing an important refuge for these species.

A second reason for not planting ponds is that it is usually unnecessary. As Darwin first noted, many pond plants and animals are particularly well adapted to finding new sites. Bugs and beetles fly in within hours, especially in the warmer months. Most other insect families (e.g. mayflies, caddis flies, dragonflies) and some annual water plants become established within the first summer.

Evidence shows that this natural colonisation occurs so rapidly that, without any help, three-or four-year-old new ponds are often as rich as sites over 50 years old. Finally, plant and animal species that colonise under their own steam will usually be more appropriate to the waterbody than those we choose ourselves and, very importantly, letting plants and animals arrive naturally reduces one of the major risks of planting-up: the accidental transfer of invasive alien plants and animals.

If plants are required to obtain a particular Nature's Contributions to People (pollution trapping, visual amenity, enhancing population of a specific endangered species) obtain plants locally from a known source ('locally' means 10–20 km from the introduction site.

KEY STEPS OF POND CREATION

Ponds can be created in any landscape or land use type. There are some key steps to follow when planning a pond-creation scheme in order to maximise the benefits.

© Ted Balmer

Box 3. Seven steps to designing a pond creation scheme

1. **Decide what the main use is** and identify how this will influence your choices. Creating multi-functional ponds is difficult, so it is best to have a single, or small number, of potential uses and a clear focus. Be careful to avoid contradictory goals (e.g. biodiversity and pollution treatment).

2. **Identify a site.** Consider the current land use (how is the site used and by whom?), assess geology, soil type and pedology, selecting areas with good natural habitat surrounding the pond creation area and making up most of the catchment. Ensure that there is a suitable regular/abundant water supply. Looking at existing ponds is an excellent way to understand the local hydrology. Ideally, choose locations where an artificial liner will not be required, and which can be accessed with construction machinery.

3. **Make sure that the site is not already important** (for wildlife, archaeology, recreation or agriculture). If existing wet habitats (springs, flushes, bogs) are present, do not replace these, but consider creating new ponds nearby to improve habitat diversity. Obtain any necessary permissions (protected site, protected species or land use change permissions). Seek expert advice if required.

4. **Check that the site is not constrained by services (e.g. water, gas, electricity)** or other infrastructure. There are major safety issues associated with excavating near electricity cables (underground and overhead). By understanding where infrastructure is located at an early stage, the scheme design can be changed to avoid impacts. Check for infrastructure associated with electricity, water, oil, gas, sewage and communications. Take account of services already planned, but not yet existing e.g. future railway tracks or roads.

5. **Design the pond(s).** Draw a sketch plan of the pond, considering size, depth and profiles, and give preference to wide shallow margins. Aim to increase the diversity of habitats present in the pondscape: five ponds of different sizes is better than one big pond. Also consider long-term management, allowing space for machinery to access the pond in case it needs adjusting or desilting. By thinking about management early in a pond creation scheme, it is possible to amend the design in order to minimise the need for later interventions. Refine the design as you learn more about site constraints and likely water levels.

6. **Dig trial holes.** Create trial holes for groundwater and surface water-fed ponds where you plan to create the new ponds. Stream-fed ponds may also need trial holes if you are creating them in natural substrates and need to ensure they will hold water. These need to be at least as deep as the proposed pond, but ideally deeper. Monitor for at least a year so that you understand water-level change.

7. **Plan the whole project and finalise designs.** Consider how your new ponds will work at the pondscape level. Can you further increase habitat diversity by staggering pond creation over several years? Think about the machinery required, health and safety, and ongoing monitoring. For smaller scale projects there may be opportunities to include 'volunteer' participation, not only to avoid, if possible, heavy machinery or to reduce cost, but to involve resident people in the site and stakeholders in the project.

More detailed information about pond creation is provide in the Freshwater Habitats Trust pond creation toolkit, which provides a wide range of suggestions about pond sizes, shapes, depths, the value of shade and the importance of grazing. Guides to the use of ponds to provide pollution and water control structures are available from a range of sources. These are included in chapter 7: Further reading and practical resources.

Box 4. Assessing hydrology and substrate – a key element of pond creation

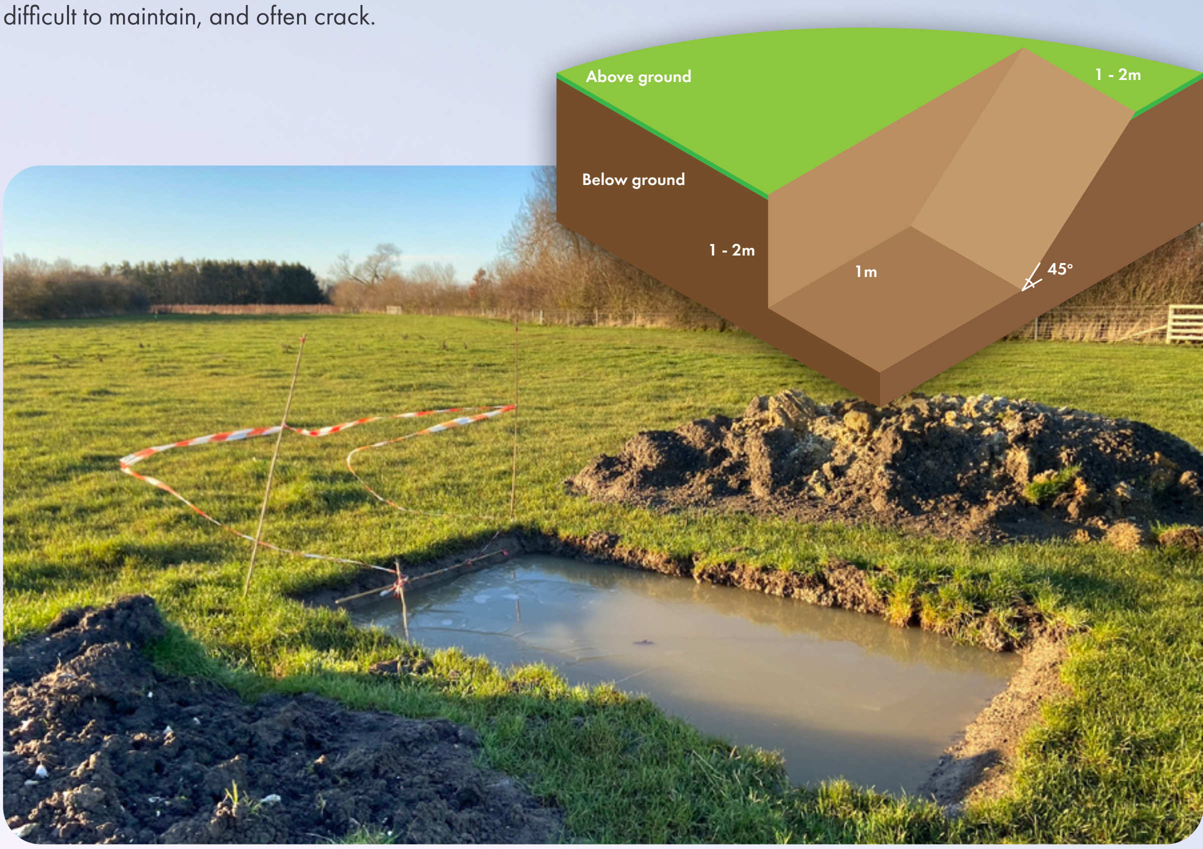
Investigating substrate and hydrology, including groundwater, is a key element of the pond-creation process. Geology and soil maps can provide useful information, but their resolution is usually too low to provide the detailed site information needed for pond creation. On floodplains, in particular, the substrate type can change from permeable to impermeable over a very short distance.

Generally, the best way to assess substrate and hydrology is to dig a trial hole where the ponds are likely to be located. This can be done using an auger, a spade or a mechanical excavator, depending on the substrate and the proposed depth of the new ponds.

If a deep layer of blue clay – which indicates waterlogging – is found, then the ponds can be created straight away. If the clay is mottled, indicating that water levels fluctuate, it is normally necessary to monitor trial hole(s) for one or two years. Longer-term monitoring (over months or years) is also likely to be necessary if the substrate includes sand, gravel or pebbles, where groundwater will be the main source of water. This will help you understand (i) the permeability of the substrate and (ii) how groundwater levels fluctuate.

In some cases (for example, sites with regular public access) dipwells may be more suitable for assessing water levels than open trial holes because they are safer for people. Information on substrates and hydrology can then feed into the pond design to ensure that depths and profiles are appropriate for the objectives of the pond.

Where water does not accumulate naturally, plastic, concrete, or clay liners can be used, but these are expensive, have a comparatively short life-span (tens rather than hundreds or thousands of years), require carbon-hungry production processes and are liable to leak. Artificial liners do not support the full range of natural hydrological regimes, mainly depending on inflowing stream, ditches or roof water. Clay linings over naturally permeable substrates are especially difficult to maintain, and often crack.



Trial holes are used to assess a new pond's substrate and hydrology before construction begins. © Freshwater Habitats Trust

Creating ponds for biodiversity
Animals and plants have evolved to live in ponds over many millions of years. Therefore, the best way to protect pond wildlife today is to create waterbodies that mimic the clean-water wild ponds common in the past, taking into account the singularities of the natural ponds of each region (see Box 1). Natural ponds come in all shapes, sizes and depths, but finding clean water can be difficult in heavily modified landscapes. Ponds with poor water quality will never support the full range of plant and animal species seen in unpolluted ponds and will have long-term management problems. If you are limited to a polluted site, you will therefore not be able to create a pond that can reach its full potential. However, almost all ponds can still be valuable for wildlife, supporting tough or widespread and resilient species. Where ponds are colonised from scratch, there is good evidence that within 5–10 years they can reach a condition similar to much longer-established ponds.

In addition to the points in Box 3, follow these simple steps to maximise gain for biodiversity:

1. Find a place with a clean-water source. Make sure the pond has natural surrounds.
   - Avoid linking the pond to a stream or ditch, unless you know the water in those inflows is unpolluted.
   - Do not add topsoil in or around the pond.

2. Create lots of shallow water (<10 cm deep) and leave the pond surface rough: lumps and bumps maximise habitat diversity. On larger ponds, there may be space for islands; make sure they are low (close to the water line), can be managed effectively and will not be quickly covered by terrestrial vegetation.

3. Locate ponds strategically: often the greatest biodiversity benefit is achieved where ponds can connect to or extend existing wetland habitats.

4. Leave the pond to colonise naturally. Do not stock it with plants, fish or other animals. In cities and urban areas, where there are often fewer natural colonisation sources, you can help the colonisation by bringing some native plants from nearby ponds, rivers and wetlands (make sure you do not break local regulations when doing this).

5. Make sure the pond will have few impacts (e.g. no frequent disturbance from dogs or duck feeding).

Creating ponds for people
'Blue spaces' are known to be beneficial for human wellbeing, and a pond or pondscape can be an important community resource or cultural asset. Whether you are working in an urban or rural setting, there are many different types of ponds and pondscapes you can create to provide benefits including education, tourism and health (see Chapter 3 and success story 6.11, 'Rhône Genevois, CH'). Make sure to plan accessibility and safety issues and infrastructure (e.g. walkways, platforms, bridges). Consider using decorative materials, such as stones, and obtaining advice from expert designers.

It is important to understand that a pond that provides these ecosystem services is less likely to also play a significant role in boosting biodiversity. However, ponds created for people – even in densely populated urban areas – usually attract some wildlife.

Box 5. Creating ponds to provide ecosystem services for people

Questions to ask before creating ponds to provide ecosystem services for people:
- How many people will use the pond and how will they access it?
- Have you considered health and safety when designing the pond? Is any additional infrastructure required?
- How will the pond be managed in the long term to maintain the function it is designed for (e.g. swimming, education or inspiration)?
- Do you also want to attract wildlife to the pond? If so, which type?
- Do you want the pond to be used for any leisure or educational activities?
- Do you have resources to keep the pond in good condition, safe and accessible to people in the long term?

4.5 PRACTICAL CONSIDERATIONS TO PREPARE FOR POND MANAGEMENT, RESTORATION AND CREATION

The specific practical preparations for pond management, restoration and creation will vary depending on your site, local legislation and project aims. During planning, ask yourself the following questions to make sure you are prepared:

Box 6. Questions to ask yourself

- Do you have a good understanding of the existing value of the pondscape (for biodiversity, human wellbeing)? If not, seek expert advice.
- Is surface water, groundwater or (where suitable) stream or ditch inflows sufficiently available on site, or will you need to use an impermeable liner and provide other water sources to supply the pond with water?
- Is permission required before starting works? This may relate to land use, protected sites or species.
- Have you checked if any services are present (e.g. overhead cables or gas pipelines near the pond)? Or if future infrastructure is planned to be constructed near the pond?
- Has the site been modified? If lots of field drains are present, these will need removing or new ponds will not hold water.
- Do machine operators have suitable experience? If not, close supervision may be required.
- What machinery is required? Smaller excavators may be necessary if access routes are narrow. Small ponds (a few square metres) can be created with 'volunteers' to involve local people in the project, but this can involve hard work and ponds may fill in quickly.
- Where will you dispose of sediments/spoil and woody debris? Do not spread this where it will wash back into ponds.
- Are there other health and safety considerations? Consider potential impacts to contractors, staff and the public.
- Have you budgeted for monitoring the ponds, fixing issues and adjusting pond designs to improve performance?

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4.6 POND DESIGNS FOR PONDS AND PONDSCAPES: USING CLIMA-PONDS

PONDERFUL has created standards for the design of climate mitigating ponds to provide standarised designs which can be rapidly and widely implemented to a set of common standards.

Designs have been created for three typical situations:

- Ponds purely intended for biodiversity and engagement (including wellbeing and health) and related Nature's Contributions to People. Containing unpolluted water, greenhouse gas production should also be minimised
- Ponds intended for the delivery of a variety of Nature's Contributions to People in rural landscape including minimising greenhouse gas production, storing water, treating polluted sediment and runoff and providing biodiversity benefits
- Ponds intended to provide Nature's Contributions to People in urban areas where water storage, pollutant retention, health and wellbeing and biodiversity are all intended benefits. The design is also intended to minimise greenhouse gas production.

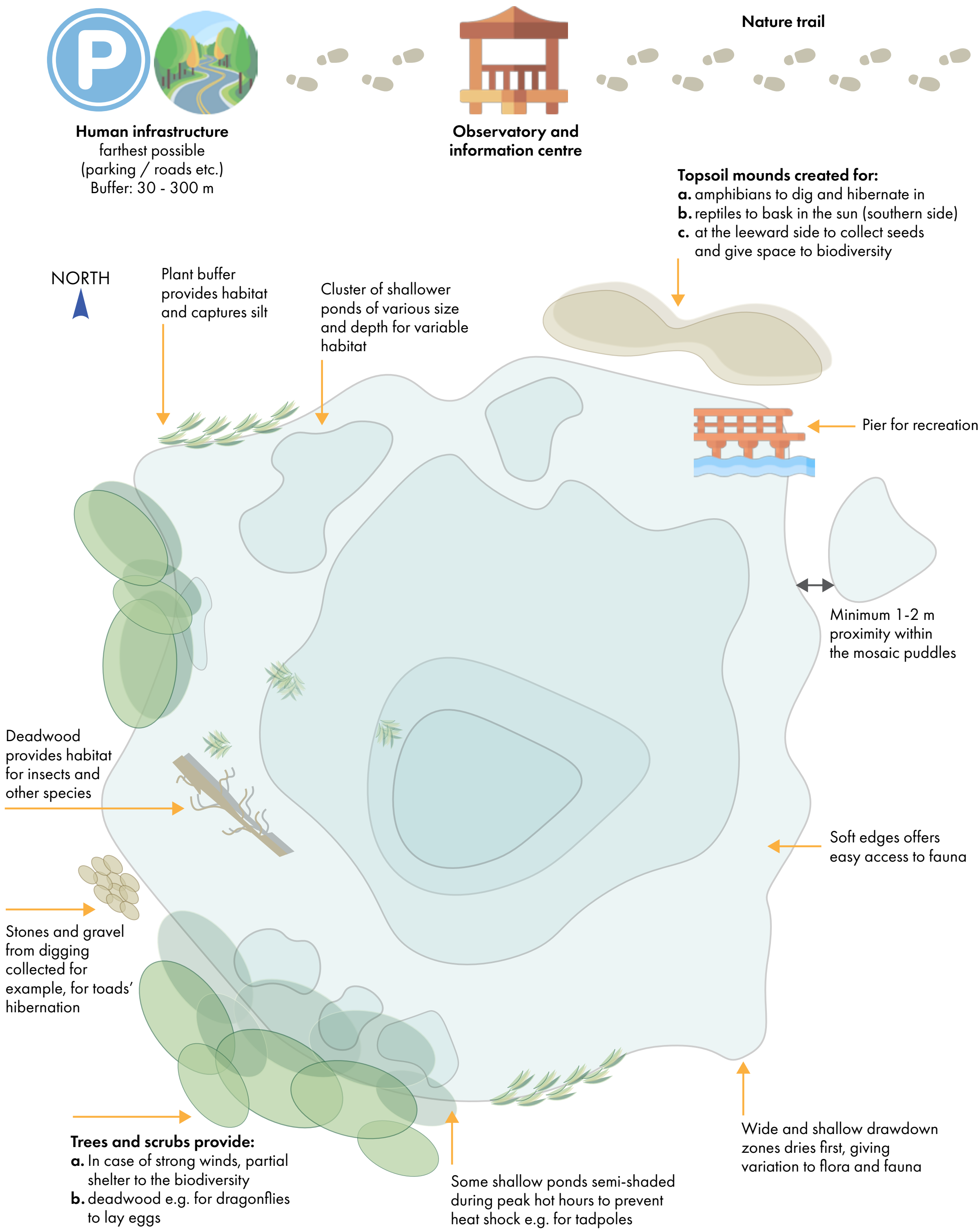

Fig. 24 - CLIMA-pond Nature design. This design prioritises maintenance of biodiversity. © Amphi International ApS

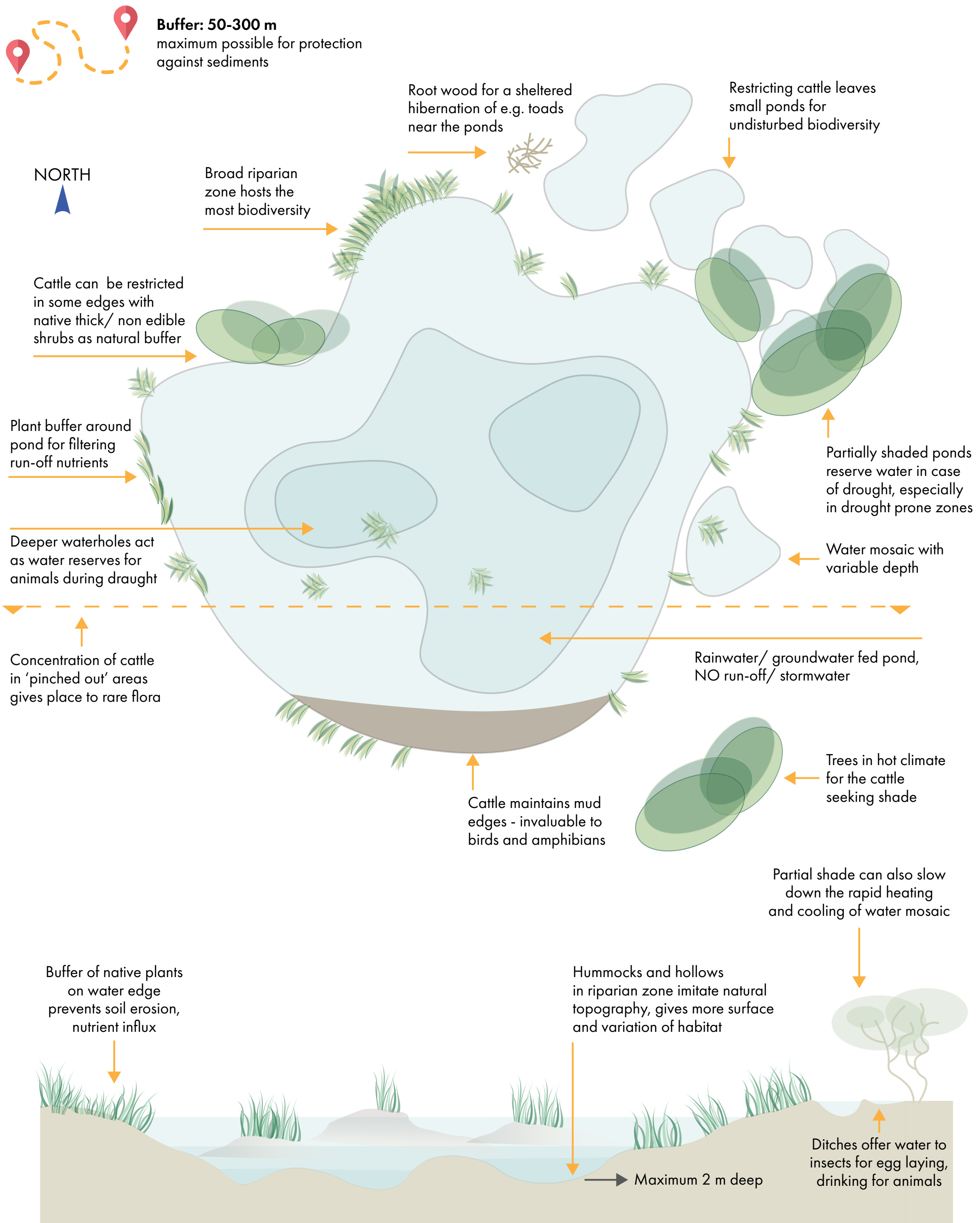

Fig. 25 - CLIMA-pond Rural design. This design provides multiple rural landscape benefits including minimising greenhouse gas production, providing flood and pollutant interception services and supporting biodiversity. © Amphi International ApS

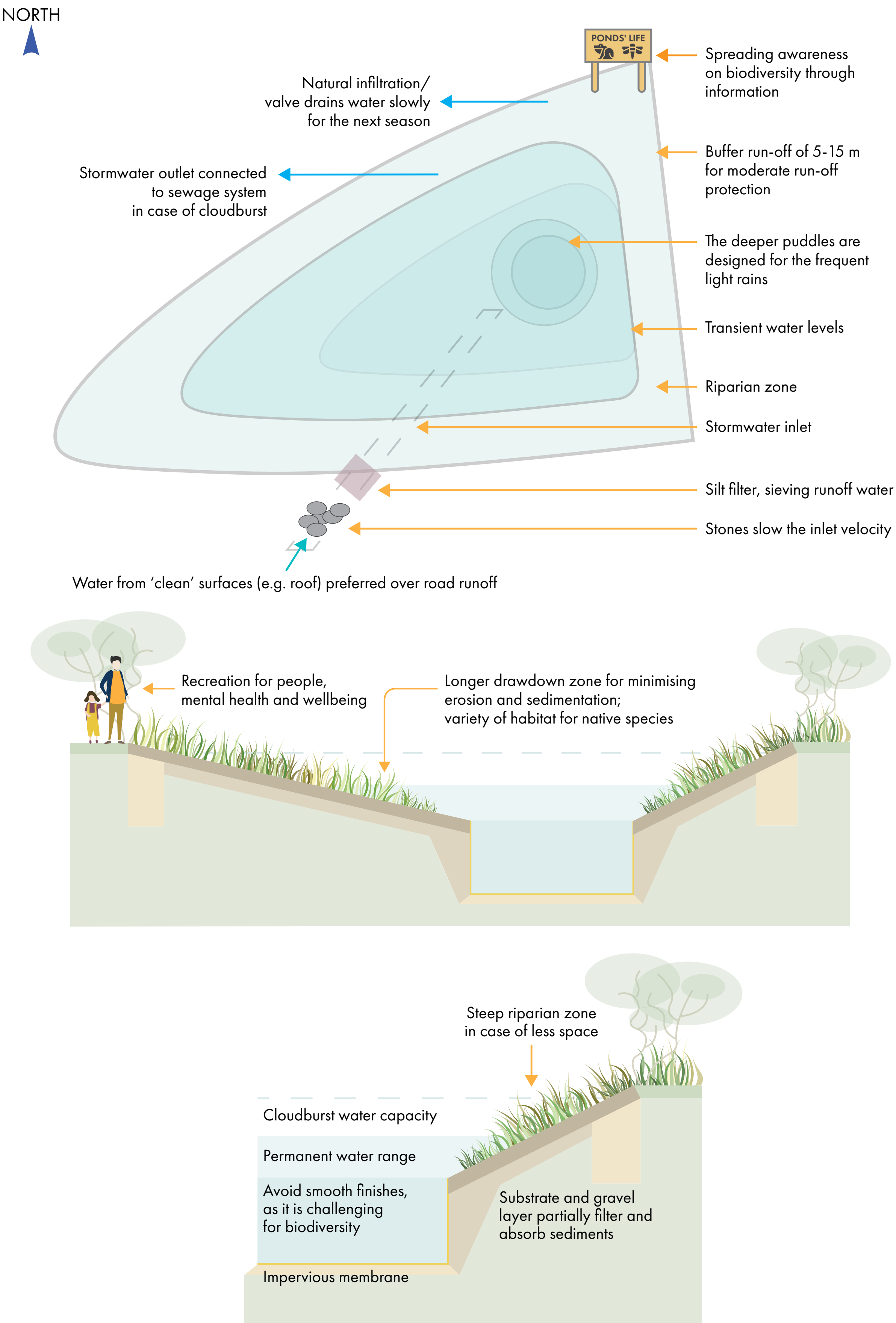

Fig. 26 - CLIMA-pond Urban design. This design is for urban locations primarily focusing on water storage, pollution interception, minimising greenhouse gas production and providing biodiversity benefits where possible. © Amphi International ApS
The **PONDERFUL** design standard for CLIMA-ponds is published separately by the **PONDERFUL** consortium.[33,34]


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5. Cost and practical constraints: financing and promoting pondscape schemes

5.1 PRACTICAL CHALLENGES AND COSTS OF IMPLEMENTING PONDS

Developers of ponds and pondscapes as nature-based solutions face a number of practical constraints that limit delivery. One key constraint is cost. In this chapter, we explore some of the issues people may face when paying for ponds, the type of costs to budget for and how this challenge can be overcome. We also discuss how policy can be both a constraint and enabler for implementing ponds and pondscapes as nature-based solutions.

Pond costs

There are a range of different costs when managing, restoring or creating ponds and pondscapes. These include one-off upfront costs and ongoing costs.

One-off costs take the project from idea to construction. These are costs that are only faced at the beginning of a project either to restore an existing pond or create a new pond. One-off costs include all the costs associated with developing, planning, and implementing the project.

Ongoing costs are those associated with maintaining the pond or pondscape once it has been managed, restored or created. Examples include ongoing monitoring, smaller repair work of pondscape infrastructure, regular removal of invasive species, and addressing impacts of public use to protect biodiversity. Ongoing costs might increase or decrease over time, depending on how the pondscape develops (e.g. how many people visit, the success of pond creation, future external pressures on the ponds such as neighbouring agricultural intensification).

Financing: covering the costs

A lack of sufficient financing is a key barrier for nature-based solution uptake in general, and is also a challenge for ponds. The **PONDERFUL** research project provided a valuable summary of this problem.[35,36]

Nature-based solutions are currently predominantly paid for using public funding, although private financing is a growth area. However, there are many different ways of financing pondscapes. The **PONDERFUL** Sustainable Finance Inventory (Table 6) identifies 24 different 'financing instruments' that pondscape developers can use to pay for ponds, including revenue-generating measures for government or private landowners, public subsidies and grants, private donations, borrowing, investing and contractual approaches.[35]

Sources of finance differ considerably and, as a result, have different obligations and requirements associated with them. These differences mean that each source of finance has different strengths and weaknesses, making them suitable for different types of project.

Table 6 - PONDERFUL Sources of Finance Inventory (McDonald et al. 2023)

Main category	Category definitions	Instruments
1. Income instruments	Instruments for raising revenue that can then be used to finance nature-based solutions. Some can be used by landowners (1.1, 1.4, and 1.5); others can only be levied by government-sanctioned associations (1.2 and 1.3) or governments (1.6).	1.1 User fees 1.2 Business improvement districts 1.3 Betterment levies 1.4 Development rights and leases 1.5 Sale of market goods 1.6 Other revenue raising measures
2. Contracting approach (cost reduction/ restructure)	Legal agreements that reduce or restructure the costs of financing nature-based solutions, either by providing assets or use of assets at below market rates (2.1) or by shifting financing of upfront costs in return for ongoing payments (2.2).	2.1 Community asset transfer 2.2 Public private partnership
3. Voluntary contributions/ donations	Voluntary payments made of own free-will, whether a direct beneficiary of the nature-based solutions (3.2) or simply to contribute (3.1, 3.3).	3.1 Philanthropic contributions 3.2 Voluntary beneficiary contributions 3.3 Crowdfunding
4.Tradable rights/ permits and payment for ecosystem services	Revenue is raised by selling the 'rights' to ecosystem services generated by the nature-based solutions. This payment can be relatively informal (4.1) or through structured markets for climate mitigation (4.2), for offsetting damage to biodiversity elsewhere (4.3), or for reducing water pollutants (4.4).	4.1 Payment for ecosystem services 4.2 Transfer-based instruments: Voluntary carbon markets 4.3 Transfer-based instruments: Biodiversity offsets and habitat banking 4.4 Transfer-based instruments: Water quality trading systems
5. Subsidies	Subsidies are a financial contribution from the government to a person, company or organisation to promote socially beneficial outcomes. They can be ongoing payments (or tax breaks) linked to outcomes or production (5.1, 5.2)	5.1 Environmental subsidies 5.2 Tax concessions
6. Grants	Direct contribution from government (local, national, or EU) to a recipient in return for undertaking a specific activity. Grants are generally one-off payments (though they may be paid in instalments), and often competitive (6.1).	6.1 Grants
7. Debt instruments	Transfer of capital in return for a promise to repay that capital over time, generally with interest. This can involve direct lending from a lender to a borrower (7.1) or be mediated through debt markets (7.2).	7.1 Loans and green loans 7.2 Bonds and green bonds
8. Ownership models (equity finance)	Financing raised by selling an ownership share of the nature-based solution, potentially with a claim to some of its profits. This can be motivated by a desire to have impact (8.1) or be purely commercial (8.2).	8.1 Impact investing 8.2 Commercial investing

Practical advice for covering costs

To help select between different ways to pay for your pondscape project, the following steps can be helpful:

- **Understand your pondscape project:** What benefits will it generate and for who? What costs will be involved (e.g. excavator, workers, liner, walkways)? Having a clear understanding of the scale of financial costs helps identify funding options. A clear understanding of the benefits can help identify sources of revenue, or strengthen your ability to generate financing.

- **Review all financing options:** This includes public sources (such as regional or national government grants and environmental or land use subsidies), as well as private sources. Taking advantage of private sources of financing may be more challenging, especially as this perspective might be fundamentally different from the one taken by a pondscape site manager, natural scientist, engineer, or a landscape architect, but may enable more, or larger, pondscape projects.

- **Think big:** It can be challenging to finance individual ponds, but additional financing options may arise when a pondscape is proposed as part of a larger project, e.g. pondscapes as one component of a larger recreational area, or part of an infrastructure development.

- **Push for policy change:** Pondscapes predominantly generate public goods which are difficult to finance, such as biodiversity enhancement. Public funding and novel policy approaches, such as the creation of markets for biodiversity benefits or other environmental services, can generate revenue. The **PONDERFUL** UK Water Friendly Farming demonstration site (success stories 6.1 and 6.4) offers an example of the potential benefit of new policy: stakeholders praised district licensing policies[‡] that fund the creation of ponds for a European protected species, the Great Crested Newt.

Overcoming policy constraints

Policies can both help and hinder pondscape management and creation. There are common barriers posed by European, national and regional policies. The **PONDERFUL** demonstration sites provide examples of the ways such constraints can be overcome.

Policies related to pondscapes often prioritise economic value over biodiversity objectives, with detrimental land uses taking precedence. Meanwhile, ponds, despite their potential benefits, are often neglected compared with other habitats, and often fall outside of key EU water and biodiversity policies, or are not sufficiently considered in national implementation programmes. Challenges identified in **PONDERFUL**'s assessment of EU policies also include[37]:

- Mistrust between policymakers and private landowners.
- Lack of farmer interest due to concerns about operational limitations.
- Obtaining financing for private land projects (funding is easier to obtain where there are clear public benefits).
- Finding long-term funding for pond management.
- Lack of resources for monitoring. Monitoring institutions often face resource constraints or lack interest, and there is a lack of baseline data, research or technical guidelines.
- Permitting processes for pond creation or restoration can be tedious in some countries.
- Lack of knowledge-sharing regarding pond benefits and nature-based solutions, which hinders policy adoption and implementation.

Examples provided by the **PONDERFUL** demonstration sites include:

- In La Pletera (Spain) and Schöneiche (Germany), policymakers reformed municipal policies to rewrite policy goals in a manner that balances economic growth with natural heritage protection.

- The designation of ponds and pondscapes as protected areas has led to better planning, e.g. at Pikhakendonk (Belgium) and Schöneiche (Germany), and has improved access to financing and institutional improvement, e.g. at La Pletera (Spain). National or local designations offer similar benefits to international ones, but often work more effectively in restricting harmful land uses. When protected areas do not yet exist, municipalities can use zoning plans as a 'stepping stone' towards later inclusion in protected areas or planning documents, as seen in Rhône Genevois (Switzerland), La Pletera (Spain), and Schöneiche (Germany).

[‡] District licensing policies create a simplified procedure for offsetting impacts on Great Crested Newt ponds. Housing developers pay set amounts to pond developers, who strategically develop new pondscape habitats.

- Zoning plans and protected areas can also help accelerate permitting processes for pond creation (e.g. Denmark, Germany, Uruguay). The designation of local micro-reserves can help define agreements with landowners, and in some cases be the subject of financing by private companies, which can, for example, give their name to the reserve.

- Financing for measures by private actors is rare, but does exist, and often involves ad-hoc stewardship agreements. Agreements between public institutions and landowners tend to focus on protected areas (e.g. Switzerland, United Kingdom), while agreements between landowners and civil society organisations extend to other areas (Belgium, Switzerland, United Kingdom).

- Successful pond monitoring is observed when civil society organisations take charge (e.g. Switzerland, Turkey), ponds are clustered into monitoring units (Albera, Spain) or long-term pond projects exist (Lystrup, Denmark).

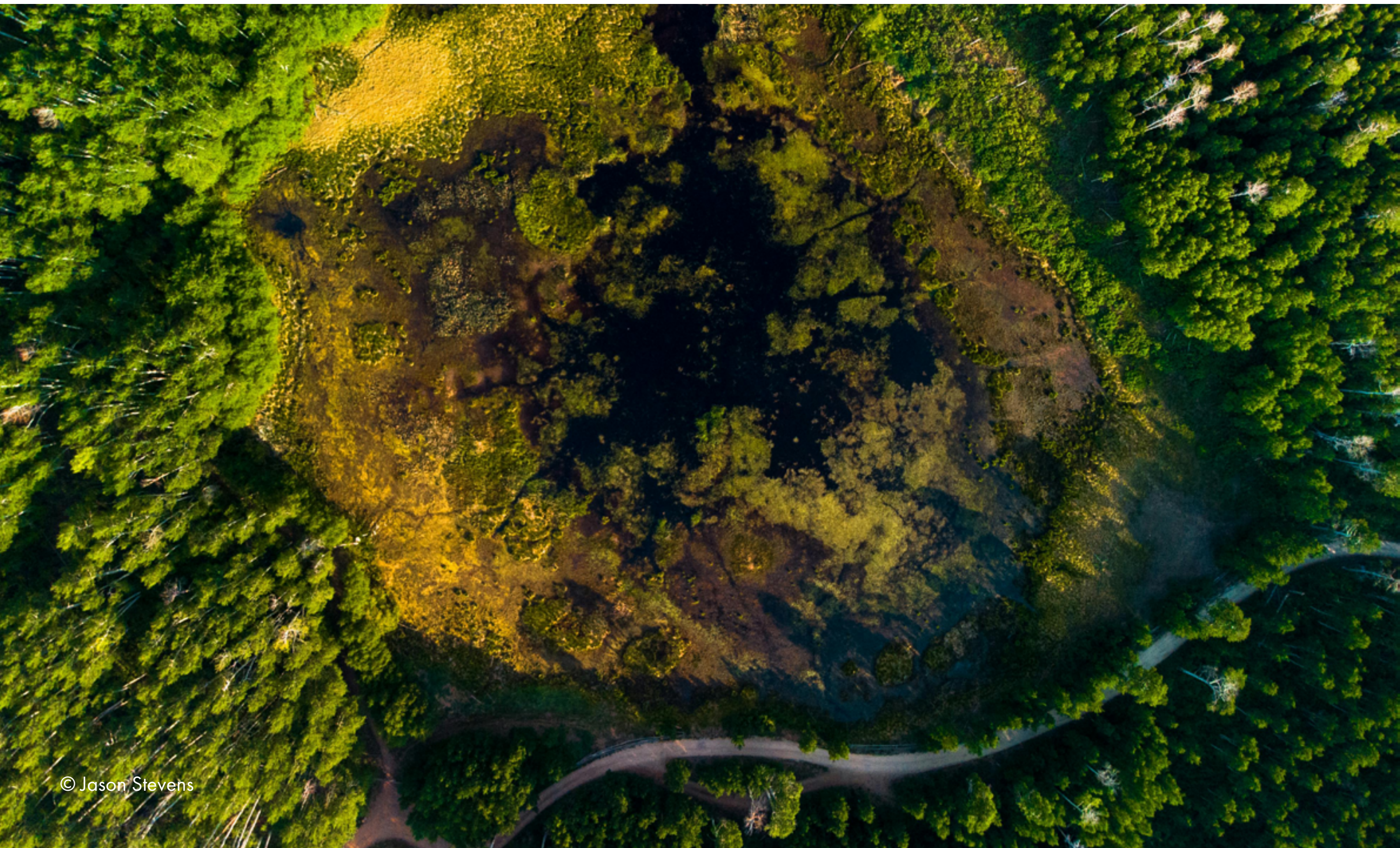
- Permitting for pond creation and land use regulation are most effective when integrated into zoning regulations (e.g. Denmark, Germany), linked to protected areas (Uruguay) or connected to financing schemes (United Kingdom).

- Effective institutions usually arise from a sustained budget and develop over time, as seen in La Pletera (Spain), and Pinkhill Meadow (United Kingdom). These can be linked to protected areas or civil society organisations engaging in partnerships with local authorities.

- Local identification with the pondscape can be increased through a protected area status, environmental education and research outreach, as seen in Belgium, United Kingdom, Germany, Spain, Switzerland and Turkey.

- Research plays a vital role in supporting policies by providing evidence, as seen in La Pletera (Spain), and by ascertaining pond benefits (e.g. Denmark, United Kingdom). Research has also increased public willingness to implement nature-based solutions (Spain, Uruguay).

For more information on these success stories, see Chapter 6.



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5.2 PROMOTING POND AND PONDSCAPE NATURE-BASED SOLUTIONS

Ponds and pondscapes generate benefits for many groups of people (see Chapter 3).

Pondscape creation or restoration can be made easier when stakeholders are aware of the benefits. The **PONDERFUL** project identified a range of ways of getting support for a pond or pondscape nature-based solution scheme including:

- **Involve communities:** When local people have a positive view of the pondscape's contributions and see the potential for it to improve their quality of life, this increases public support for management, restoration and creation.

- **Encourage technical support and knowledge exchange:** Pondscape managers benefit from focused technical support, collaboration and knowledge exchange to help the implementation of nature-based solution measures. So far, support and exchanges related to the implementation of nature-based solutions for climate change adaptation and mitigation are focused on rivers and streams, wetlands, moorlands, forest and peatlands. It is important to raise the profile and public appreciation of pondscapes, which can provide the same benefits. This would ensure coherence in the management of all freshwater bodies.

- **Celebrate success:** Positive pondscape nature-based solution examples should be shared. These success stories demonstrate the potential of nature-based solution measures and can be a powerful incentive for other pondscape managers to adopt best practices. Demonstration projects can showcase the benefits of sustainable practices and help build trust in these approaches. To facilitate widespread learning, information should be shared in a way which is easily accessible.

- **Network:** Facilitating knowledge exchange across multiple levels and different stakeholder groups is important. At a regional level, this should include communities and local authorities, regional policymakers and civil society. They may also need to include legal and regulatory bodies, as these groups work together to shape management decisions. The idea is to create an environment that encourages learning and lay the foundations for linking visitors, inhabitants, civil society, managers and decision-makers at all levels.

- **Communicate and educate:** Educational campaigns are needed to raise awareness of the value of pondscapes, including the contributions they make to people and the species they support, as well as the threats they are facing. This can strengthen stakeholders' sense of belonging to, and connection with, ponds and pondscapes.

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6. Pondscapes as nature-based solutions: success stories from the PONDERFUL DEMO sites

6.1 PONDSCAPES FOR BIODIVERSITY

CREATING A BIODIVERSITY HOTSPOT WITH A SMALL PONDSCAPE ON FLOODPLAIN (UK)

PONDSCAPE PINKHILL

IDENTITY CARD

Pondscape area: 12 ha
57 ponds (2.7 ha of water surface)

Dominant landcover:
- pondscape: low intensity floodplain grassland
- surrounding environment: agriculture, water storage reservoir

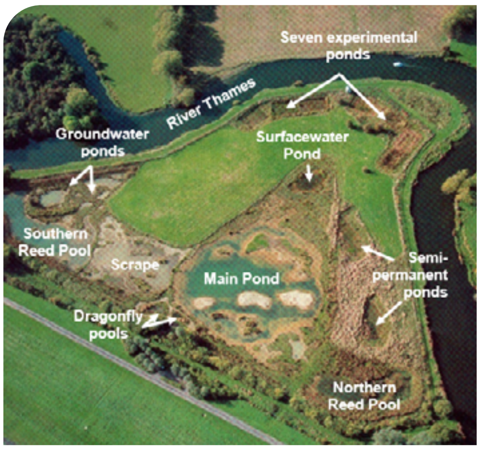
Bioclimatic zone: Oceanic

The Pinkhill pondscape is located on the ancient floodplain of the River Thames, which has a long wetland heritage. The first pond complex (created in 1990) is less than 3 ha in area, but is exceptionally rich and now supports around 20% of all Britain's freshwater plant and larger invertebrate species. The site's richness is due to a range of factors. There are ponds of different sizes, ranging from 5 m^2 to 0.3 ha. Some ponds dry every year and others are semi-permanent, which provides many different habitats. Most ponds have extensive areas of shallow water and wetland around their edges.

It was important to design the ponds so that their water quality was as clean as possible. To do this, none of the ponds have direct links to the polluted River Thames. In addition, most of the ponds are fed by groundwater which has low levels of polluting nutrients.

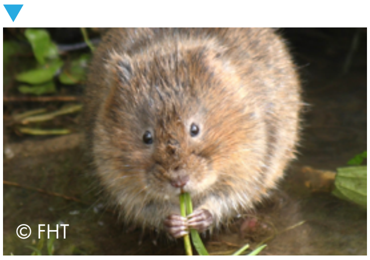
Management is undertaken to maintain the site's conservation value. This includes cattle grazing, managing scrub, cutting meadows, creating new ponds and managing/remodelling existing ponds. Management is led by Thames Water, with additional partnership projects undertaken with the NGO Freshwater Habitats Trust.

Pinkhill provides clear evidence that it is possible to create new pondscapes of exceptional biodiversity value, even when there are quite limited areas of land available.



Pinkhill Meadow is one of three floodplain meadows in this pondscape

European water vole (*Arvicola amphibius*)



Pond complex, shortly after it was created in 1990

Lesser Water Plantain *(Baldellia Ranunculoides)*

Round-fruited Rush *(Juncus compressus)*

CREATING A BIODIVERSITY HOTSPOT WITH A LARGE PONDSCAPE (SWITZERLAND)

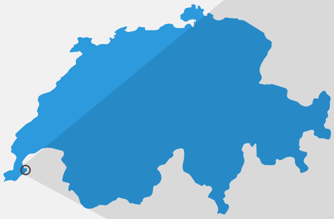
PONDSCAPE BOIS DE JUSSY

IDENTITY CARD

Pondscape area: 610 ha
69 ponds and 300 small pools
(3 ha of water surface area in total)

Dominant landcover:
- pondscape : woodland
- surrounding environment: agriculture

Bioclimatic zone: Continental (oceanic influence)



This large pondscape is located in a woodland near the city of Geneva. A dozen of the large ponds were dug in the 1960s, with the aims of draining the forest and for storing water in case of fire. Today, the main management objective is biodiversity conservation. Several other ponds of various sizes have been dug in the clay substrate.

This pondscape is a local biodiversity hotspot, hosting 2/3 of the regional richness of aquatic plants, dragonflies and amphibians (including the conservation priority species European Pond Turtle (*Emys orbicularis*) and Yellow-bellied Toad (*Bombina variegata*)). Pond creation here has benefited both aquatic biodiversity (including plants, invertebrates, amphibians and reptiles) and terrestrial animals (e.g. large and small mammals, bats, birds).

Ongoing management of the pondscape has taken place for the last 20 years. Success here has been driven by:
- The support of external consultancies following a prescribed management plan that targets biodiversity (pond creation, pond restoration, removal of exotic species, tree management, management of terrestrial habitats, enhancement of pond connectivity).
- The creation of a dense network of ponds of different size (from 300 small 1 m^2 pools to large 5000 m^2 ponds), shape and design. Semi-natural woodland ensures good connectivity between ponds.
- The implementation of protection statutes.
- The reintroduction of threatened species.

The high level of active management required means that continuous funding is necessary. Management action has proved to be the key for the successful protection and enhancement of biodiversity at the site.

© HES-SO

Bombina variegata © Eric Sansault

Emys orbicularis © Maurizio amendolia

PROMOTING AMPHIBIAN COMMUNITIES: CREATING HABITATS AND TRANSLOCATION OF GREAT CRESTED NEWT POPULATIONS (BELGIUM)

PONDSCAPE PIKHAKENDONK

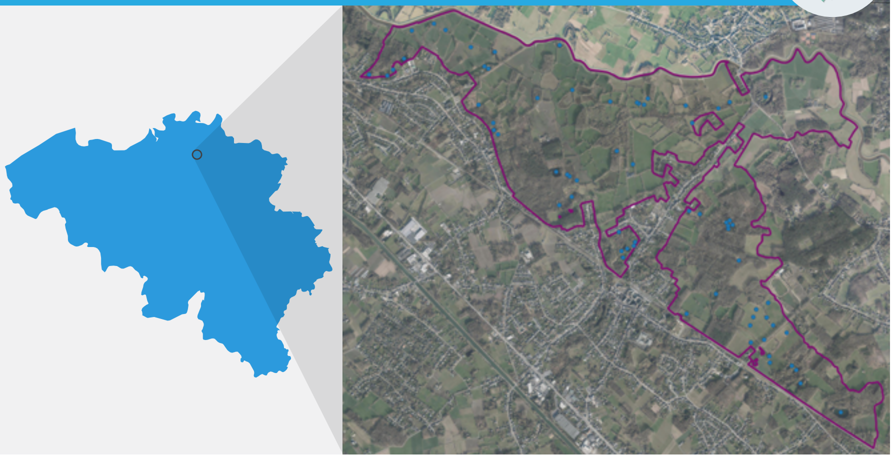
IDENTITY CARD

Pondscape area: 5 km^2
62 ponds (10.2 ha of water surface)

Amphibian species richness: 7

Dominant landcover: extensive grazing and meadows

Bioclimatic zone: Atlantic



The landscape in Pikhakendonk consists largely of meadows scattered in a dense network of old hawthorn hedges and some forest patches. The pondscape is a NATURA 2000 area and contains 62 small ponds. Several of these ponds have been recently created as part of a translocation project for the Great Crested Newt (*Triturus cristatus*). A number of old ponds and ditches have been restored through dredging and margin reprofiling to enhance habitat suitability for aquatic communities.

The current amphibian community is particularly rich and abundant, with the presence of two species listed on the Habitats Directive (Great Crested Newt (*Triturus cristatus*), Common Frog (*Rana temporaria*)) and five other species (Common Toad (*Bufo bufo*), Marsh Frog (*Pelophylax ridibundus/kurtmuelleri*), Alpine Newt (*Ichthyosaura alpestris*), Smooth Newt (*Lissotriton vulgaris*), and the non-native Levant Water Frog (*Pelophylax bedriagae*).

In 2016, an existing population of Great Crested Newt from a nearby location (15 km away) was translocated to the pondscape on request from the Flemish government in collaboration with the Agency for Nature and Forests (ANB) and the Research Institute for Nature and Forest (INBO). The translocation was needed as the original habitat of this species was due to be damaged by large-scale river restoration in the River Dijle valley.

In addition to this translocation of adults, a scientific breeding programme was established by INBO. Juveniles (3,205 individuals) bred in captivity were released in several ponds (in 2017–2020). The population dynamics of the translocated newt population is regularly monitored by INBO and Natuurpunt (an independent volunteer association). By 2023, the translocation was judged to be successful, as multiple ponds supported Great Crested Newts and the newly established population seemed to be breeding successfully. Translocation is a good example of nature-based solutions when habitats are highly isolated, preventing natural colonisation.


© Louisa Plüskow


Triturus cristatus © Pieter Jan Alles


© Louisa Plüskow

ACTIVE MANAGEMENT OF THREATENED AMPHIBIAN SPECIES (DENMARK)

PONDSCAPE FYN ISLANDS

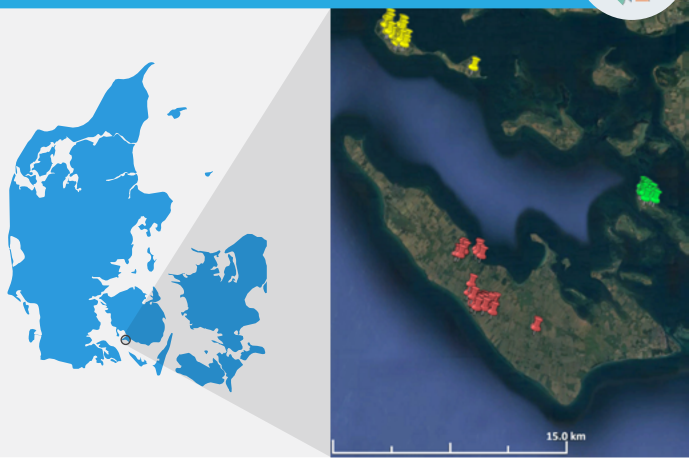
IDENTITY CARD

Pondscape area: 15 km^2
64 ponds (4 ha of water surface)

Amphibian species richness: 5

Dominant landcover:
- pondscape: pasture
- surrounding environment: pasture and arable land

Bioclimatic zone: Continental



The Fyn Islands pondscape covers Ærø, Avernakø and Birkholm, three small islands (88 km^2, 6 km^2 and 1 km^2 respectively) out of approximately 55 islands of the South Fyn Archipelago. Most of the land on these islands is used for agriculture.

This archipelago is a 'hot spot' for the European Fire-bellied Toad (*Bombina bombina*), a highly threatened species in Europe. Today, this species can be found in numerous ponds on the three islands, thanks to over 35 years of pondscape management for the species. Only two populations on Avernakø and Hjortø are original, all others on the remaining islands having been restored with the help of a breeding programme. The habitats of the toads are partially protected by two Natura 2000 sites, established especially for the species.

Management of the pondscape for the European Fire-bellied Toad is aimed at improving and enlarging both aquatic and terrestrial habitats, as well as preserving genetic variability of the remaining populations. Thanks to several projects financed by local and international (EU LIFE Programme) funders, over 80 ponds have been created or restored since the 1990s. In addition, on Avernakø nearly 35 ha of arable land has been permanently transformed to meadows where fertilisers, pesticides and soil treatments are not used.

Creation and restoration of ponds in clusters supports habitat connectivity and increases the diversity of aquatic habitats. Also, municipalities and the Danish Nature Agency have helped farmers start cattle grazing by financing fencing of the meadows. Grazing with the right species and at the correct density is a key factor in maintaining the habitats in favourable conditions for amphibians.

As the local communities of the pondscape became familiar with the species, this success story has contributed to an increase in public environmental awareness and knowledge. *Bombina bombina* is also used for marketing of local tourist attractions (e.g. guided tours to see and listen to calling toads).


© Aarhus University

Bombina bombina © Marek Szczepanek

CONSERVATION OF LAKE LITTORAL PONDS FOR PROMOTION OF BIRD COMMUNITIES (TURKEY)

PONDSCAPE LAKE MOGAN (DIKKUYRUK)

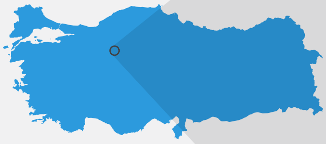
IDENTITY CARD

Pondscape area: 1.8 km^2
15–20 ponds (6.8 ha of water surface)

Water bird species richness: 83

Dominant landcover:
- pondscape: nature reserve
- surrounding environment: peri-urban and rural

Bioclimatic zone: Central-Anatolian cold arid steppe climate

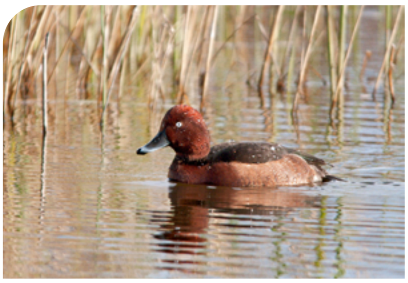


The Lake Mogan pondscape includes several littoral ponds that were formed by decreasing water levels after a major floodgate was built upstream in 2015. This pondscape is a key element in the conservation of the lake's bird community on a wider geographical scale. Indeed, Lake Mogan is identified as an 'Important Bird Area' (IBA) in Turkey, with around 249 bird species identified in the region (83 species of water birds). The lake, and especially the pondscape, provide habitat for breeding Squacco Heron (*Ardeola ralloides*), Red-crested Pochard (*Netta rufina*), Ferruginous Duck (*Aythya nyroca*; Near-threatened on the global IUCN red list) and White-headed Duck (*Oxyura leucocephala*; Globally Endangered on IUCN red list).

Besides the important bird community, the area is especially rich in other groups (amphibians, reptiles, mammals), although the invertebrate community requires further study. The area also hosts large populations of the endemic plant *Centaurea tchihatcheffii* (Critically Endangered on the IUCN red list), which is associated with wetlands that dry out in spring and summer. It is found throughout the steppes and pastures of southern Ankara towards the Konya Plain.

The pondscape is part of the Gölbaşı Special Environmental Protection Area (Gölbaşı SEPA), which was established in 1992 to curb the urbanisation of the peri-urban area of Ankara and to protect and conserve the area's high biodiversity value. Its recent management plan includes several measures that target the protection of biodiversity; the pondscape is declared a 'Sensitive A' zone (requiring absolute protection of reedbeds and ponds). The implemented measures include:
- Prohibition of the construction of closed areas, excavation and filling.
- Prohibition of fishing.
- Removal of existing tourism facilities.
- Monitoring and recording of breeding bird species.
- Closing bird breeding areas to human activities during the breeding period.
- Monitoring the plant *Centaurea tchihatcheffii*, and protection of key population of this species by fencing.

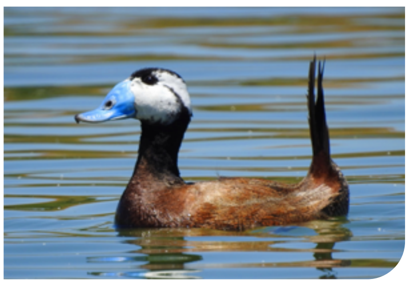
This success story illustrates the large benefit brought by a lake littoral pondscape that sustains and promotes regional freshwater biodiversity.



Aythya nyroca © Moretta Tabaccata

© METU

Oxyura leucocephala © Aissa Djamel Filali



PONDSCAPES AND CLEAN-WATER PONDS ARE VITAL FOR MAINTAINING FRESHWATER BIODIVERSITY (UNITED KINGDOM)

PONDSCAPE WFF

IDENTITY CARD

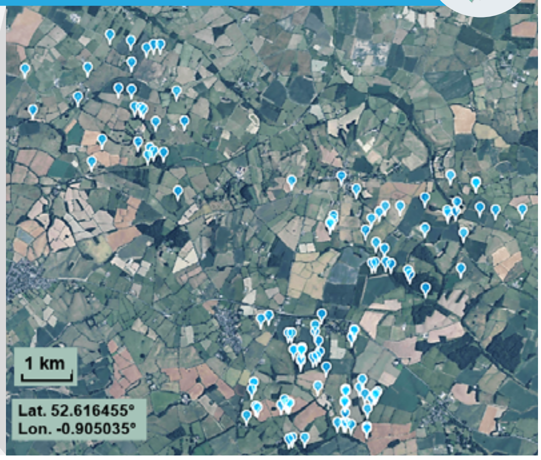
Pondscape area: 30 km^2
123 ponds (4.6 ha of water surface)

Aquatic plant species richness: 86

Dominant landcover:
pondscape: agriculture

Surrounding environment: agriculture

Bioclimatic zone: Oceanic



The Water Friendly Farming (WFF) project is located in the English Midlands. It aims to investigate the effectiveness of different techniques that could support biodiversity and ecosystem functions in the landscape.

PONDERFUL research showed that ponds are vital for maintaining freshwater biodiversity in this agricultural region, when assessed using aquatic plants. Across the 30 km^2 area, surveys of all waterbodies (streams, flushes, ditches, ponds) showed that almost all (95%) of the region's wetland plants were found in ponds, compared to 33% in ditches and 40% in streams. If all ponds were lost, more than half of the wetland plant species (56%) would be lost from the area. These findings highlight how important it is to maintain networks of ponds if we are to retain freshwater biodiversity in the countryside.

Twenty new clean-water ponds were created in 2013 by the Water Friendly Farming project. These new ponds have proved to be exceptionally important for regional freshwater biodiversity. Ten years after their creation, the clean-water ponds supported seven regionally rare species, including five that are not present in any other waterbodies. Overall, these ponds increased the wetland plant richness in their catchment by 16%. Richness of regionally rare species increased by 83%.

The critical factors for creating clean-water ponds were:
- Ensuring that the land around the ponds was not polluted: the best ponds were surrounded by unimproved grazed grassland or woodland.
- Making sure that the ponds did not have a stream or drain inflow, since these usually bring pollutants and silt into ponds.

These results emphasise the great value of creating new clean-water ponds and the need to share practical guidance.


© Freshwater Habitats Trust


© Freshwater Habitats Trust

6.2 PONDSCAPES AS NATURE-BASED SOLUTIONS FOR FLOOD-RISK REDUCTION

IMPLEMENTING A POND IN A PUBLIC PARK FOR STORMWATER PROTECTION AND BIODIVERSITY ENHANCEMENT (DENMARK)

PONDSCAPE LYSTRUP

IDENTITY CARD

Pondscape area: 5 km^2
18 ponds (2.1 ha of water surface)

Cumulative volume of water: 18,600 m^3
But the pond buffer areas allow storage of a much larger volume during storm events

Dominant landcover: residential (55%) and grassland (40%)

Bioclimatic zone: Continental

After several severe storms caused enormous damage, Aarhus Municipality decided that Lystrup should become a pilot project for the implementation of several nature-based solutions (rainwater retention basins, dykes and swales). A demonstration project was established by Aarhus University. This involved residents in both the design and the implementation phase, and combined climate adaptation and the creation of habitat for biodiversity. The aim was also to increase recreational use and the stakeholders' involvement in the maintenance of the area post-construction.

The demonstration project, covering about six hectares in a large urban park in the middle of Lystrup (Hovmarksparken), was a partnership including the local community, a school, the local council (the Aarhus City Council), a water utility company (Aarhus Vand), and scientists (Aarhus University).

A large retention pond, swales and dykes were constructed in what was previously a species-poor grassland. Additionally, a cattle-grazing NGO was established to manage the area, give guided wildlife tours and develop site-specific play activities in parallel to the construction work.

The transformation of the park also required change in its management through the integration of biodiversity objectives: re-scheduling the mowing regime and the introduction of cattle grazing.

The retention pond contributes to biodiversity, especially for amphibians: Smooth Newt (*Lissotriton vulgaris*) and Common Frog (*Rana temporaria*) are already breeding there, and the protected Great Crested Newt (*Triturus cristatus*) is also expected to use these habitats in the future.

The effectiveness of these ponds as a nature-based solution has been demonstrated during several storms. The new pond and associated dykes and swales have reduced damage to property and infrastructure.


© Aarhus University


© Aarhus University


© Aarhus University

A PONDSCAPE FOR MITIGATING FLOODS (TURKEY)

PONDSCAPE GÖLBAŞI DÜZLÜĞÜ

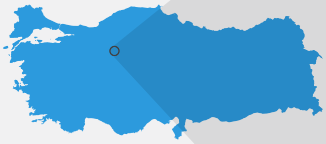
IDENTITY CARD

Pondscape area: 0.4 km^2
30 ponds (1.7 ha of water surface)

Volume of water stocked during a flood event: 1 million m^3

Dominant landcover:
- pondscape: wetland
- surrounding environment: urban

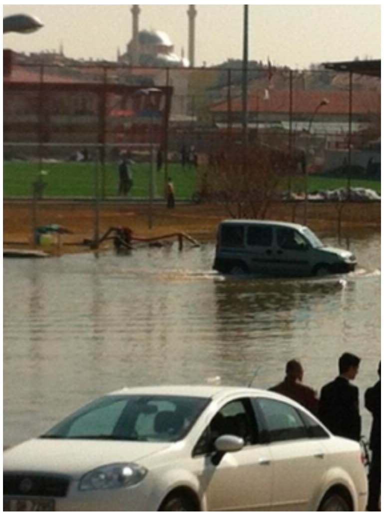
Bioclimatic zone: Central-Anatolian cold arid steppe climate

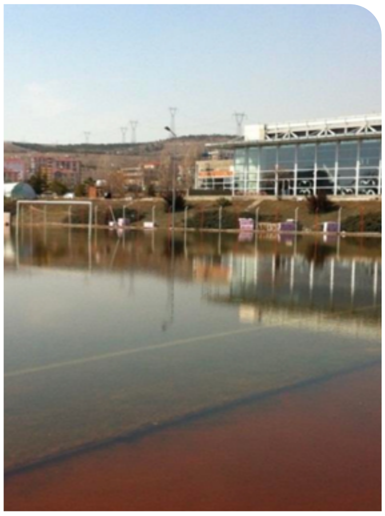


The Gölbaşı Düzlüğü pondscape used to be part of upstream Lake Eymir. It was created by building motorways and lowering water levels within Lakes Mogan and Eymir. This resulted in the formation of 30 ponds within a dense reed belt in the wetland area between both lakes. The water from upstream Lake Mogan goes through a concrete-lined channel, crosses the Gölbaşı Düzlüğü pondscape, and finally enters Lake Eymir. The pondscape has a very high water-storage capacity of approximately 1 million m^3. This large volume makes the pondscape very effective at preventing downstream flooding. This feature makes it an excellent example of green infrastructure in an urban area.

The upstream Lake Mogan overflows periodically due to heavy rain, particularly in the spring, damaging the surroundings. For example, flooding in 2011 and 2012 caused severe damage to Gölbaşı district and its settlements. The 'Ankara Basin Flood Management Plan', published by the Ministry of Agriculture and Forestry, demonstrated the impact of flooding events. Based on that, Gölbaşı Düzlüğü can accommodate severe flood water (occurring once every 500 years). A hydrological model of the Gölbaşı Düzlüğü pondscape was produced to investigate the flood prevention capacity of the area. This pondscape has the potential to retain excess water for a significant period of time, allowing for natural drainage and helping to protect Ankara.

Since the ponds are surrounded by dense reeds, they provide high-quality shelter and breeding areas for birds. Almost all species that breed in the ponds of Lake Mogan pondscape also breed here (see Lake Morgan DEMO site above). In recent years, efforts have also been made to restore and conserve the pondscape by utilising its potential through a People's Park project. The pondscape has high potential for improving the wellbeing of local people.





View of the pondscape and flooded areas around Lake Mogan © METU & O. Çağrı Bozkurt

6.3 PONDSCAPES AS PURIFICATION SYSTEMS

PONDS FOR TREATING AGRICULTURAL RUN-OFF

PONDSCAPE BOIS DE JUSSY

IDENTITY CARD

Pondscape area: 610 ha
69 ponds and 300 small pools
(3 ha of water surface area in total)

Dominant landcover:
- pondscape : woodland
- surrounding environment: agriculture

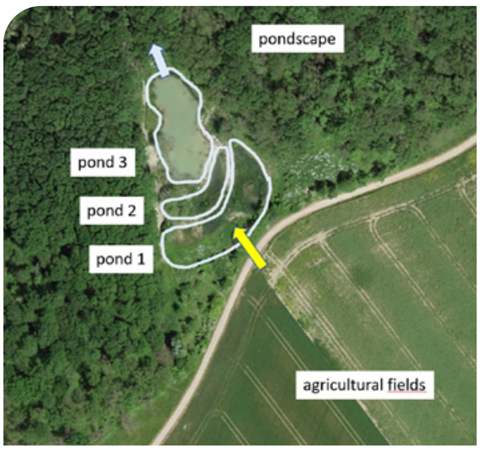
Bioclimatic zone: Continental (oceanic influence)

The NBS is located by the yellow circle.

The Bois de Jussy is a pondscape rich in diversified waterbodies (60 ponds from 100 m^2 to 5000 m^2, and 300 small pools 1-2 to 50 years old) where the biodiversity has developed successfully, in particular amphibians, dragonflies and aquatic vegetation. A forest surrounding the ponds ensures an effective buffer area. Nevertheless, the catchment also includes agricultural fields, with resulting pollution from nutrients and pesticides entering the pondscape through small ditches.

To address this problem, and to purify the inflows, the site managers recently implemented three new ponds as NBS in the pondscape. As illustrated in the figure, the polluted water (yellow arrow) is intercepted by a first well-vegetated pond before flowing into a second and, later, a third pond. The purified water (blue arrow) then flows downstream towards the pondscape where it will feed other waterbodies. The monitoring of the water quality and also of the biodiversity proved the efficiency of this NBS. For example, three threatened amphibian species (*Bombina variegata*, *Triturus cristatus* and *Rana dalmatina*) breed there, along with a rich invertebrate community (including dragonflies).

This type of local scale NBS can also be implemented efficiently on a larger scale, also for water treatment in small villages. A success story is for example related in Ireland (Co Waterford), where a set of five large ponds treat the effluents of 500 residents of the village of Dunhill, while being at the same time a hotspot of biodiversity.[15]



The polluted water (yellow arrow) is intercepted by a first well-vegetated pond, before flowing into a second and later a third pond. The purified water (blue arrow) then flows downstream towards the pondscape where it will feed other waterbodies.

Cordulia aenea (Odonata) © Julie Fahy

6.4 PONDSCAPES WITH AN OPTIMISED CARBON BALANCE

PONDSCAPES AS NBS WITH AN OPTIMISED CARBON BALANCE. CLEAN WATER PONDS ARE CARBON FRIENDLY: WATER FRIENDLY FARMING (WFF).

PONDSCAPE Water Friendly Farming

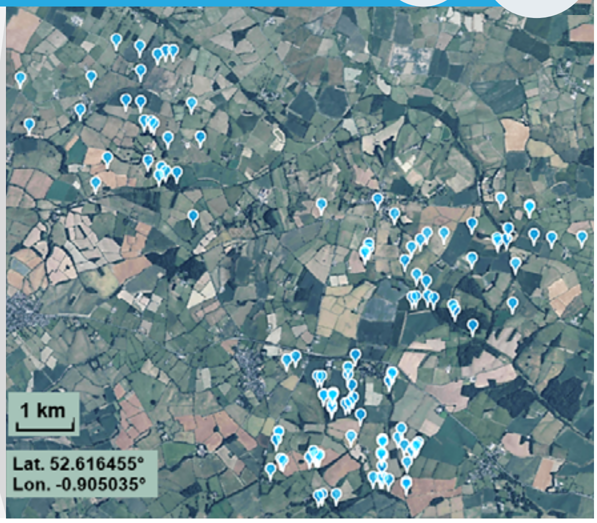
IDENTITY CARD

Pondscape area: 30 km^2
250 ponds (4.6 ha of water surface)

Dominant landcover:
pondscape: agriculture
surrounding environment: agriculture

Bioclimatic zone: Oceanic

Water quality
- Total nitrogen mean value: 2.3 mgN/L
- Total phosphorus mean value: 0.12 mgP/L
- Chlorophyll a mean value: 15 µg/L



Whatever the societal challenge addressed, minimising carbon footprint should be an objective when using any ponds or pondscape as NBS. This objective can even be the central target for some pondscapes. **PONDERFUL** research involving measurements made in 400 ponds across Europe, Turkey and Uruguay found that the key factor allowing an optimised carbon balance (balance between sequestration and emissions) is the water quality of the ponds. Indeed, a pond with good water quality, particularly near-natural nutrient levels and well-oxygenated water, will emit a low amount of methane (CH4), a greenhouse gas acknowledged to have a strong warming impact. This gas is usually produced in large quantities in ponds of low water quality, for example in highly hypertrophic ponds that are largely anoxic.

The UK DEMO-site Water Friendly Farming (WFF) is a success story in the creation of clean water ponds. This case study demonstrates that even in areas dominated by agriculture it is possible to have high quality ponds. The water quality measurements made during the **PONDERFUL** project showed relatively low values of nutrients (Total Phosphorus and Total Nitrogen) and also low values of Chlorophyll a (an indicator of primary production). Such ponds are expected to be particularly climate-friendly, with low methane emissions.

As set out in this handbook, the critical factors for creating clean water ponds are: (i) ensuring that the land around the ponds is not polluted: the best ponds are surrounded by unimproved grazed grassland or woodland (ii) making sure that the ponds do not have a stream or drain inflow, since these usually bring pollutants and silt into ponds.

Greenhouse gases have been intensively sampled in 250 ponds in the **PONDERFUL** project. Such floating chambers catch the bubbles of methane emitted in the anoxic sediments of the pond. © HES-SO

One of the newly created clean water ponds. The drainage area is free from polluted water and the runoff has a low content in nutrients. © Freshwater Habitats Trust

6.5 PONDSCAPES FOR FOOD PRODUCTION

LOW INTENSITY CATTLE PRODUCTION CO-EXISTS WITH AQUATIC BIODIVERSITY (URUGUAY)

PONDSCAPE URUGUAY

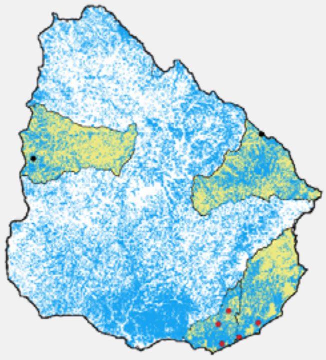
IDENTITY CARD

Pondscape area: 175,000 km^2

Number and density of ponds:
170,000 tajamares (ponds)
Densest region: Canelones, 4 ponds/ha

Dominant landcover in the pondscapes: cattle grazing (on natural grassland or pastures) and agriculture

Bioclimatic zone: temperate grasslands, humid subtropical climate.



The different departments where pondscapes were studied: in red by the **PONDERFUL** team at CURE, in black, by a team at CENUR Litoral Norte.

In Uruguay, rural ponds (tajamares) are mainly constructed for watering cattle and for small-scale irrigation. Their numbers have been increasing dramatically since the early 2000s and this is associated with the intensification of agriculture (crops and livestock). Depending on the agricultural production, tajamares are located in basins of varying land use intensity (e.g. intensive cattle production on seeded pastures versus extensive cattle production on natural grasslands).

Evidence from **PONDERFUL**, in addition to other studies, showed that ponds and pondscapes located in areas with low land use intensity have better water quality, lower risk of cyanobacterial blooms, higher aquatic biodiversity, and lower greenhouse gas emissions. At the local and landscape levels, ponds created in areas of low intensity land use can reduce the negative effects of agricultural intensification on water quality and biodiversity. Pond management is also important as the presence of diverse riparian vegetation reduces erosion and nutrient inputs, and, at the same time, provides habitat for native fauna and flora. Fencing the ponds to prevent direct access by livestock also contributes to better water quality and higher biodiversity; it is particularly beneficial for aquatic plants and amphibians.

This success story evidences how cattle production, when carried out at low intensity, enables coexistence with aquatic biodiversity. Applying environmental guidelines to the management of rural ponds also promotes positive effects and increases the benefits for people, nature and livestock.

Nymphoides humboldtiana © UDELAR

© UDELAR

6.6 PONDSCAPES AS NATURE-BASED SOLUTIONS FOR TOURISM AND HEALTH

CO-EXISTENCE OF NATURAL HABITATS AND TOURISM (SPAIN)

PONDSCAPE LA PLETERA

IDENTITY CARD

Pondscape area: 0.6 km^2
20 ponds (33 ha of water surface)

Number of people visiting the pondscape (number/year): 126,000

Dominant landcover:
- pondscape: coastal salt marshes
- surrounding environment: tourist residential estate, agriculture

Bioclimatic zone: Mediterranean

The pondscape of La Pletera is located in the Costa Brava (Catalonia), a popular tourist destination, near the Mediterranean seaside resort of L'Estartit. This saltmarsh and the 20 associated ponds were created in 2014 when the old settlement was replaced by a fully functional saltmarsh ecosystem. Restoration actions included removal of paved streets, a promenade and dams.

The site is now home to 47 aquatic plant species, 104 water birds and 17 families of invertebrates. Relatively few species, which are adapted to the variable temperatures, salinity and nutrient composition, are able to colonise these salt marshes. These species, however, have a very reduced distribution due to the destruction and urbanisation of these coastal habitats. With the presence of these rare species, these ecosystems make an important contribution to regional diversity. The creation of several new lagoons has helped the conservation of the endemic Iberian Toothcarp (*Aphanius iberus*). The Kentish Plover (*Charadrius alexandrinus*), a bird that builds a cryptic nest on the sand, has also benefitted from the restoration measures.

Today, the area is managed by The Natural Park (Parc Natural del Montgrí, les Illes Medes i el Baix Ter) board and the Town Council of Torroella de Montgrí-L'Estartit. Examples of management include: controlling and adapting public access, maintenance of infrastructures (paths, viewpoints, signage, etc.), management of protected species, environmental education and other outreach activities. There are peripheral footpaths and the public has access to the beach, but not to the dunes or the salt marsh, in order to prevent human pressure in these natural areas.

At this site, biodiversity conservation has proved to be compatible with high visitor numbers. Approximately 100,000 people (walkers and cyclists) visit the pondscape each year for leisure, tourism and nature-watching, using the peripheral footpaths and the viewpoints.

SAFE MOSQUITO CONTROL IN TOURISTIC ZONES (SPAIN)

PONDSCAPE LA PLETERA

IDENTITY CARD

Pondscape area: 60 ha
20 ponds surrounded by salt marsh vegetation

Number of people visiting the pondscape (number/year): 126,000

Dominant landcover:
- pondscape: coastal salt marshes
- surrounding environment: tourist residential estate, agriculture

Bioclimatic zone: Mediterranean

The pondscape at La Pletera is a restored natural habitat located in an area with high tourism pressure on the Spanish Mediterranean shoreline (Costa Brava).

In natural well-preserved ponds, predators (e.g. dragonflies, water bugs, beetles, amphibians, fish) usually control the density of larval mosquitos. Mosquitos thrive in artificial or altered habitats, as in other aquatic habitats where predators are scarce. They can cause health problems and economic losses in areas where tourism is one of the most important economic activities, such as the Costa Brava coastline, where salt marshes (such as La Pletera) are very close to campsites and tourist accommodation.

There are salt marsh mosquitos adapted to temporarily flooded natural areas. Females lay their eggs on dry sediment, where a subsequent flooding event causes the hatching of one single generation of larvae. The simultaneous appearance of millions of individuals after a sudden mosquito emergence strongly affects the economy of tourist areas beside salt marshes.

Active management at La Pletera has proved particularly effective at limiting mosquito numbers. A mosquito control service (Servei de Control de Mosquits de la Badia de Roses i el Baix Ter) oversees and controls mosquito emergence by applying an antilarval biological insecticide (*Bacillus thuringiensis israelensis* (Bti)) on the water after larvae emergence. Bti is a bacterial protein crystal that degrades within a few hours of use. It is safe for most of the aquatic species found in the saltmarsh.

Vegetation monitoring and mapping has enabled the Servei de Control de Mosquits de la Badia de Roses i el Baix Ter to target the application of Bti (and to avoid widespread use). In a salt marsh, small changes in topography have a strong effect on vegetation distribution, which can change dramatically with only a difference of a few centimetres in elevation. The ground height will affect how long the soil is submerged when water levels are high, which in turn dictates which plants can survive there. The strong relationship between flooding, water level, mosquito hatching and vegetation makes the use of vegetation maps very effective for mosquito control.

The vegetation map as a tool for the mosquito monitoring (green colours indicate areas where mosquito larvae are frequent) © Xavier Quintana

Spreading Bti in targeted areas of the pondscape
© Xavier Quintana

6.7 PONDSCAPES FOR EDUCATION

DEVELOPMENT OF A POND AND WATER EDUCATION CENTRE IN THE MIDDLE OF A MUNICIPALITY (GERMANY)

PONDSCAPE SCHÖNEICHE

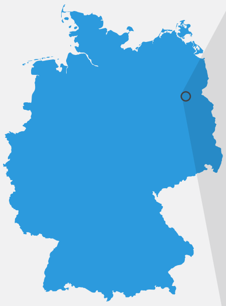
IDENTITY CARD

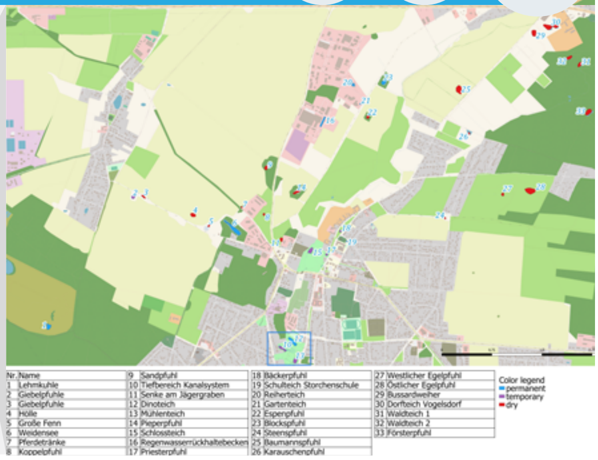
Pondscape area: 16 km^2
33 ponds (3.2 ha of water surface)

Number of people visiting the pondscape (number/year): 20,000

Dominant landcover:
- pondscape : grassland, pasture
- surrounding environment: agriculture and urban

Bioclimatic zone: Continental





This peri-urban pondscape is situated near Berlin (Germany), in the centre of a town (Schöneiche) with about 15,000 inhabitants. The ponds are ancient kettle holes, created by glaciation 10,000–12,000 years ago. Around 90% of the pondscape is accessible to the public and visitor numbers are therefore high (17,000 visitors/year). The local NGO 'Naturschutzaktiv Schöneiche' has developed the Kleiner Spreewaldpark as a centre for education and inspiration. Local people, in particular families, are attracted by footpaths along ponds and waterways, by rich wildlife, and by activity opportunities (e.g. a children's playground).

Information boards have been installed around the site to educate visitors. The site is also used for educational school visits. Being close to residential areas is a big benefit because people visit the site regularly, identify with the site and are aware of environmental change.

The impacts of global warming and change of land use on water availability in the area are directly visible from the drastic annual changes of water level in Kleiner Spreewaldpark. Eighteen of the 33 ponds are now permanently dry. This may motivate local people to engage in action to prevent further loss of local ponds.

These types of nature-based solution are ideally implemented where natural ponds can be found in urban areas. Being close to residential areas means that local people visit the education centre frequently and acquire a deeper understanding of annual changes occurring in the ponds and the threats they face.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A PEOPLE'S PARK PROJECT NEAR AN URBAN AREA (TURKEY)

PONDSCAPE GÖLBAŞI DÜZLÜĞÜ

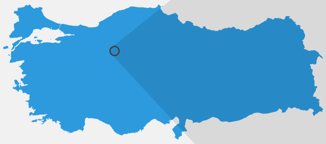
IDENTITY CARD

Pondscape area: 0.4 ha
30 ponds (1.8 ha of water surface)

Number of people visiting the pondscape (number/year): 140,000

Dominant landcover:
- pondscape: nature reserve
- surrounding environment: urban

Bioclimatic zone: Central-Anatolian cold arid steppe climate



The pondscape Gölbaşı Düzlüğü consists of 30 ponds surrounded by urban infrastructure and separated from each other by dense reeds. Currently, a People's Park project, including the restoration of the pondscape, is being created in an area of approximately 60 hectares. With this restoration project, it is aimed to protect and support local biodiversity, to increase the public's benefit from and awareness of the region, and to serve as an exemplary model for green infrastructure to improve flood resilience.

The project's primary aim is to find protection measures for *Centaurea tchihatcheffii*, considered 'Critically Endangered' (CR) according to the IUCN criteria. Additionally, the project aims to identify other species that are threatened or endangered, as well as sensitive areas and potential threats to protected areas. A total of 494 plant species were identified within the larger area of the Gölbaşı Special Environmental Protection Area, including three species of amphibians, 12 species of reptiles, 83 species of birds, and 25 species of mammals. Furthermore, the project includes activities such as protection and monitoring efforts in the region, collecting solid waste around the lake and ponds, and educating residents and schools.

This success story evidences the potential of pondscapes to be used by people for leisure and nature education, while promoting its biodiversity.

© Golbasi Duzlugu

▲ *Orthetrum cancellatum* © Charles J. Sharp

Centaurea tchihatcheffi © Yanardoner Sevgi ▼

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6.8 PONDSCAPES AS NATURE-BASED SOLUTIONS FOR SUPPORTING IDENTITIES

TEMPORARY PONDS, LOCAL IDENTITY AND RECREATION (SPAIN)

PONDSCAPE ALBERA

IDENTITY CARD

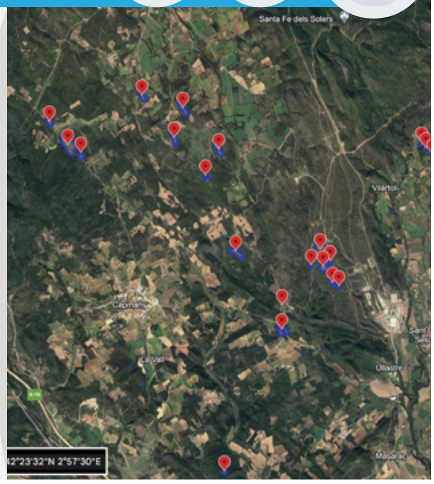
Pondscape area: 25 km^2
23 ponds (29.8 ha of water surface)

Number of people visiting the pondscape (number/year): 72,500

Number of stakeholders involved in cultural heritage protection: 8

Dominant landcover: Mediterranean scrub

Bioclimatic zone: Mediterranean



This group of 241 wet depressions and 23 ponds is located at the foot of the Albera mountains. All the ponds at this site are very shallow and temporary, some with relatively short hydroperiods (from around two to nine months). In especially dry years with low rainfall, all the ponds can remain completely dry. A number of the ponds are priority habitats as defined by the EU Habitat Directive: '3170 Mediterranean temporary ponds' and '3130 Oligotrophic to mesotrophic standing waters with vegetation of the *Littorelletea uniflorae* and/or of the Isoëto-Nanojuncetea'.

This region has been inhabited for thousands of years, and the local community of Albera has a strong cultural identity which is linked to the landscape, including the many ponds and flooded depressions. The region has many historical monuments, including 24 menhirs and dolmens (standing stones, or megaliths, dating from 3,500–1,800 BCE), seven Romanic churches (9th to 12th century) and hundreds of kilometres of stone walls. For the inhabitants of this region, ponds and their Romanic and megalithic heritage are essential components of their identity. There are several organisations which restore, maintain and disseminate information about this heritage (e.g. Empordanès Excursionist Club, Art and Work Group, Jonquerenc Excursionist Club, Cantallops Cultural Action Association).

Some megalithic monuments were assigned names related to ponds (e.g. Menhir Estanys I, Dolmen Estanys II). Similarly, one Romanic church (Santa Cristina de Canadal) shares its name with two ponds (Canadal Petit pond, Canadal Gran pond). Moreover, the most popular walking trail in the area is called the 'Itinerari dels estanys' (i.e. itinerary of lakes/ponds), showing how central ponds are to the cultural heritage of the Albera region.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6.9 LAND USE MANAGEMENT IN THE PONDSCAPE AS A NATURE-BASED SOLUTION FOR IMPROVING HABITAT QUALITY

LAND USE MANAGEMENT IN THE PONDSCAPE FOR REDUCING AGRICULTURE IMPACTS (SPAIN)

PONDSCAPE ALBERA

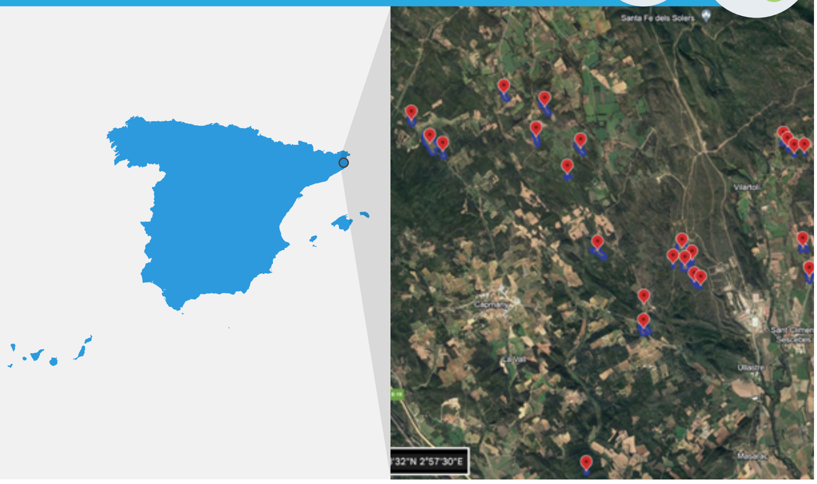
IDENTITY CARD

Pondscape area: 25 km^2
23 ponds (29.8 ha of water surface)

Number of species on the Annex II+IV of the Habitat Directive: 9

Dominant landcover:
Mediterranean scrub

Bioclimatic zone: Mediterranean



The Albera pondscape consists of 23 main ponds and 241 floodable depressions with different degrees of flooding, all of them of natural origin. All ponds are very shallow and temporary with relatively short hydroperiods (from around 2 to 9 months). Some of these ponds are priority habitats under the European Habitats Directive: '3170 Mediterranean temporary ponds' and '3130 Oligotrophic to mesotrophic standing waters with vegetation of the Littorelletea uniflorae and/or of the Isoëto-Nanojuncetea'.

The conservation status of ponds is normally heavily influenced by the land use of both the pondscape and its catchment. From 2010, the Institució Alt Empordanesa per a la Defensa i Estudi de la Natura (IAEDEN), an environmental NGO, established agreements with 29 private landowners in the Albera pondscape to reduce agricultural land use intensity. This covered 14 hectares of the pondscape. In this collaboration framework, low-impact agricultural management is promoted and different projects for environmental conservation are developed. For example, vineyards and olive groves are cultivated using 'ecological techniques' without herbicides and insecticides and grasslands are scythed rather than being used as cow pasture. The aim of the collaboration is to conserve the natural cycle of flora and avoid extra nutrients in ponds. This allows for more 'pond friendly' land use in several areas of the Albera pondscape.

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ACTIVE MANAGEMENT OF A PONDSCAPE FOR BIODIVERSITY WITH MULTIPLE STAKEHOLDERS (BELGIUM)

PONDSCAPE GETTE VALLEI

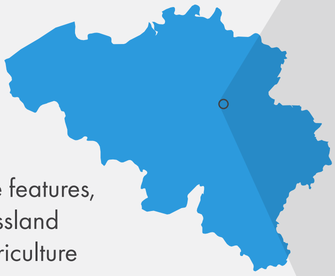
IDENTITY CARD

Pondscape area: 4.79 km^2
41 ponds (0.8 ha of water surface)

Aquatic plant species richness: 59

Dominant landcover:
- pondscape: woodland and small landscape features, including hedges, agricultural plots and grassland
- surrounding environment: predominantly agriculture with small forest patches

Bioclimatic zone: Atlantic



The Gete Vallei is one of the last large open spaces in Flanders. The pondscape has largely been protected from intensive agriculture and urbanisation. The Gete Vallei pondscape is characterised by its unique biodiversity.

This pondscape has been managed for biodiversity conservation for several decades, with good results. The NGO Natuurpunt plays a key role in nature conservation in this region. The current management is largely organised by a team of local volunteers, which is supported by professionals from Natuurpunt. Natuurpunt owns pieces of land in the region, which are designated as nature reserves to protect them. These reserves are then managed following an approved management plan.

In addition, the NGO collaborates with local farmers and private landowners in the region to manage private land for the purpose of biodiversity conservation. Natuurpunt also aims to enlarge the area under formal protection by obtaining additional land to be designated as a nature reserve.

Management in this area targets both terrestrial and aquatic biodiversity, and largely focuses on the maintenance of historical landscape elements, such as flower-rich grasslands, hedges, farmland ponds and semi-natural forest patches. Over the past decades, more than 20 small farmland ponds have been created to enhance aquatic habitat availability and connectivity. Existing ponds are periodically managed by dredging and cutting back shoreline vegetation. The long-lasting management efforts have proved to be successful in conserving biodiversity in the region, most notably the long-term maintenance of a large population of Great Crested Newts (*Triturus cristatus*).

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6.10 PUTTING A PONDSCAPE UNDER PROTECTION

THE DESIGNATION OF A PONDSCAPE AS NATURE RESERVE (BELGIUM)

PONDSCAPE TOMMELEN

IDENTITY CARD

Pondscape area: 0.18 km^2
144 ponds (1.3 ha of water surface)

Area protected (e.g. nature reserve): 95%

Dominant landcover:
- pondscape: extensive grazing land with some forest patches
- surrounding environment: urban

Bioclimatic zone: Atlantic

The Tommelen pondscape was created unintentionally by bombing during World War II. It was designated as a nature reserve in 2006. It is currently owned by the municipality of Hasselt and has been managed by the nature conservation NGO Natuurpunt (and local volunteers) since 1996.

The designation of the pondscape as a nature reserve (approximately 80% of the area is currently under protection status) has been a first major step in the effective protection of the pondscape. This also resulted in the creation of a management plan that targets biodiversity conservation and provides access to essential financing to maintain the pondscape. Part of the area is fenced from the public in order to reduce disturbance by visitors. The designation has also resulted in the creation of footpaths to make the area more accessible to local people. Tommelen is now an important green space in close proximity to the city, and is frequented by people for recreation and wildlife-watching.

Today, the site hosts an exceptionally rich amphibian community, including both the Great Crested Newt (*Triturus cristatus*) and the European Tree Frog (*Hyla arborea*).

Hyla arborea © Wim Dirckx

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© Filip De Clercq

6.11 MULTIFUNCTIONALITY AT THE PONDSCAPE LEVEL

COMPLEMENTARITY OF POND TYPES AND FUNCTIONS IN A PONDSCAPE (SWITZERLAND)

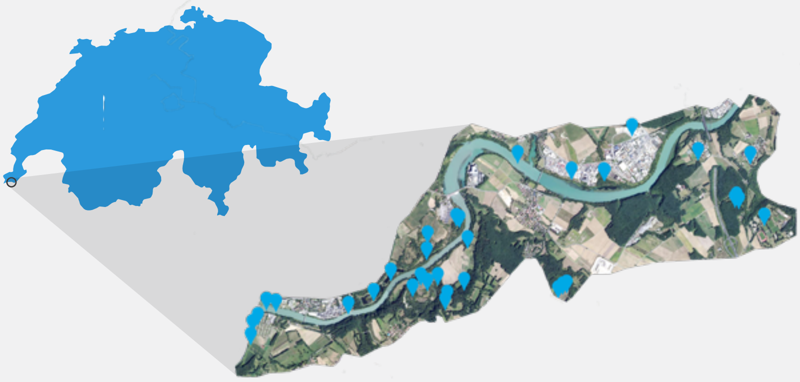
PONDSCAPE RHÔNE GENEVOIS

IDENTITY CARD

Pondscape area: 15 km^2
46 ponds (13.3 ha of water surface)

Dominant landcover:
woodland and agriculture

Bioclimatic zone: Continental



Between 1970 and 2018, 15 large ponds (ranging from 5,000 m^2 to 30,000 m^2) as well as many medium- and small-sized ponds were created at this site. Some ponds have been dug to restore natural habitats on previously developed land and others to create new opportunities for recreation, such as swimming and fishing. They demonstrate the multiple roles a pondscape can play.

Separating ponds for nature from recreational ponds simultaneously promotes the protection of pond biodiversity and delivers numerous Nature's Contributions to People.

This is a landscape scale nature-based solution, with the implementation of a large set of smaller scale nature-based solution. These are several features for managing the flow of visitors, together with the full protection of several natural areas: footpaths, parking, barbecues, beaches, fences, pontoons for fishing and nature observatories. Outcomes for biodiversity are achieved by creating new habitats for target species (e.g. toads, swallows) and reintroducing threatened species (e.g. European Pond Turtle). Populations are monitored to measure success. Bird-watching is also promoted in several locations.

Factors which have helped make this site so successful include:
- Designing ponds for a specific purpose, rather than trying to create multifunctional ponds.
- Implementing a management plan and controlling the flow of visitors.
- Encouraging collaboration between local authorities, NGOs and private consultancies.

This pondscape is a good example of using nature-based solutions to enhance biodiversity, improve human health and mitigate against a changing climate. This type of nature-based solution can potentially be included in local strategies and policies and would benefit from financial subsidies. Depending on the local geology, some costs can even be offset by selling materials extracted on site (e.g. gravel).

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