Knowledge Reservoir

Want to know more about the importance of water?
Cast your eye over the Knowledge Reservoir to find out.

THE MACAULAY INSTITUTE

Contents

The Water Cycle

Did you know?

Scotland is one of the wettest countries in Europe, receiving on average about 1400 mm of precipitation annually.

The natural system for recycling water works by taking it from the oceans, transporting it to the hills and then flowing back down to the sea.

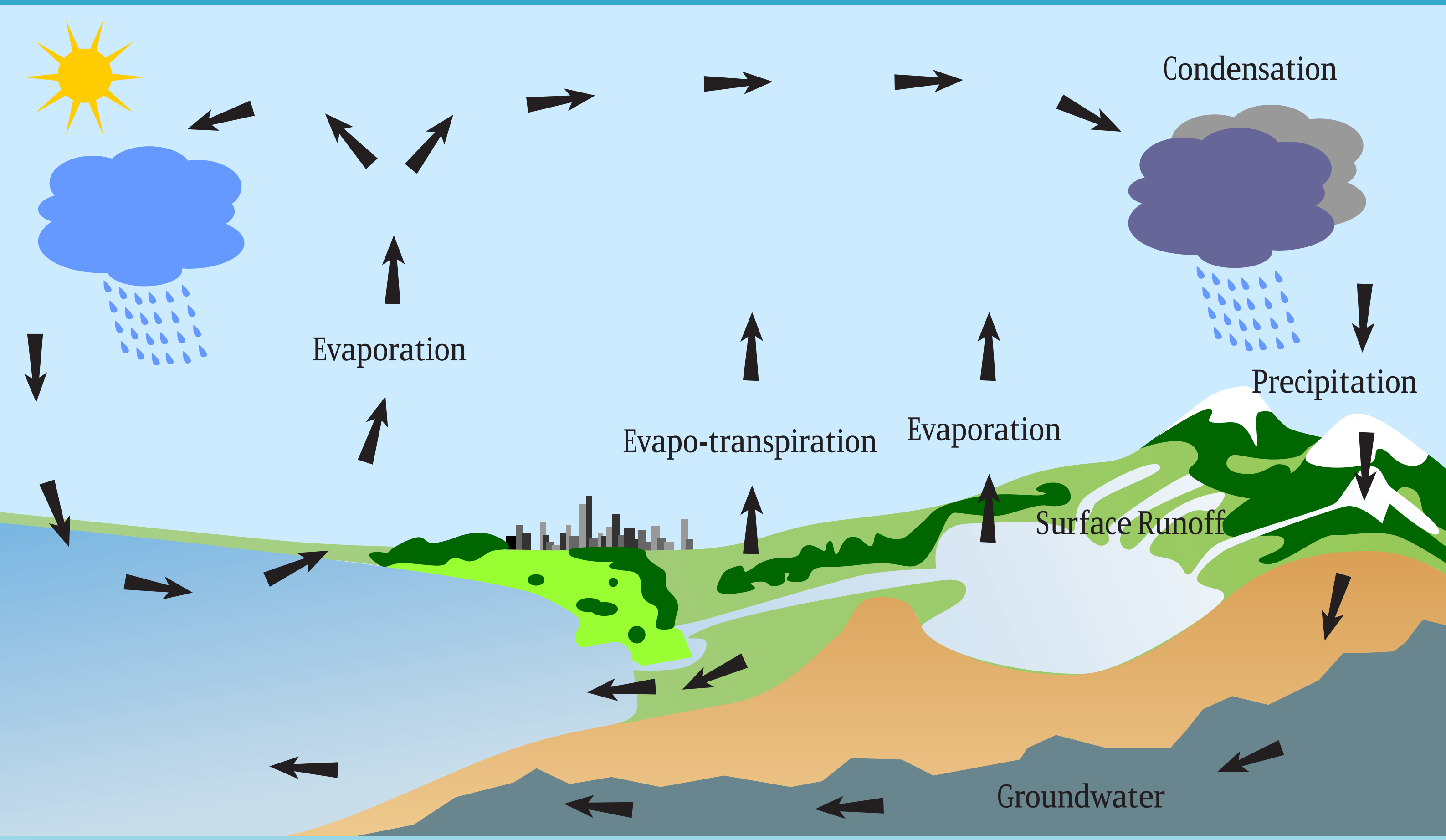
What is the Water Cycle?

The water that you drink has come from somewhere to reach the tap, and goes somewhere else when you flush the toilet. The natural system for recycling water works by taking it from the oceans, transporting it to the hills and then flowing back down to the sea.

The water cycle begins with evaporation of water from the surface of the oceans and evapo-transpiration from the surface of the land. As moist air rises, it cools and water vapour condenses, forming clouds. Moisture is transported around the globe in clouds until it returns to the surface as precipitation. If precipitation falls on land, it either:

1) returns to the atmosphere via evapo-transpiration, or
2) flows over or through the soil to rivers and lochs as surface runoff, or
3) drains through the soil into the rocks beneath and becomes groundwater

Surface runoff flows into rivers and lochs and is carried back to the oceans, where the cycle begins again. Groundwater flows into rivers and lochs along the way.



An intimate relationship

A key feature of Scotland's water cycle is the close relationship between precipitation and the soil. Since evaporation accounts for a relatively small part of the cycle here, most of the water that falls from the sky flows either over or through the soils on its way back to the oceans. Understanding soils and how water flows through them is therefore very important.

How clean is the rain?

Rainfall over Scotland is generally low in pollutants, and levels of certain pollutants, such as sulphur, are falling. However, levels of nitrogen remain a concern. Acidifying pollutants such as sulphur and nitrogen are major drivers of change in aquatic ecosystems, which suffer and adapt in response. If the source of pollution is removed ecosystems may recover. However, populations of some species may not recover completely if pushed too far – a sorry reminder that many of these man-made environmental problems are irreversible. Find out more in… "Acidification and Recovery".

1. Water is delivered to the land…

Upland Environments

Much of the rainfall received in upland environments is carried quickly to rivers as runoff, either over the ground or through the soils. This is because the soils are thin and unable to store much water and the underlying rocks are often impermeable – water cannot flow through them. This means that rivers fill up quickly, and the life within them has to cope with rapidly changing conditions.

Rivers tend to fill up quickly in upland environments

A lot of water flows through the soil in upland environments, picking up organic material on the way. This is an important source of food for aquatic life. Unfortunately a high organic content also turns the water yellow – which, although perfectly palatable, is an unwelcome ingredient when washing your whites! This has proved an expensive problem for the water industry, which spends millions of pounds every year removing the colour from the water.

Rainfall which travels rapidly over the land tends not to have much contact with the underlying rocks, so its chemistry on entering the rivers is relatively unaffected by the geology of the area. Groundwater on the other hand, which can sit around in the rocks for tens of years before gradually seeping into the rivers, often has a chemistry very similar to that of the local rock type. This is most strongly reflected in the chemistry of rivers during the summer, when groundwater is the main input.

Lowland Environments

Under natural conditions, rivers in lowland settings fill up more slowly than those in upland areas, for a number of reasons, such as:

- Slopes are shallower, soils are deeper and underlying rocks are often permeable. As a result, more rainfall is typically soaked up and stored.
- There is usually less rainfall at lower elevations than in the mountains.
- Rivers are winding, and slow the water down, which can prevent flooding.

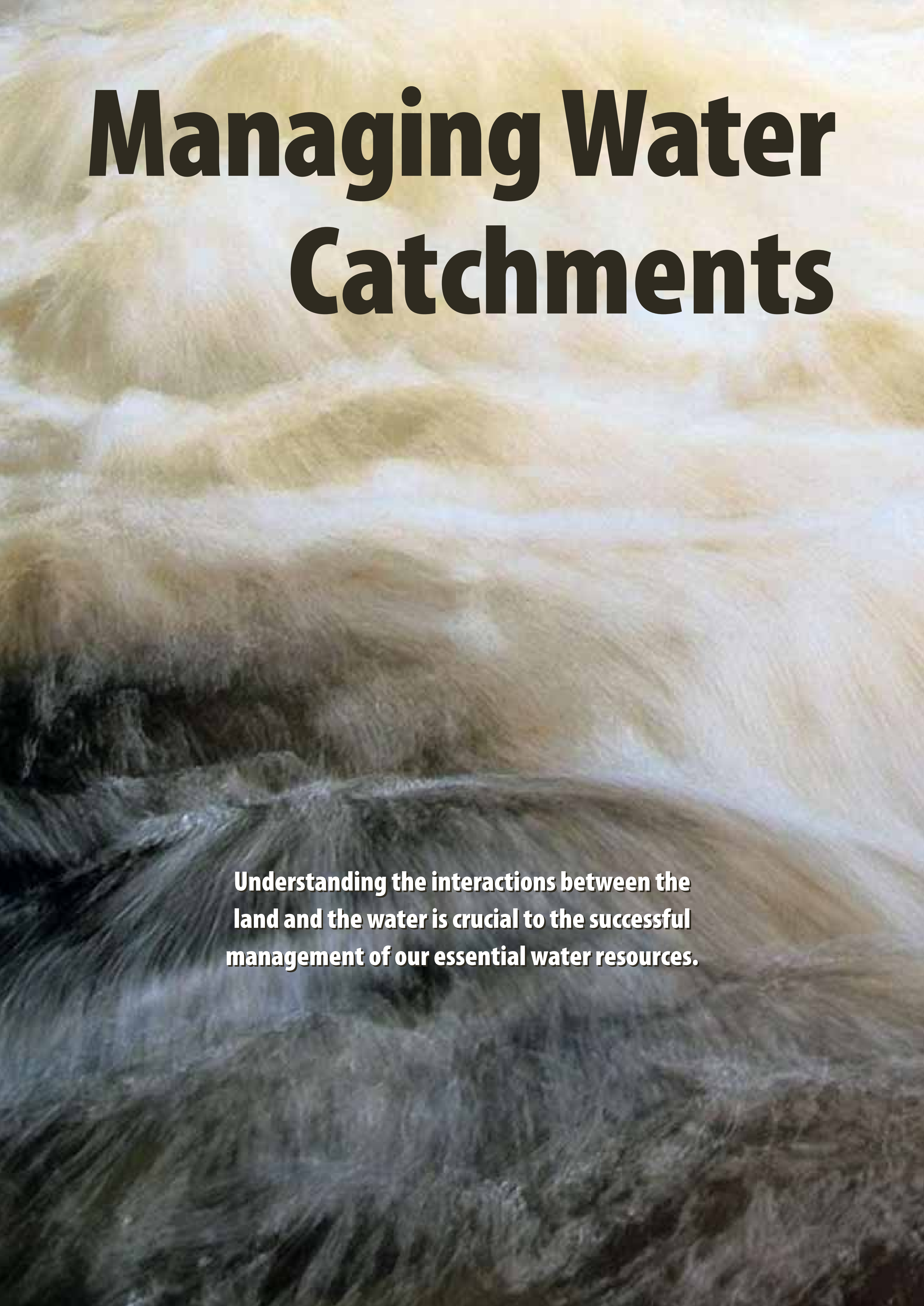
However, many rivers in lowland areas have been artificially straightened to improve drainage and maximise agricultural productivity. Without natural floodplains and a winding course, rivers cannot hold as much water, so flooding often occurs in the lower regions of many lowland rivers. As a result, lowland settings can often respond as quickly to rainfall as upland settings.

The natural scenario - a long lost ideal?

We also often see excess fertilisers, such as nitrates and phosphates, being washed into lowland rivers from nearby farmland. This is particularly pronounced in purely lowland rivers where there is no dilution by waters from upland areas. This problem is tackled by implementing various best management practices, which are outlined in "Links Between Land and Water".

2. Water is delivered to the sea…

When water reaches estuaries and coastal areas, it is nearing the end of its journey, soon to begin the cycle again. Everything that happens to the water on its course over and through the landscape affects the quality and quantity of the water when it reaches the sea. It is therefore vital that we deal with problems in water quality or quantity as high up in river systems as possible, in order to avoid transferring problems from one setting to another.



Managing Water Catchments

Understanding the interactions between the land and the water is crucial to the successful management of our essential water resources.

What is a catchment?

Think of it as a funnel, collecting the water that drains into an area and channelling it into streams, rivers, lochs or oceans. We all live in a catchment – all the land on our planet is part of a catchment related to a particular body of water. Catchments include rural areas such as agricultural land, forests and grasslands, and urban areas, such as city centres and housing. Catchments vary in shape and size, depending on the shape of the land. The boundary of a catchment is identified by drawing a line along the highest elevations between two areas on a map.

Why are catchments important?

Catchments are important because we all rely on water - and other natural resources - to exist. How we treat the land within a catchment affects both the quality and quantity of water available to ourselves and wildlife. Our catchments provide us with water for drinking, washing, agriculture, industry and recreation, and wildlife with food and shelter.

Below right: A catchment in Glenfiddich, Scotland showing the boundaries defined by the highest points of the region

How does a catchment work?

Beginning at the ‘top’ of a catchment in the higher parts of a region, water normally drains into small streams. It flows into larger and larger streams, which eventually join a river. The volume of the water in the river increases as more of these tributary streams join. The amount of water that reaches a river from its catchment area is affected by:

- the size of the catchment area,
- the amount of rainfall and snow (precipitation),
- the amount of water lost through evaporation,
- the gradient of the land,
- surface run-off (water flowing over the surface of the land),
- the soil type
- the vegetation
- how the land is used, such as for farming, forestry, or towns and cities.

Why do some areas flood?

Sandy soils allow the ground to soak up water faster, which reduces the surface runoff, so the rivers fill up more slowly. Clay soils, on the other hand, allow less water through, increasing the surface runoff and allowing the river to fill up more quickly. By holding water in (and on) their roots and leaves plants can reduce the surface run-off to rivers, slowing the process of filling rivers.

In cities, water reaches rivers more quickly, because of the many highly impermeable surfaces such as pavements and roads, which force the water to travel down urban drainage systems, and onwards into the rivers.

What is Catchment Management?

To manage a catchment we need to look at the close relationship between river systems and their surrounding land areas. As water moves through a catchment (either over the surface or through the ground) it picks up soil particles, nutrients, and other contaminants, such as oil from roads, and moves them into the river system. The quality of the water in the rivers is therefore affected by the activities occurring in the surrounding catchment.

Human activities such as agriculture, transportation and construction all affect river systems and how they function. Understanding the interactions between the land and the water is crucial to the successful management of our essential water resources.

Why do we need to look at this scale?

What happens in one part of a catchment can have 'knock-on effects' in other parts of the same catchment – usually downstream. For example, fertilisers spread on the land in one area of a catchment can be washed off the land into the river system. As the water flows along in the rivers it may carry the fertilisers with it, affecting the water quality down stream of where the fertilisers entered the river system. There's more information about this in "Nutrient Enrichment of Freshwater"

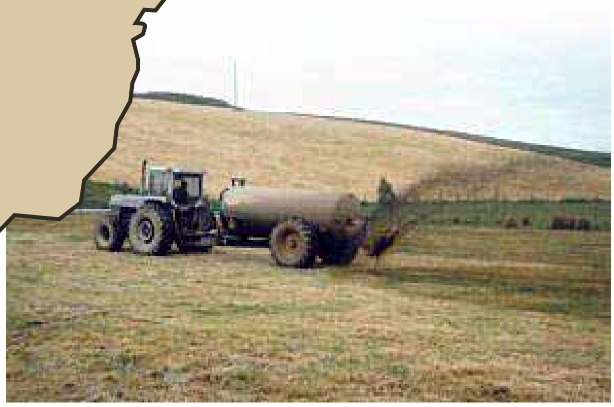
The same thing happens in urban areas where substances (e.g. oil, dust) can be washed off surfaces (e.g. roads, pavements, roofs) and enter rivers via the urban drainage system. Again these substances can be transported downstream by the water in the rivers. The quality of the water affects both what the water can be used for and the wildlife it can sustain.

Flooding can be a problem if we don't consider the impacts of building on flood plains or trying to straighten the course of rivers and streams. What solves a problem in one part of a catchment might actually create a problem in another.

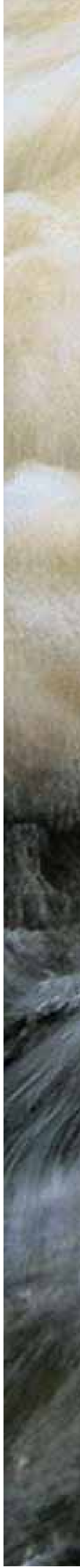
This is why it is important to consider the 'big picture' and adopt a catchment-wide approach to management rather than focusing only on local issues.

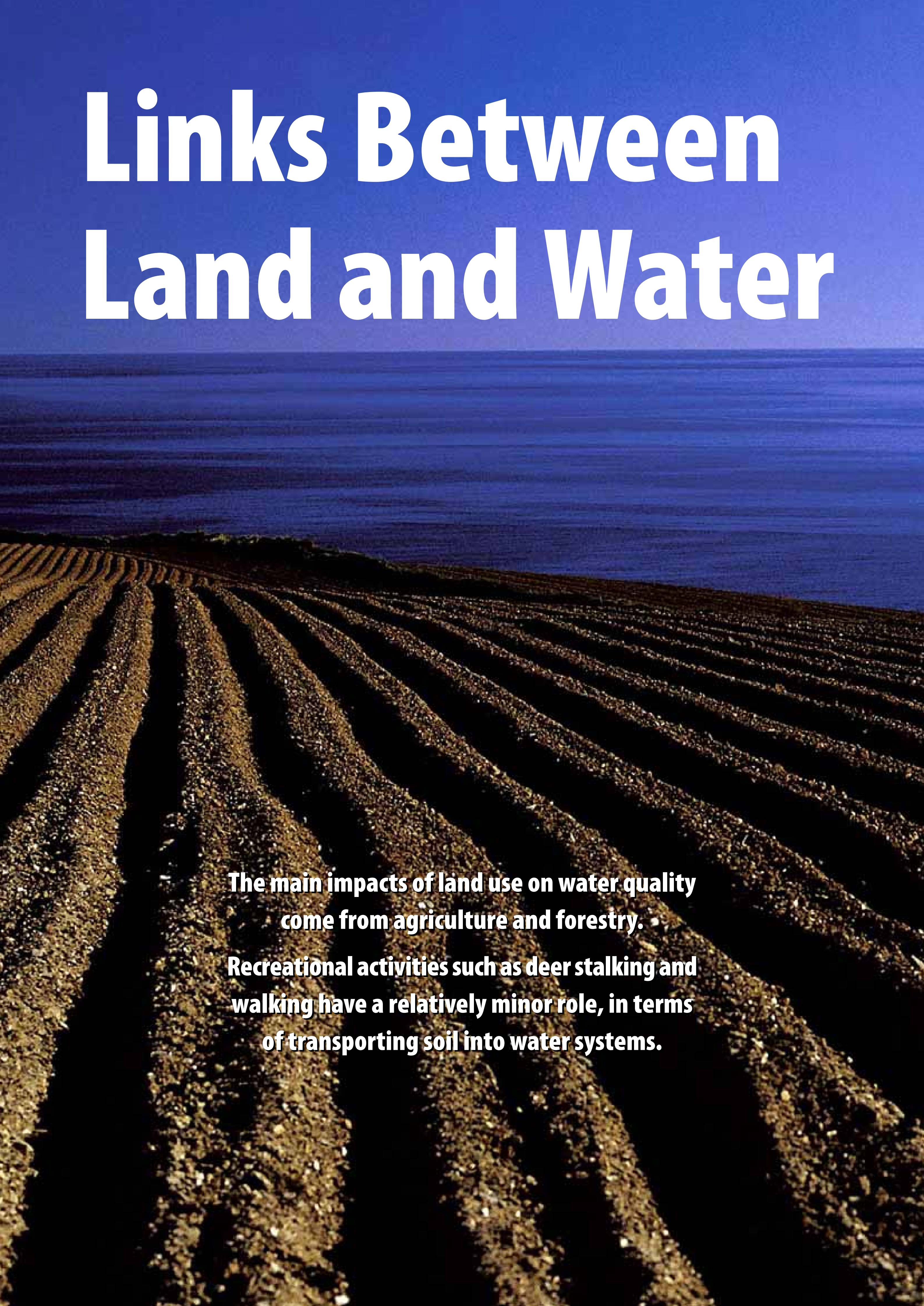
Did you know?

The Amazon Basin is the largest catchment in the world, at approximately 5.6 million square km, about ten times the size of Spain! It also has the largest number of tributaries and discharges the greatest volume of water to the sea - an average of about 200 million litres per second. That's the equivalent of emptying 400 swimming pools every second! The Amazon catchment includes parts of Peru, Bolivia, Venezuela, Columbia, Ecuador and Brazil.



Above: Fertilisers spread in one part of a catchment can be washed off the land into the river system





Links Between Land and Water

The main impacts of land use on water quality come from agriculture and forestry.

Recreational activities such as deer stalking and walking have a relatively minor role, in terms of transporting soil into water systems.

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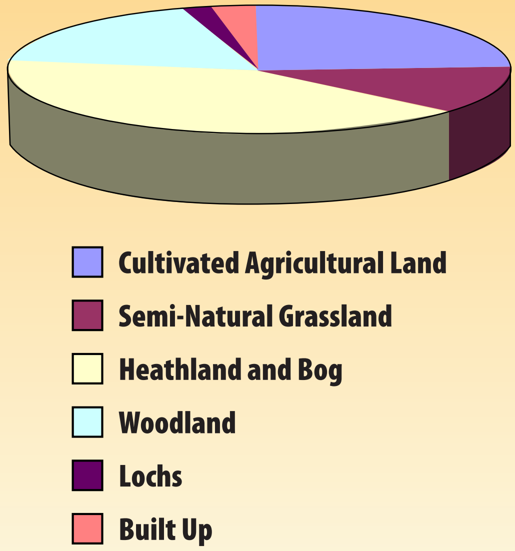
Agriculture

Agriculture can have a large effect on water quality both at the surface and in groundwaters.

How land is used in Scotland



Do arable crops cause more water contamination than other types of farming?

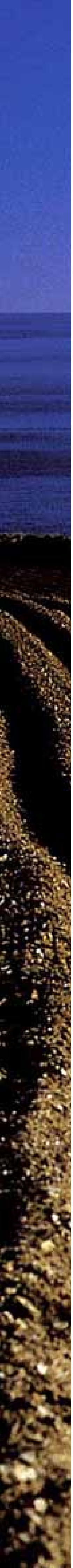
Arable crops require fields to be ploughed. This involves having periods of bare fields, when soil erosion is greater and more soil is transported into water systems. There are generally two main effects of transporting soil into water courses:

1) the physical effect of the soil particle itself
2) the biological effect caused by added pollutants that are attached to the soil, such as phosphorus.

Left: Bare fields are more vulnerable to soil erosion

What is nitrification?

Nitrates are added to arable crops on a regular basis in the form of fertilisers. These can have harmful effects on water if too much fertilizer is added to the land. This is because the nitrates are dissolved in the water and easily transported away from the field. Nitrification occurs when nitrates enter a water course and use up the oxygen needed by plants in the water, causing algae to build up. (See "Nutrient Enrichment of Freshwater").



What are Nitrate Vulnerable Zones?

In response to concerns about nitrate levels in water, Nitrate Vulnerable Zones have been established across Scotland. These identify areas of land where farmers must adopt certain practices, to ensure that nitrate levels in water stay below a certain legal level. For example, farmers spreading farm waste, such as slurry, in these areas must, by law, keep a precise record of their activities.

What about pesticides?

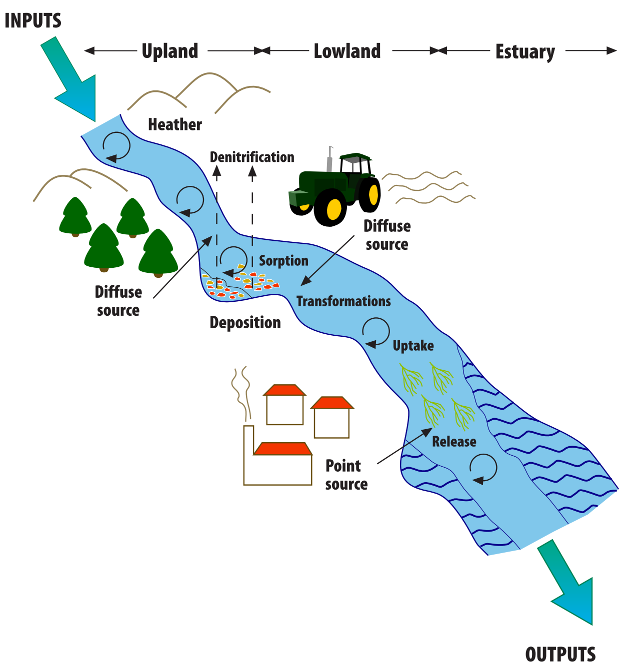
Pesticides, fungicides and herbicides are commonly added to crops to kill bugs, control weeds and prevent disease such as mildew. If they are carried by surface or groundwater to water courses however, they can pollute the water and damage the wildlife within it.

How do livestock affect water quality?

The presence of livestock can also affect the quality of water in an area. Bacteria from manure such as E. coli, can make their way into water courses, and are known to cause health problems in humans. Animal waste itself can also reach water courses if spread in the wrong place or at the wrong time of year. It is therefore important that farmers know when and where to spread the waste.

How do heavy metals contribute to water contamination?

Although some heavy metals are essential for life, others can be highly toxic to aquatic life.



Metals such as copper, found in pig slurry, can make their way into water courses. In extreme cases, high levels of lead in water have caused deformities in fish.

There are many other sources of heavy metal contamination besides agriculture however, such as distilleries, industrial areas and even the ingredients of some pharmaceutical products.

How can we minimise water contamination from agriculture?

Best management practices are methods which attempt to reduce the movement of pollutants - such as sediments, nutrients and pesticides – from the land into surface or groundwater. They aim to strike a balance between protecting the environment and maximising economic productivity. In farming these methods include:

- Developing buffer strips and riverbank woodland: this practice involves leaving a strip of land next to a water course uncultivated. This is achieved by either leaving it as rough pasture or planting trees. Think of them as giant filtering systems, which trap the sediments and nutrients that are carried in the water running off fields. They also help to diversify the river channel by creating additional habitats for wildlife.
- Encouraging minimal cultivation: arable crop fields are not re-ploughed, but instead have the next crop drilled into them. While this does reduce soil erosion and therefore soil contamination to water courses, the downside is that it tends to lower the quality of soil structure.
- Using contour ploughing: ploughing up and down slopes creates channels which can increase the rate of soil erosion. Contour ploughing encourages farmers to plough following the contours of the land instead.
- Constructing fencing by water courses: fencing which restricts livestock access to water courses is another way of minimising water contamination.

Forestry

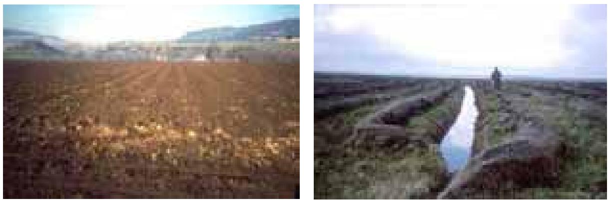
Planted forests can affect the surrounding water courses in different ways during the life of the plantation. Forestry activities that may impact on the soil are both fewer and less frequent than with agriculture. Soils are generally disturbed only when a site is being established, treated or felled, and these events could be separated by intervals from 40 to 80 years.

How do forests affect the quality of surrounding water courses?

Locating a forestry site

Trees consume water as they grow, which means that large forestry plantations may reduce the amount of water available to the rest of the catchment. Once the trees are felled, more water is likely to return to the streams and rivers. These changes to water levels might cause problems if housing developments are not properly designed to cope with the full range of conditions.

Establishing a site



Sites were often ploughed before being planted

Ploughing sites to prepare them for tree-planting increases the risk of soil erosion and contaminates nearby water courses. Fortunately, ploughing for forestry is less common than in the past. Badly designed and constructed forest tracks pose another threat to water courses, and can increase the amount of sediment transported to the water. This contamination from sediments damages the flora and fauna of an aquatic system, reducing the light levels entering the water. It also disrupts water treatment works and supplies.

Treating a site: Fertilisers and Pesticides

Some forests are treated with fertilisers and pesticides to help the trees grow. These chemicals can pollute water supplies and damage ecosystems in the same way as those from agriculture.

Felling a site

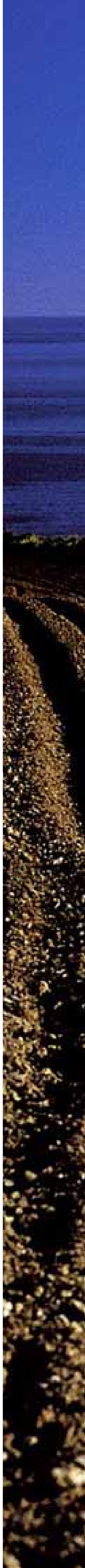
Felling a site close to water increases the risk of sediment being transported to water systems

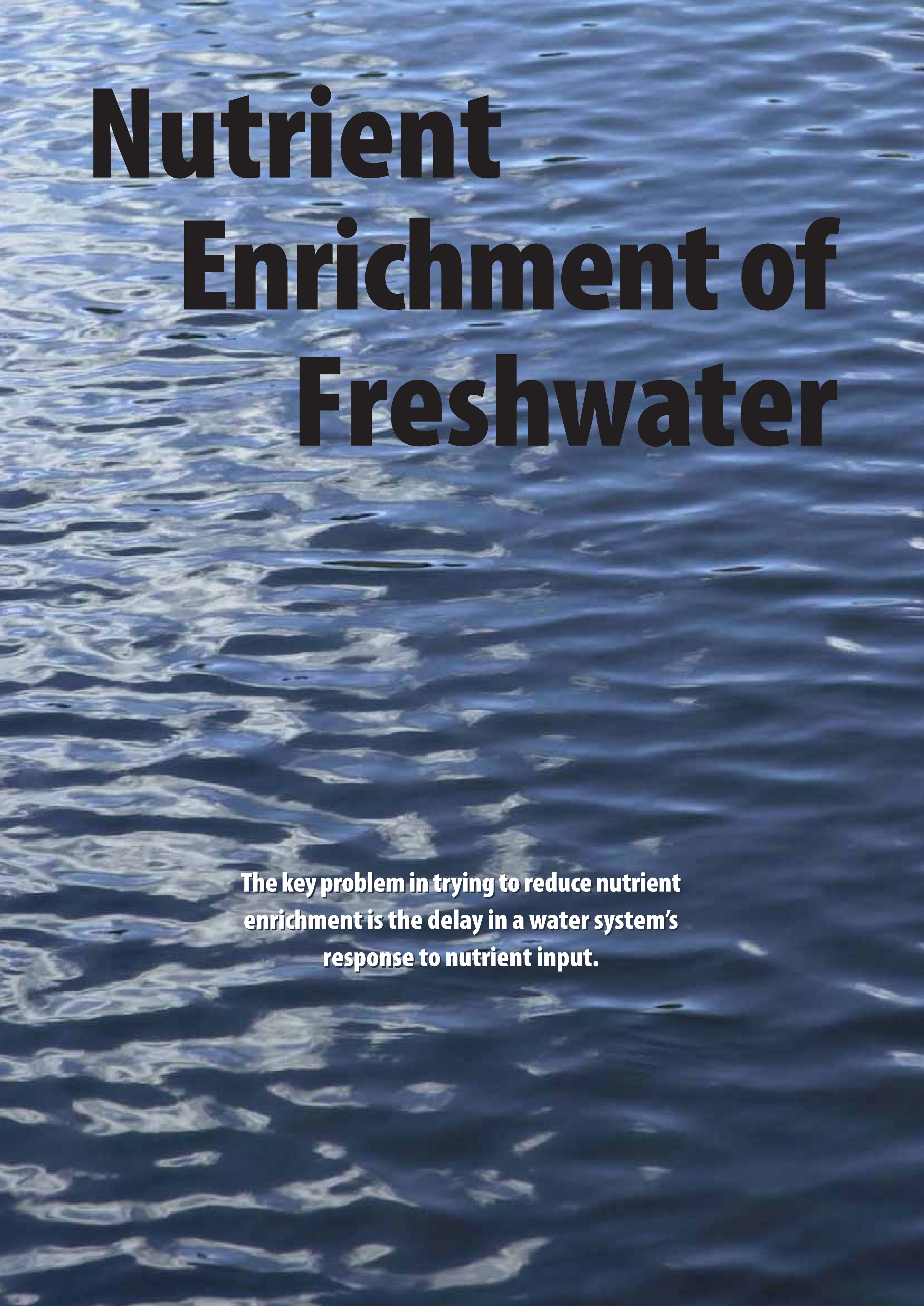
Felling a site close to water increases the risk of sediment being transported to water systems. Felling may also cause nitrates to leak from the soil, because they are no longer taken up by trees.

How can we minimise water contamination from forestry?

In forestry, best management practices aim to achieve a balance between protecting water quality and maximising the production of wood crops. These include:

- Matching species to sites: Selecting tree species to suit the natural conditions of a site reduces the need for fertiliser.
- Constructing buffer strips and riverbank woodland: as with agricultural land use, buffer strips are important in forested areas, protecting water courses from sediments, contaminants and erosion, and also reducing the potential for acidification (See Acidification and Recovery).
- Using non-invasive methods for planting: modern techniques are becoming increasingly less intrusive, and involve roughing up the surface of the soil instead of ploughing. This disturbs the soil less and therefore reduces water contamination.
- Maintaining forest tracks: tracks are maintained on a regular basis to minimise sediment transport.





Nutrient Enrichment of Freshwater

The key problem in trying to reduce nutrient enrichment is the delay in a water system's response to nutrient input.

What's wrong with nutrient enrichment?

When a water system receives too many nutrients, algae begin to grow in the water, a process called eutrophication. As they develop, the algae turn the colour of the water from clear blue to "pea-soup" green. Although this is a natural process, human activities, such as agriculture and industry, can speed it up. These conditions make the water unsafe for recreation and endanger the health and diversity of organisms living in the water.

Where do the nutrients come from?

Sources

The nutrients which cause eutrophication may come from point sources, such as sewage treatment works or industrial effluents, or from diffuse sources, such as fertilisers washed from agricultural land. Unfortunately fertilisers that are added to crops to make them grow also help the algae to grow if they reach lochs and rivers.

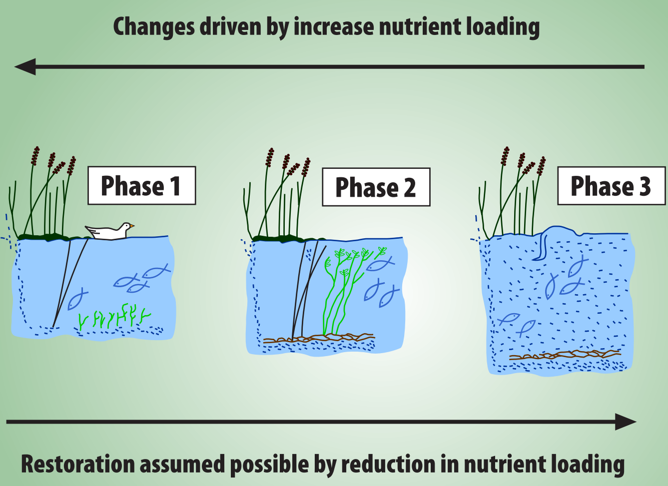
Transport

While nutrients from point sources are directly transferred into water courses through pipes, nutrients from diffuse sources rely on groundwater and surface waters to be carried through and over the soil. Diffuse sources can be broadly divided into:

• Nitrates, which are soluble and carried along dissolved in the water, and

• Phosphorus, which is less soluble and attaches to moving sediments.

Left: Too much algae clouds the water and blocks sunlight



What are the consequences of nutrient enrichment?

The consequences are different for lochs and rivers:

Lochs

Nutrient enrichment of loch water, which sits around for a long time before being flushed out into rivers, promotes the growth of algae. By clouding the water and blocking sunlight, algae cause underwater plants to die, removing an important habitat and feeding ground for wildlife. In addition, when they die, algae use up oxygen required by organisms in the water, such as insects and fish. Excess phosphorus in lochs can promote the growth of toxic cyanobacteria. These blue-green coloured "algae" can be fatal to livestock and humans drinking the contaminated water.

Rivers

Most river water is constantly moving, so the problem of algae from nutrient enrichment is smaller than in lochs. High flow events may even prevent the growth of algae altogether in upland rivers. During very dry periods, the situation in lowland rivers may be more similar to that of lochs.

It is also important to consider the bigger scale, looking at the impact of nutrient enrichment on the catchment as a whole. Although it may not greatly affect rivers, nutrient enrichment can affect ecosystems further downstream, such as connected lochs, estuaries and coastal areas.

How can we reduce nutrient enrichment?

The key problem in trying to reduce nutrient enrichment is the delay in a water system's response to nutrient input. Nutrients are held in underwater sediments and groundwater for years at a time, which makes monitoring any changes in water quality very difficult. Any attempt to reduce the effects however, first involves looking at the source of the problem.

Controlling Point Sources

The impact of sewage treatment works depends on the size of population. Amongst the pollutants that may be discharged is phosphorous, which is used in many cleaning materials like washing powders and dish-washing products. One way to reduce nutrient enrichment is to remove the phosphorus from the effluent before it leaves the treatment works. This has been reasonably successful for deep lochs and is now applied to most treatment works that discharge into rivers. In shallow lochs however, there are more interactions between sediments and the overlying water. Since phosphorus can be held in sediments in lochs for many years, removing the source of the phosphorus may only be a starting point to solving the problem.

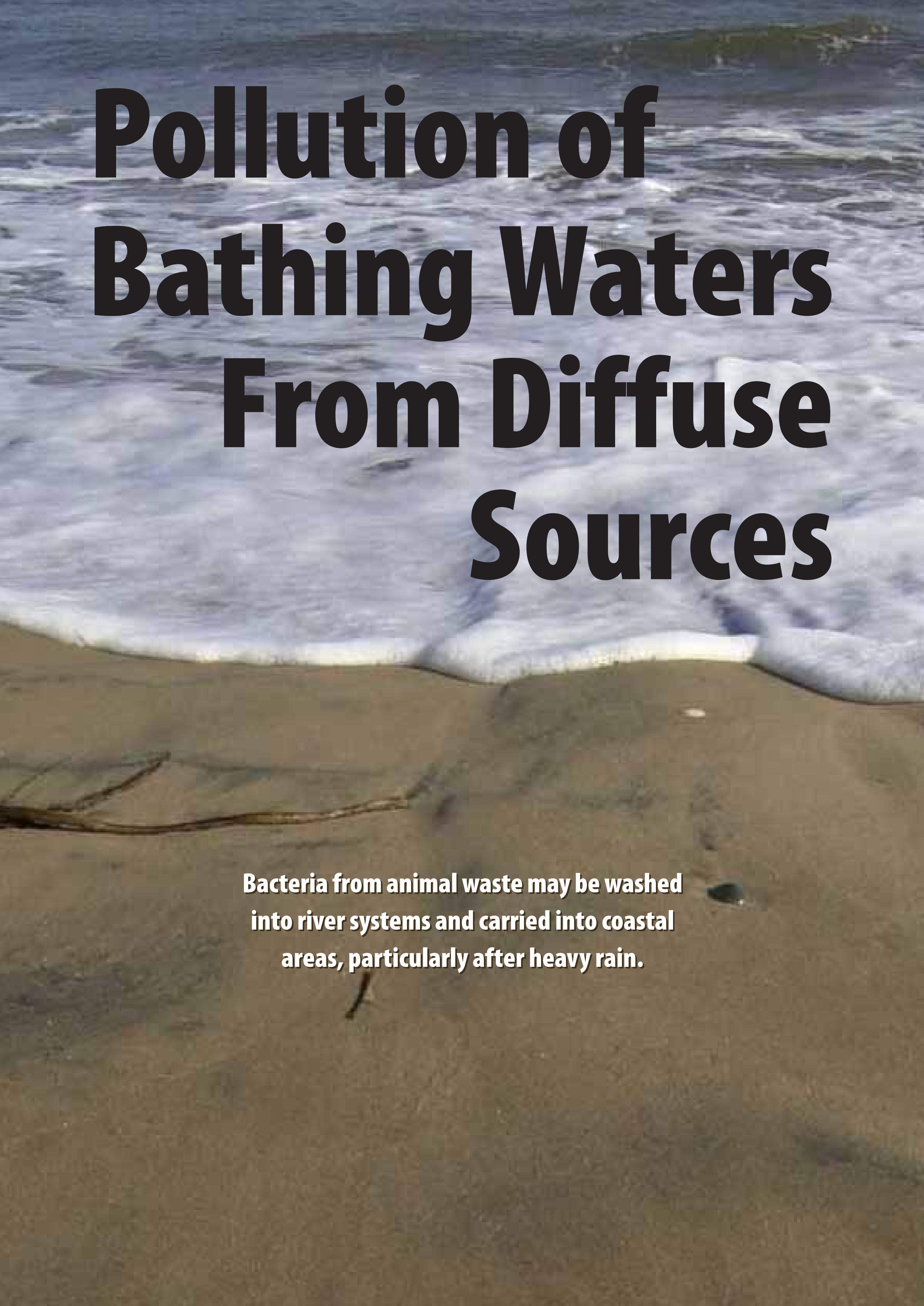
Controlling Diffuse Sources

Best management practices help to decrease the levels of nutrients working their way through soils into water courses from diffuse sources. One of these is to ensure that farmers spread animal waste during the drier periods of the year, to minimise the risk of nutrients being rapidly washed through the soil by heavy rainfall or flooding. Another is to develop buffer strips along the river bank to act as a barrier between the agricultural land and the water course (see chapter on Links Between Land and Water).

Removing the drainage pipes from beneath fields is another option, in areas of high conservation interests. The land may then no longer be suitable for crop production, but can be used for pasture. This might have an impact on a farmer's income, but be of benefit to the environment and society as a whole.

Harnessing the power of nature

Removing fish from water systems can actually help to restore water quality. By removing fish their food – zooplankton – can develop. The zooplankton feed on the algae, thereby controlling the algae levels of the system. This process is called Biomanipulation and leads to a restoration of clear water. Plants may then grow again by themselves, or be planted, to help maintain a stable system. Eventually fish can be reintroduced to the water. The aim of this restoration process is to re-establish a self-sustaining ecosystem – one that can survive without constant human management.



Pollution of Bathing Waters From Diffuse Sources

Bacteria from animal waste may be washed into river systems and carried into coastal areas, particularly after heavy rain.

How are bathing waters polluted?

Scientists from the Scottish Environmental Protection Agency (SEPA) and Scottish Water first raised concerns about polluted bathing waters in the 1990s. They realised that bacteria from animal waste may be washed into river systems and carried into coastal areas, particularly after heavy rain. This kind of pollution is called diffuse pollution as it comes from a range of different sources in the surrounding environment. It is harder to control than pollution from point sources, such as sewage treatment works, because it involves managing the land to control the source of contamination.

How can we minimise contamination of bathing waters from agricultural sources?

It is possible to reduce contamination of bathing waters from animal waste by following certain procedures, known as best management practices. Some of these are outlined in the chapters on Nutrient Enrichment and Links Between Land and Water. The Scottish Executive also provides farmers with guidance on how best to manage farm wastes. One of these is the "4 Point Plan".

Below left: The proximity of agricultural areas to coastlines can pose problems for bathing water quality
Below right: Managing water margins can minimise spread of fertilisers into water courses

The 4-Point Plan

This guidance encourages farmers to:

- Minimise dirty water around steadings: this dirty water can contain nutrients and bacteria from livestock manure, giving it high polluting potential. Re-routing access tracks for cows to avoid routes that can carry slurry to watercourses is one example.
- Use nutrients more efficiently: nutrients, such as fertilisers, lost to the surrounding environment are both a financial loss and a threat to the environment.
- Carry out risk assessments for manure and slurry: these help farmers plan where and when to spread waste, and reduces the risk of contamination.
- Manage water margins: restricting livestock access to water courses and minimising the spread of fertilisers near water reduces contamination, protects nearby wildlife habitats and may also benefit livestock.

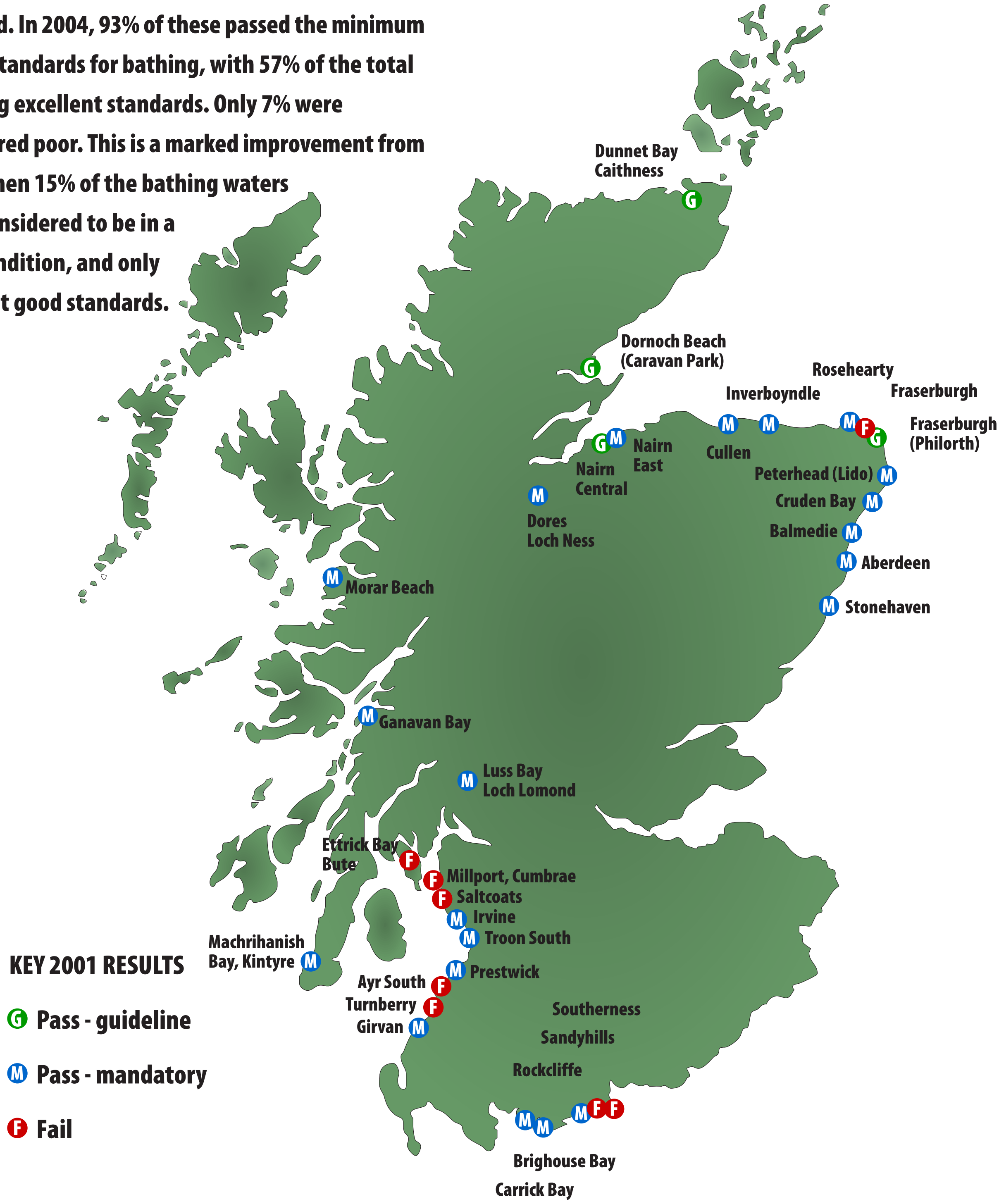
How do you know if it's safe to swim?

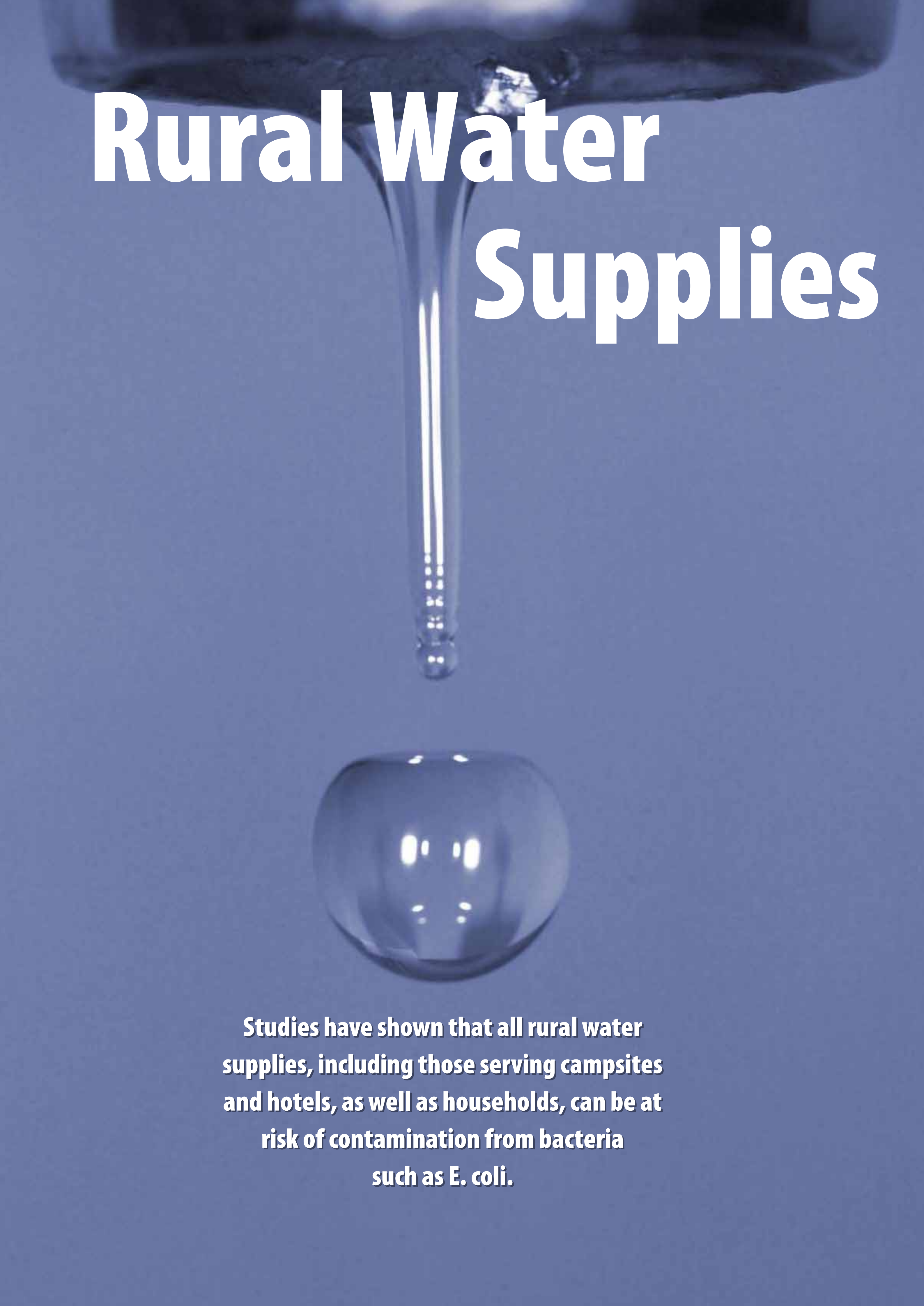
A particularly successful strategy for keeping up to date with bathing water quality involves the beach signs that were set up by the Scottish Executive on five beaches in south-west Scotland in 2003. A team of scientists use continuously monitored data on rainfall and river flow conditions to predict the likely contamination to the beach area. The beach signs can be updated as conditions change, displaying their predictions on current water quality.

Beach signs in south-west Scotland show whether the water is safe for bathing

Did you know?

There are 60 beaches designated for bathing in Scotland. In 2004, 93% of these passed the minimum safety standards for bathing, with 57% of the total reaching excellent standards. Only 7% were considered poor. This is a marked improvement from 2001 when 15% of the bathing waters were considered to be in a poor condition, and only 40% met good standards.



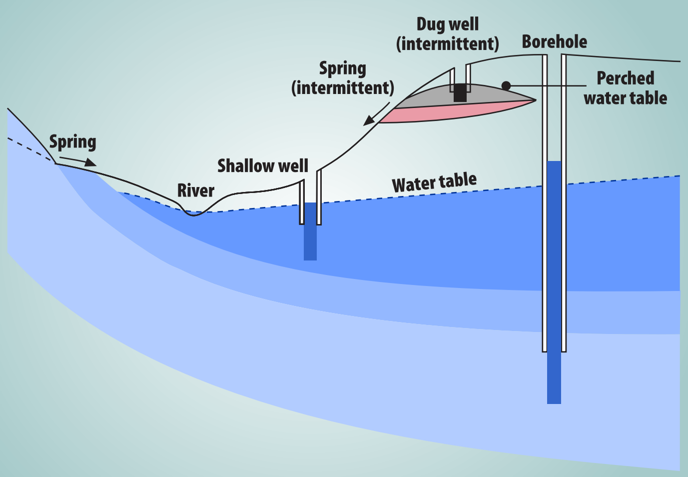


Rural Water Supplies

Studies have shown that all rural water supplies, including those serving campsites and hotels, as well as households, can be at risk of contamination from bacteria such as E. coli.

What do rural water supplies look like?

Rural water supplies can be wells, springs or boreholes. At the surface they can all look quite similar. Modern collection chambers are typically made up of a series of concrete rings set on top of one another. They often look like ordinary water wells, and are set within the water table, to depths of two-eight metres. While wells tap the underlying shallow groundwater (up to depths of eight metres), springs are points in the surface where water naturally flows out of the ground. Water normally has to be pumped from boreholes, which go much deeper into the ground and underlying groundwater.



How are rural water supplies contaminated?

Studies have shown that all rural water supplies, including those serving campsites and hotels, as well as households, can be at risk of contamination from bacteria such as E. coli. The key problems are:

- Adjacent land uses that introduce bacteria to the soil, such as grazing by animals
- Inadequate fencing to exclude stock and wild animals such as deer
- Poor construction and maintenance

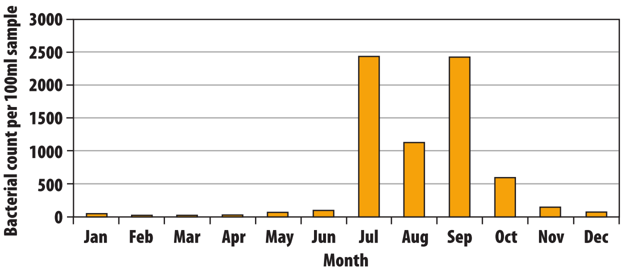
Above right:A typical rural water supply
Left: Sources of drinking water

- Lack of sealing between two concrete rings, allowing contaminated water to seep through
- Water supplies being set too low in the ground, so that surface water can enter the collection chambers
- Insufficient protection to prevent water running down the edge of the concrete ring and seeping into the supply lower down
- Cracks or holes in the concrete and in the lids which provide prime routes for contamination by bacteria

Left: Holes in rural water supplies provide easy routes for bacterial contamination

Can regular monitoring help?

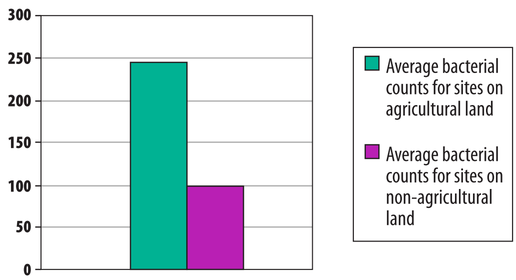
Not always! One of the key problems with the contamination of rural water supplies is that regular monitoring of a supply makes little difference to our knowledge of the water quality, because contamination can occur over short periods of time. Sites may become contaminated after periods of heavy rainfall for example, when there is more water rushing through the soil, carrying bacteria with it. As the graph shows, a water supply may be clean one month and contaminated the next. The only obvious pattern is that contamination is greater during wetter, and possibly warmer, periods, as reflected in the greater contamination rates for the wet summer of 2002.



Graph showing bacterial contamination levels through the year

Which water supplies are most at risk?

The graph clearly shows that sites on agricultural land have greater contamination levels than those on non-agricultural land. This may be simply because agricultural land is more biologically productive. Sites near septic tanks or those used for grazing by wild animals such as deer however, can also be at risk.



Graph showing bacterial contamination levels for agricultural and non-agricultural sites

How does risk assessment help?

It is clear that simply measuring the quality of water supplies, even on a regular basis, is insufficient to ensure clean, safe drinking water at all times. Risk assessment allows us to understand both the likelihood and consequences of a private water supply being contaminated. It is possible to minimise the chances of contamination by following certain procedures, known as best management practices.

Did You Know?

Most of the Scottish population has ready access to clean and reliable sources of water. However, it is estimated that 60 000 people obtain water from a private source rather than an official water supplier. There are about 30,000 of these private water supplies in rural Scotland, the majority of which cater for only one household.

Best Management Practices

Guidelines have been established for both the general site area and the water supplies themselves. Site requirements include ensuring that septic tanks and sites of sewage spreading, for example, are not located within 50 metres of a water supply. Guidelines for the supplies themselves, whether they are wells, springs or boreholes, include the following:

- Set the concrete chamber in the ground so that the top is high enough to prevent the direct flow of surface water into the chamber
- Construct a cement apron sloping away from the water supply
- Dig and line cut-off ditches, to divert nearby surface or ground water
- Fence off the supply to protect it from animals
- Chlorinate the supply regularly (e.g. once a year)
- Install a UV filter near to the point of use to kill bacteria

Water supplies ser too low in the ground allow contaminated surface water to enter the collection chamber

Acidification & Recovery of Freshwater Systems

Acid Rain Toll on British Trees
The Guardian, July 8, 1989

Minister admits acid rain guilt: UK power station emissions 'have damaged Norway's lakes'
The Guardian, March 20, 1986

Salmon and trout rivers 'ruined by acid rain'
The Independent, March 5, 1990

Role of car exhausts in 'acid rain' controversy
The Times, October 2 1986

There were prominent headlines of the 1980s and 1990s in Europe and North America, when air pollutants from highly industrialised regions caused widespread damage to freshwater ecosystems far downwind. In Europe about 30 countries took part in tough negotiations that finally brought about international treaties to reduce emissions of sulphur and nitrogen oxides. Sulphur deposition declined by more than 50% from 1980 to 2000, and some lakes and streams have begun to recover as a result. But recovery is slow and the process may be increasingly influenced by climate change.

What is acidification?

Acidification is a process in which pollution from factories and car exhausts is converted into acidic chemical compounds in the atmosphere, the best known being acid rain. Acidification of soils and water is caused by acid rain. Sulphur makes the largest contribution, but nitrogen compounds are also important.

Where did the problem come from?

The problem began in the 1850s with the onset of the Industrial Revolution and the accompanying surge in burning fossil fuels. This caused a steady rise in the emission of acidic pollutants to the atmosphere. Legislations such as the Clean Air Act were introduced through the 1950s and 1960s to reduce emissions, but regulations really took off in the late 1970s, when Scandinavia targeted the UK as being responsible for the acidification of their soils and lakes.

What are the consequences?

During the 1970s and 1980s, acidification was a serious threat to aquatic life as well as the health of soils and fisheries. This decline in environmental quality had significant implications for countries whose economies depended on forests and fisheries.

When sulphur and nitrogen are deposited on soil, the water draining from these soils into water systems contributes to the acidification of the water. The presence of forests and the nature of the surrounding soils and geology also affect the acidification levels in a particular area.

Lakes and rivers

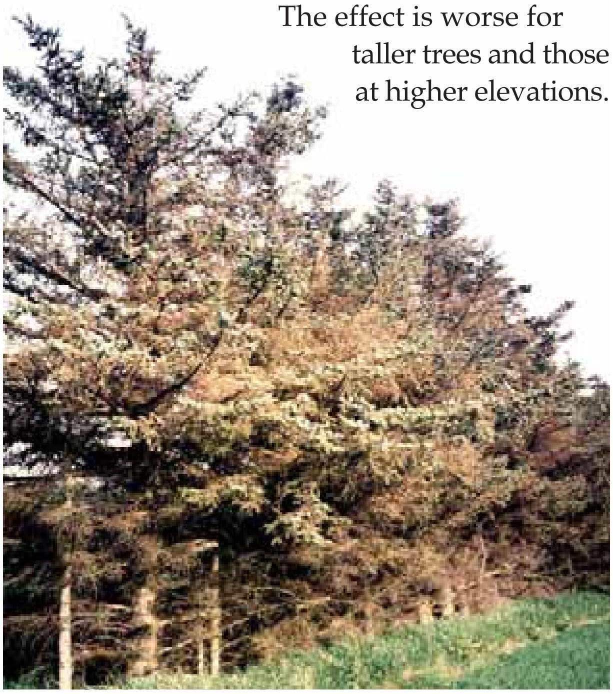
Lakes polluted by acid rain can support only the hardiest species. Acidification damages entire freshwater ecosystems by killing fish and upsetting the food web within the system. When fish die this removes the main food for birds. Birds can also die from eating toxic fish and insects, and fish can die from eating toxic animals too. Acid rain can even kill fish before they are born.

Acidification damages entire freshwater ecosystems by killing fish and upsetting the food chain

Acid rain shows its effects on lakes mostly in the springtime, when fish lay their eggs. If the eggs come into contact with the acid, an entire generation can be killed. Fish usually die only when the acidification levels in a lake are high. Under lower levels, they can still become sick, suffer stunted growth, or lose their ability to reproduce.

Forests

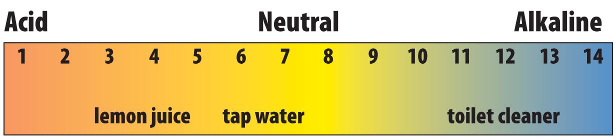
Forests promote the acidification of soils and subsequently surface water in areas of high acidic deposition by a process known as scavenging, in which oxides of sulphur and nitrogen in clouds and mist are captured by forest canopies. In this way, forests actually increase the deposition of acidifying particles and gases from the atmosphere. The effect is worse for taller trees and those at higher elevations.



Soils and Geology

Not all lakes that are exposed to acid rain become acidified. Some are naturally able to cope with the acidification by neutralising the acidity. This is mainly due to the types of rock in the catchment. For example limestone areas are can neutralize the acid, whereas granite or sandstone areas cannot. Unfortunately, a significant area of the Scottish uplands - where most acid rain falls - has a lot of granite rock and lochs and rivers are therefore very vulnerable to acidification.

In heavily acidified areas, such as Galloway, in south western Scotland, acid runoff comes from soils which cannot neutralise acid rain. Generally speaking, soils which are deep, well-developed and rich in minerals are better at neutralising than organic rich, peaty soils. Areas receiving acid rain which have organic soils are therefore more vulnerable to acidification.



A Tale of Acid Attacks, Death and Survival in Scottish Waters

Galloway is the area most affected by acidification in Scotland. There are a number of reasons for this:

- The area experiences high rainfall.
- The location in the south west corner of Scotland ensures it is a prime target for air pollutants being blown across from Northern Ireland.
- The geology of the area is mainly granite.
- Soils in the area are either thin and poorly developed or organic rich.

Recovery in Galloway

Annual sampling of sixty lochs in Galloway began in 1979 so it has been possible to keep a close record of their acidity. With the reduction in acid rain, the acidification levels of the lochs have decreased slowly, and over the last 20 years, the fish catches have increased as a result. Sampling also shows that the soils are recovering and the forests are more productive.

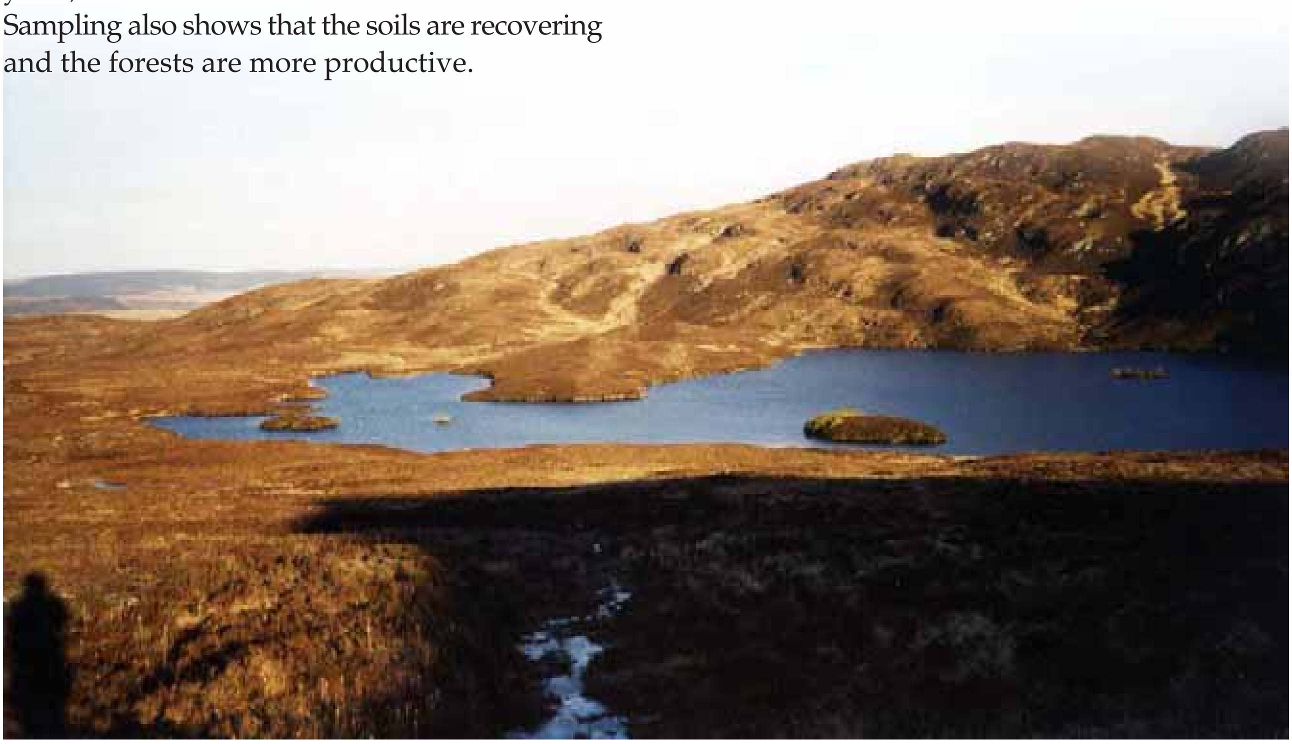
Time is of the essence…

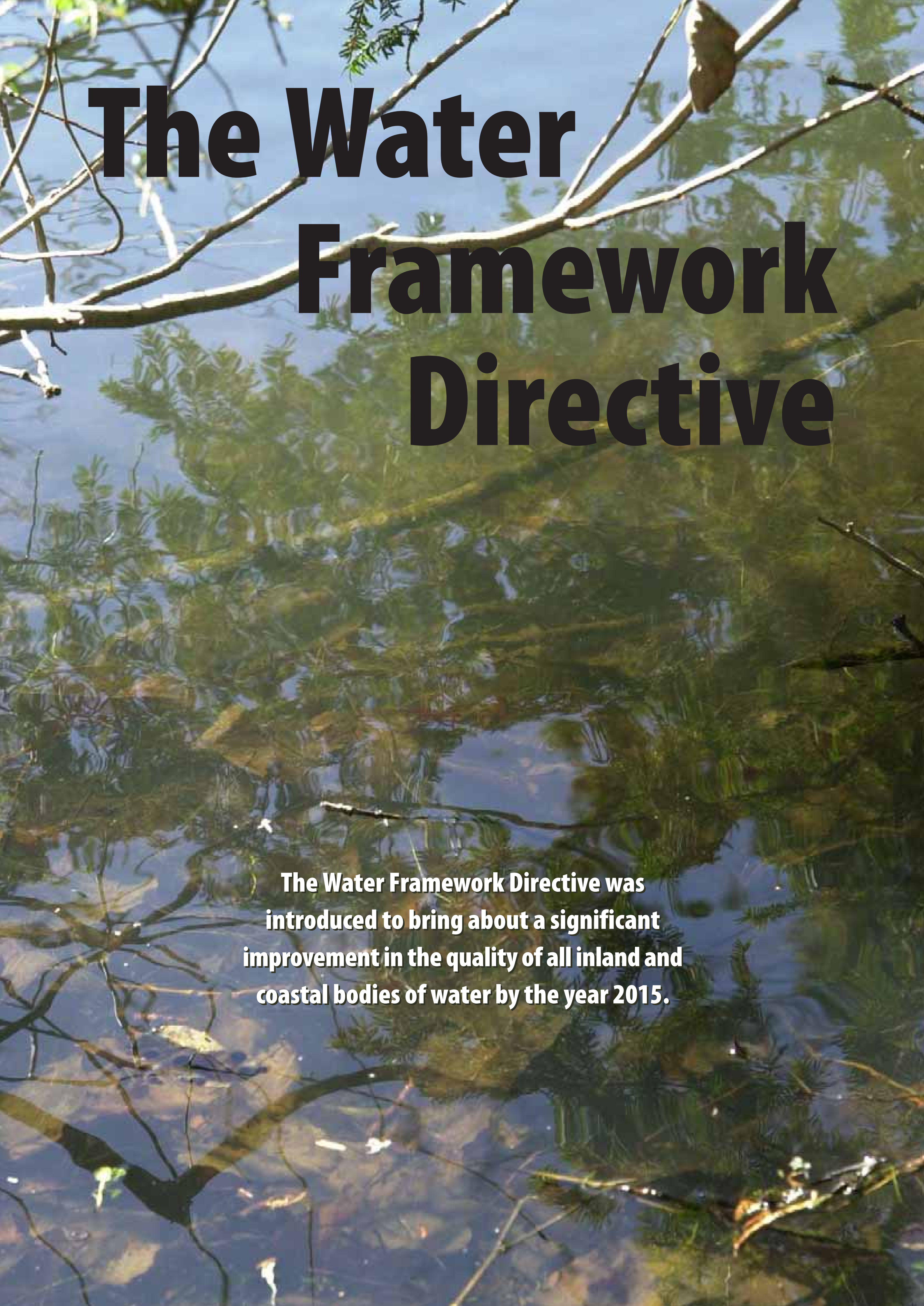
The problem with all these efforts is that the rate of recovery can be much slower than the original rate of decline. Often, it takes a long time to notice the effects of recovery, such as increased fish stocks after reduced pollution levels. Removing the source of pollution does not immediately improve the situation – it takes many years for smaller organisms to re-populate the loch, and re-establish the food chain.

Where are we today?

Recovery from surface water acidification is one of the big environmental success stories of the 20th century. The majority of surface waters throughout Europe and North America have shown significant recovery from the effects of acidification through tight controls on emissions from factories and cars. The biodiversity of our streams, rivers and lakes is slowly returning and our forests are showing signs of improving health and productivity.

The concern for the future lies with Asia and China where dramatic economic development and population growth is resulting in uncontrolled emissions of sulphur and nitrogen. If emissions continue at the current rate, the soils and waters of Asia and China will acidify, with serious environmental and social consequences. We need to hope that lessons can be learnt from the European and North American experience!



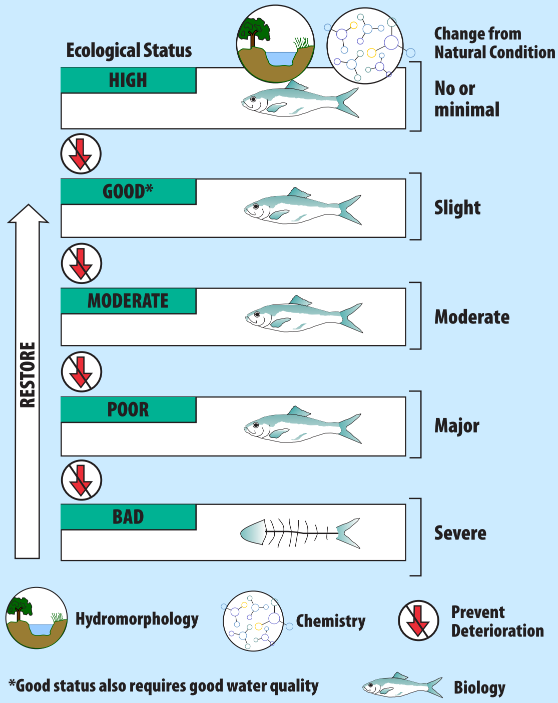


The Water Framework Directive

The Water Framework Directive was introduced to bring about a significant improvement in the quality of all inland and coastal bodies of water by the year 2015.

What is the Water Framework Directive?

Recently policy makers across Europe have joined forces to develop a plan for managing water in all countries, in response to potential long-term threats. This plan, known as the Water Framework Directive and was established by the European Union in 2000. The directive became law in Scotland in 2003 when The Water Environment and Water Services (Scotland) Act was passed.



What will the Water Framework Directive achieve?

The Water Framework Directive was introduced to bring about a significant improvement in the quality of all inland and coastal bodies of water by the year 2015. Some key elements of the Directive are:

- To use ecological targets, not chemical ones: in the past, scientists monitored water quality by studying its chemistry. Today, they are just as concerned with the ecology and flow patterns of the water as with the chemistry.

Left: The process of restoration: The Water Framework Directive will use the conditions of plants and animals as an indicator of water quality.

- To focus on diffuse pollution: this is a key priority for all waters. Tackling diffuse pollution will involve managing the land itself and not just the source of the pollution, and can only really be overcome through an increased understanding from all those involved.
- To engage all interested parties in a discussion on the future management of one of our most important natural resources.