Output 8: Learning resources for Water Characteristics

Introduction

The learning resources in this guide have been designed to support 'short episodes' of focussed learning' on a specific topic within the Water Characteristics section following the Recognition of Prior Learning (RPL) using the multiple-choice question sets. Each episode has a title and number that relates it to a specific multiple-choice question or questions within the subject area.

The resources cover the physical, chemical and biotic aspects of fresh and marine water. The aim is to provide experienced husbandry operatives enough information, insight and understanding of the properties of water and the natural and human influences that can impact on water quality with consideration given to the implications to aquaculture.

The multiple-choice questions and learning resources have been designed to satisfy the level of knowledge and understanding prescribed by the Scottish Aquaculture MA level 2 (husbandry operative)

The RPL/APL system is designed for experienced work-based learners with some knowledge, as well as knowledge gaps who wish to 'fast track the assessment and accreditation of their knowledge.

(See spread sheet guide to Scottish Optimal RPL and follow up through guided self-study learning)

Recommended pedagogy for RPL/APL

Step 1- Undertake multiple choice questions for the section

Step 2 Automated RPL to determine which questions have not been answered correctly in full

Step 3 (a) Automated documentation and QA of correct responses for submission for accreditation of specific knowledge

Step 3 (b) Self -study guided by the RPL results and feed back

Step 4 Second Multiple Choice (MC) with alternative question (same topics and level) or complete alternative approved summative assessment leading to accreditation.

(Note: Alternative MC questions will need to be developed by the VET user as only one set is available from the optimal project.)

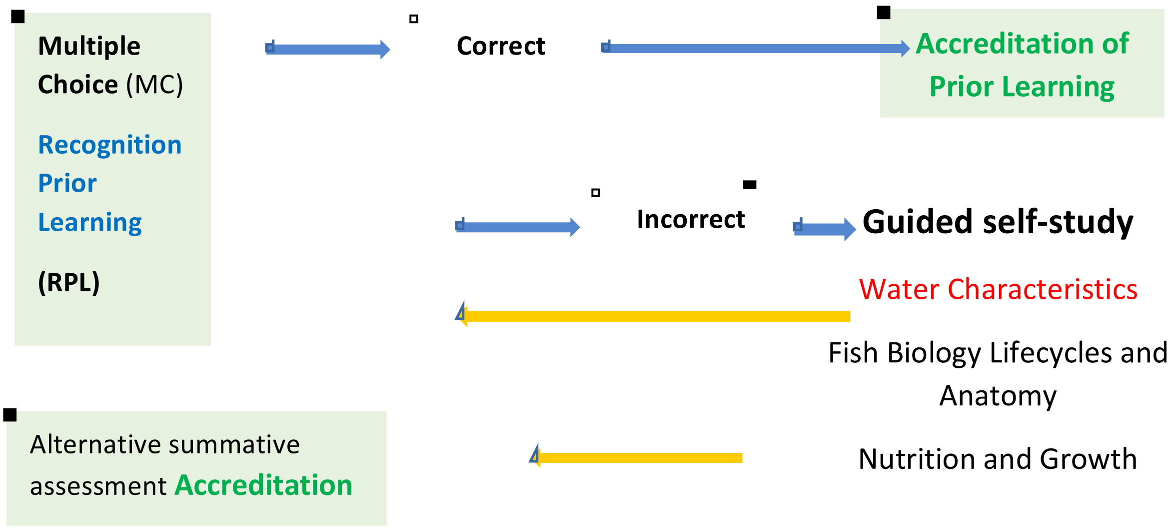
Using these resources

The multiple-Choice questions can be presented by response tools via hand-held devices or presented within a Virtual Learning Environment, which is the recommended method for independent work-based learners.

A well designed VLE with high level assessment functionality and grade book will allow the full automation potential of the system to be gained, as well as supporting communication with tutors, farm supervisors and peers.

Funded by the Erasmus+ Programme of the European Union

This project has been funded with support from the European Commission. This publication reflects the views only of the authors, and the Commission cannot be held responsible for any use, which may be made of the information contained therein.



Graphic to illustrate recommended RPL/APL pedagogy for experienced work-based operatives

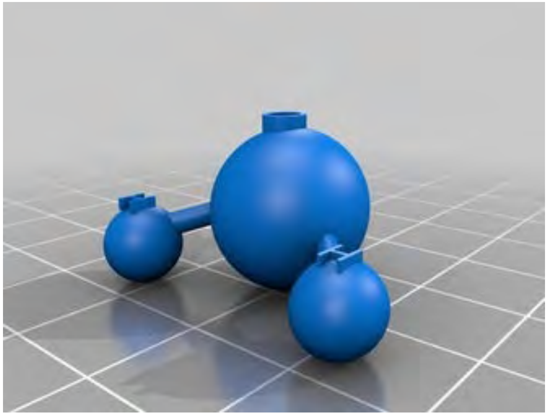
B1 Water characteristics

Physical state of water

Water is the most abundant compound on Earth and is important to all life on Earth. When water is pure it is a tasteless, colourless, odourless fluid.

What is pure water?

Water is considered pure at the point of condensation, but it soon picks up many other compounds after condensation, including gases and solids.



We as humans are most familiar with water as a fluid that we drink and use every day. But how many people understand water and its composition? It can be assumed that everyone knows what water is and most will be familiar with its chemical formula, H^2O. However not everyone will know what H^2O means.

What does H^2O mean?

The H part refers to Hydrogen atoms and the O refers to Oxygen atoms, which form together to create a water molecule. Each water molecule is made up of two Hydrogen (H^2) atoms and one Oxygen (O) atom. There are many millions of water molecules in a single drop of water.

It is the interaction of these molecules that makes water a unique substance. It is the only substance on Earth that naturally occurs in three physical states, liquid, gas and solid. When water transitions through the three states the hydrogen bonds within the molecules break up and the molecules either drift apart or move together and bond more closely. The natural process, called the 'Hydrological Cycle', describes the changing state of water as it moves around the Earth.

The main influences on the physical state of water found naturally are temperature and atmospheric pressure. Either or both of those influences can change water from one physical state to another.

What are the physical states of water?

The physical states of water are:

Gas (vapour) – Water as a gas is always present around us in the air. It may not always be visible, but it can be seen when we boil water in a kettle. The boiling process changes water from a liquid to a gas or water vapour. This is known as evaporation.

The H^2O molecules in water as a gas move further apart than they are in water as a liquid, which makes the gas (vapour) lighter than liquid water or solid water.

As gas (vapour) starts to cool it becomes visible and this is how clouds form.

Liquid (water) – When water is in a liquid state the H^2O molecules move closer together than when in either a gaseous or solid state (ice). When changing from a solid to a liquid, this process is called ‘melting’. When it changes from a gas to a liquid, the process is called ‘condensation’.

Solid (ice) – Frozen water is a solid. When water is frozen the H^2O molecules will move further apart than those found in liquid water. This makes ice less dense than liquid water, which is the reason why ice will float in water due to the air trapped in between the molecules.

B2 Water characteristics

Water temperature and dissolved oxygen relationship

The temperature of water is a most influential factor in the aquatic environment. This is because most aquatic animals are cold blooded, and the temperature of the aquatic environment will determine their levels of activity. As the activity levels of aquatic animals increases, so does their oxygen requirement. However, it is important to note that as the water temperature rises the oxygen solubility of the water decreases. As oxygen is essential for fish for their respiration and survival, this temperature oxygen relationship is a major consideration within aquaculture for all species and at all states of their development.

What can influence the dissolved oxygen level of water?

There are many other factors that can influence the dissolved oxygen levels in water, including the dissolved solids content. This means that saltwater in the marine environment will hold less oxygen than freshwater, however the effects of temperature on the marine environment are less severe than those experienced in the freshwater environment. This is because large water bodies such as lochs and the sea take a long time to warm up and cool down which provides some water temperature stability.

The table below shows an example of the relationship between water temperature and dissolved oxygen levels in freshwater and saltwater (35ppt):

Temperature 0^{C}	Freshwater (0^{2} mg/l)	Saltwater (0^{2} mg/l)
0	14.6	11.5
10	11.3	9.3
20	9.1	7.4

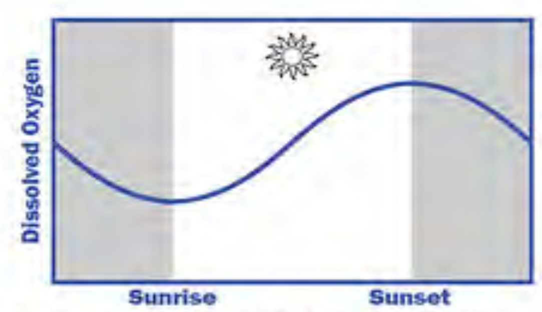
Table: Dissolved Oxygen concentrations at differing salinities and temperature

How is dissolved oxygen normally measured?

Dissolved oxygen in water is usually measured using an oxygen meter with a probe that provides the oxygen levels either as a percentage saturation or as milligrams/litre (mg/l)

The table above clearly shows that salinity and temperature influence the dissolved oxygen available in water. There are seasonal variations which can impact on temperature and ultimately dissolved oxygen. In winter, when water temperature is low, the dissolved oxygen levels will be high. Conversely, in summer when water temperature is high the dissolved oxygen levels will be lower.

Do oxygen levels change during a 24-hour cycle?



The normal daily cycle of dissolved oxygen production. Production starts when the sun rises and stops when it sets.

There are daily variations that can impact on oxygen availability, particularly in the warmer summer months. This is due to the activity of aquatic plants (including algae), which will produce oxygen during daylight hours when photosynthesising but alternatively will use oxygen and produce carbon dioxide during darkness through respiration.

This diurnal (night and daytime) cycle of biological activity can cause oxygen levels to plummet under extreme summer conditions.

This can have a major and at times disastrous impact on aquaculture operations.

B3 Water characteristics

The effect of altitude on dissolved oxygen in water

The dissolved oxygen in water enters from the air through slow diffusion and physical agitation such as splashing (waterfalls), wind and wave action, or by the activity of plants when they are photosynthesising. This leads to what is called water that is 'fully saturated' with oxygen, meaning no more oxygen can enter under those conditions. Biological activity, most notably respiration and photosynthesis, will cause oxygen levels to fluctuate. But there are other factors which can affect the dissolved oxygen concentration of water.

Dissolved oxygen enters the water from the atmosphere assisted by wave action.

What are the other non-biotic factors influencing the dissolved oxygen concentration of water?

The dissolved oxygen concentration of water is affected by several factors including temperature, salinity and altitude. Warmer temperatures will cause the dissolved oxygen levels to decrease as will increased salinity (dissolved solids) in the marine environment.

The barometric pressure is lower at high altitude

How does altitude influence dissolved oxygen levels?

At lower altitudes the dissolved oxygen concentration in water will be higher than that in similar waters at higher altitudes. This is due to the decrease in air pressure (also called barometric pressure) as altitude increases, as the air is less dense. You may have heard references to the air being 'thinner' by climbers on Mount Everest, who need to use oxygen equipment as they reach the higher altitudes?

The air is less dense at high altitude due to all molecules, including oxygen, being spread further apart and as a result this means the diffusion of oxygen from the air into water is reduced by the low air pressure.

B4 Water characteristics

Water Density

The density of any material is the measure of its mass in a specific volume of space. This suggests that most materials will be at their most dense when they are solid. Water however is unusual in this respect as when it cools and solidifies into ice it becomes less dense than when in a liquid state. This is due to the action of the molecules that make up water, which move further apart when and it approaches the freezing point, rather than closer together, as do molecules in most other materials.

Ice can cover a lake and eliminate oxygen exchange leading to a total loss of fish stocks in extreme cases such as northern Canada

At what temperature is water at its most dense?

When pure water reaches a temperature of 4° C it is has reached its maximum density. When it is cooled further it starts to expand and becomes less dense. On freezing at 0° C it will float (as ice cubes do when added to a drink). The reason ice floats in water is the air trapped in the spaces between the molecules. As ice melts, water becomes denser until it reaches a temperature around 4^0C, where it is at its most dense, as the water molecules are now closer together. Once the water temperature goes above 4^0C the density will reduce as water warms up, due to the water molecules moving further apart. If heating continues it will ultimately turn into a gas (vapour) and is at its lowest density.

What effect does salinity have on water density?

Freshwater is less dense than oceanic sea water which has a salinity of 35 ppt typically. This allows freshwater to sit on top of dense seawater in estuaries and semi enclosed sea lochs and fjords. These phenomena have a major impact on the environmental conditions for fish and other sea life.

Scottish sea lochs and Norwegian and Icelandic fjords are fed by large rivers creating a marked salinity gradient

Sea lice are not able to tolerate sustained exposure to freshwater as they are adapted the marine environment and can be deterred, by less saline surface waters, which is a positive impact. However, salmon can be deterred from feeding if the layers of freshwater build up on top of the sea water due to the density differential. They feed most vigorously in full strength sea water (35 ppt)

B5 Water characteristics

Relationship between water salinity and freezing point

The effects of temperature on the marine environment are less severe than those experienced in the freshwater environment. This is because large water bodies such as lochs and the sea take a long time to warm up and cool down which provides a degree of water temperature stability.

This is due to the unique interactions of the water molecules, which move further apart when the temperature cools, solidifying as ice when it reaches it freezes at 0^0C. As the water temperature increases to 4^0C the molecules are closer together and water is at its most dense. Then, as it heats further, the molecules will move further apart reducing the density.

Standing on a frozen Baltic sea which has a low salinity of 3-9 ppt

What effect does salinity have on the physical properties of water?

The density of water is also influenced by other factors, including salinity. As dissolved solids (salts) are added to pure water this increases the salinity, which in turn increases the density. When the salinity of water is increased this also has other effects including, raising the boiling point of water and decreasing the freezing point.

Why does rising salinity decrease the freezing point?

When water freezes the water molecules bond together to create crystalline structures, we call ice. If salt is added to water the molecules will not bond so readily, and so will require a lower freezing point to allow the molecules to bond. This freezing point for normal salinity sea water (35 ppt) will be around -2^0C, however freshwater will freeze at 0^0C. It is also worth noting that as saltwater freezes any salt in the water will be pushed out of the ice and will increase the salinity and density of the surrounding water.

B6 Water characteristics

The properties of ground water

The naturally occurring process whereby water moves around the terrestrial and aquatic environments is called the **'hydrological cycle'**. This is a continuous process where water changes state between solid, gas and liquid as it moves between the earth, oceans and the atmosphere. Starting with the oceans, as water evaporates it will condense into clouds which then move over land and fall to the surface as precipitation (rain/snow) which fills the lakes and rivers and flows back to the sea. However, not all water will immediately return to the sea via this route as some will be retained for a longer period as ground water.

What is groundwater?

Groundwater is the water which is found beneath the earth's surface having trickled through soil and permeable rocks to be stored in underground rock formations called aquifers, through which it slowly moves. The aquifers are continually recharged by water from the surface and eventually stabilise at saturation point, to define what is known as the **water table**.

Shallow well in Thailand with a water table near to the surface

Does groundwater ever emerge to the surface?

The ground water can appear at the surface through natural means, emerging from springs or in wetland areas. As water emerges slowly in some regions with porous rock formations, there are often significant quantities of ground water stored in **aquifers**.

Groundwater reserves can be tapped and recovered by sinking wells or boreholes down to the water table and pumping it up to the surface. It is utilised by many industries including agriculture, drinking water supplies and aquaculture.

Does groundwater have any advantages for aquaculture use?

As a source of freshwater for aquaculture, ground water has several advantages over other sources, such as rivers and still waters:

- Low suspended solids
- Stable and moderate temperature
- Stable flow pattern (spring or pumped)
- Disease free
- Stable high-water quality

This combination of characteristics makes ground water ideal as a fish hatchery water supply.

Does groundwater have any disadvantages for aquaculture use?

There can be some significant disadvantages of groundwater as an aquaculture supply source:

Groundwater is essential to human survival and food production in Africa

- Expensive pumping costs
- Low oxygen levels
- Low temperatures
- Can be limited flows in small aquifers
- Supersaturation risks (e.g. nitrogen)

What is the main disadvantage of groundwater for aquaculture use and how can it be overcome?

The main disadvantages of groundwater are the low dissolved oxygen levels and or supersaturation of other gases such as nitrogen, both of which can cause major problems if used as an aquaculture water supply. The oxygen levels are usually low due to a lack of exposure to the air as the water has been underground.

Supersaturation of other gases can occur when the water is pumped under pressure to the surface. Both problems can be alleviated by degassing the incoming water to remove excess gases such as nitrogen whilst aerating through splashing in air and or direct injection of oxygen to the water supply.

B7 Water characteristics

Chemical characteristics of ground water

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What are the main chemical limitations of groundwater?

The main disadvantages of groundwater are the low dissolved oxygen and or **supersaturation** of other gases such as nitrogen, both of which can cause major problems if used as an aquaculture water supply. The oxygen levels are usually low due to a lack of saturation from the air as the water has been underground. Supersaturation of other gases can occur when the water is pumped under pressure to the surface. The principal gases found in water are nitrogen, oxygen, and carbon dioxide.

Groundwater purity cannot be taken for granted

When water becomes supersaturated with a gas, excess gas will be released as small bubbles that can be visible, like carbon dioxide release when you open a fizzy drink.

How does water become supersaturated?

The total amount of dissolved gases that water can hold will depend on a range of factors including temperature, salinity and pressure. When the concentration of a gas such as nitrogen reaches the waters holding capacity for a given pressure, the water is 'saturated'. If, however the amount of gas exceeds the waters carrying capacity, it becomes 'supersaturated'.

For example, if water measured as 100% saturation for a given gas (nitrogen or oxygen), were pumped under pressure and on being measured again showed a total dissolved gas reading of 115%, this water has become supersaturated.

What are dissolved gases?

Dissolved gases are those which can be carried in an aquatic solution. The gases most commonly dissolved in water are carbon dioxide, oxygen and nitrogen.

- **Nitrogen**

Nitrogen is the most common of the inert gases in fresh and saltwater. Supersaturation of nitrogen can occur when water is pumped under pressure, or when a pipeline has a crack or leak that allows air to be taken in under pressure. This can create problems for aquaculture using a pumped ground water source which may already be low in oxygen and high in nitrogen. In this scenario supersaturation can cause major problems as the exposure of fish to supersaturated water can lead to gas bubbles starting to appear in their blood and tissues, giving rise to a condition known as **'Gas Bubble Disease'**. This can cause mass mortalities if not addressed.

- **Oxygen**

Dissolved oxygen (DO) is the most important chemical parameter in aquaculture, as fish require it constantly for respiration. The total amount of dissolved oxygen in water is heavily influenced by water temperature, salinity and altitude. Oxygen normally enters the water through direct diffusion from the air or photosynthesis by aquatic plants. Although supersaturation with oxygen is not usually a problem for aquaculture, it can be when influenced by photosynthesis in static ponds. Daily fluctuations and oxygen supersaturation due to **photosynthesis** can be extreme enough to stress carp, a tolerant pond aquaculture species, making them more disease prone.

- **Carbon Dioxide**

Carbon dioxide is not normally a problem for natural waters but can become an issue for aquaculture if the water supply comes from a source where aquatic plants are photosynthesising and respiring. When aquatic plants photosynthesise, they produce oxygen which will increase dissolved oxygen levels in the water. However, at night when plants cannot photosynthesise but continue to respire, they use oxygen and produce carbon dioxide. In some circumstances such as an intense algal bloom, carbon dioxide levels can be elevated through respiration, leading to supersaturation.

Surface agitation by a simple paddle wheel aerator is often enough to drive of supersaturated gases

What are the practical solutions to supersaturation?

If an incoming water supply is found to be supersaturated, particularly with nitrogen, the problem can be alleviated by 'degassing' the incoming water to remove excess gases. This can be achieved through mechanical aeration which splashes and agitates the water. Cascading water through a vertical degassing tower filled with media to create a large surface area and break up the water, direct injection with oxygen or a combination of methods can be used successfully.

B8 Water characteristics

Biological influences on Dissolved Oxygen

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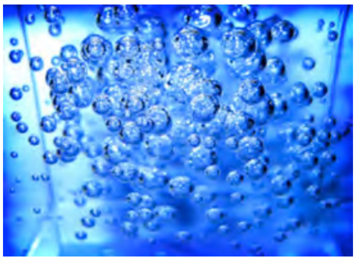


Plants can act as natural day-time oxygen generators

What is photosynthesis and how does it impact on DO?

Photosynthesis is carried out by all green plants during daylight hours. During the process plants will use carbon dioxide, nutrients and sunlight as an energy source to grow.

The by-product of photosynthesis is oxygen. But during the hours of darkness when photosynthesis stops, oxygen is utilised by plants and carbon dioxide produced as a by-product of respiration.

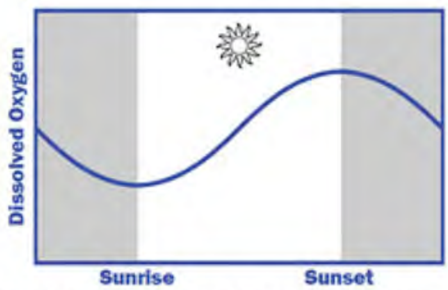
Heavy algal growths can crash dissolved oxygen levels overnight

Both processes are naturally occurring, but they can create problems in extreme circumstances. This **'diurnal range'** becomes more accentuated when biomass of plants and other aquatic organisms is high. When the aquatic plant growth is excessive, as can occur during periods of rapid algae (phytoplankton) growth known as 'blooms', there will be a major increase in oxygen production.

Normally, when the system is in balance, this natural daytime oxygenation of the water is beneficial. However, when a heavy plant biomass respires during darkness, the oxygen levels can drop to dangerously low levels by dawn. The risk is highest when night follows a dark day with heavy cloud cover, as day-time photosynthesis is inhibited, and by nightfall the water body has an unusually low level of dissolved oxygen.

Does carbon-dioxide production present any danger?

A secondary danger within this process is the production of carbon dioxide during the hours of darkness by plants and other aquatic organisms, some of which is converted to carbonic acid. In waters that



The normal daily cycle of dissolved oxygen production. Production starts when the sun rises and stops when it sets.

are neutral or slightly acidic, this can cause the pH to drop to dangerously low levels

B8 Water characteristics

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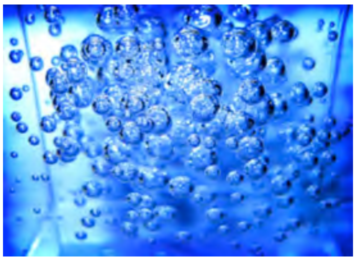

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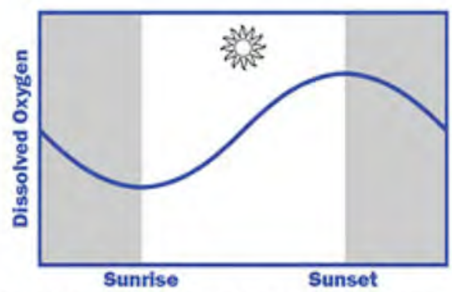

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Does carbon-dioxide production present any danger?

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B9 Water characteristics

Physical water characteristics influence on Dissolved Oxygen

There are a range of physical, biological and chemical influences that determine the dissolved oxygen concentration of natural waters. Some physical factors are fixed and predictable, such as altitude, whereas others, particularly temperature are seasonally variable.

Wind driven wave action helps to introduce more oxygen to the surface of the oceans

Alongside biological factors, water temperature has the most impact on dissolved oxygen concentrations. Salinity is a good example of a chemical factor that influences how much oxygen can be dissolved in water. Biological factors are the most dynamic, namely **photosynthesis** and respiration and **diurnal fluctuations** can be dramatic, especially during the heat of summer.

What physical factors influence dissolved oxygen levels?

Much of the oxygen that enters the water does so from the atmosphere by diffusion and from biological activities (photosynthesis and respiration) during the summer. The agitation of water surfaces through natural phenomena, such as waterfalls and wind and wave action, increases the uptake of oxygen by physical means.

Some fish farm aeration devices, such as paddlewheel aerators used in static ponds exploit this phenomenon, lifting water on large paddles, spreading it thinly to increase oxygen diffusion.

As water heats up its capacity to hold dissolved oxygen reduces

Water temperature is the physical factor that has the most dramatic impact on the solubility of oxygen. But other factors can have an influence, particularly biological and to a lesser degree, chemical factors, most notably salinity. Altitude and light penetration (which is determined by turbidity and the strength of the sunlight), are significant physical influences to be aware of.

How do salinity and water temperature influence the dissolved oxygen level of water?

Salinity influences dissolved oxygen levels at all water temperatures. Consequently, saltwater in the marine environment will hold less oxygen than freshwater, at the same temperature. However, the effects of temperature on the marine environment are generally less severe than those experienced in the freshwater environment. This is because large water bodies such as the sea, sea lochs and fjords take a long time to warm up and cool down, which helps to stabilise water temperatures.

The table below shows an example of the relationship between water temperature and dissolved oxygen levels in freshwater and saltwater (35ppt):

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How does altitude influence dissolved oxygen levels?

At lower altitudes the dissolved oxygen concentration in water will be higher than that in similar waters at higher altitudes. This is due to a decrease in air pressure (also called **barometric pressure**) as altitude increases, as the air is less dense. You may have heard references to the air being 'thinner' by Mount Everest climbers, who need oxygen equipment as they reach the higher altitudes? The air is less dense at high altitude due to all molecules, including oxygen, being spread further apart and as a result this means the diffusion of oxygen from the air into water is reduced by the low air pressure.

How can water turbidity impact on dissolved oxygen levels?

Photosynthesis is carried out by all green plants during daylight hours as it is a light requiring process. Plants need carbon dioxide, nutrients and sunlight as an energy source to grow. The by-product of photosynthesis is oxygen which benefits all aerobic aquatic life forms. But during the hours of darkness when photosynthesis is impossible, oxygen is utilised by plants and carbon dioxide produced as a by-product. This is a process known as respiration.

Turbidity can be a temporary or natural state.

The turbidity of water has a major influence light penetration and therefore photosynthesis and oxygen production.

In still waters or the sea light penetration can be measured by a simple plate like device known as a 'Sechi disc' held on a cord, which is lowered in to measure the depth at which it disappears. This depth it disappears is known as the Sechi disc reading, which provides an indication of the depth of the **'photic zone'**. There is enough light penetration within the photic zone to support photosynthesis and plant growth.

B10 Water characteristics

Biological Oxygen Demand (BOD)

Dissolved oxygen (DO) is the most important chemical parameter in aquaculture, as fish always require oxygen for respiration and survival. The total amount of dissolved oxygen is heavily influenced by water temperature, salinity and altitude. Oxygen normally enters water through direct diffusion from the air and **photosynthesis** by aquatic plants. The available dissolved oxygen is used by fish, plants and other aquatic life for respiration.

What impact do decomposers have on DO?

Aquatic **decomposers**, including bacteria and other microorganisms also respire and use oxygen as they consume and breakdown organic material in the aquatic environment. In nature this includes dead aquatic vegetation and organisms, as well as incoming terrestrial leaf litter. All of which are broken down without any adverse effect, returning chemical nutrients to the aquatic system.

Aerobic bacteria decomposing organic matter proliferate

However, organic pollutants such as agricultural and industrial effluent can overload the natural system and have a range of damaging effects on water quality, including:

- Increased suspended solids
- Decreased oxygen levels
- Increased ammonia
- Increased phosphate

What is Biological Oxygen Demand (BOD)?

Although low levels of **organic detritus** are produced naturally, high organic levels usually indicate incoming organic pollution. Therefore, the concentration of organic substances in a water sample is an important indication of water purity. The amount of oxygen needed by aerobic microorganisms to break down organic waste can be used as a measure.

This is known as the Biological (also called Biochemical) Oxygen Demand (BOD).

The BOD test measures the amount of Dissolved Oxygen (DO) required by aerobic (oxygen requiring) bacteria to;

- break down organic material in a measured water sample (1 litre),
- at a set temperature (20^0C),

Collecting water samples for BOD testing

- over a specific time (5 days).

The output value from the test is expressed as milligrams of oxygen consumed/litre sample.

A range of water samples ready for BOD testing

The BOD measure is used to assess the impact that effluent discharged by water users is having on the aquatic environment. A low BOD indicates good water quality, whereas a high BOD indicates poor water quality, probably caused by organic pollution.

What are biological indicators of organic pollution?

As the microorganisms (including bacteria) in the aquatic environment use oxygen to break down the waste, this deprives other **'aerobic'** aquatic life forms. This can impact on the diversity of aquatic life in the environment as the more sensitive 'clean water fauna' with a higher oxygen demand are destroyed. Once the waste has been broken down the BOD levels drop, unless the organic inputs from agriculture, industry or aquaculture are persistent. In which case aerobic bacteria will be constantly breaking down the organic waste keeping the BOD high. T

he presence or absence of clean water fauna such as stonefly, mayfly and shrimps provide a reliable indicator of water purity. As any aquatic life killed by organic pollution takes some time to recover, **biological sampling** is a good indicator of recent organic pollution. Intermittent organic pollution easily missed by a 'one off' BOD test, can be detected through biological sampling

How do the water authorities control organic pollution?

Fish farms and other water users must comply with the '**effluent discharge consents'** imposed by the water authorities. Each water user with a discharge consent then has their effluent monitored and tested to make sure the BOD stays within the set limits. These discharge consent standards ensure that the capacity of the aquatic environment to break down organic waste, without detriment to the aquatic flora and fauna, is not exceeded.

B11 Water characteristics

Human impacts on the Biological Oxygen Demand (BOD)

Many human activities can have an environment impact, but unfortunately impacts on the aquatic environment are sometimes more difficult to detect. Some aquatic pollution issues have become high profile globally, such as the damage done to marine life by plastics entering the oceans. Whilst others such as land-based and urban organic pollution are more mundane and may not reach the headlines as regularly.

Some sewage works are under capacity for the large population they serve

What are the main causes of pollution?

The main human activities with potential to cause pollution are:

- Agriculture
- Industry
- Forestry
- Urbanisation
- Aquaculture

There are many chemicals used in a wide range of industrial processes, that can enter waterways and cause chemical, as opposed to organic pollution. Although chemical pollutants can be toxic to aquatic life to varying degrees, and sometimes devastating, the nature of their impact differs to organic pollutants.

Farm slurry organic fertilisers can have a devastating BOD when flushed of the land into water courses

Each of the activities above has the potential to produce waste organic material that can affect water quality in various ways, including:

- Increased suspended solids, which can reduce light penetration and plant growth.
- Decreased dissolved oxygen (DO) levels which can threaten aerobic (oxygen requiring) aquatic life.
- Increased nitrogenous waste, which can be toxic in the case of ammonia or lead to eutrophication (nutrient enrichment) of the aquatic system.
- Increased phosphate which can lead to **eutrophication**, as it normally sets the upper limit on plant

growth in freshwaters.

Although low levels of organic detritus are produced naturally, high levels of organic substances found in water samples are often indicative of pollution from the above human activities. Natural waters can be chemically tested to show the concentration of organic substances contained.

By taking samples of the local flora and fauna, biological monitoring can help to interpret water test results. The **biological indicator species** are sensitive to any intermittent organic pollution which may have occurred in the recent past. Whereas the water chemical test is based on the conditions at the time the sample was taken. In rivers, organic pollution that passed through the system several weeks previously, can go undetected by chemical tests.

1 Litre of water in darkness at 20 C for 5 days

How is the concentration of organic substances measured?

The amount of oxygen used by microorganisms to break down waste organic material can be measured using a Biological (also called Biochemical) Oxygen Demand (BOD) test. This determines the amount of Dissolved Oxygen (DO) required by aerobic bacteria to break down organic material in a water sample (1 litre) at a set temperature (20C) over a specific time (5 days). The output value from the test is expressed as milligrams of oxygen consumed/litre sample. A low BOD indicates good water quality, whereas a high BOD indicates poor water quality and the likelihood of organic pollution.

How can organic pollution by aquaculture be minimised?

Other than 100% closed **Recycling Aquaculture Systems (RAS),** aquaculture will introduce some level of organic waste into the aquatic environment. This is unavoidable, as feeding fish produce organic waste in the form of fish faeces, as well as soluble wastes such as ammonia as a by-product of protein metabolism. However, the negative impacts can be held at an acceptable low level if the farm operates within its 'Effluent Discharge Consent'. Regulation by the water authorities ensures that the capacity of the aquatic environment to naturally break down the organic wastes is not exceeded.

RAS filtration removes organic solids, lowering BOD and strips ammonia

Mitigating measures by aquaculture facilities to ensure they operate within their consent include:

- The introduction of on-site waste treatment facilities by land-based farms, such as settlement ponds and filtration systems.
- Fallowing sites between fish production cycles to allow the aquatic environment to recover from the effects of an intensive cage farming operation.
- Feeding higher quality more digestible diets to ensure nutrients are retained as fish growth and the excretion of solid organic wastes and soluble metabolic wastes is minimised.

- A range of improved fish feeding practices to minimise uneaten food and fish feed wastage.

What impact can land based agriculture have on water quality?

Agricultural organic pollutants can result from accidental (or intentional) discharge of pollutants into the aquatic environment such as slurry, silage effluent or waste milk spillage from dairies. Pollution from these sources can be avoided through on-farm facilities for containment, handling and transport of organic wastes and well managed application of organic fertilisers (such as slurry) to the land.

Silage needs to be securely contained to eliminate high BOD discharges

Once any waste organic material has entered the aquatic environment, aerobic bacteria will immediately start to break it down. The microorganisms (bacteria) will use dissolved oxygen to break down the waste. If the organic discharge exceeds the environments natural cleansing capacity, other aquatic life could be deprived of oxygen, impacting on the diversity of fauna and flora.

The sensitive biological indicator species are the first to be eliminated. Once the waste has been consumed and broken down the BOD levels will start to drop, unless the discharge is persistent, which increases the risk of an adverse environmental impact.

B12 Water characteristics

Biological Indicators

Although organic detritus is produced naturally, high levels of organic substances in the aquatic environment could be indicative of pollution from human activities. The level of dissolved organic substances in a water sample can be determined using a **Biochemical Oxygen Demand (BOD)** test. This provides an indication of the status of the aquatic environment at the time the test was taken.

Stonefly nymphs need oxygen rich unpolluted conditions

Establishing the distribution of the local aquatic fauna and flora, particularly indicator species sensitive to organic pollution, helps to interpret the BOD test results. This form of biological sampling is complementary to the BOD test and offers certain advantages.

What are biological indicators species?

Biological indicators are those species of fauna and flora which are considered reliable indicators of environmental conditions in the aquatic environment. The absence or reduction in diversity of indicator species can be indicative of pollution or adverse conditions. This information can be used to assess the impact of human activities such as agriculture, aquaculture and sewage treatment from urbanisation.

Invertebrate kick samples are taken from the fast-flowing riffles not pools

River and stream invertebrates are the most useful indicator species in aquatic environments and the basis of the most widely used biological monitoring systems. This is because different invertebrates have quite specific environmental requirements, and therefore, depending on the species, their presence or absence, diversity and abundance can be indicative of water quality.

What are the practical advantages of biological sampling?

In the UK there are several biological sampling methods for scoring the aquatic environment. The sampling methods used rely on the presence or absence of certain indicator species which has several advantages over using chemical analysis:

- Easy to obtain and examine large samples
- Does not require specialised equipment
- Direct evidence of pollutant effects on fauna

- Provides a long-term view of water conditions unlike chemical analysis which detects pollution still present
- Can highlight intermittent and chronic pollution incidents

This water and substrate look clean, but will biological sampling reveal recent organic pollution?

Are there any practical disadvantages of biological sampling?

There can be disadvantages associated with using biological sampling methods:

- Collection of samples can be complicated
- Sampling, identification of specimens and analysis can be time consuming
- Any potential for natural fluctuations in populations are not taken into consideration

The systems used in freshwaters are most effective when sampling faster flowing riverine habitats with a coarse gravelly substrate, rather than still or slow-moving waters. Their silty substrate naturally limits species diversity, irrespective of the presence or absence of organic pollution.

Ecdyonurus, a high scoring pollution intolerant mayfly nymph

What is the basis of the biological sampling and scoring system?

The scoring of the samples provides what is known as a **'Biotic Index'**. The score is determined by the presence of a range of invertebrate species, with the highest scores given to pollution intolerant species and lowest scores to more pollution tolerant species.

Pollution **intolerant** species (High scoring)

1. Mayfly nymph (Ephemeroptera sp)
2. Stonefly nymph (Plecoptera sp)
3. Caddis larvae (Trichoptera sp)

Pollution **tolerant** species (Low scoring)

1. Blood worm (Chironimid sp)
2. Flatworm (Platyhelminthes sp)
3. Oligochaete worms (Annelida sp)

The low scoring blood worm's Haemoglobin stores oxygen

These invertebrates are 'detritivores' designed to consume partially decomposed detritus. The blood worm and worms, the most tolerant of organic pollution, contain haemoglobin allowing them to store oxygen and survive the most oxygen depleted conditions. Consequently, their numbers rapidly increase following organic enrichment as the clean water fauna declines.

Mid-range species:

There are other invertebrate species that are 'mid-range' as they can be found in clean healthy waters but also in waters that may lack some of the more intolerant species such as Mayfly.

1. Shrimp (Gammarus sp)
2. Water louse (Asellus sp)

The presence of the mid-range species does not necessarily indicate a polluted environment, but they are not high scoring in the Biotic index. Their absence may be indicative of a moderately polluted environment as they are reasonably tolerant species that thrive on organic detritus as a food source.

How does the most commonly used biotic scoring system work?

In the UK the most common system is the **Biological Monitoring Working Party (BMWP) score**.

This method requires a timed kick sample to be carried out in the substrate of a riverbed to disturb invertebrates which are captured by a fine mesh hand net held vertically on the riverbed 50 cm downstream.

The invertebrate species are identified, and the number of species and species abundance recorded. Each species is given a number according to the biotic index scoring. This information is used to calculate an overall score that indicates the level of pollution occurring in the aquatic environment in the area sampled.

An example of the final scoring after the counting and calculation has been done is shown in the table below:

Water quality	No of taxa (species)	BMWP score
Excellent	>18	>110
Good	>15	>80
Fair	>12	>50
Poor	>9	>30
Polluted	<9	<30

Table: Biological Monitoring Working Party (BMWP) scoring system

As this table shows, the higher the score the cleaner the aquatic environment, and alternatively the lower the score the more polluted, although this system will not indicate what the pollutant may be. This information can only be obtained through more scientific testing and detective work to find the pollutant source.

The marine Norway lobster (Nephrops sp) requires a clean substrate

Can biological sampling be applied to the marine environment?

In the marine environment a biological grading system applying the same principles is used to measure the impact of organic waste from cage-based aquaculture settling on the seabed. Samples are taken along a transect starting under the cages and moving outwards. This system assesses the ecological status of the seabed and grades as poor, moderate or good. In a typical transect it would be expected that the seabed ecology and diversity of fauna and flora would improve as you move further away from the cage site. The organic sediment directly under the cages is dominated by detritivores, such as marine worms

(Annelida), the most tolerant of oxygen depleted environments.

The presence or absence of sensitive indicator species at defined distances from the cages determines whether the ecological impact has been adequately minimised. These standards are set by the water authority responsible for monitoring the impact of fish farms on the marine environment.

B14 Water characteristics

Nitrogen cycle

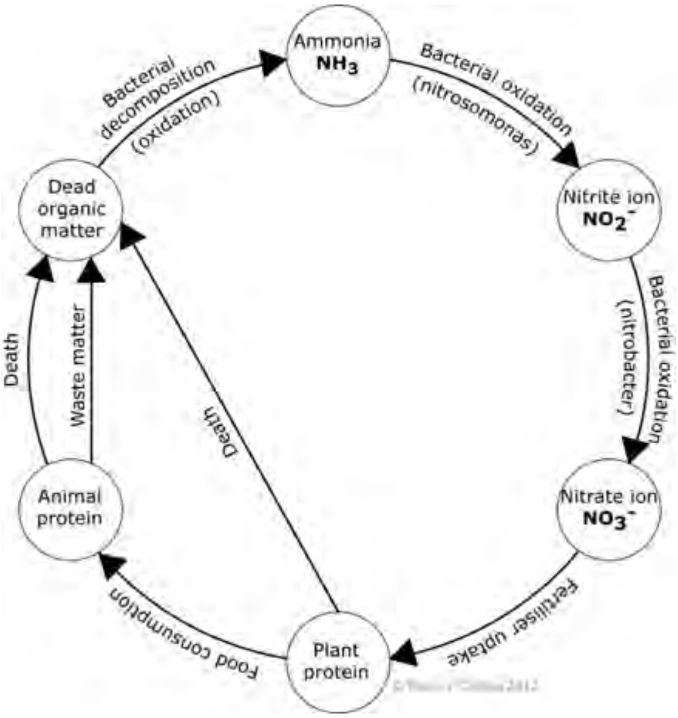
The Earth's atmosphere contains many elements, including Oxygen (O2). However, oxygen is not the most abundant as Nitrogen (N2) forms approximately 78% of the atmosphere by volume.

Nitrogen is a critical component of all plants and animals, but most cannot utilise the atmospheric source. Nitrogen in the atmosphere is fixed by bacteria and certain plants working **'symbiotically'** with the bacteria. Some of the plants which can **fix Nitrogen** include:

- Legumes – peas, beans, peanuts
- Blue green algae – Cyanobacteria

How is nitrogen recycled in natural environments?

Nitrogen is converted to several nitrogenous compounds as it is passes through the cycle. Nitrogen gas is not toxic within aquaculture, although it can cause problems when it is **supersaturated** in the water supply through either pumping from below ground or heating. This can result in fish losses due to **Gas Bubble Disease**, a condition like the bends that divers can suffer from.



There are a few **nitrogenous compounds** that are important to fish farmers, as some are more toxic to fish than others:

- **Ammonia (NH_3)**

Ammonia (NH_3) in water is produced by the decomposition of plants and animals and is a by-product of protein metabolism excreted by most aquatic animals. Ammonia will take two forms; Ammonia (NH_3) and the ionic form Ammonium (NH_{4++}). The amount of total ammonia and other nitrogenous compounds in water will fluctuate according to processes in the nitrogen cycle, but it is important to note that the proportion of Ammonia in the form of (NH3) will increase as the temperature and pH increases.

Although ammonia will be detected at low levels in most aquatic environments, high levels are often indicative of organic pollution. This can usually be attributed to human activities such as agriculture, aquaculture and other industries. The ammonia produced in aquaculture can come from fish metabolic wastes and waste fish feed. If not managed, it can cause farmed fish and the surrounding aquatic environment problems. Ammonia is a significant problem in aquaculture as NH_3 is toxic to fish and relatively small quantities can lead to stress. An NH_3 concentration greater than 0.2ppm can increase mortalities in salmonid fry.

- **Nitrite (NO_2)**

When any nitrogenous wastes are introduced to the aquatic environment the nitrogen cycle is triggered. Any ammonia that builds up is oxidised by **Nitrosomas bacteria** into a compound called Nitrite (NO_2) which is toxic to fish at relatively low levels.

- **Nitrate (NO_3)**

In a healthy aquatic environment Nitrite (NO_2) is converted through oxidisation by Nitrobacter into Nitrate (NO_3). Not all nitrate in the aquatic environment comes from the breakdown of aquatic nitrogenous products and land-based sources leaching NO3 into the water are often more significant. Some of the nitrogen fixed from the atmosphere by bacteria will leach into the aquatic environment where it can be utilised by aquatic plants. As an essential plant nutrient, an increased input of nitrates can stimulate excessive plant growth, causing dissolved oxygen fluctuations over a 24-hour cycle.

B15 Water characteristics

Toxicity of nitrogenous compounds

Nitrogen is converted to several nitrogenous compounds as it is passes through the **nitrogen cycle**. Nitrogen gas is not toxic within aquaculture, although it can cause problems when it is supersaturated in the water supply through either pumping from below ground or heating. This can result in fish losses due to Gas Bubble Disease, a condition like the bends that divers can suffer from.

There are a few nitrogenous compounds that are important to fish farmers, as some are more toxic to fish than others:

- **Ammonia (NH3)**

Ammonia (NH3) in water is produced by the decomposition of plants and animals and is a by-product of protein metabolism excreted by most aquatic animals. Ammonia will take two forms; Ammonia (NH3) and the ionic form Ammonium (NH4). The amount of total ammonia and other nitrogenous compounds in water will fluctuate according to processes in the nitrogen cycle, but it is important to note that the proportion of Ammonia in the form of (NH3) will increase with increasing temperature and pH.

The most toxic nitrogenous waste is ammonia

Although ammonia will be detected at low levels in most aquatic environments, high levels are often indicative of organic pollution. This can usually be attributed to human activities such as agriculture, aquaculture and other industries. The ammonia produced in aquaculture can come from fish metabolic wastes and waste fish feed. If not managed it can cause problems to farmed fish and the surrounding aquatic environment. Ammonia is a significant problem in aquaculture as NH3 is toxic to fish and relatively small quantities can lead to stress. An NH3 concentration greater than 0.2ppm can increase mortalities in salmonid fry.

- **Nitrite (NO2)**

When any nitrogenous wastes are introduced to the aquatic environment the nitrogen cycle is triggered. Any ammonia that builds up is oxidised by Nitrosomas bacteria into a compound called Nitrite (NO2) which is toxic to fish at relatively low levels.

- **Nitrate (NO3)**

Nitrate (NO3) is created as part of the Nitrogen cycle and is non-toxic to fish. In a healthy aquatic environment Nitrite (NO2) is converted through oxidisation by Nitrobacter into Nitrate (NO3). Not all nitrate in the aquatic environment comes from the breakdown of aquatic nitrogenous products and land-based sources leaching NO3 into the water are often more significant.

Some of the nitrogen fixed from the atmosphere by bacteria will leach into the aquatic environment where it can be utilised by aquatic plants. As an essential plant nutrient, an increased input of nitrates can stimulate excessive plant growth, causing dissolved oxygen fluctuations over a 24-hour cycle.

B19 Water characteristics

Fish nitrogenous wastes

All animals produce waste products from digestion and metabolism, some of which are toxic. The metabolism of fats and carbohydrates produces carbon dioxide and water, whilst protein metabolism produces **nitrogenous wastes**. Some **metabolic wastes** are filtered from the blood by the liver and kidney and excreted in urine and fish faeces. Although, the gills primary function is to absorb oxygen, they also excrete carbon dioxide and ammonia, the most toxic nitrogenous waste product.

Ammonia, a toxic nitrogenous waste is excreted from gills

Gills are essential to maintaining a stable concentration of internal fluids through a process called **'osmoregulation'**.

In what form is ammonia produced by fish?

Ammonia produced by fish can take two chemical forms; Ammonia (NH_3) and the **ionic** form Ammonium (NH_{4++}), collectively known as 'total ammonia'. The amount of total ammonia and other nitrogenous compounds in water will fluctuate according to the chemical processes within the nitrogen cycle. Most significantly, the amount of Ammonia (NH_3) in water will increase when the water temperature and pH increases. The ammonia produced by fish is converted to other less toxic compounds within the nitrogen cycle.

What does a high concentration of Ammonia indicate?

Although ammonia is present in low concentrations in most aquatic environments due to the biological activity of bacteria, plants and animals, elevated concentrations can be indicative of organic pollution. High levels of ammonia are often attributed to human activities such as agriculture, aquaculture and other industries.

How much of the feed going into this fish rearing pond will get consumed?

The ammonia produced in aquaculture can come from fish urine, faeces and waste feed. If not managed, this can cause problems to both the fish in the holding units and the surrounding aquatic environment. This is a problem for aquaculture because ammonia in the form of NH_3 is toxic to fish and relatively small quantities can increase fish stress levels.

For example, concentrations greater than 0.2ppm can lead to increased mortalities in salmonid fry.

B20 Water characteristics

Measurement of water salinity

Water salinity is a measure of the **concentration of dissolved salts**, often referred to as the 'saltiness' of the water. The salts contributing towards the salinity of freshwater and marine environments include sodium chloride first and foremost, magnesium, sulphate and potassium. The salinity of freshwaters is relatively low, but dependant on a range of factors, including; geographic location, freezing, evaporation and precipitation, and therefore varies.

What happens when freshwater meets seawater in an estuary?

Seawater contains additional chemicals, including sodium chloride, magnesium, sulphate and potassium and has a density greater than freshwater. As the salinity of sea water increases so does the density, influenced by other factors including pressure and temperature. If there is a big increase in freshwater entering a sea loch or fjord, from a large flooded river, this can alter the **salinity profile** considerably. As the freshwater is less dense it will 'float' as a layer on top of the saline water. In such situations fish in cage sites will be affected, including their feeding behaviour.

Loch Etive is a low salinity Scottish Sea loch due to incoming freshwater and a sill that restricts mixing

In the marine environment full-strength oceanic seawater is 35 parts per thousand (ppt) but can fluctuate either side of this figure. This measure can also be expressed as grams per litre (35 gm/l). Salinity can vary particularly in the marine environment, which will be dependent on a range of factors particularly in inshore waters which can be influenced by freshwater input.

Some of the global variation in water salinity can range between lows in freshwater < 0.5ppt to extremes at the higher end, such as can be found in the Dead Sea >280 ppt.

How do we measure salinity?

There are a range of methods available to measure salinity, with some more accurate than others. The method employed will depend on the accuracy required. This parameter is importance to aquaculture as large variations in salinity can have a negative effect on fish feeding and behaviour in the holding units.

The main methods used to measure salinity are:

Measure water density: – This is done using an instrument called a **'hydrometer'.** A hydrometer measures salinity based on the relative density of a liquid, usually by measuring the specific gravity.

Refractometer: – This instrument measures the degree at which light changes direction when shining through a solution. This gives a figure which is compared against a refractive index, that measures the concentration of a solution.

Sophisticated CTD devises can measure conductivity (to derive salinity) and depth

Titration: – This measures the amount of chloride in a water sample by adding an indicator solution to a sample, causing it to change colour. This change can then be interpreted using a titrator.

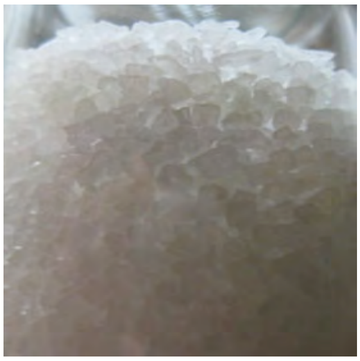
Electrical conductivity: – Salinity can be measured using a probe normally attached to a meter. An electrical current is passed between two electrodes. This measures conductivity which is influenced by the concentration of dissolved solids in a solution.

All methods described above are reasonably accurate, but electrical conductivity is the most accurate measure. The accuracy of other methods can be affected by several factors including sampling location and the time between a sample being taken and then tested. Interpretation of the results could be affected by sampler error.

B21 Water characteristics

Salinity of seawater

Water salinity is a measure of the **concentration of dissolved salts**, often referred to as the 'saltiness' of the water. The salts contributing towards the salinity of freshwater and marine environments include sodium chloride first and foremost, magnesium, sulphate and potassium. The salinity of freshwaters is relatively low, but varies, dependant on a range of factors, including; geographic location, freezing, evaporation and precipitation.



Common salt 'Sodium Chloride NaCl) is not the only chemical that determines salinity

As seawater contains additional chemicals including sodium chloride, magnesium, sulphate and potassium, its density is greater than freshwater. An increase in the salinity of sea water increases its density, influenced by other factors including pressure and temperature.

By how much can salinity vary?

In the marine environment full-strength **oceanic seawater is 35 parts per thousand (ppt)** but can fluctuate either side of this figure in different regions. The measure can also be expressed as grams per litre (35 gm/l).

The Dead sea has a salinity of > 280 ppt, 8X the salinity of the north Atlantic making it very dense

Variations in water salinity globally range between freshwater lows < 0.5ppt to high end extremes such as can be found in the Dead Sea >280 ppt. Salinity varies in the marine environment dependent on a range of factors.

Following a big freshwater input to a sea loch or fjord from a large river in flood, the salinity profile is altered considerably. As the freshwater is less dense it will 'float' as a layer on top of the dense saline water. In such situations fish held in cage sites can be affected, including their feeding behaviour.

Can fish adapt to changes in salinity?

Some species of fish have evolved to be able to adapt to or live in a range of salinities during their lifecycle. The Atlantic Salmon is a good example. As an anadromous species, which hatches in freshwater, feeding on invertebrates and growing up to become a parr, before making its journey to the north Atlantic feeding grounds. To survive it must smoltify. This is a process of physiological change so as the Atlantic salmon smolt on entering full strength sea water can **'osmo-regulate'**. Then it can make its way to the productive Atlantic shelf for a new life of intensive feeding and rapid growth consuming marine crustaceans and fish.

B25 Water characteristics

Water pH (Acidity)

Most people have heard of pH, but what does it mean? The commonly used pH is an abbreviation for 'parts Hydrogen' and is a measure of the **Hydrogen ion or proton (H+) concentration** of a solution. As the Hydrogen ion (H+) concentration increases so does the acidity, and the opposite happens with an increase in Hydroxyl ions (OH-) and the solution will become increasingly alkaline.

This occurs because water molecules (H_2O) naturally dissociate into hydrogen and hydroxyl ions. When both Hydrogen and Hydroxyl ions are in balance a solution is classed as neutral (pH 7), but if it swings either way it can become acidic (< pH 7) or alkaline (> pH 7).

When an acidic substance is added to water the Hydrogen ion concentration increases, which in turn lowers the pH. Conversely, when an alkaline substance is added to water the Hydrogen ion concentration reduces, which in turn raises the pH.

What influences the pH of natural waters?

The marine environment's pH is relatively stable in comparison to freshwater and higher than neutral (typically 8.0 – 8.5). This is due to the quantity of dissolved substances contributing to the salinity including sodium chloride, magnesium, sulphate and potassium.

Are there geological influences on the pH of fresh water?

Rainwater is slightly acidic with a pH of 6.0-6.5 due to the acidifying effect of carbon dioxide in the atmosphere. But on hitting the earth's surface the pH is affected by the soil and rock types it filters through before draining into watercourses, still waters and the marine environment. Some soils and rocks have a bigger influence on pH than others. This occurs because the softer sedimentary rocks are acting as a 'buffer' against acidic solutions due to the higher levels of calcium carbonate and magnesium carbonate commonly found in the softer marine (calcareous) sedimentary rocks. These chemicals react with the Hydrogen ions, reducing their concentration. So, soft sedimentary rocks of marine origin, such as chalk, sandstone and limestone will raise the pH (indicating increased alkalinity).

Limestone is a sedimentary rock of marine origin formed from calcium rich sea creatures

Hard rocks such as granite offer no such **'buffering capacity'** and peat bogs can even increase the pH due to their natural acidity.

Water with high levels of dissolved carbonates is commonly referred to as '**hard water'**, whereas water with few dissolved carbonates is called **'soft water'**. The geology and soil types through which water percolates has a major influence on water hardness and pH, but these are not the only influences.

Can biological processes influence the pH?

The activities of plants and animals in water can significantly affect the pH. When plants are photosynthesising during daylight hours, they remove and use carbon dioxide (CO2), causing the pH to increase. This is because as carbon dioxide levels in water decrease, the levels of carbonic acid formed from carbon dioxide are correspondingly lower. However, the opposite occurs during the hours of darkness when plants and other aquatic animals are respiring and there is no photosynthesis. This leads to an increase in carbon dioxide and carbonic acid, decreasing the pH of the water. This naturally occurring process known as **'pH Flux'** is often influenced by human activities.

Dense growth of aquatic plants can influence pH due to night-time CO2 production

Some land-based and industrial activities can cause the **acidification** of natural waters. Power stations and manufacturing processes which burn fossil fuels release nitrogen and sulphur dioxide gasses. Once in the atmosphere, they react with water droplets which ultimately will fall as 'acid rain'. On impact with a rich soils and sedimentary rocks of marine origin, the acidity is buffered. However, where the acidified droplets fall onto coniferous water catchments based on nutrient poor acidic soils their impact can be amplified, as coniferous pine needles are naturally acidic on breaking down and the run-off can be very acidic. Commercial coniferous forestry operation can radically lower the pH of natural waters in a catchment and in extreme cases fish mortalities result from the pH rapidly dropping to sub optimal levels.

Water pH meters are accurate and very easy to use once calibrated

What does each increment on the pH scale signify?

The pH of a solution is measured on a scale which has a range of 0 – 14. A neutral pH is known as a 7 on the scale, but when the pH moves away from neutral it doesn't simply increase or decrease by a single unit. For example, if a waters pH drops from 7 to 6, because the pH scale is logarithmic, every single numerical increase represents a ten-fold change in the Hydrogen ion concentration. Therefore:

- pH 6 is 10 times more acidic than pH 7
- pH 5 is 100 times more acidic than pH 7
- pH 4 is 1000 times more acidic than pH 7

How can we measure pH in the field as opposed to a lab?

There are several ways water pH can be measured in the field, including; digital meters, pH paper and chemical testing. The two most commonly used methods are as follows:

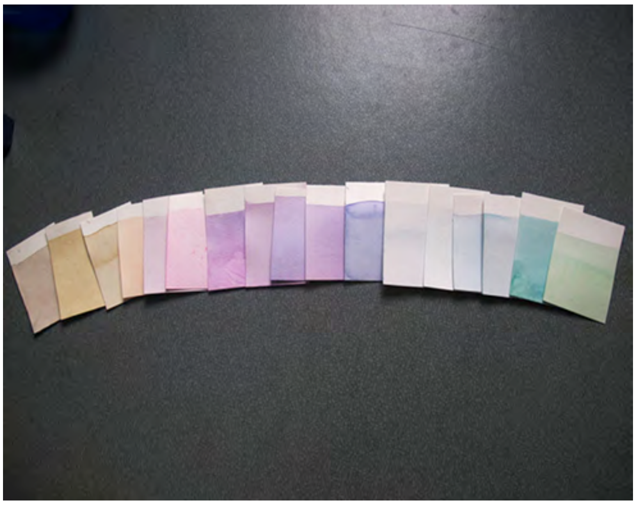
1) Using a meter

Before using a digital meter, it must be calibrated to ensure any readings are accurate:

- Calibrate the meter in a substance with a known pH if possible
- Probe should be rinsed with deionised water to ensure it is clean, then dried off
- Collect sample in a clean container and place probe in sample ensuring the meter temperature matches the temperature of the sample
- Let the meter settle in the sample and record the reading

2) Using pH paper

It is important to know the difference between pH paper and Litmus paper before testing the pH of a sample. Litmus paper indicates whether a sample is acidic or base (alkali), whereas pH paper strips will indicate the actual pH value of a sample.



pH paper is a quick visual guide and an adequate indication of pH for many practical purposes

Guidelines:

- A sample should be collected in a clean container
- A test strip should be added to the sample for a few seconds until the indicator bars change colour
- The test strip should be compared with the colour chart supplied with the kit.
- The colour on the strip should compare with the chart and the reading recorded.

Both pH meter and paper methods will give an accurate enough reading for practical purposes, but the digital meter is the most accurate if calibrated and tested correctly. Using pH paper is the least expensive method and will give accurate enough results for most practical purposes.

B26 Water characteristics

The pH scale

Most people have heard of pH, but what does it mean? The commonly used pH is an abbreviation for 'parts Hydrogen' and a measure of the **Hydrogen ion or proton (H+) concentration** of a solution. As the Hydrogen ion (H+) concentration increases so does the acidity, and the opposite happens with an increase in Hydroxyl ions (OH-) and the solution will become increasingly alkaline.

This occurs because water molecules (H_2O) naturally dissociate into hydrogen and hydroxyl ions. When both Hydrogen and Hydroxyl ions are in balance a solution is classed as neutral (pH 7), but if it swings either way it can become acidic (< pH 7) or alkaline (> pH 7).

Large 10-fold increases in Hydrogen ions can be detected by crude colour change pH tests

When an acidic substance is added to water the Hydrogen ion concentration increases, which in turn lowers the pH. Conversely, when an alkaline substance is added to water the Hydrogen ion concentration reduces as they become chemically bound up, which in turn raises the pH.

What does the pH scale mean and how can we interpret it?

The pH of a solution is measured on a scale which has a range of 0 – 14. When the pH is 1 it is extremely acidic and when it is 14 it is extremely alkali. A neutral pH is known as a 7 on the scale. When the pH changes by a factor for example, pH 7 becomes more acidic and drops to 6 this is large change in hydrogen ion concentration. This is because the **pH scale is logarithmic**, which means for every single number increase there is a ten-fold change in the hydrogen ion concentration. Therefore the following applies:

- pH 6 is 10 times more acidic than pH 7
- pH 5 is 100 times more acidic than pH 7
- pH 4 is 1000 times more acidic than pH 7

B30 Water characteristics

Natural and human influences on water pH

Rainwater is naturally slightly acidic with a pH of 6.0-6.5 due to the carbon dioxide in the atmosphere, but when it hits the earth's surface the pH is affected by the types of soil and rocks it filters through before draining into watercourses, still waters and the marine environment. Some soils and rocks will have a bigger influence on the pH than others.

This occurs because the softer sedimentary rocks are acting as a **'buffer'** against acidic solutions due to the higher levels of calcium carbonate and magnesium carbonate commonly found in the softer marine (calcareous) sedimentary rocks reacting with the **Hydrogen ions** and reducing their concentration. So, soft sedimentary rocks of marine origin, such as chalk, sandstone and limestone will raise the pH (indicating increased alkalinity).

Hard rocks such as granite offer no such **'buffering capacity'** and peat bogs can increase the pH due to their natural acidity. Water with high levels of dissolved carbonates is commonly referred to as 'hard water', whereas water with few dissolved carbonates is called soft water. The geology and soil types through which water percolates has a major influence on water hardness and pH. But these are not the only influences.

Peat bogs are a natural acidifier of waters in their catchment

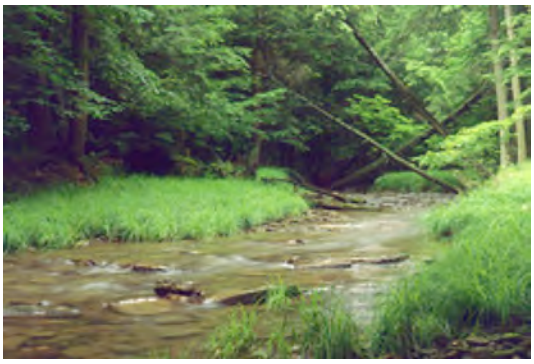
Can biological processes influence the pH?

The activities of plants and animals in water can also significantly affect the pH. When plants are **photosynthesising** during daylight hours, they remove carbon dioxide (CO2), causing the pH to increase. This is because as carbon dioxide levels in water decrease, the levels of carbonic acid formed from carbon dioxide are correspondingly lower. This increases the pH and the water becomes more alkaline.

However, the opposite occurs during the hours of darkness when plants and other aquatic animals are respiring and there is no photosynthesis. This leads to an increase in carbon dioxide and carbonic acid, decreasing the pH of the water. This naturally occurring process known as **'pH Flux'** is often influenced by human activities.

What influence can land-based human activities have on pH?

Coal burning power stations 'belch' nitric and sulphur oxides into the atmosphere



Coniferous forests planted in hard rock catchments acidify water courses

Some land-based and industrial activities can cause the **acidification** of natural waters. Power stations and manufacturing processes which burn fossil fuels release nitrogen and sulphur dioxide gasses. Once in the atmosphere, they react with water droplets which ultimately will fall as 'acid rain'. On impact with a rich soils and sedimentary rocks of marine origin, the acidity is buffered.

However, where the acidified droplets fall onto coniferous water catchments based on nutrient poor acidic soils, their impact is amplified. Coniferous pine needles are naturally acidic when they break down and the run-off can become very acidic.

Commercial coniferous forestry plantations can radically lower the pH of natural waters in a catchment and in extreme cases fish fry mortalities result from the pH dropping rapidly to sub optimal levels.

B32 Water characteristics

Water hardness

Water hardness is a measure of the **concentration of dissolved materials** in water - calcium and magnesium salts of carbonate, sulphate and chloride. Most waters can be classified as either hard or soft, as determined by the rock and soil types they have flowed through or over.

How does rock type influence water hardness?

Hard rocks such as granite do not easily dissolve and so will release very little in the way of dissolved minerals. The water in those hard rock areas is normally considered soft. Areas with softer rocks such as chalk, limestone and sandstone which will dissolve easily in water and release calcium and magnesium ions, are normally considered hard water areas.

The limescale from seepage at this pipe pump junction proves the water is hard

The minerals released are largely made up of calcium and magnesium carbonates. In areas where there is hard water, evidence of this can be observed in kettles as limescale forms when water is boiled.

Natural freshwaters can be classified by their hardness, which is usually expressed in terms of the equivalent quantity of calcium carbonate ($CaCO_3$) in milligrams per litre or parts per million.

Softness or hardness	Concentrations of $CaCO_3$
Very Soft	<50mg/l $CaCO_3$
Soft	50 -100 mg/l $CaCO_3$
Hard	100 - 300 mg/l $CaCO_3$
Very Hard	>300 mg/l $CaCO_3$

Table: Water hardness measured in $CaCO_3$ concentrations

What are the characteristics of hard waters?

Water hardness is closely related to water conductivity and pH, in that harder waters will tend to have higher conductivity and pH.

The higher mineral content in hard waters generally make them more productive than soft waters due to the dissolved minerals that can be utilised by plants.

B33 Water characteristics

Water alkalinity

When discussing alkalinity, it is important to understand that alkalinity and pH are not the same thing. Alkalinity is a measurement of a water's capacity to neutralise acid or **hydrogen ions**, whereas pH is measure of the concentration of hydrogen ions. The alkalinity of water is commonly determined by calcium carbonate which is released from calcareous rocks - chalk, limestone and sandstone of marine origin which contains fossilised sea creatures.

Limestone is a common calcareous sedimentary rock that formed from calcium rich marine sea creatures

However, calcium carbonate is not the full story. What is referred to as the total alkalinity is determined by the concentration of all the following ions with the capacity to neutralise Hydrogen ions in the water:

- Bicarbonate
- Carbonate
- Hydroxide

For water starting with a neutral pH 7, any increase shows it is getting more alkaline due to the decrease in hydrogen ions and increase in hydroxyl ions. A decrease below the neutral pH 7, would show it is getting more acidic.

Why is alkalinity important?

The alkalinity of water is its ability to neutralise acidity. Alkaline compounds such as carbonate, bicarbonate and hydroxide act as a 'buffer' to any pH changes and help to maintain a stable aquatic environment.

This is important for fish and other aquatic life, protecting them against rapid pH changes, which are potentially damaging. Aquatic organisms will generally function well within a pH range 6.0 – 9.0, with any levels outside of this range likely to have a negative impact on the aquatic environment.

How is alkalinity measured?

It can be measured using chemical titration or a digital photometer.

The photometer measures a base control sample against the water sample which has a colour reagent added. The photometer measures the quantity of light penetrating the sample, which in turns will convert to show the alkalinity of the water.

Total alkalinity can be measured using chemical titration. A water sample has a measured amount of acid added over time to bring the sample down to a pH of 4.2. Once this pH is reached there should be no alkaline compounds remaining in the sample. The amount of acid used to reach this point is then used in a calculation to record the milligrams/litre of calcium carbonate in the sample.

B35 Water characteristics

Permanent and temporary water hardness

Water hardness is something that most people have heard of, but before discussing the different types of hardness it is important to first understand what makes a water soft or hard.

Water hardness is a measure of the concentration of dissolved materials in water, mainly calcium and magnesium. Most waters can be classified as either hard or soft, and which classification they will fall into is influenced by the rock and soil types they have flowed through or over.

Granite is a hard-volcanic rock and does not release minerals into the water catchment

Hard rocks such as granite are volcanic origin, do not dissolve easily and release very little in the way of dissolved minerals. The water in hard rock areas is normally soft water.

Soft rocks such as sedimentary chalk, limestone and sandstone are marine origin and dissolve easily in water to release calcium and magnesium ions. They are normally hard waters.

The minerals released are largely made up of calcium and magnesium carbonates. In hard water areas limescale forms in the kettle when water is boiled and when using soap when very little lather is evident. These are the signs of hard water.

What is the difference between Temporary and Permanent hardness?

In the natural environment temporary hardness is caused by rainwater dissolving insoluble calcium and magnesium carbonates from soft rocks and soils such as chalk or limestone. This occurs because rainwater is naturally acidic at a pH of 4 – 6 and it dissolves the insoluble compounds into soluble hydrogen carbonates. Naturally carbonated water has dissolved carbon dioxide is slightly acidic, helping to dissolve insoluble calcium carbonate.

What is the main difference between temporary and permanent hardness?

Temporary hardness is caused by the presence of dissolved calcium bicarbonate, magnesium bicarbonate and other compounds.

The major difference between temporary and permanent hardness is that temporary hardness can be reduced either through boiling which leaves 'lime scale' behind in a kettle or by the process of lime softening, which involves the addition of lime (calcium hydroxide) to the water. The lime softening process works by removing the calcium and magnesium ions, which cause hardness, through precipitation.

The term temporary hardness is the one most commonly used; however, it can also be referred to as either Carbonate hardness or Alkaline hardness.

What causes permanent hardness?

Permanent hardness is usually caused by the presence of calcium and magnesium sulphates or chlorides. Permanent hardness cannot be removed by boiling water, unlike temporary hardness, but can be removed by ion exchange or by using other water softening equipment. The process of water softening involves the removal of calcium, magnesium, iron and other ions which cause water hardness.

Chalk is a marine origin soft and soluble sedimentary high in calcium carbonate

In the natural environment permanent hardness is caused by the action of water movement and rainwater dissolving the soluble compounds calcium sulphate and magnesium sulphate from soft rocks and soils such as chalk, limestone and sandstone.

The term Permanent hardness is the one most commonly used however you may also see it referred to as either Non - Carbonate hardness or Non - Alkaline hardness.

B36 Water characteristics

Total Dissolved Solids (TDS)

Water hardness and Total Dissolved Solids (TDS) are sometimes considered to be the same, however this is not the case as there are major differences between the two.

Water hardness is a measure of the concentration of dissolved substances in water, mainly calcium and magnesium. Most waters can be classified as either hard or soft, and the classification they fall into is influenced by the rock and soil types they have flowed through or over.

What is Total Dissolved Solids (TDS)?

Total dissolved solids (TDS) refers to a measure of all organic and inorganic substances dissolved in the water, whether molecular, ionised or micro granular. They cannot be filtered using filter paper, unlike undissolved suspended solids, which can be.

This drinking water sample has no visible suspended solids but are there any dissolved solids?

This means TDS is a measure of all dissolved solids including salts, calcium, magnesium and iron. A high TDS reading, usually in parts per million (ppm), will normally indicate a high level of water hardness.

It should be noted however that TDS measures all dissolved solids, whereas hardness generally is a measure of the calcium and magnesium ions in water. The two should not be confused, but TDS does show the' total mineral content' of water rather than a 'specific mineral content' as measured by hardness.

What does the conductivity of the water tell us about TDS?

It is also important to note another variable closely linked to TDS and by association water hardness – **electrical conductivity.**

Water and electricity can be a dangerous mix. However, water itself is a poor conductor of electricity because distilled water does not contain any dissolved salts or other materials and can't conduct electricity. Conductivity is a measure of the ability of a substance to conduct an electric current, which is directly related to the concentration of salts dissolved in water.

Salts and other materials such as carbonates, sulphides and chlorides, dissolve into positively and negatively charged ions. As the TDS increases so does the ion content and as a result the conductivity also increases.

Why measure conductivity?

Measuring conductivity can give a good approximation of TDS. Conductivity is measured using a digital meter which will give a reading in units called micro siemens/cm. To calculate an approximate

TDS the following conversion should be used 1 part per million (ppm) TDS is equal to 2 micro siemens/cm.

B37 Water characteristics

Suspended solids

Water is only "pure" at the point of condensation. After condensation when water forms a cloud and falls as rain, a wide range of compounds, both gases and solids will become dissolved in water. In underground aquifers, rivers, lochs or the marine environment, water has varying quantities of materials (organic and inorganic), either dissolved or in suspension.

High suspended solids are a common natural occurrence, but often intensified through land use

All this material, the Total Suspended Solids (TSS) and Total Dissolved Solids (TDS) grouped together and combined, is called the Total Solids (TS) of a water. However, there are differences between the TSS and TDS.

Total Suspended Solids (TSS) is the dry weight of all undissolved suspended particles in water that can be trapped by a filter paper. This can include fine particulate matter such as sand, silt and organic waste from aquaculture or agriculture sites.

Total Dissolved Solids (TDS) is the measure of all organic and inorganic substances dissolved in the water, whether molecular, ionised or micro granular. Those are dissolved solids that cannot be filtered using filter paper, unlike TSS which can be.