National Operational Guidance

Ecology and environmental science

This section outlines some basic concepts of environmental science, pollution studies and ecology relevant to fire and rescue service (FRS) personnel; a basic understanding of these subjects and their interrelationships will provide them with some of the tools necessary to prioritise environmental protection activities.

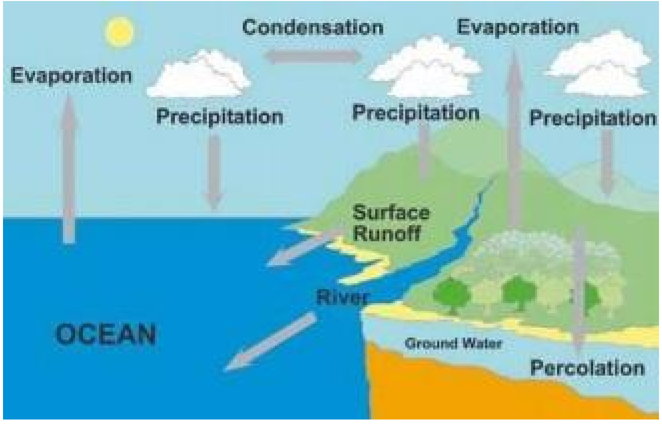
Environmental science

There are three relevant underlying natural laws of physics: the law of the conservation of matter; the first law of thermodynamics; the second law of thermodynamics.

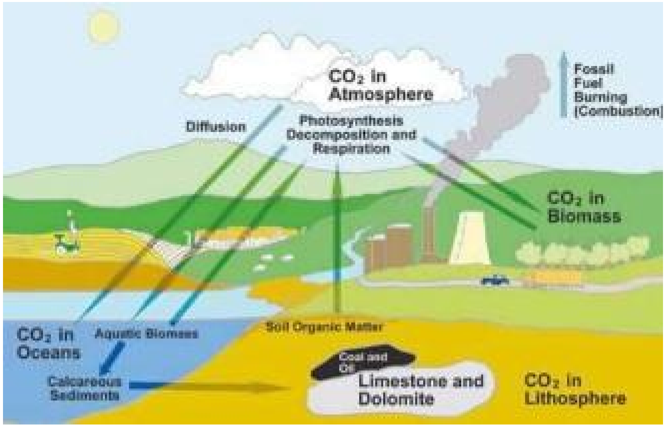
Where is 'away'?

The law of the conservation of matter states that no atoms are created or destroyed; there is no such thing or place as 'away' (Dr Anne Miller 2001). So, when waste is thrown, flushed, washed or otherwise taken 'away', it merely ends up at another location.

On a global scale, material continually cycles around the global system; this is known as biogeochemical cycling. The images below show how water and carbon move around the globe. If pollution of the water or air occurs in one part of the world, it can affect others. Examples include acid rain, ozone depletion and concentrations of chemicals such as Perfluorooctanesulfonic acid (PFOS) in the environment. Emissions of greenhouses gases such as Carbon dioxide (CO2) into the atmosphere is another example which is leading to impacts such as climate change and the acidification of the seas.



The water cycle



The carbon cycle

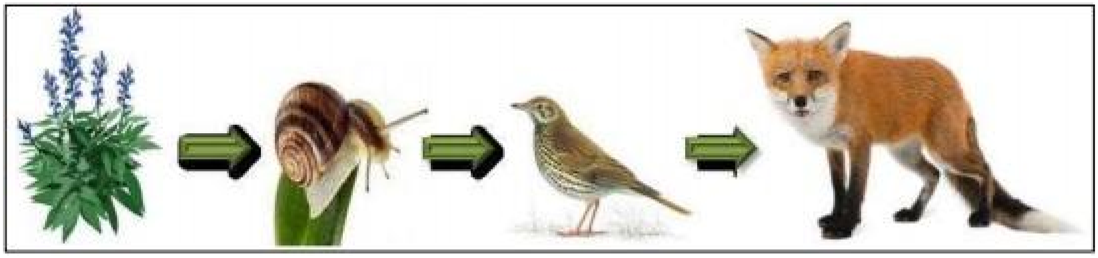
If waste or pollution is created it will always take a lot more energy to clear it up once it becomes dispersed than if it can be contained when it is still in one place; for instance, on the surface of a highway on in highway drains, rather than dispersed in a river or groundwater. In some cases, clean up may not even be possible or practicable once a pollutant has entered the environment. Containment as close to the source as possible is therefore the best approach and is the basic principle behind the hierarchy of pollution control, see, Environmental protection operational strategies and techniques.

Ecology

The relationship between plants, animals and the environment is called ecology.

A simple way to view ecology is as a series of interconnected food chains. Each food chain is a linked series of living things, each of which is the food for the next in line in the chain. Pollution may destroy one or more components causing species higher up the food chain to starve or species lower down the food chain to overpopulate. Ecosystems consist of species within trophic levels or stages in a food chain These trophic levels can be divided into:

- Producers
- Primary consumers
- Secondary consumers
- Tertiary consumers
- Detritivores



A simple food chain

Producers

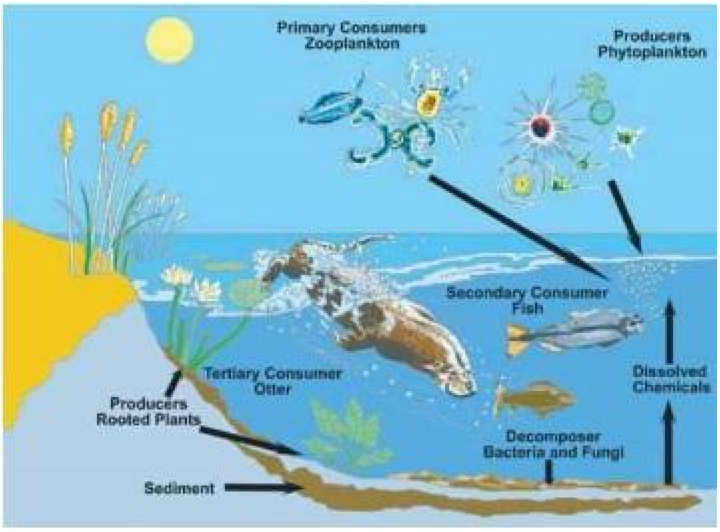
These are mainly plants with some bacteria and protists such as. Protozoa, which produce their own nutrients using sunlight. Should these organisms, which are sensitive to pollutants, be eliminated everything else would starve.

Consumers

Primary consumers or herbivores feed directly on living producers. Secondary consumers, or carnivores, feed on living primary consumers. Tertiary consumers, also carnivores, feed on living secondary consumers. Omnivores eat everything and so may be at any or all of these levels.

Detritivores, sometimes called decomposers, feed only on dead organisms and the waste products of living organisms, but eventually all the producers and consumers will end up in the detritivores area. They take in complex organic materials and break them down into simpler components, some of which they use, and others which they release into the environment. Eventually these simple components will become available to be taken up again by the producers, so completing the loop.

Most ecosystems are much more complicated than those described above since they contain some organisms that feed at different levels in different situations or at different stages of their lifecycle.



A simple aquatic food chain

Why it is important to protect the water environment

All living things need water to live. Rivers and lakes are fragile ecosystems that depend on water to be non-toxic, clear and containing adequate dissolved oxygen. Importantly for humans, we all depend on clean water for drinking water supplies. Clean water is also important for the watering of livestock the irrigation of crops and gardens, economic, industrial and recreational uses such as fishing and bathing. Pollution of surface and groundwaters can impact all these uses.

Pollutants are defined as anything that harms the environment. Water pollutants include not only chemicals, oils and pathogens but also organic materials, heat and suspended solids. Most of the major categories of pollutants are shown in the table below.

Pollutants released during fires, road traffic collisions and other emergency incidents can pollute air, land and water. fire and rescue services can take action to protect all of these in appropriate circumstances, but it’s usually the water environment that the FRS can protect most readily.

Incidents that threaten the water environment

The FRS deals with a variety of emergency incidents that may pollute the water environment. The safety of public and personnel will always remain the highest priority. But, protecting public and private drinking water supplies and the environment should still be prioritised.

In some circumstances it may be the actions of the FRS that cause the pollution or contribute to its severity, for example when foam is used as an extinguishing agent. In these circumstances, UK environmental law requires FRS to take mitigating actions see Environmental law for more information. Where the risk to the environment is high, incident commanders may decide on a course of action to reduce or eliminate environmental impact completely. Guidance on operational tactics designed to protect the water environment is available here.

FRS incident types with the potential to pollute the water environment

Incident type	Effect
Fires	Firewater run-off will be contaminated with products of combustion any firefighting agents used such as firefighting foam and any other pollutant that may be present which can dissolve in or washed be off site by the water used. If uncontrolled it may enter the drainage systems and then, surface or groundwater and or sewage treatment works. Smoke may also deposit pollutants contained within it when the plume grounds, from where it can be washed into the water environment when it rains. Or pollutants may be washed out of the plume itself by rainfall.
Road Traffic Collisions (RTCs)	Fuels, lubricants and fluids, such as cooling or brake fluids, may be released by the crash, along with any pollutants being transported

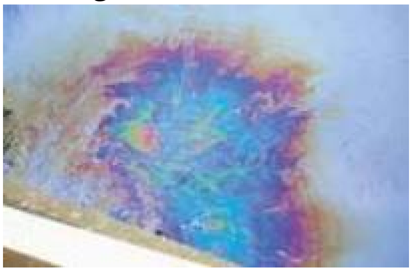
Incident type	Effect
Spillage or release	Incidents that involve the spillage or release of a material that harms the environment; these materials may include: • Hazardous materials • Eco-toxic – materials that are not classified as hazardous materials but are toxic to the environment such as inks, dyes or detergents • Organic materials – milk, beer or sewage • Inorganic materials – Silt, cement or sand

Spillages of oils and fuels are one of the most common sources of water pollution in the UK, causing approximately 10% of the total water pollution incidents. Just half a litre of oil can cover an area of water equal to a football pitch. In England in 2017 there were 230 confirmed pollution incidents following an RTC. The figures do not take account of incidents where FRS actions prevented pollution.

The FRS attends around 250,000 fires each year and in England and Wales alone there are around

4,000 hazardous materials incidents and 10,000 incidents classified as spills and leaks (source www.gov.uk), many of which present potential and actual pollution to attending FRS personnel. This risk requires a common approach to environmental protection if we are to meet the aims of the EC Treaty, Article 6, to promote sustainable development (EC 1992).

A firefighter contains all on a roadway using a clay drain mat following a vehicle fire.



Iridescence by the outfall indicates that a small quantity of the oil has entered a nearby stream at the outfall from the road

Pollutant Categories

There is a very wide range of potential water pollutants which can be group into range of categories. See table below.

Categories of water pollutants
Acids and alkalis
Anions for example sulphide, sulphite, cyanide
Detergents

Categories of water pollutants
Domestic and industrial sewage effluent and sludge
Farm effluents, slurries and manures
Food and beverages including processing wastes and animal feeds
Firefighting foams and additives, for example flurochemicals
Gases taken into solution in water such as chlorine, ammonia
Heat
Leachate or digestate, this may be from landfill or anaerobic digestion plants
Metals such as. cadmium, zinc or lead
Nutrients especially phosphates and nitrates
Oil, mineral and vegetable, and oil dispersants
Organic chemicals for example formaldehydes, phenols
Pathogens
Pesticides
Polychlorinated biphenyls (PCBs) and other persistent substances
Radionuclides
Solvents
Suspended solids such as silts and sands

Organic pollutants

Organic matter includes:

- Agricultural wastes such as slurry and silage
- Blood
- Food and drink
- Sewage
- Substances containing organic materials including many fire foams

Although many of these pollutants are not in themselves toxic, they can still have serious indirect consequences. This is because rivers, lakes and other waterways are organic matter processing systems. Adding large quantities of organic matter disrupts the balance of the system.

Microbes process any organic matter spilt into a waterbody and their populations grow exponentially due to the extra food source. As the microbes increase, they consume more dissolved oxygen, reducing oxygen levels in the water. If enough organic pollutant is available, all the dissolved oxygen will eventually be used, and anaerobic conditions will arise. In such conditions most species of aquatic animals will die.

If anaerobic conditions persist, for example due to a continuous discharge of sewage, specialised microbes, called ‘sewage fungus’, will thrive. This appears as a grey filamentous growth in the water. A smell of bad eggs will usually be noticed. Some aquatic organisms are particularly sensitive to any reduction in dissolved oxygen levels and will be affected even if anerobic conditions do not arise, for example, stonefly and mayfly larvae, trout and salmon and will be affected detrimentally by small changes.

Over time, the organic matter is used up and disperses. River water re-oxygenates moving downstream as oxygen dissolves in from the atmosphere and from aquatic plant growth. The temperature and flow rate will influence how quickly this happens. Employing aeration or other pollution mitigation tactics such as the addition of hydrogen peroxide will speed up this process as well as keep aquatic life alive until dissolved oxygen levels in the river recover.

Organic Pollution incidents, such as milk can have serious but usually temporary effects on the local ecosystem

Measuring organic pollution -Biochemical Oxygen Demand (BOD)

The ‘oxygen sag’ is an indirect measure of the amount of organic matter in a liquid. The biochemical oxygen demand (BOD) test is designed to quantify the amount of change imposed on the river by the entry of the particular organic substance. A measure of oxygen requirement will indicate the likely impact of an organic pollutant on the river.

This test provides a standard by which organic pollutants can be compared and it's used to monitor both river pollution and the effectiveness of treating organic materials before discharge into the water environment.

BOD values for different wastes and effluents

Typical BOD values	(mg oxygen/l)
Natural rivers	0.5–5.0
Crude sewage	200–800
Treated sewage	3–50
Poultry waste	24,000–67,000
Silage liquor	60,000
Dairy waste	300–2,000
Skimmed milkand cream	70000-40,0000
Brewery waste	500–1,300
Orange juice	80,000
Paper mill effluent	100–400
Typical firefighting foam concentrate	50,000-600000

Biological water quality testing methods

An assessment of the number and type of living organisms in surface water can also be used to monitor organic and other forms of pollution such as heat or chemical pollution. These assessments are referred to as biological indicators.

Different organisms have different tolerances to low oxygen levels or pollutants. Using the presence or absence of particular organisms, visible with naked eye, pollution levels can be assessed by specialists. An ecologist moves across a river pushing a net over the riverbed. They can then identify and count the organisms caught in the net. The more sensitive the organisms present, the better the quality of water in the river.


Environment Agency officer sampling a river

Inorganic and organic toxic chemical pollutants include substances like metals and acids, and mamufactured organics such as:

- Pesticides
- Polychlorinated biphenyls (pcbs)
- Polycyclic aromatic hydrocarbons (pahs)
- Fluorochemicals
- Phenols

Many of these are highly toxic and can cause damage or complete destruction of aquatic ecosystems. They can also have serious impact on people too either through direct exposure to them in the environment or indirectly for example by eating contaminated food.

The specific toxic nature and impact of these chemicals varies and is influenced by a variety of properties exhibited by the chemical, for example its persistence in the environment as well as environmental conditions. The table below describes these properties in more detail.

Definition of key terms

Environmental term	Description of meaning
Persistence	Persistence of chemicals indicates that they are stable and long-lived in the environment, resisting degradation, for example lead, cadmium, mercury, PCBs, many fluorochemicals and other man- made organics
Xenobiotic	May harm biological organisms they include many manufactured substances, especially pesticides, lead, cadmium and mercury
Biodegradation	Breakdown of a complex chemical into (simpler) components by actions of biological organisms. It's not always broken down into more benign components, for example the pesticide Dieldrin biodegrades into photodieldrin, which is considerably more toxic

Environmental term	Description of meaning
Bioconcentration (Biodegrading)	Extraction of chemicals from the environment, and concentration within the organism. For example, seaweed concentrates iodine from the seawater within its tissues, so it's very useful for humans as a source of concentrated iodine. Similarly, plutonium is present at very low levels in seawater. It's concentrated within tiny algae, (phytoplankton) that make up the producers in the open sea ecosystem (up to 3,000 times stronger in one of these algae than in the sea water). Algae also concentrate PCBs to 2,000 times the ambient sea water levels
Bioaccumulation or biomagnification	Concentration of pollutant; gradient that occurs in moving from one trophic level to another, such as when an animal eats a plant or another animal

Perhaps the best-known example of a pollution event that affected humans was in the 1950s in Minemata Bay, Japan. Mercury (mercuric sulphate) was discharged untreated into Minemata Bay over many years where it accumulated in the sediment offshore. Here it was naturally converted into methyl mercury, a more soluble toxic form readily taken up by plants and animals. The level of methyl mercury found in these plants and animals increased the higher up the food chain the species was located due to bioaccumulation. When the local population ate species of carnivorous fish at the top of this food chain they were ingesting 500,000 times the normal seawater concentration of mercury. This led to a number of serious health problems and birth defects.

Other Common Pollutant Types

There are wide range of other pollutant types. These together with their likely impacts on ecosystems are described in the table.

Types of Pollution and their effects

Type of pollution	Effects
Suspended inorganic solids such as silt pumped into a river	• Substrate changed due to the riverbed being covered with silt • Fish gills and filter feeders become blocked • Fish spawning areas and eggs smothered • Light penetration is reduced, reducing photosynthesis and plant growth • Changes in the community of organisms present • Loss of diversity
Thermal Pollution for example. from fire runoff water	• Water body is heated • Oxygen content of the water is reduced • Self-purification processes are accelerated if oxygen levels don't fall too low. Some species, such as trout, salmon and pike are particularly sensitive to elevated water temperatures • Changes in the community of organisms present • A loss of diversity occurs

Type of pollution	Effects
Inorganic chemicals	• May be toxic • May change acidity or alkalinity (pH) of the water • Change in the community of organisms present • A loss of diversity occurs
Oils and fuels	• Physical coating of animals and plants, particularly water foul • May be toxic • Reduction in oxygen levels • Changes in the community of organisms present • Loss of diversity
Organic matter such as a milk spillage	• Reduction of oxygen levels • Changes in the community of organisms present • Loss of diversity
Nitrogen and phosphates such as a fertiliser spillage	• Eutrophication, producing algal blooms, which can lead to deoxygenation of water bodies and changes in the community of organisms present • Loss of diversity • Many fertilisers are also acutely toxic, particularly those based on ammonia compounds

Type of pollution	Effects
Toxic and persistent organic chemicals	• Poisonous • Changes in the community of organisms present • A loss of diversity occurs • Bioaccumulation and persistence possible
Pathogens	• Spread disease

Environmental conditions

Environmental conditions in any particular geographical area of the UK can directly influence the toxicity and fate of pollutants in a body of water. Environmental specialists within the FRS should consider these when pollutants are released into the water environment.

Hardness: in hard water, high concentrations of dissolved calcium and magnesium reduce the toxicity of metals such as cadmium, lead or copper. Such waters will also be better able to cope with an acid spill due to better buffering capacity. However, the toxicity of other substances such as ammonia is increased.

Acidity: the solubility of many metals is increased as water becomes more acidic. This can lead to negative impacts on aquatic ecosystems.

Temperature: high water temperatures naturally reduce dissolved oxygen levels. These conditions also encourage greater microbial growth, so the effect of an organic spill during the summer period may be more severe, but self-purification is accelerated.

Mixtures: pollutants can change their toxicity in the presence of other toxins. They may produce three possible outcomes:

- Additive toxicity
- Increased toxicity
- Decreased toxicity

For example, the presence of chromium can increase the toxicity of nickel ten-fold whereas the presence of strontium can decrease it three-fold.